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H2 international

THE E-JOURNAL ON HYDROGEN AND FUEL CELLS

→ IRON NUGGETS AS H_2 TRANSPORTER

→ ANALYSIS: WHY DO WE NEED H_2?

Hydrogen regions, Part XX: Emscher-Lippe

HYDROGEN + FUEL CELLS EUROPE

CONNECTING INDUSTRY WITH HYDROGEN AND FUEL CELLS TECHNOLOGY

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HYDROGEN FUEL CELLS EUROPE

HANNOVER MESSE

NEW PERSPECTIVES

In shifting times, Hydrogeit Verlag does not want to stick unnecessarily to the old, but actively advance, shape and intensify what we can best do: inform, document, classify and report – on all the many interesting developments and activities in the hydrogen and fuel cell sector.

This should continue to be possible in the usual quality both in HZwei and H2-international. In view of the diverse challenges and current changes in the energy industry as well as in the political spectrum, some adjustments are now unavoidable. In the editorial of the January 2025 edition, I already informed you that Hydrogeit Verlag has teamed up with Gentner Verlag in order to make both magazines, the German and the English edition, fit for the future.

But what does that mean specifically? As some have certainly noticed in the meantime, the appearance of HZwei and H2-international was increased to five times a year in early 2025. In 2026, it will increase further to six times, which means significantly more input for the readers and at the same time a lot more space to present the advertising customer. However, this is only the beginning.

On April 1, 2025, Hydrogeit Verlag will be giving both the German magazine HZwei and the English e-journal H2-International over to Gentner Energy Media. The preparatory measures for this have been running for some time so that a seamless transition is guaranteed.

We are very pleased that our editorial team will be largely preserved; only in the distribution of tasks will there be some adjustments. For example, our long-time freelancer Eva Augsten, as a future editor-in-chief, has been busily preparing for the new tasks for weeks. In addition, together with our long-time graphic team Neonbold, she created a fresh, more modern layout that will give this new era a visual expression.

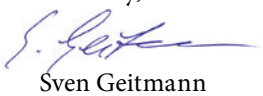
From then on, Gentner Verlag is taking over all areas of subscription support, accounting, sales and advertising acquisition. The family-owned Stuttgart-based company releases a total of 17 magazines – among others "Erneuerbare Energien" and "Photovoltaik," so HZwei and H2-international ideally complement the portfolio in terms of content.

In order to further expand the range of offers, talks with other potential partners are already underway. For example, they are about stabilizing our expertise in the financial sector – after the painful loss of our long-time analyst Sven Jösting. At the same time, there are interesting considerations for reshaping the international experience. So look forward to a new outfit, even more clarity and additional formats that will gradually settle in starting April 2025.

I am very happy to be able to put the main responsibility in good hands after over 20 years of releasing HZwei on my own and to have found a partner in Gentner Verlag who can further develop both HZwei and H2-international and lead them into a hydrogen-rich future. I am not completely disappearing from the scene, however, but will continue to advise from the stern of the boat – and at the same time I am excited to see what new fields of work will arise from this changed setting.

When I look back on what has happened since 1997 – my early days in the H_2 and FC sector – I am confident that a lot will happen in the next few years. It is an honor for me that as a HZwei and H2-international editor I was able to accompany the development, with all its highs and lows, and maybe also contributed to where we are today. Now, I'm looking forward to what's to come.

Sincerely,



Sven Geitmann
Owner of Hydrogeit Verlag

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Source: FutureProofShipping

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Source: Referenzfabrik.H2@Fraunhofer IWU

FOUNDATION STONE LAID FOR 100-MW PLANT

Fig.: Foundation stone laid by the project partners [Source: Salzgitter]

Europe's largest production plant for green hydrogen is to be built in Salzgitter. The foundation stone was laid on February 12, 2025 so that around 9,000 tonnes of green hydrogen can be produced annually starting 2026. This CO_2-free H_2 gas is to be used for the production of CO_2-reduced steel. For the project partners, this represents the "beginning of the industrial use of hydrogen."

The 100-MW electrolysis plant, which uses HydrogenPro's pressurized alkaline electrolysis technology, is being built by the international technology company Andritz at the Salzgitter Flachstahl site in order to ensure more environmentally friendly and lower-emission steel production in the future.

Gerd Baresch, managing director of technology at Salzgitter Flachstahl GmbH, said: "Today's laying of the foundation stone is another big step within our SALCOS® program. We hereby show that in the transformation of our company, we are progressing towards a low-CO_2 steel production." As part of the SALCOS® project, a direct reduction system, an electric layer stove (both under construction) and the 100-MW electrolyzer are being gradually built. In 2026, the first products are to be produced, but the switch to almost CO_2-free steel production at the Salzgitter location will not be completed until 2033. •

H_2 COMING FIRST TO NEUSS

Nordrhein-Westfalen (NRW) is well on the way to becoming a key hub for hydrogen in Europe. In the tradition-rich energy-producing state, there are not only countless H_2 initiatives on the local, regional and national level. Since January 29, 2025, there has also been another hydrogen roadmap that was created on behalf of the Rhine district Neuss with the support of the hydrogen hub Wasserstoff Hub Rhein-Kreis Neuss/Rheinland e.V. It was developed by DMT Energy Engineers GmbH, among others.

Stefanie Peters, managing director of the Neuman & Esser Group and member of the German National Hydrogen Council, stated, "This roadmap is different from other studies, because concrete projects are presented here." In addition, challenges and obstacles are named and also paths by which to overcome them.

Dr. Dieter Ostermann, CEO of Wasserstoff Hub Rhein-Kreis Neuss, confidently said, "Our region has the potential to take a pioneering role in the national and international hydrogen economy." Study author Dr. Thomas Kattenstein, who presented the results in the Neusser Zeughaus in front of over 200 guests, confirmed, "Hydrogen is coming – and first in Neuss." Corresponding political support is certain, because Düsseldorf and Neuss want to be CO_2-free by 2035. NRW wants to "become the first climate-neutral industrial region," according to State Secretary Silke Krebs. •

Fig.: David Zülow, Dirk Brügge, NRW minister Mona Neubaur and Dr. Dieter Ostermann (left to right)
[Source: Wasserstoff Hub RKN/Rheinland]

SCHOLZ AT OPENING OF H_2 STATION

Chancellor Olaf Scholz took time for the opening of a new H_2 gas station four days before the federal election. In Bremerhaven, together with representatives of HY.City.Bremerhaven as well as Bremen's mayor Andreas Bovenschulte and SPD member of the Bundestag Uwe Schmidt, Scholz cut the rib-

Fig.: First official refueling by the German chancellor
[Source: HY.City.Bremerhaven/Fotoscheer]

bon, releasing the operating activities. The planning and design work had taken five years – the actual construction period "only" one year.

Chancellor Olaf Scholz said at the opening, "We want and will remain a strong, successful industrial country. We will only succeed in the long run if we prioritize being CO_2-neutral as part of our prosperity."

The project Hy.City.Bremerhaven is part of the Hyways for Future market activation program for the transport sector establishment of green hydrogen in the metropolitan region Northwest Germany. As part of the HyLand program of the national innovation program for hydrogen and fuel cell technology, it was funded with a total of 5.5 million euros by the German ministry of digital and transport infrastructure. •

DAIMLER TRUCK RECEIVES 226 MILLION-EURO PROMOTION

The German ministry for digital and transport Affairs (BMDV) and the German states of Baden-Württemberg and Rhineland-Palatinate are funding a small series production of 100 FC trucks with over 226 million euros. "This funding is not only a strong signal for Daimler Truck, but for the entire commercial vehicle industry," says Karin Rådström, CEO of Daimler Truck.

The funding project is part of the EU's IPCEI hydrogen program. In addition to the development of the vehicles and the construction and operation of the fuel cell trucks, the money will also be used to carry out feasibility studies. These will examine the H_2 supply chain and the necessary processes in preparation for planned series production.

Daimler had already submitted the funding application in 2021. The company will now receive almost two thirds of the eligible project share. However, a significant part of the total investment for the development of the fuel cell truck will remain with Daimler Truck. Important components are to be built at various production sites in Germany and made available for final assembly.

The Kassel and Mannheim plants are among those involved. The fuel cells will come from Cellcentric's pilot production in Esslingen and will be assembled into a fuel cell system at the Gaggenau plant. The further development of the tractor units based on the Mercedes-Benz GenH2 Truck will take place at the Mercedes plant in Wörth.

The 100 FC trucks are expected to be delivered to customers from the end of 2026. For a transformation to sustainable goods transport with H_2 drives to succeed, however, a nationwide tank infrastructure and sufficient supply of green and inexpensive hydrocarbons would have to be set up in the next few years, Rådström emphasizes. •

Fig.: Minister of transport Volker Wissing visited the Daimler Truck test and development center in Wörth am Rhein. At the wheel: Daimler Truck CEO Karin Rådström [Source: Daimler Truck]

TWO H_2 TRUCKS FOR BMW FACTORY IN LEIPZIG

Fig.: H_2 truck at an H_2 gas station [Source: BMW]

As part of the H2Haul project, the first two Iveco S-Eway Fuel Cells were handed over on February 20, 2025. Together, the project partners BMW, Teal Mobility, Bosch and Totally are presenting these fuel cell-powered semitrailers at the BMW factory in Leipzig. The occasion was the start of the commercial phase of the EU support project H2Haul to test H_2 trucks in long-distance transport. On this occasion, the opening of a new hydrogen refueling station from Teal Mobility in Leipzig was also celebrated. Another of these modern stations will be built in Hormersdorf near Nuremberg under the TotalEnergies brand.

Michael Nikolaides, head of production network and logistics at the BMW Group, said: "For the first time, hydrogen-powered trucks are now being used for German automotive production. We have been working with our partners to implement the pilot fleet for several years. This project is an important milestone for gaining experience in series operations and further promoting this important technology."

A total of 16 H_2 trucks at H2Haul will be funded by the Clean Hydrogen Partnership and tested in various European countries. The knowledge from the practical company should help to further bring the technology to market maturity and to pave the way for a broad introduction in road freight transport. •

MORE INSOLVENCIES

The current tense economic situation does not stop at the H_2 industry. Home Power Solutions (HPS) now had to step into a series of insolvencies. The Berlin company is currently looking for investors who enable the Heliocentris successor to continue working or restructuring. Dr. Henrik Colell, the co-founder and long-time managing director of both HPS and the predecessor Heliocentris, left HPS in October 2024. His long-standing companion and former CEO Zeyad Abul-Ella has not been there since December 2023. In mid-January 2025, the new chairman of the board was Roman Thomaßin, who succeeded Matthias Holder.

Before that, companies such as Proton Motor and HH2E (see reports in H2-international Jan. 2025) had already released employees. Inhouse Engineering also registered insolvency at the end of 2024, but has now found a company, Schubert GmbH, that is taking over part of the assets. However, what will become of the previous fuel cell activities and In-house 5000 is currently still open.

Hydrogenious LOHC Technologies also announced in December 2024 that it would have release about a quarter of its staff. This affected around 50 employees at the Neuss and Erlangen locations. In mid-February 2025, however, the message came in that the chemical company Covestro and the Winkelmann Group, Chevron Technology Ventures and Anglo American Platinum would invest 17 million euros as part of a new funding round to secure the business ramp-up.

It is currently still open whether things will run similarly happily with Quantron and Hyzon. Quantron AG initiated the insolvency proceedings on January 1, 2025, after the manufacturer of H_2 commercial vehicles had played well to the media for years. Company founder Andreas Haller wanted to renovate the company himself. However, there seems to be no hope for the US Hyzon Motors. After the manufacturer of FC trucks prepared employees for layoffs at the end of 2024, the board voted in January to dissolve the company.

The company Pepper Motion, which, among other things, carried out the system integration of the electrical drive train in H_2 commercial vehicles from Paul Nutzfahrzeuge, has been in the insolvency self-administration process since February 2024. In the summer of 2024, however, a Turkish investor bought up Pepper, so its future is secured for the time being. In the meantime, Paul ramped down its H_2 activities significantly. In mid-February 2025, the Vilshofen-based truck builders announced that a mediation agreement was concluded with the Mercedes-Benz commercial vehicle center in Germany in order to promote the sale of the PH2P® hydrogen trucks.

With Nikola, another commercial vehicle provider is currently threatening to decline, so things could run similarly there as with the US provider of alternative H_2 storage for aircraft Universal Hydrogen, who went bankrupt last summer. •

Fig.: After layoffs, Hydrogenious is getting new money and a new management team [Source: Hydrogenious]

Advance report for Hannover Messe 2025

PROGRESS IN ALL AREAS

Processes for the production, storage and use of hydrogen scaling, reducing costs and increasing efficiency: The trade fair Hydrogen + Fuel Cells Europe in Hannover is again proving the progress the hydrogen economy can show. **Author:** Jens Peter Meyer

Fig. 1: In 2024, the Hydrogen + Fuel Cells Europe was well attended

No energy transition without hydrogen. H_2 is a central energy storage medium in a world liberated by fossil energies, and its use is the key to decarbonizing industrial processes. At the Hydrogen + Fuel Cells Europe 2025 from March 31 to April 4, which takes place at the Hannover Messe, visitors can learn which solutions and technologies the hydrogen industry can already offer today. Over 500 exhibitors from all areas of hydrogen use are presenting their services and products – from start-up to large, internationally known companies, to renowned research institutes.

This year, organizer Tobias Renz again is offering visitors two forum areas: At the Technical Forum, the exhibitors will have the opportunity to present their latest developments and products in short lectures. This also includes an "elevator pitch" on the subject of hydrogen production. At the Public Forum, exhibitors and guests from industry and politics will discuss new projects and developments. Here the production of green hydrogen and its derivatives from renewable energies, CO_2-neutral industrial production and fuel cell applications are in focus.

H2-international, in this trade fair preview, is focusing on a selection of innovations that visitors expect this year.

HYDROGEN TRANSPORT Hydac is showing a new sensor-based clamping tape for hydrogen tanks in Hannover. The "Hy-Ros H_2 Mount Smart" is said to be the world's first sensor-based transport protection for this application. The clamping tape equipped with sensors is intended to improve the safety of H_2 vehicles, because it enables reliable real-time monitoring of the tank attachment. The circumference of H_2 tanks can change by up to 2.5 percent in the refueling and emptying process, which is a challenge for the fastening systems.

Hydac compares its preventive approach to a tire pressure monitoring system. The data about the condition and integrity of the fastening is continuously supplied, which means that any deviations can be recognized early and appropriate measures can be initiated.

→ Hydac, Hall 13, Stand C44

COMPONENTS FOR FUEL CELLS AND ELECTROLYSIS SYSTEMS The Swiss company Celeroton TurboCell has specialized in the development and production of ultra -high turbo compressors and drive systems for fuel cell applications. The products are used in applications such as intralogistics, the heavy-duty area, in stationary systems, drones and the marine sector. The company has expanded its portfolio of next-generation compressors and wants to increase the number of quantities. The complete solutions consist of the gas-stored turbomachine with an electric motor as a construction unit and coordinated electronics.

New is the CTI-1100 compressor, the second generation of the turbo compressor with integrated inverter of the company. The new generation should have a higher efficiency and improved aerodynamics and at the same time offer a com-

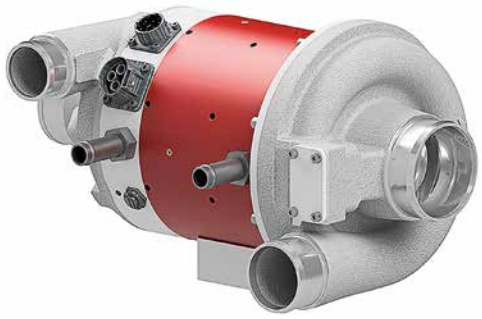

Fig. 2: The compressor CTE-4000 ensures the air supply of fuel cells [Source: Celeroton TurboCell]

pact size. Thanks to the efficiency and a long lifespan of the compressor system, customers should be able to achieve low total operating costs.

Likewise new is the CTE-4000 compressor with CC-4000-inverter, which is intended for the air supply of fuel cells with a net output of 100 to 200 kW. The new system is available with an optional turbine expander and in several aerodynamic modes. In addition to a portfolio made of standard systems, Celeroton TurboCell also offers tailor-made solutions for specific customer requirements.

→ Celeroton TurboCell, Hall 13, Stand D50

Fig. 3: In hydrogen applications, the quick detection of gas leaks is particularly important [Source: Pilz]

The automation company Pilz presents solutions for functional safety in the hydrogen industry. It is about recognizing gas leaks reliably and quickly, always keeping pressure, level, voltage and electricity in view and safely monitoring combustion processes. Proven security principles of automation are used. Pilz also shows how hydrogen applications can be protected against manipulation and incorrect operation.

Safe automation is also a topic on the accompanying lecture program of the trade fair: At the Public Forum, Albert Cot, Market Development Engineer at Pilz, is reporting on the challenges of "functional security" and "industrial security" in hydrogen applications. At the Technical Forum, Thomas Braasch, Sales Engineer at Pilz, is dealing with the importance of functional security and industrial security in electrolysis procedures.

→ Pilz, Hall 13, Stand D34

Neo Hydrogen Sensors, part of the Neooxid Group, offers H_2 measurement technology and burners. At this year's Hannover Messe, the company is presenting a new generation of intelligent hydrogen sensors. According to the company, conventional H_2 gas sensors often reach their limits when highest demands on concentration resolution and the resistance to pressure, temperature and moisture are required. Such requirements prevail, for example, in the automotive industry or aerospace technology. The sensors of Neo Hydrogen Sensors GmbH should meet exactly these challenges and enable precise H_2 measurement, even under the most extreme conditions.

In addition, the company presents catalytic hydrogen burners for an emissions-free combustion. These include catalytic convertors for the efficient cleaning of electrolysis gases. The company has maintained a branch in Canada since 2021 and can therefore also serve the innovative market of this year's partner country of the Hannover Messe.

→ Neo Hydrogen Sensors, Hall 13, Stand E19/3 (NRW Pavilion)

The engineering office Emcel specializes in advice and engineering in the field of hydrogen, fuel cells and e-mobility. For customers, the engineers develop concepts for the energy transition and sector coupling and support in the development of products. This can be vehicles, hydrogen refueling stations or electrolyzers.

The team led by managing director Marcel Coneille also offers its customers the measurement of the hydrogen purity and quality. The company's H_2 quality system enables continuous real-time monitoring of the hydrogen quality on site and at all points in the value chain. Fair visitors can experience live how the measuring device detects different contaminants. Because at the stand, the company wants to demonstrate how reliably and easily the measurement technology can be to ensure the hydrogen purity today.

→ Emcel, Hall 13, Stand E15

Fig. 4: The engineering office EMCEL presents a measuring device for hydrogen purity [Source: Emcel]

Heraeus Precious Metals, a provider of precious metals, is coming to the exhibition center with the new Actydon brand. The new product family belongs to "Actydon | Platin". These are platinum catalysts, the area of application of which is primarily electrodes of PEM electrolyzers and PEM fuel cells, which are also used in other fuel cell and electrolysis technologies. "Actydon | Iridium" includes the corresponding iridium solutions. Among them are innovative catalyst solutions with low iridium content and catalysts that combine iridium with ruthenium.

Fig. 5: Under the Actydon brand, Heraeus sells precious metal catalysts for hydrogen applications [Source: Heraeus]

Heraeus Precious Metals also offers a precious metal recycling for hydrogen applications, and also recycling entire stacks. The company recycles old materials as well as production residues and production waste, such as paints and pastes from the fuel cell and electrolyzer area with high precious metal return rates. "Actydon | Loop" depicts the recycling family of the company's product portfolio. The recycled precious metal can be used for the next generation of applications in the hydrogen economy.

→ Heraeus Precious Metals, Hall 13, Stand C21

RESEARCH In order to reduce the material and manufacturing costs for PEM electrolyzers, the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) is researching scalable production processes for catalyst-coated membranes (CCM). At this year's Hannover Messe, the Institute is presenting microporative transport layers (MPLs), which the researchers have made scalable for the first time using industrial screen printing systems. The approximately 20-µm fine MPLs should enable the use of catalyst layers with significantly reduced iridium loading by improving the connection to the catalyst and thus increasing its use. In addition, they should simplify the use of thinner membranes so that ohmic losses can be reduced.

Fig. 6: Fraunhofer ISE has produced a microporous titanium layer on a titanium fiber substrate with the screen printing process, which is supposed to serve as an MPL [Source: Fraunhofer ISE / Joscha Feuerstein]

The institute also examines customer-specific procedures for the production of membrane electrode assemblies (MEAs) for electrolyzers and fuel cells. Various MEA designs with a reduced precious metal load can be seen at the exhibition stand, manufactured with commercially available materials.

In addition, Fraunhofer ISE is showing the 3D exhibit "Wasserstoff-Modellregion" (hydrogen model region) as a typical local, self-contained hydrogen infrastructure with regional production, distribution and storage, but also with connection points to national and international infrastructures. The exhibit is intended to represent the competencies of Fraunhofer ISE over the entire hydrogen value chain.

→ Fraunhofer ISE, Hall 13, Stand C41

The institute for technical thermodynamics of the German aerospace agency (DLR) also deals with catalysts for electrolysis and fuel cells. The researchers use flame spray pyrolysis. According to the institute, this technology needs little resources to produce materials quickly and in large quantities. It does not change the heat or the chemical composition if it is used on a larger scale. With this technique, the DLR has developed stable catalysts for PEM fuel cells and electrolyzers. These should show an extraordinary performance and durability. And that with reduced amounts of precious metal catalysts.

In addition, the researchers are working on the use of pressure hydrogen for heat pumps or air conditioning systems. A heat exchange reactor is operated with different metal hydride powders, which also produces heat and cold. The heat and cold can then be used, for example, in trains, trucks, buses, in industry or for neighborhood solutions. The hydrogen-based heat pump can be integrated into any H_2 infrastructure with a pressure difference between hydrogen supply and consumer. The aim is to increase the overall efficiency of the system – simply by converting the energy in the compressed hydrogen into a heat pump effect.

At another stand in Hall 2, the DLR is presenting its research in the field of mobility. For example, the research center has developed a hybrid SOFC battery system that is to be used in cruise ships. It combines the highly efficient solid oxide fuel cell technology (SOFC), which offers significant emission reductions and fuel flexibility, with a lithium-ion battery storage in order to meet the fluctuating energy requirement of a ship.

→ DLR Thermodynamik, Hall 13, Stand B36

→ DLR, Hall 2, Stand A48

Fraunhofer IMM also deals with hydrogen as a drive for ships. At the booth of this year's Hydrogen + Fuel Cells, the institute is presenting the Gamma project. As part of the project, a bulk carrier is to be converted so that it can be supplied with climate-neutral fuels and green electricity. Fraunhofer IMM is bringing its experience in the development of compact reformer systems, on which the innovative fuel system for the ship is based.

Ammonia and green methanol are brought on board and then converted into hydrogen with cracker and reform technologies. After cleaning, the hydrogen is converted into electricity in fuel cells, which supplies the ship with electricity and the power generators operated with fossil fuels are replaced. The technological approach of Fraunhofer IMM reduces the size of the reactors by up to 90 percent, which is particularly advantageous for mobile and space-limited

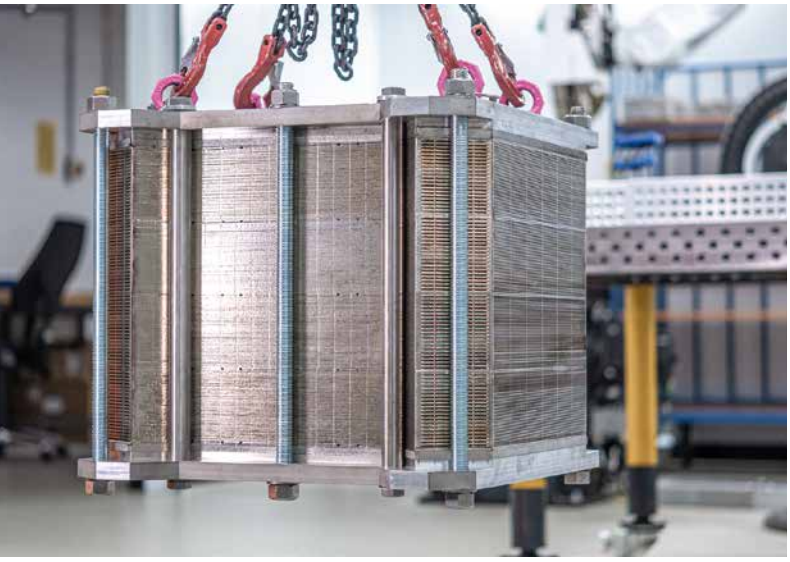

Fig. 7: The methanol reformer of Fraunhofer IMM [Source: Fraunhofer IMM]

applications. The researchers have now managed to convert 700 kg of methanol into hydrogen per day in a compact methanol reformer. The plan is to further expand this service.
→ Fraunhofer IMM, Hall 13, Stand C47/1

HYDROGEN TRADE The gas provider Air Liquide assumes that the purely battery-electric drive, especially for heavy load vehicles, can often not be economical due to high costs for the necessary charging infrastructure. The use of renewable hydrogen in mobility also offers short refueling times and a long range of the vehicles. Therefore, the gas provider expects steadily increasing amounts of hydrogen in the mobility sector. The company creates hydrogen in the 20-MW PEM electrolyzer "Trailblazer." It is said to be the largest electrolyzer in Germany currently connected to a pipeline.
→ Air Liquide, Hall 13, Stand E27/1

The Westfalen Group, a petrol station operator and provider of gases, is presenting its services for H_2 supply to the last mile – whether through electrolysis on site, trailer supply or cylinder and bundle deliveries. The company is active in numerous hydrogen projects. This includes the construction of an electrolyzer in France to supply the steel producer ArcelorMittal. In the Netherlands, Westfalen is cooperating with the energy supplier Alliander in a pilot project in which hydrogen is fed into a natural gas network. Daimler Truck uses mobile trailer solutions from Westfalen for the supply to its fuel cell test stands.

One of the long-term H_2 projects is the joint venture Two4H2, which Westfalen founded together with RWE last year. The aim is to build an H_2 gas station infrastructure especially for heavy goods traffic. In addition, both companies are still working on an H_2 refueling hub in Lingen, which has a public hydrogen gas station and a non-public refueling station for tank vehicles.
→ Westfalen, Hall 13, Stand E21/1

Fig. 8: Westfalen delivers hydrogen by trailer [Source: Westfalen]

SYSTEM INTEGRATORS Siemens is introducing itself at the industrial show as a partner along the entire H_2 value chain for OEMs, EPCs, operators, end customers, governments and municipalities. The company wants to support customers in making hydrogen a future-proof, profitable and scalable business. Siemens offers its expertise in digitalization, automation and electrification.

The solutions from Siemens range from the first pilot projects to scalable and standardized blueprints. This also includes the production of green electricity, the network connection and the H_2 production. Siemens also provides concepts for storage, transport and use that are tailored to the requirements of hydrogen.
→ Siemens, Hall 13, Stand C48

Fig. 9: Siemens is presenting its expertise in production, storage, transport and use of hydrogen [Source: Siemens]

JOINT STANDS Baden-Württemberg is offering companies from the southern German state the opportunity to present their products and services at a joint stand. The-Länd-Gemeinschaftsstand (see Fig. 9) will be organized and super-

vised by the state agencies E-Mobil BW and Baden-Württemberg International as well as the economic promotion office of the region Stuttgart. All three institutions provide information about various offers regarding knowledge transfer, networking and support for business and science in Baden-Württemberg.

Industrial energy solutions based on hydrogen and fuel cell technologies are the focus of the trade fair this year. Around 40 companies, startups, SMEs, business associations and networks are presenting current trends and developments when using fuel cells and electrolyzers in industry. Highlights are, for example, a low-PFAS membrane production, highly efficient fuel cell stacks and innovative electrolysis technologies.

In addition to H_2 and FC technologies, current developments, proven know-how and skills for battery technology, electromobility, research, IT as well as machine, tool and plant engineering are being presented at the exhibitions. •

→ Baden-Württemberg-Gemeinschaftsstand, Hall 13, C78

Fig. 10: Around 40 exhibitors will be represented at the Baden-Württemberg stand this year [Source: e-mobil BW]

Start of series production of container solutions

HYDROGEN STORAGE AND SAFE TRANSPORT

Transport iron to use hydrogen: The new H_2 storage technology of Ambartec AG conveys iron granulates and obtains the hydrogen on site through oxidation. In mid-February 2025, Ambartec, together with Purem by Eberspächer, signed a cooperation agreement (MOU) to prepare a serial production of this iron-nugget hydrogen storage and for its transport in standard 20-foot containers.

Authors: Sven Geitmann, Jens Peter Meyer

Dresden-based Ambartec AG has worked on a storage and transport process for hydrogen in recent years, in which no hydrogen is transported at all, but iron. Iron, which is available in the form of small nuggets, removes oxygen from the water when these two media are brought together, that is, it rusts or oxidizes. What remains is hydrogen that can be used on site. The oxidized iron is then transported back so that the iron nuggets can be reused for the next transport, which works more than 5,000 times. The storage is renewed by reducing the iron oxide with added hydrogen.

Iron nuggets are relatively easy to store in unpressurized vessels. Several of these vessels are then installed in containers so that they can be transported easily and in large quantities. Matthias Rudloff, CEO and one of the co-founders of Ambartec AG, told H2-international: "We're not limited by the German emissions law nor any accident regulation or the like. We deliver hydrogen to every company – this is not difficult with our storage solution." His vision is that the iron nuggets in the near future "are only driven back and forth as bulk cargo in intercontinental transport."

Compared to conventional 300-bar pressurized gas storage, this technology offers the advantage of significantly larger storage capacity. A volume of 1,000 liters can release 90 kg of hydrogen. The company recently received funding from the EU and the German state of Sachsen. Together with the technical university TU Bergakademie Freiberg, the storage technology is to be expanded promptly to 800 kg of hydrogen. The preparation of series production is being funded by Sachsen and the EU with funds from the program "FuE-Verbundprojektförderung 2021-2027" (R&D joint project support) with more than 4 million euros. The aim is to build Europe's first H_2 storage power station at the Freiberg location by early 2026.

Fig.: Container-based demonstration unit [Source: AMBARtec]

USE AS STATIONARY H_2 STORAGE POWER STATION The transport of releasable hydrogen in the form of iron nuggets is only one aspect of Ambartec's technology – it can also serve as stationary H_2 storage power stations. It thus offers an alternative to large electricity storage from lithium-ion batteries, the market of which is currently growing. The combination of the storage with a reversible high-temperature solid oxide electrolysis cell (SOEC) should offer a lot of potential. If the power supply is high, the unit can provide SOEC hydrogen, which serves to load the storage. The water required for the SOEC is also obtained during this. When unloading with water vapor, the hydrogen is created, which is then used in the SOFC operation (solid oxide fuel cell) for electricity generation. Although a reversible SOFC is still very expensive today, Ambartec CEO Rudloff is certain that there is a noticeable cost advantage compared to battery storage for larger systems with more than one megawatt-hour power storage capacity.

Rudloff is relying especially on the German power station security law. This requires that long-term energy stores are provided for power plants so that 1 MW is available under full load for at least 72 hours. With the container solution, this is possible at any time, according to the company CEO. "If hopefully the first tenders come this year, we can offer something exciting," he says.

The Sachsen company is currently targeting the public with their innovative technology, since the storage method is now ready for marketing: "You can already order. From the beginning of next year we can provide hydrogen in containers," says Rudloff. From 2028, Ambartec plans to sell several hundred of these 20-foot standard containers every year – each of which holds ten vessels with iron nuggets. The CEO also reports: "Purem by Eberspächer is now accompanying us in gaining important findings for the later series production and effectively using the knowledge gained for product optimization – with the aim of producing the final product as low costly as possible."

Ambartec is presenting its hydrogen storage technology at the Hydrogen + Fuel Cells Europe taking place as part of Hannover Messe (see exhibition preview on page 9). •

Start of the year for the industry at Hyvolution 2025 in Paris

STAYING POWER OVER SPLENDOR

As a mood barometer at the start of the year, the Paris-hosted Hyvolution with 530 international exhibitors and brands as well as over 15,000 specialist visitors from 65 countries reflects both the tense climate across Europe and the commitment of an international industry – with a correspondingly great echo in the French media that reported comprehensively. **Authors:** Silke Frank, Uta Mummert

Perhaps it is the interplay of economic and ecological interests that not only shows itself in the exhibitor diversity of the Hyvolution, but also makes this European leading event so special with French charm: It presented itself in an almost balanced relation of regions, countries and institutions with and in addition to component, production system, fuel cell and electrolyzer manufacturers.

However, it may also be the mix of parallel events for a wide variety of target groups – from the C-Level Summit organized for the third time to specialist conferences and discussion rounds to mobility, industry, regulation and financing up to the 120 workshops in the forums in the middle of the exhibition halls.

Perhaps it is also the Paris location as an important European hub and home of many European headquarters of international corporations. Or everything together.

The now eighth Hyvolution took place in a similar size to 2024 from January 28 to 30, 2025. A total of 15 hydrogen associations from all over the world presented themselves in two exhibition halls, and the twelve country pavilions also testified to the global interest in the economic factor hydrogen. Representatives from production countries discussed transport routes and energy storage solutions with importers and users.

The exhibitors came primarily from France, but also a third from India, Poland, Taiwan, Canada, Belgium, Italy, Chile, Morocco, Brazil, Japan, Germany, Hungary, Iceland, Colombia – just to name a few countries. At the head of the foreign exhibitors were Germany (41 exhibitors), Italy (23) and Great Britain (21).

In addition to larger transport and industrial applications, smaller motor vehicles also got into the spotlight on the three days of the fair. Brands such as Hopium and Stellantis are increasingly relying on innovative small-format solutions, while in motor racing, projects such as Missionh24 in cooperation with Bosch are trying to set new standards.

PERSEVERANCE IS SCHEDULED Nevertheless, the situation all over the EU remains uncertain. The exhibitors and trade visitors know that the next few years will not be easy for the hydrogen industry. A period of perseverance is required. Who will be able to invest a few more years or to keep investors happy through steady communication? Who will hold out until the large buyers from industry can really use hydrogen in large quantities? One of the exhibitors tells us that his company has not tackled a new hydrogen project since summer 2024.

If you have been in the scene for a long time, the ups and downs of the industry are not new. At the moment the hydrogen economy is on the descending part of the curve of the "Gartner Hype Cycle," and the coming years will show whether this technology is going towards "Valley of Disillusionment" or everyone can get the curve back to rise ("Slope of Enlightenment").

Is the still not solved chicken-and-egg problem between refueling station

Fig. 2: Numerous side events [Source: Silke Frank]

infrastructure and vehicles now moving over to challenges when switching from construction to series production? In Paris is still agreement: Only via numbers of units can the costs be reduced and the market finally be penetrated. The first manufacturers of production facilities could now deliver systems, but in view of the uncertain future, many companies still shy away from these relatively large investments. Agile manufacturers offer modular systems for industry or laboratory systems for the meantime, but this is not a long-term goal.

Nevertheless, something is happening on the market, and that was also evident at Hyvolution. Here are just a few examples:

- Siemens France and Fertilhy signed a memorandum of understanding (MOU) at the fair to optimize the planning of an industrial production facility for the production of low-carbon fertilizers in northern France.
- Schneider Electric and Breathing in Paris sealed their partnership around a technology-based platform for automated certification for hydrogen and PTX supply chains.
- Helion Hydrogen Power and M Reformer also signed a strategic partnership at the fair.
- Equans and Inocel announced that they would offer a scalable solution together to cover the energy requirements of infrastructures, smart grids, buildings, data centers or ports with their fuel cell system.
- he well-known adventurer Mike Horn, who invested a few million euros in the startup Inocel, stopped by Incognito at the Hyvolution.

Two Brazilian H_2 associations were honored: Both for Fernanda Delgado, managing director of the ABIHV (Associação Brasileira da Indústria do Hidrogênio Verde), as well as for the president of the Brazilian hydrogen association, Paulo Emlio de Miranda, was Hyvolution 2025 one key European event. This visit was particularly special for the latter, since in cooperation with Medef International and, among other things with Brazilian participation, the Natural Hydrogen Alliance was founded.

With a country pavilion and a delegation of more than 20 representatives of regulatory authorities, industry associations, companies and consulting companies, according to Guarani de Morais, investment analyst in the Apexbrasil office in Europe, this was the largest Brazilian presence at an international hydrogen event. In addition to an embassy reception, the focus was on high-level discussions on regulation, financing and project structure as well as the expansion of strategic partnerships.

The large number of preliminary events, (embassy) receptions and networking events, which were also organized outside the exhibition halls, speaks for an unbroken international dynamic and commitment of the players.

The large hype of 2020/2021 is over. Overall, the image of a somewhat disillusioned industry was shown – full of short and medium-term challenges, but also full of long-term prospects. The coming years will be crucial for the breakthrough of hydrogen technology as a load-bearing pillar of a global sustainable energy future. •

Hyvolution Paris is part of a trade fair series that has been designed and organized by GL Events since 2016. The international player of the event industry has long since recognized the global importance of the hydrogen economy: Since 2023 has been the satellite Hyvolution Chile, and in 2025 another Hyvolution event will appear, in Canada.

Authors:

Silke Frank
Hydrogen Moves GmbH, Winnenden
→ silke.frank@hydrogen-moves.de

Uta Mummert
→ hyvolution@mummert.fr

Guest article by Friederike Lassen, chair of the DWV

HYDROGEN RAMP-UP NOW RESOLUTELY STRUCTURED

Germany is at a crossroads: Is hydrogen the load-bearing pillar of our climate-neutral energy supply or does it remain a large, expensive promise? The political course of the coming months will decide whether we create a globally competitive hydrogen market – or whether Germany loses connection to international development. This was pondered with our members at the German hydrogen association Deutscher Wasserstoff-Verband (DWV). We therefore formulated and published recommendations before the election of the German parliament under the title "H2Five: Fünf vor 2030" (five before 2030). **Author:** Friederike Lassen

The German government has set itself ambitious goals: 10 GW of electrolysis capacity in Germany is to be set up by 2030. The reality looks bleak: At the end of 2024, final investment decisions for just 1 GW were available. That is only ten percent of the aimed goal – a blatant deficit that is due to a variety of problems: excessive bureaucracy, unclear regulatory requirements and high costs. Colleagues and industrial players are hesitating to conclude long-term delivery and acceptance contracts. They lack the certainty that hydrogen projects will pay off economically. Without scale effects, the production costs remain high and competitiveness is low.

The new federal government must now act and send investors clear signals. In addition to reducing electricity costs – one of the largest cost factors for hydrogen – the EU requirements of additionality, locality and temporal correlation must be met in order for the ramp-up to not be delayed unnecessarily. The European Commission has set strict guidelines for the classification of green hydrogen, but in practice they slow down the development instead of promoting it. Only when hydrogen can be affordable can it displace fossil alternatives. In addition, we need the possibility of using grid electricity based on hourly emission values

for the production of low-carbon hydrogen, which does not meet the requirements for green hydrogen.

BUREAUCRATIC HURDLES BLOCKING RAMP-UP However, it is clear that the regulatory framework for the hydrogen market is currently one of the largest hurdles for investments. In addition to adapting the EU criteria, urgently needed is implementation of European proof of origin systems for hydrogen in Germany, in the sense of a book & claim system. This is the only way to meter and track hydrogen – similar to electricity – and use it across borders.

Approval procedures must also be accelerated massively. There is currently no uniform legal framework for electrolyzers, pipelines and hydrogen infrastructures. While wind and solar parks already enjoy regulatory privileges, complex approval requirements still apply to electrolyzers. In our view, the incoming federal government must resume the work on the hydrogen acceleration law and introduce binding management periods for approval procedures.

INDUSTRY AND MOBILITY NEED RELIABLE MARKETS The hydrogen market will not get going without a stable demand. Industry is one of the greatest potential customers, but so far there is a lack of concrete incentives. The implementation of the RED III (Renewable Energy Directive) industry quota must be implemented sensibly to ensure reliable demand. Sitting out the poor economic situation is not an option, because the competition does not sleep in China and the USA.

Hydrogen also remains essential in the mobility sector. From our point of view, the introduction of a binding subquota for renewable hydrogen in the transport sector by 2030 must create a stable minimum demand. At the same time, financial incentives are needed to improve the economy of hydrogen-powered vehicles – for example by maintaining the toll exemption for emissions-free commercial vehicles or adapting the taxation of hydrogen compared to diesel. The construction and expansion of hydrogen refueling stations along the TEN-T network must be promoted more ambitiously in order to ensure a nationwide supply.

WITHOUT STORAGE AND INFRASTRUCTURE, HYDROGEN REMAINS INEFFICIENT The expansion of storage capacity is essential to ensure safe hydrogen supply. Existing natural gas stores can be converted, but that is not enough to meet the increasing demand. A clear and binding storage strategy is needed that defines the transition from the natural gas to the hydrogen economy. At the same time, approval processes for new constructions and conversions must be drastically accelerated.

The expansion of the H_2 infrastructure must not stall either. The first successes have been achieved with the approved H_2 core network, but there is no strategy for connecting industry and business. Many companies are faced with the question of whether they should invest in hydrogen technologies – these investments will not appear without clarity about the infrastructure. Alternative transport solutions must be developed in particular for decentralized production systems that are not connected to the core network.

GERMANY NEEDS TO REVAMP ITS IMPORT STRATEGY Germany will not be able to cover its hydrogen requirements solely by domestic production. The import via pipelines and ship carriers will be essential. But the German port infrastructure is insufficiently prepared for hydrogen imports. The federal government must therefore provide financial support for the expansion of H_2 import terminals and port infrastructures.

At the same time, existing natural gas pipelines should be upgraded for the transport of growing quantities of renewable hydrogen. Within Europe, close synchronization of grid expansion with the European hydrogen grid is necessary to ensure a reliable supply.

IMPROVE FINANCING INSTRUMENTS, MAKE INVESTMENTS EASIER A functioning hydrogen market needs stable financing instruments. Practice shows that many advanced projects are currently not coming to the final investment decision. Increasing construction costs, shortage of skilled workers and regulatory uncertainties inhibit progress. Increased use of the European Hydrogen Bank and better integration with existing support programs could eliminate structural disadvantages for German companies.

The ramp-up of the hydrogen economy is crucial for the future of industrial location Germany. So far, however, there has been no resolute implementation. In many places, policymakers are hesitant, overly cautious and too slow. The direction is clear: Costs must be reduced, bureaucracy must be reduced, storage and infrastructure must be expanded and stable demand secured. Only then can hydrogen become a real alternative to fossil fuels – and Germany take on a leading role in the global hydrogen economy.

A STRONG VOICE FOR THE HYDROGEN ECONOMY The ramp-up of the hydrogen economy requires a strong and united voice that effectively brings the interests of the industry into the political debate. The German hydrogen association DWV is taking on this task: As a representative of the entire value chain – from the production to transport to use – it is committed to ensuring that the right course is set for a successful hydrogen future. The DWV ensures that the demands of the industry are heard in politics and brings companies, research institutions and political decision-makers to one table. Only with a clear strategy, coordinated measures and a common voice can Germany survive in the global competition for the hydrogen markets of the future – at the DWV, we've taken on the duty of working towards this goal. •

On October 30, 2024, Friederike Lieben succeeded Werner Diwald, who had managed and shaped the DWV since 2014. Diwald developed the association from a band of idealistic H_2 friends to an industrial lobby association that belongs to both the German and the European level. Now, the DWV is in a phase of restructuring and renewal.

Author:

Friederike Lassen
Deutscher Wasserstoff-Verband, Berlin
→ lassen@dwv-info.de

Fig. 1: The Ecore One can be operated via the EMS touchscreen [Photo: Infener]

Everything combined in one unit

INFENER WANTS TO SUPPLY ENTIRE NEIGHBORHOODS WITH SELF-SUFFICIENT ENERGY

The Swiss company Infener wants to promote hydrogen throughout Europe. Decentralized H_2 hubs will be used to generate green electricity as well as green heat. The Ecore One is a compact containerized solution that combines various energy technologies in one unit: electrolyzer, fuel cell and battery as well as compressor and a heat pump with its own energy management system or EMS. H_2 production is due to start 2027 at a site in the Black Forest, Germany. However, the needs of regional industry are already far greater today. **Author:** Niels H. Petersen

"The components – from the electrolyzer and fuel cell to batteries and heat pumps through to the H_2 compressed gas storage tank – are available individually," says Tobias Gruber, Head of Products at Infener. The young company's innovation is to combine these technologies efficiently into a single energy system. The Ecore One is flexibly scalable and therefore not just limited to single-family homes. It can also supply larger buildings such as hotels, companies or entire neighborhoods with self-sufficient and CO_2-neutral heat and electricity – or the system can be operated to serve the grid if required. The built-in PEM electrolyzer covers an output of between 10 and 50 kW.

The complete plug-and-play solution also received the German Innovation Award last year. The jury was impressed by the energy system, which can be adapted to different buildings and comes in a compact turnkey solution, making it "particularly convenient." Another advantage is that "this solution eliminates the need for equipment rooms, as the transportable containers are located outside the building," according to the jury.

The young company – headquartered in Stansstad, south of Lucerne in Switzerland – is a spin-off from the W&P Engineering Group. "We recognized hydrogen as a key area for the future back in 2018," explains Gruber. The Ecore One was the first idea of the two founders Joel Vogl and Felix Schmid. The system is designed to enable an independent and hydrogen-based supply of electricity and heat to buildings. "However, we quickly realized that the demand for hydrogen was greater," says Gruber.

Many energy-intensive industries want to switch to hydrogen, but the supply is simply not there yet, according to Gruber. "That's why we have also started to implement hydrogen hubs and large-scale projects," he says, describing the holistic approach. The aim is to meet the demand from energy-intensive industries and medium-sized companies in a decentralized manner and independently of the core network. The company is currently growing continuously and is implementing projects in Norway and Portugal, for example.

INVESTMENT OF 45 MILLION EUROS REQUIRED Plans for the hub in the Black Forest are already far advanced: It will be built in Villingen-Schwenningen on an area of around 10,000 m² (108,000 sq ft) in the Salzgrube industrial park. This is because the industrial region is not expected to be connected to the cross-regional H_2 pipeline before 2040. For this reason, the electrolysis capacity of the plant will gradually increase from 5 MW to 20 MW from 2027 – enough to produce around 2,000 metric tons of green hydrogen per year in the final stage. The investment is expected to amount to 45 million euros. The energy requirements of the regional logistics, transport and industrial sectors are already greater today.

The design of the hub is visually impressive thanks to its natural wood cladding. It was designed by the Hamburg architecture and design office Hadi Teherani. As for project management on site, this will be undertaken by the architecture firm Schleicher.

Fig. 2: Heat pump at the front and solar inverter on the wall [Photo: N. Petersen]

Fig. 3: Tobias Gruber (left) with the two founders Joel Vogl (CEO) and Felix Schmid [Photo: Mary Goldau]

This is not just about the efficient generation of electricity and heat. Even the waste heat from the operation of the fuel cells is used and further optimized with the help of the heat pump so that it can be used for industrial processes or in heating networks. The oxygen that is also produced during electrolysis is primarily used for oxyfuel combustion. This also helps to decarbonize industrial processes more effectively. Direct electricity supply contracts, known as power purchase agreements or PPAs, with operators of wind and photovoltaic plants in the region provide the green electricity for the operation of the H_2 hubs. Potential customers have also already been acquired: The logistics company Noerpel is planning to use the green hydrogen to refuel H_2 truck or bus fleets, and the Move transport association is also supporting the project.

In addition to the 20-MW hub in Villingen-Schwenningen, further projects are already being planned in Gengenbach and Neumünster. The commissioning of the 50-MW hub in Neumünster, for example, is planned for 2027. Gengenbach is located just a few kilometers south of Offenburg in Baden-Württemberg. The town wants to help establish the use of green hydrogen, says former mayor Thorsten Erny, who was in office until the end of 2024 and supported the project.

2,000 TONS OF GREEN HYDROGEN PER YEAR The project on the Kinzigpark I industrial park is currently in the design phase. Whether or not it will be built still depends on the results of this planning phase and the signing of the PPA for green electricity as well as the final investment decisions. Local politicians, municipal utilities and the regional economic development agency are already supporting the project. The plan is to produce around 2,000 metric tons of H_2 per year.

Politicians want to support the expansion of H_2 production with their targets: The EU is planning to expand electrolysis capacity to 40 GW by 2030, with Germany alone aiming for 10 GW. However, only 100 MW have been installed in Germany to date. Infener has set itself ambitious goals for the coming years and wants to play an active role in shaping the European hydrogen economy. "We want to contribute up to 9 GW in the next few years," says Tobias Gruber. •

Large-volume hydrogen storage in Etzel salt domes

H_2 CAVERN STORAGE – ENABLERS OF THE ENERGY TRANSITION

Since the 1970s, crude oil has been stored in the Ostfriesland town of Etzel, and since the 1990s, natural gas has been stored in the underground salt caverns. As part of the research and development project H2Cast Etzel with the DLR as a scientific project participant, the first large quantities of hydrogen were brought into the Niedersachsen location in 2024. The novelty: The imitation of a realistic cavern operation, regardless of the so far outstanding hydrogen core network infrastructure.

Authors: Hendrik Langnickel, Carsten Reekers, Claudia Käding, Wiebke Germer, Armin Garbe, Alexander Dyck

Storag Etzel GmbH is the operator of one of the largest underground storage sites for crude oil and natural gas in Europe. Up to 3.9 billion cubic meters of natural gas can be stored in the caverns in Etzel, which are artificially inserted into the salt domes. This makes up a sixth of the total German gas storage capacity.

These stores have a special core function for the energy industry, since in the face of strong fluctuations through the divergence of electricity production, import and demand, they ensure the maintenance of security of supply. This is particularly important when implementing a complete energy supply through renewable energies. Bottlenecks in times of seasonal differences in needs or dark doldrums, in which windlessness and little sunlight limit the production of solar and wind power, can be efficiently bridged by flexible and quickly adjustable gas power plants.

At the same time, excess electricity not compensated by the power grid can be stored on a large scale by the production of the chemical energy source. This is exactly when the large-volume, flexibly usable storage becomes "enablers of the energy transition".

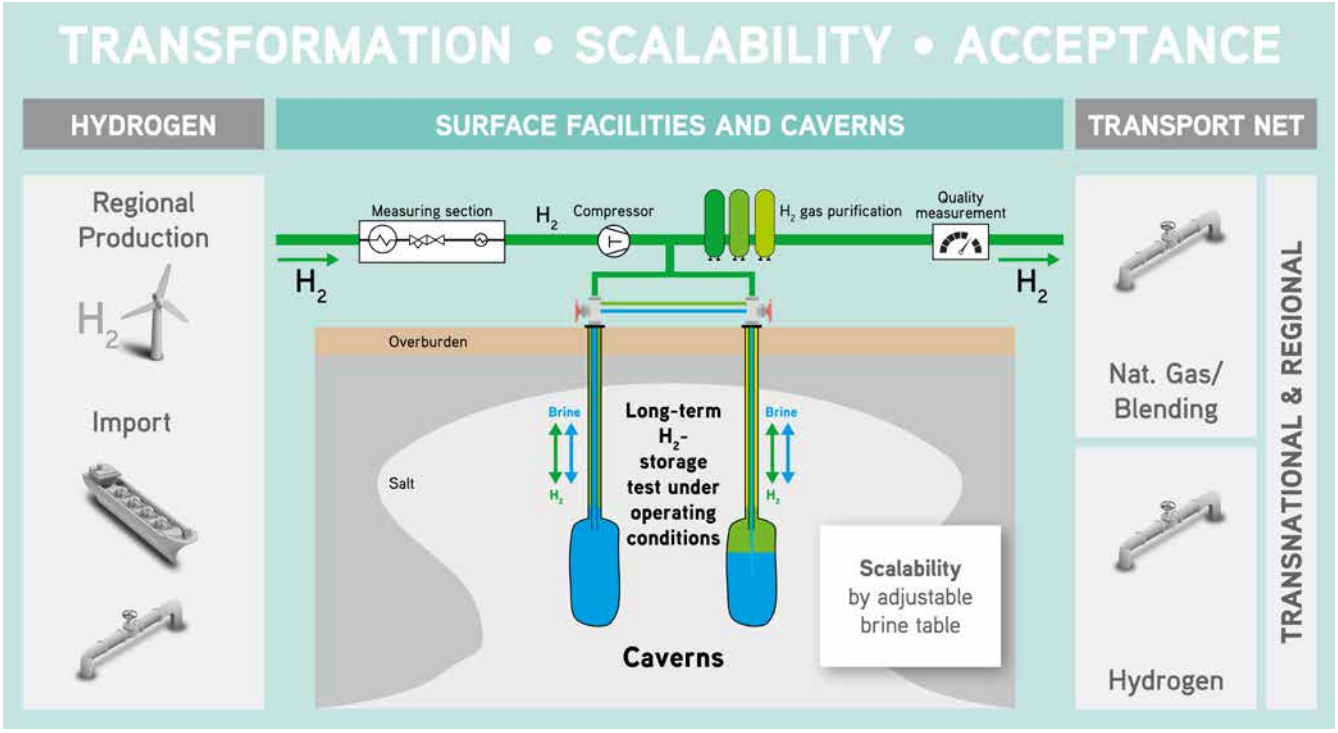

Fig. 1: Graphic overview of the research project H2CAST Etzel [Source: STORAG ETZEL]

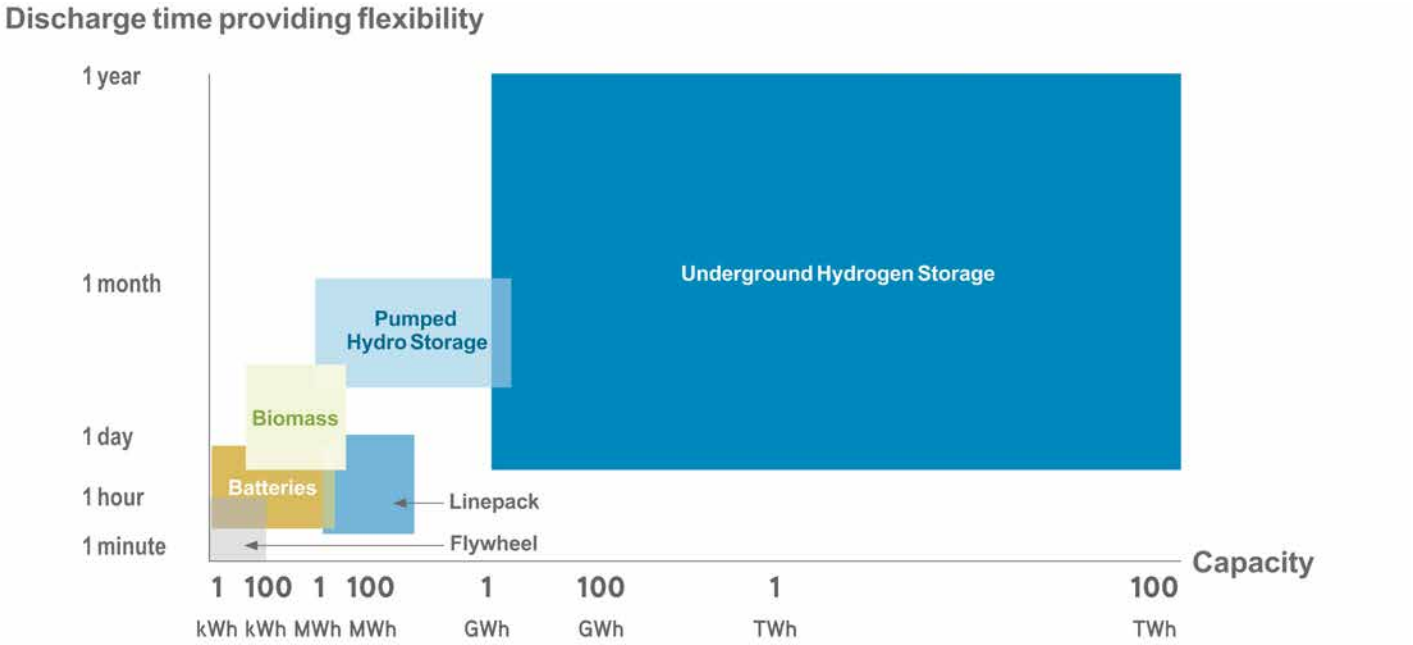

Fig. 2: Capacity versus flexibility of different storage technologies [Source: Peterse et al.]

PARALLEL DEVELOPMENT OF A STORAGE INFRASTRUCTURE With the approval of the H_2 core network by the German network agency in October 2024, an important building block was laid for the market ramp-up of the German H_2 economy. But in addition to building an extensive transport network for hydrogen to decarbonize the German energy sector, H_2 storage options are also required. "Our simulations show how essential it is that storage options are expanded on a large scale in parallel with the hydrogen infrastructure, as hydrogen deficits or surpluses cannot be compensated solely by grid breathing (storage of hydrogen in certain network sections by varying the pipeline pressure) of the gas pipelines," says Dr. Hendrik Langnickel, expert for gas technology at the German aerospace center (DLR).

However, the necessary demand for H_2 cavern storage until the operation of the core network in 2032 can hardly be achieved through solely new constructions. The research project **H_2 C**avern **S**torage **T**ransition Etzel (H2CAST Etzel) funded by the German ministry of economic affairs and climate protection and the German state of Niedersachsen deals with a possibility to cover the storage demand. Storag Etzel, Deep.KBB, Gasunie, the Technical University of Clausthal, Socon, Hartmann Valves and the institute for networked energy systems of the DLR are dealing with the proof of the feasibility of adaptation and conversion of existing gas caverns and essential boring equipment for the underground storage of hydrogen.

The consortium is faced with a variety of challenges. Which materials are to be used in the cavern drilling and the associated surface systems and whether the hydrogen can be stored very efficiently is only some of the questions of the project. The conversion of existing caverns for the storage of hydrogen is possible in a shorter time compared to a new construction and also economically and ecologically advantageous. This could also close the predicted gap between storage demand and availability in order to decouple the production of and demand for hydrogen through intermediate storage.

GASES SHOW DIFFERENT BEHAVIORS Due to the high volatility of renewable energies throughout the year, it can be assumed that H_2 storage requirements for injection and withdrawal can be expected throughout the year, which are also subject to great dynamics [Bekebrok et al]. Longer periods of several weeks without storage, as occurs in natural gas, are not to be expected in hydrogen operation. In addition, it can be assumed that the volume flows for H_2 storage operation assume higher values, since hydrogen has only about a third of the energy density of natural gas [Nationaler Wasserstoffrat].

An increasing orientation of the system operator to redundant systems and an improved controllability of the surface systems for covering larger spectrums in the storing and withdrawal processes is the result. The resulting significant effects on the operation of the caverns, gas treatment, maintenance and upkeep are the focus of the investigations of the project.

H2CAST – AN INNOVATIVE PILOT PROJECT After converting the pilot caverns and successful density tests under maximum gas pressure last year, Storag Etzel has currently started storing hydrogen in Etzel. A total of 90 tonnes of hydrogen have been brought underground for the research project. By the summer of 2025, 200 trailer deliveries with a pressure of 300 bar are expected to arrive, because due to the outstanding core network, hydrogen is currently being supplied by truck.

Does a lack of connection to the H_2 core network mean that research questions regarding caverns have to remain open? "By no means," replies Carsten Reekers (Storag Etzel), project manager of the research and development project. "For this reason, we are working with a total of two caverns that are connected to each other via the local surface test systems (gas treatment, measurements, compression). This means that the hydrogen should be moving back and forth between the two caverns without the need for a pipeline connection. This enables us to realistically map hydrogen production and consumption with one of the caverns."

USE SYNERGIES FROM SIMULATION AND REAL OPERATION A scientific basis for what the future operation of a hydrogen cavern in the H_2 transport network could look like is provided by a comprehensive technical simulation model from the DLR. The model includes a numerical simulation of a cavern as well as a simplified view of a surface system that serves to compress, relax and purify hydrogen. These model components flow into a realistic simulation of a complex hydrogen infrastructure.

For the H2CAST project, the area of northwestern Germany including the appearing H_2 core network has been simulatively mapped in dynamic operation. However, an expansion to the whole of Germany and the adjoining European space in the future is sought. The results can then be validated using pilot tests in Etzel. The synergy of simulation and verification in the field equips the cavern operator for a variety of possible scenarios. In addition, the Institut für Vernetzte Energiesysteme (institute for networked energy systems) also has high-precision analytics with which the withdrawn hydrogen can be examined for changes.

A pilot project was launched with H2CAST that provides essential insights as a blueprint for the conversion of further caverns for hydrogen storage in Germany. The location Etzel is characterized as a special node with extensive connection to the European natural gas network. In addition, Etzel is located in the immediate vicinity of the only German deep water port in Wilhelmshaven with the corresponding H_2-ready pipeline connection, which will also play a significant role for hydrogen import in the future. The expansion options for the project are accordingly diverse. One thing is certain for project manager Reekers: "We are ready to go when the H_2 market is." •

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Authors:

Dr. Hendrik Langnickel
Deutsches Zentrum für Luft- und Raumfahrt, Oldenburg
→ hendrik.langnickel@dlr.de

Carsten Reekers
STORAG ETZEL GmbH, Friedeburg
→ info@storag-etzel.de

Claudia Käding, Wiebke Germer, Armin Garbe, Alexander Dyck

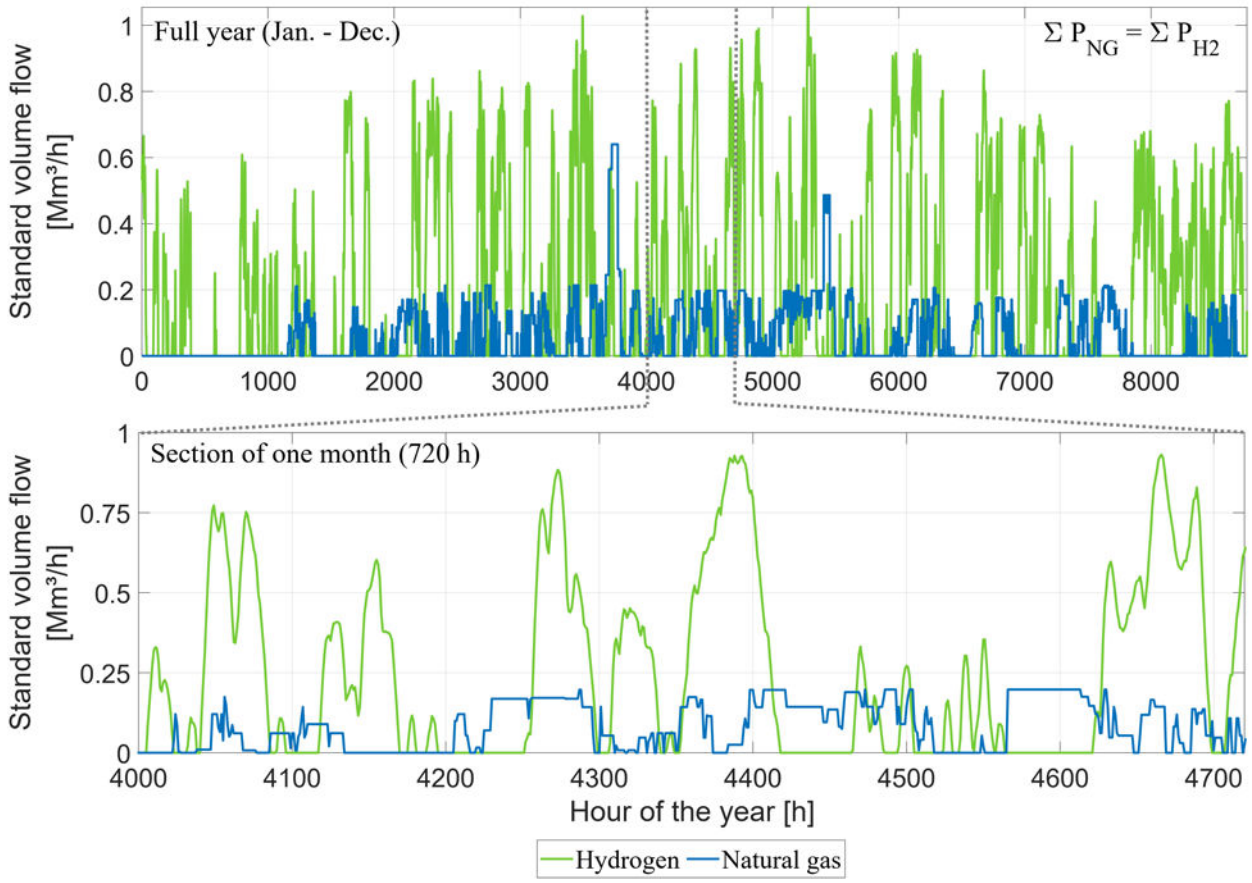

Fig. 3: Comparison of the simulation results for feed-in volume flows of natural gas and hydrogen operation [Source: Bekebrok et al.]

How the dragging electrolysis ramp-up can be countered

HYDROGEN FROM BIOGENIC WASTE RESOURCES

In the current strategies for hydrogen production, still today, with a few exceptions such as the recently published Bavarian hydrogen strategy 2.0, the focus has been on electrolysis from wind or solar power. A slow, but safely back to the foreground hidden champion has not yet entered many heads: hydrogen from biogenic wastes. Such systems usually have higher full load hours, a better GHG balance and are now also ready for the market – this has recently been proven in the project Bioh2ref.

Authors: Andy Gradel, Edwin Hirtreiter

Even though the difficulties of the current legislative period have so far not necessarily made the conditions for hydrogen technologies easier, alternatives to electrolysis from renewable streams seem to be gradually arriving in politics, industry and society. It was different at the beginning of this project: The federal government at that time had only half a year earlier, at the last second, scrapped the draft of the emissions law (BImSchG) containing the exclusion of biohydrogen from the quota trading for greenhouse gases (GHGs), strategies at all levels could be found like advertising brochures for electrolyzers, and throughout the EU, a negative mood in relation to bioenergy spread – not least because other countries have dealt less sustainably than Germany in the past. It is different today, and numerous companies are sprouting from the start-up landscape.

Fig. 1: Pilot plant for the steam reforming of biogas for the production of green hydrogen [Source: BtX energy]

WHY BIOGENIC HYDROGEN? In the European Union, hydrogen from biogenic residues is considered an "advanced organic fuel" and thus enjoys a double GHG quota calculation. This means that the multiplier is currently smaller than with RFNBOs (renewable fuels of non-biogenic origin), but they also do not have the technological possibilities for GHG-negative hydrogen production. The system from the BioH2ref project currently has the only valid certificate for green hydrogen as a quota-capable fuel in Germany and was certified with a GHG reduction of around 250 percent, so an avoidance of approx. 25 $kg_{CO2ÄQ}$ per kg hydrogen. At better times on the GHG quota market, the proceeds have far been surpassed by the production costs.

Biogenic hydrogen can thus be the stirrup holder for a quick run of the hydrogen industry through the transport sector by creating an infrastructure and can solve the chicken-and-egg problem of large electrolyzers. It does not have to be limited to steam reforming. Alternatives for non-fermentable raw materials such as old wood, sewage sludge and other wastes are already in the advanced R&D stage. Processes such as pyrolysis or gasification technologies with subsequent synthesis treatment are available for these, where BTX Energy GmbH is also working on individual process steps for this path with industry friends.

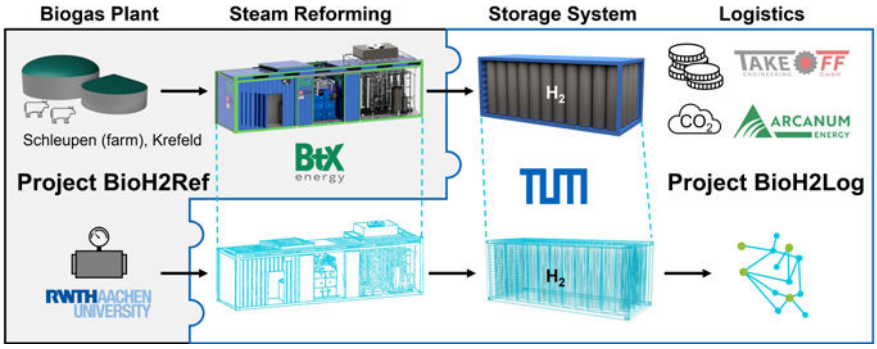

Fig. 2: Cooperation between the Bioh2ref and Bioh2Log projects
[Source: Technische Universität München – TUM School of Engineering and Design]

SISTER PROJECT BIOH2LOG Through the collaboration of the German economy ministry-funded funding projects Bioh2ref (FKZ 03440A-C) and BIOH2LOG (FKZ 03E5452A-C, see Fig. 2), it is possible to analyze the entire hydrogen value creation chain: From the biogas plant via the steam reform system and the subsequent storage up to delivery to the hydrogen buyer. The first part of the process chain, biogas production and the implementation of raw biogas to hydrogen of purity 5.0, was experimentally tested in the Bioh2ref project and brought to market maturity. The second part of the process chain, the storage and distribution of the hydrogen generated, is highlighted in detail in the Bioh2Log project.

At the chair for plant and process technology at the Technical University of Munich, the development of dynamic models of the steam reforming system and the hydrogen storage container is taking place. These models are supported and validated by the measurement data collected on the pilot system by BTX Energy GmbH and applied university RWTH Aachen as well as through experimental studies on a hydrogen storage container consisting of type IV pressure containers.

In addition, a digital twin of hydrogen logistics is being designed at the chair for support technology material flow logistics of the Technical University of Munich in order to take into account both decentralized production and decentralized acceptance. The industrial partners Arcanum Energy and Takeoff Engineering GmbH complete the view of the organic water process chain through ecological and economic studies as well as market searches. ARCA-NUM Energy focuses on calculating greenhouse gas reductions in the process chain, while Takeoff Engineering GmbH develops possible business cases for biohydrogen. Here, too, special attention is paid to the decentralized character of production and acceptance.

Together with the results from the Bioh2ref project, dynamic models for hydrogen production, storage and distribution as well as economic and ecological models will be available at the end of the Bioh2Log project, which enable a smooth market launch of biohydrogen technology.

TECHNOLOGICAL AND LEGAL HURDLES The project funded by the then German ministry of economics began in 2022 with many open questions of technological and legal nature. The use of raw biogas, which was only pre-cleaned with an activated carbon filter, challenges in thermal dynamics, flow mechanics and the reaction to interference or fluctuations in gas quality. All aspects of the pressure loss and reaction kinetics had to be reorganized and calculated, whereby literature data or experience were not available for all process-relevant interpretations. In the project, the performance and efficiency of the system technology at partial and full load as well as in flexible operation were examined. Above all, the multi-stage reactor technology has made considerable development progress, so that the cold gas efficiency of around 45 percent could be increased to the objective of around 60 percent.

The framework conditions for the "biogenic hydrogen" product were also a significant risk factor at the beginning of the project, as also with the participation of BtX energy GmbH in conversations with politicians only half a year earlier, by amending the German emissions law, a recognition of the fuel on the THG quota market was in view. Also, due to the novelty of the process and equivalent procedures for other wastes, there were no investment subsidies for a ramp-up of the technology. During the project period, hydrogen from biogenic wastes was classified as a "advanced biofuel" in the 37th emissions ordinance and thus also allowed for funding mechanisms for the development of generation capacities for such fuels. At the moment, however, these, as well as many other programs, are not equipped with corresponding means due to the greatly reduced climate transformation fund (KTF).

FURTHER IDENTIFIED POTENTIAL FOR INCREASING EFFICIENCY The BTX Energy GmbH composite project with RWTH Aachen and the farming family Schleupen with its biogas plant has reached its project goals and brought the technology to market maturity. However, this should not yet be the end of the innovation. In the project, relevant potential for optimization was identified by connecting further heat sources and sinks, further pressure loss optimization, increased exhaust gas recooling and further development of the reactor technology that are to be pursued. In the long term, a theoretical efficiency of over 70 percent could then be possible, but the corresponding R&D must still be made for this, and the approaches would have to be tested in practice.

CONCLUSION AND OUTLOOK After the project success, the technology is now considered one of a few fully market-mature solutions to produce biogenic hydrogen. The first commercial system with four times the performance of the pilot from Bioh2ref is currently under construction. At the same time, they are working on implementing the optimization potential mentioned. It is important that this can also be retrofitted to plants that may arise in the next few years so that an earlier project start does not lead to nuisances later. The conclusion is therefore: Biogenic hydrogen is ready and future-proof, and can be an efficient lever for excellent profitability when using the right material. •

Authors:

Dr. Andy Gradel
BtX energy GmbH, Hof
→ andy.gradel@btx-energy.de

Edwin Hirtreiter
Technische Universität München – TUM School of Engineering and Design
→ edwin.hirtreiter@tum.de

H_2Mare researches offshore technologies

HYDROGEN PRODUCTION DIRECTLY ON THE HIGH SEAS

Offshore wind power stations generate significantly more electricity and more regularly than their onshore counterparts. In the lead project (Leitprojekt) H_2Mare, scientists are working to exploit this potential – and to produce green hydrogen and derivative products directly at sea in the future. Current progress is being made, among other things, in the coupling of wind turbines and electrolyzers. **Author:** Christian Hiemisch

Fig. 1: Power-to-X containerized system for offshore use [Source: KIT]

At sea, strong and constantly blowing winds ensure the best conditions for generating renewable electricity. If this could be used directly for the production of green hydrogen, it could significantly reduce the costs compared to hydrogen production on land. Because this way not only are the costs for an intricate grid connection unnecessary but also the energy losses as a result of the additional conversion processes.

Partners from research and industry are working in the hydrogen project H_2Mare on directly coupling a water electrolyzer with a wind power station and thus making available innovative technologies to produce green hydrogen offshore. In order for this to be successful, both the electrolyzer and the wind turbine must be adapted and, if possible, directly electrically connected to each other. The fluctuating power supply as the basis for the entire subsequent conversion process, including water treatment and the regulated coordination of the system, is one of the biggest challenges for the development engineers. But that is exactly what is now happening for the first time in a megawatt-scale test system.

FOR THE FIRST TIME, WIND TURBINES ARE DIRECTLY CONNECTED TO ELECTROLYZERS In order to practically test the direct coupling and its consequences, the H_2Mare project OffgridWind in the Danish city of Floe has built a corresponding test system – for now on land. There, the H_2Mare project partner Siemens Gamesa has electrically connected two electrolyzers for H_2 production to the wind turbine, the way this could later happen on the high seas. With this setup, the project team can also test the switching between two systems and thus optimal operational management.

With this structure, the effects on the control system can be identified, further assessed and adjusted if necessary, as this will also be one of the critical aspects at sea. In the coming months, H_2Mare will now investigate how the fluctuating electricity production affects the functioning of the system.

What a wind power station with integrated hydrogen production would look like H_2Mare has likewise already analyzed: In the future, all necessary systems could be housed on a platform directly next to an offshore wind turbine.

Fig. 2: OffgridWind system (inside) in Floe, Denmark
[Source: Thomas Schwabe, Siemens Gamesa, Leitprojekt H_2Mare]

TEST FACILITY FOR SEAWATER DESALINATION These systems also include a seawater desalination unit for electrolysis. A corresponding test system from H_2Mare project partner Fraunhofer IWES in Bremerhaven has been put into operation. It filters seawater, treats it, heats it and thus produces ultra-pure water. Different from other test projects, H_2Mare is actually directly working with water from the North Sea in its tests. Later, waste heat from H_2 production will heat the water.

Because the treated seawater is only available at fluctuating temperatures, experts in the H_2Mare project H_2Wind are currently testing the system with different operating temperatures. Initial results show that water temperature fluctuations affect the start-up behavior and energy requirements of the desalination system, but only insignificantly influence the production volume of ultrapure water.

DEMONSTRATION OF A POWER-TO-X PROCESS CHAIN AT SEA But it is not just hydrogen production that is being examined in the project. Subsequent products also play a role. In the H_2Mare project PtX-Wind, the production of further power-to-X products at sea, for example methane, methanol, Fischer-Tropsch products and ammonia, is being tested. For this, in addition to water, CO_2 and nitrogen are needed. These should, among other things, be obtained directly on site from the air (direct air capture) or the sea.

The developed concepts for all synthetic products PtX-Wind wants to test first on land. For the first demonstration of a power-to-X process chain – consisting of co-electrolysis and the synthesis of fuels – scientists at EnergyLab of the Karlsruhe Institut für Technologie (KIT) have built a power-to-liquid (PtL) containerized system. In this, fuels are produced from hydrogen and CO_2 using Fischer-Tropsch synthesis. In 2025, the entire PtL process chain, coupled with a co-electrolysis from the German aerospace center (DLR) will be demonstrated on a floating platform at sea. In addition to the co-electrolysis, this will house a direct air capture system, PtL synthesis and wastewater treatment in containerized systems and produce Fischer-Tropsch products that can later be used as sustainable fuels such as diesel or kerosene.

The results of the research activities in H_2Mare will be presented to the public at the project end conference in autumn 2025. •

THE HYDROGEN LEAD PROJECT H_2MARE

In Leitprojekt H_2Mare, the offshore production of green hydrogen and other power-to-X products is being researched. Around 30 project partners from research, industry and society are working closely together for this. Next to H_2Giga (series production of electrolyzers) and TransHyDE (transport and storage infrastructure), H_2Mare is one of three hydrogen lead projects of the German ministry for education and research. As part of the national hydrogen strategy, the lead projects will contribute the expansion goal of ten gigawatts of electrolysis capacity by 2030.

Author:
Christian Hiemisch
Fraunhofer IWES,
Leuna
→ christian.hiemisch@iwes.fraunhofer.de

RH_2INE – development of a hydrogen-powered inland waterway network

H2TANKTAINER FOR SHIP REFUELING

Anyone involved in international shipping knows that without setting and maintaining the right course, it's almost impossible to reach your goal. This realization is also what drives inland shipping stakeholders on both sides of the German-Dutch border and what motivates them to actively and resolutely pursue the goal of climate neutrality. The transnational RH_2INE (Rhine Hydrogen Integration Network of Excellence) initiative is providing them with support in tackling this complex challenge. The first milestones include the development of a quick and simple solution for refueling inland vessels with hydrogen. **Author:** Stefan Garche

RH_2INE was launched in 2019 on the initiative of the Province of Zuid-Holland (PZH) in the Netherlands and the Nordrhein-Westfalen Ministry of Economic Affairs in Germany. Since 2021 it has been coordinated on the German side by the regional body NRW.Energy4Climate. The aim of the two Rhine regions is to create a sustainable alternative to fossil fuels for transporting goods on the River Rhine. All parties involved quickly agreed that hydrogen was the only sustainable energy source for inland navigation vessels on fast-flowing waterways such as the Rhine.

Fig. 1: H2TankTainer [Source: Argo Anleg]

RH_2INE has now developed into an international network of public and private stakeholders. Starting from the nucleus along the Rhine, the partners want to jointly create an emission-free North Sea-Rhine-Mediterranean corridor by 2030. The prerequisite for this is a suitable framework and infrastructure for the use of hydrogen in the inland transportation chain.

H_2 REFUELING – A KEY challenge One of the main challenges is refueling the ships with hydrogen. It was therefore clear to the ship operators from the outset that the hydrogen would have to be delivered to the inland waterway vessel in swap containers. This is because exchanging empty tanks for full

HOSE REFUELING NOT A SOLUTION

"A ship has to fill up with at least 2 metric tons of hydrogen during a bunkering process, i.e. when taking on energy. With a hose, this would take 12 hours or longer, and it would not be possible to load or unload during this time for safety reasons," explained Robert Graf-Potthoff, technical inspector at global logistics service provider Rhenus Schiffsmanagement, in a recent article in RH2INE magazine.

STANDARDIZATION OF THE H2TANKTAINER FOR CESNI / ES-TRIN
Pressure levels: max. 300, 500, 700 bar
Container: ISO 10', 20', 30' and 40'
Transportation options: ship, truck, train (regulations: ADN, ADR, RID, ES-TRIN, IMO)
Data communication: pressure, temperature, design pressure in each section
Communication protocol: J2799

ones only takes around 30 minutes in port and does not interrupt the parallel processes that are taking place on board.

One solution was found in a standardized swap body for hydrogen – a so-called multiple-element gas container (MEGC), also known as a "TankTainer." Various companies such as Air Liquide and Argo Anleg are developing different formats for different types of ships.

STANDARDIZATION OF THE ENERGY SUPPLY Previously, TankTainers could only be approved as individual components for a single ship. This made pooling impossible. This is because each ship would need three TankTainer sets – at immense investment cost – to ensure the continuous refueling process.

To remedy this situation, various European government authorities are working together to standardize this technology. Their goal: that TankTainers should not only become the European standard for inland shipping, but they should also be usable as energy storage systems for other purposes. To this end, they are deliberately defining the technical specifications in broad terms. The authorities are receiving support from RH_2INE partners such as the Port of Rotterdam, Air Liquide and Argo Anleg. The standard is expected to be published in the first half of 2025.

OTHER RH_2INE PILOT PROJECTS In addition to the introduction of the H2TankTainer, RH_2INE has achieved other notable successes in inland shipping. As part of the initiative, ships with H_2-compatible dual combustion engines as well as with hydrogen/fuel cell propulsion have been developed. The "flagship" of this development is the MS Letitia, an inland waterway vessel from the HTS Group, which was designed with close support from the Center for Fuel Cell Technology (ZBT) in Duisburg.

Various subsidies have made it possible to finance the fuel cells, an initial set of TankTainers and accompanying EU research (greenH2shipping). The latter is intended to provide proof of reliability and economic viability for the first 1,000 hours of operation. This is the prerequisite for acquiring further funding for low-emission inland vessels and their infrastructure in future funding calls.

One of RH_2INE's pioneering projects is the bulk carrier MS Antonie, which was developed under the leadership of the European freight forwarder NPRC. With a hybrid power system, it can be operated both emission-free and with conventional energy sources. This increases the flexibility of the energy supply.

The Dutch shipping company Future Proof Shipping (FPS) has also developed two ships, the H_2 Barge 1 and 2, which combine hydrogen fuel cell technology with battery systems to enable a completely emission-free journey. To date, the two ships have already transported around 20,000 containers within the Netherlands from Delfzijl to Rotterdam.

Rhenus Logistics is relying on the "Mannheim I+II" coupled convoy, which is also powered by fuel cells, batteries and, if required, diesel-electric generators. It will regularly transport containers between Antwerp or Rotterdam and Mannheim, Ludwigshafen, Wörth and Karlsruhe. Like the MS Letitia, this ship is also adapted for low water with up to three push barges.

MS ANTONIE
Size: 135 x 11 m (443 x 36 feet)
Energy supply: 400-kW H_2/FC / 1-MWh battery
Capacity: 3,700 metric tons of salt transport Delfzijl – Rotterdam (replaces 120 trucks)
Savings: 880 t/a CO_2 and 8 t/a NO_x

Fig. 2: MS Antonie, visited by the Dutch king (center) in Duisburg at the end of 2023 [Source: Robin Alysha Clemens]

EXPANSION OF THE NETWORK Since its foundation, RH_2INE has undergone considerable development from a bilateral project to a broad-based EU-wide network. Today, its partners include more than 45 public and private sector stakeholders, including the major ports of Rotterdam, Duisburg, Basel and Antwerp-Bruges. In addition to the Netherlands and Germany, organizations from Belgium, France, Austria and Switzerland have now also joined the initiative. This considerably extends the reach of the project.

Since 2025, the initiative has been coordinated by the Belgian WaterstofNet cluster. This takes over the newly established program office, whose work plan provides for various English-language working groups that deal with a wide variety of matters such as standardization, financing and funding mechanisms, necessary port infrastructure and TankTainer logistics. WaterstofNet has already been heavily involved in these areas, in particular through its participation in CONDOR, a Dutch project that forms part of the RH_2INE initiative with a focus on Dutch waterways. This experience means the cluster is ideally placed to perform its role as RH_2INE coordinator.

FINANCIAL AND POLITICAL SUPPORT FOR RH_2INE Since 2019, the initiative has been able to acquire extensive funding from EU programs such as the Connecting Europe Facility (CEF) or Horizon Europe as well as from national and regional governments. It uses this funding to drive forward research and development, the construction of infrastructure and the transition to hydrogen technologies, and to expand the network.

H_2-BARGE 1+2
Size: 110 x 11 m (360 x 36 feet), retrofit
Energy supply: 3 x 275-kW fuel cell / 274-kWh batteries
Route: Rotterdam – BCTN Terminal Meerhout (Belgium)
Savings: 2,000 t/a CO_2 per ship

Fig. 3: H_2 Barge 2 [Source: FutureProofShipping]

RH₂INE also plays a key role in supporting policymakers and harmonizing guidelines with European and regional institutions. In the past, for example, the initiative has actively promoted the faster regulation of hydrogen use in inland shipping with its proposals. It has also been able to influence political decarbonization plans for the transport sector, particularly in Nordrhein-Westfalen and the Netherlands.

The success of the decarbonization of inland navigation is reflected in the joint declaration of intent "Perspectives for sustainable Rhine navigation 2030." This was initiated by the MUNV (Ministry for the Environment, Nature Conservation and Transport of the State of Nordrhein-Westfalen) and signed by 80 partners from Germany, Belgium, Switzerland and the Netherlands at the Rhine 2024 regional conference, in which Rhine navigation was classified as indispensable for sustainable logistics

In addition, the resolution passed by the German Conference of Transport Ministers in October 2024 also bears the initiative's hallmark since it emphasizes inland navigation as the mode of transport for Germany's future. New measures for efficient inland shipping are to be bundled in the "New markets for inland navigation" strategy.

The National Ports Strategy of the Federal Ministry for Digital and Transport also takes into account the transformation of inland shipping. According to this, it is to be harmonized nationwide and classified as "nationally significant" and incorporated respectively into regional planning in order to secure port areas for port-related use.

And finally, the National Action Plan for Climate-Friendly Shipping (NAPS) – in addition to the National Ports Strategy – also addresses inland shipping with measures that RH₂INE is also implementing. These include standardized, containerized energy storage systems. In addition, the action plan calls for an extension of the BordstromTech funding program as well as low-interest loans or guarantees from the German state-owned investment and development bank KfW.

THE CHALLENGES OF DECARBONIZATION Despite all these successes, the decarbonization of shipping is still in its infancy: There are currently around 10,000 ships on the Rhine, each with a lifespan of up to 100 years. The aim is to operate them in a climate-neutral manner in the future. One of the main challenges here is the economic viability of hydrogen operation. At present, such ships are more expensive to purchase and operate than conventional diesel ships. The profitability of the new technology depends on several factors, including startup subsidies as well as falling hydrogen prices and the willingness of customers to bear higher transportation costs. Well thought-out business models are needed to meet these challenges.

The harmonization of regulations at European level also remains a complex task. There are still uncertainties regarding the storage and transportation of hydrogen in particular, which are slowing down its introduction. Technological development must also keep pace with the challenges. Access to green hydrogen is currently limited, but is gradually expanding.

Last but not least, the development of a comprehensive refueling infrastructure, initially along the Rhine, requires considerable investment and targeted coordination. In particular, the filling of the TankTainers should take place at larger hubs due to the quantities of hydrogen required.

RH₂INE PLANS RH₂INE is responding to all these challenges with a series of ambitious plans. These are aimed at broad acceptance and scaling of the technology as well as retrofitting the existing fleet.

Stakeholders want to have at least 50 hydrogen-powered ships in operation by 2030. With regard to TankTainers, a pool for H_2 swap bodies is to be created that is open to all shipping companies as well as other parties. The high acquisition costs must be offset against a maximum period of use.

MS LETITIA
Size: 135 x 17 m (443 x 56 feet)
Year of construction: 2023
Savings: 2,800 t/a CO_2 (replaces 250 trucks)
Route: Rotterdam – Duisburg takes 20 h there and 14 h back
Power output: 1.2 MW (six 200-kW fuel cells from Ballard in containers), plus batteries and backup diesel-electric system with the same output
The ship contains 52 m (170 feet) of electrical cabinets and 20 km (12 miles) of cable.

Fig. 4: In the middle of the MS Letitia there are four container areas separated by two partitions, which are capable of holding a total of 16 energy containers for the fuel cells, the batteries and the tank containers [Source: RensenDriessen Shipbuilding, Photo Maritime Filming Group]

A leasing company will likely be founded or commissioned for this purpose in the future.

The network also wants to further involve new partners – regions and stakeholders – in order to ensure area-wide infrastructure and cooperation. By strengthening its lobbying work, RH_2INE will increasingly advocate for forward-looking regulation and financial support at EU level in the future. In the Netherlands, the initiative has already been able to secure a strong financial commitment from the government through a "Climatfonds" for renewable ship propulsion systems. More than 200 million euros are available for up to 150 ships and their infrastructure in the runup to 2030.

RHENUS MANNHEIM I+II
Size: coupled convoy 193 x 11 m (633 x 36 feet) with three push barges 193 x 22 m (633 x 39 feet)
Savings: ship and 1 push barge: 72% less CO_2 and NO_x
Route: Rotterdam/Antwerp – Mannheim/Wörth
Power output: 400-kW fuel cells, plus 840-kWh batteries and backup diesel electrics

Fig. 5: Mannheim I [Source: Rhenus Port Logistics Services]

CONCLUSION Inland shipping must also be decarbonized in order to meet Europe's transport climate targets. RH_2INE impressively demonstrates how international cooperation combined with technical innovations can enable the transition to emission-free inland navigation. And with its clear focus on sustainability, innovation and collaboration, the initiative is a role model for similar activities worldwide.

However, the coming years will be decisive: Can the initial vision of a green Rhine corridor as a Central European strategy become a reality? In any case, the message remains clear along the way: The future of inland navigation is the joint responsibility of politics, business and society. •

→ at the Hannover Messe in the NRW Pavilion, Hall 13

Author:

Stefan Garche
Hydrogen Office H2.NRW of the state of Nordrhein-Westfalen at NRW.Energy4Climate, Düsseldorf, Germany
→ stefan.garche@energy4climate.nrw

H_2 hubs as the key to sustainable and efficient hydrogen mobility

NOW STUDY ON HYDROGEN DISTRIBUTION

The transport transition is a central component of the German climate protection strategy. As part of this, hydrogen is seen as a key energy source, especially for heavy-duty goods vehicles. But how can hydrogen refueling stations (HRSs) be supplied with hydrogen efficiently, sustainably and economically? A joint study by the National Organisation Hydrogen and Fuel Cell Technology (NOW GmbH) and the German Energy Agency (dena) examines four supply options via a future H_2 pipeline network. In the study, H_2 hubs that act as connecting elements between the emerging H_2 network and the HRSs are of particular importance. **Author:** Carsten Beyer

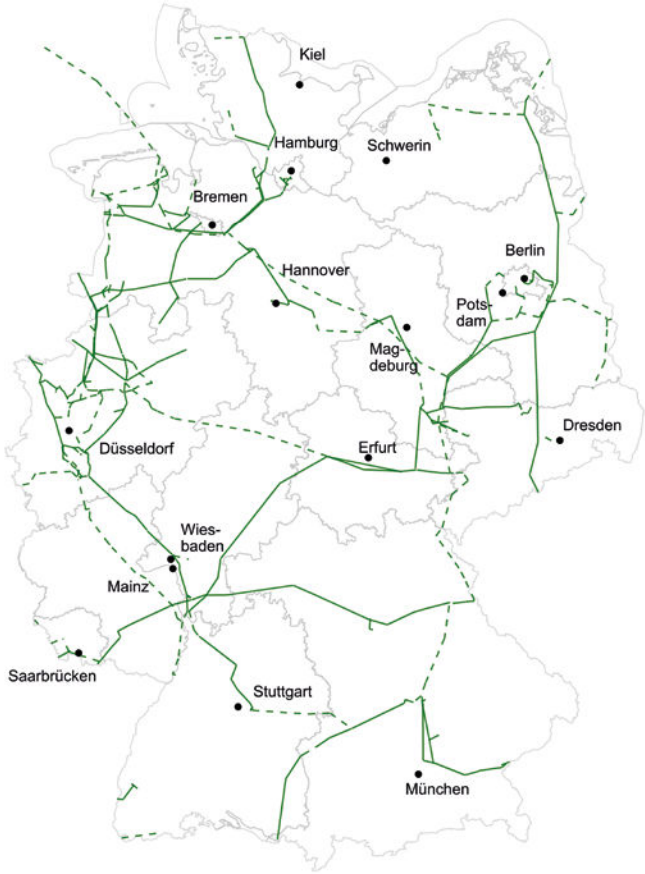

Fig. 1: Map of the planned core H_2 network in Germany with the planned infrastructure and the connections between generation and consumption regions [Source: Federal Network Agency]

The demand for hydrogen in road freight transport in Germany is estimated to increase to up to 2 million metric tons per year by 2045. In this scenario, nationwide supply will require the construction of more than 2,000 H_2 filling stations. The planned core H_2 network, which is to reach a total length of 9,700 kilometers (6,025 miles) by 2037, can play a central role in this. It consists of 60 percent repurposed natural gas pipelines and is to be gradually supplemented by distribution networks in order to open up regions away from the main routes. The network will not only be able to serve industry and power plants, but also other sectors such as the mobility sector, creating a flexible and resilient hydrogen infrastructure.

THE ROLE OF H_2 HUBS One of the key findings of the study is that it is economically attractive and technically feasible to supply HRSs via the H_2 pipeline network. The technical-economic analysis of the four supply options shows that an H_2 hub, which acts as a central supply point for a number of other HRSs and is connected to the H_2 core network, is the most attractive option.

The H_2 hubs act as links between the core H_2 network and the regional filling stations and are directly connected via a spur line. They take over central processes such as the purification, compression and storage of hydrogen. This achieves economies of scale that not only reduce costs, but also reduce the technical requirements for operating the filling stations. The hydrogen is then distributed by trailer at different pressure levels to the surrounding filling stations – the study assumes a radius of 50 kilometers (31 miles). Depending on capacity utilization, it is also conceivable to supply customers who do not come from the mobility sector but have similar hydrogen quality requirements.

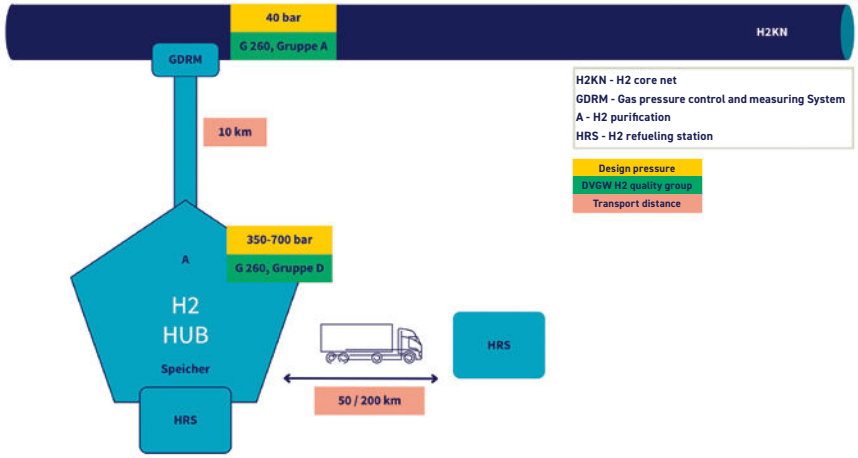

Fig. 2: HRS supply by trailer from an H_2 hub connected to the core H_2 network. This is the preferred connection option to the H_2 pipeline network in the study.

H_2 hubs also offer flexibility in the integration of different hydrogen sources. They can be supplied via pipelines from the core network (the subject of the study), by local electrolysis or by other means of transportation such as trains and ships (this was not investigated in the study). This makes them a key building block for efficient and sustainable hydrogen mobility in Germany.

TECHNICAL AND REGULATORY CHALLENGES Ensuring the quality of hydrogen for use in fuel cell vehicles is one of the key challenges facing H_2 hubs. The hydrogen obtained from the pipeline must be processed in accordance with the purity requirements of DIN EN 17124, which requires additional investment in innovative technologies. It is equally important that grid charges and grid connection fees are set promptly in order to create planning security for investors.

Transportation distances are a major cost driver. The positioning of H_2 hubs near regions with a high demand for hydrogen and a high density of filling stations is therefore crucial. At the same time, a regulatory framework must be created that enables the smooth integration of H_2 hubs into the existing infrastructure.

CONCLUSION The results of the study show that hydrogen filling stations can be supplied with hydrogen efficiently, sustainably and economically via an H_2 pipeline network in the future. H_2 hubs have a central role to play here. If the proposed recommendations for action are implemented, they could become a key component of a sustainable hydrogen infrastructure.

The long-term goal is to ensure a nationwide hydrogen supply that integrates not only the transport sector, but all applications. This requires close cooperation between politics, industry and science in order to ensure the technical feasibility and economic viability of such a sustainable hydrogen infrastructure. H_2 hubs offer a flexible and scalable solution that allows the infrastructure to be gradually adapted to increasing demand. •

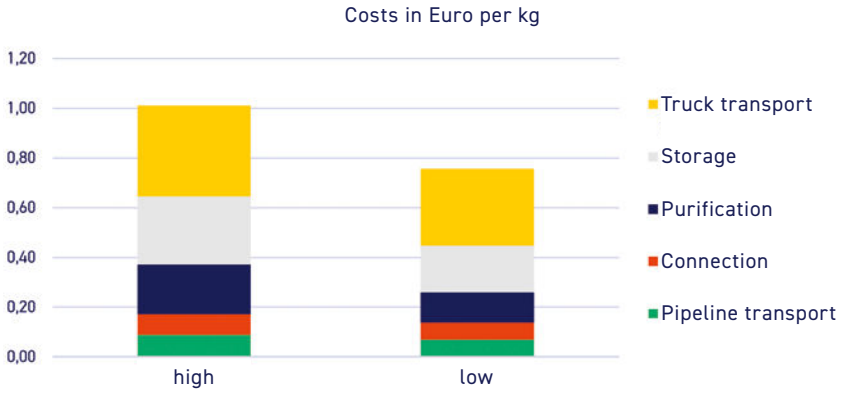

Fig. 3: Specific transportation and processing costs for H_2 supply by trailer from an H_2 hub with connection to the core H_2 network: cost components in two different scenarios of the preferred connection option for 2030.

RECOMMENDATIONS FOR THE STRUCTURE

The study formulates nine specific recommendations for action to create an efficient supply of hydrogen filling stations via an H_2 pipeline network:

- Integration of planning: H_2 networks and filling station infrastructure must be closely interlinked during development in order to exploit synergies.
- Demand assessment: The establishment of a central platform for recording hydrogen demand facilitates the planning and identification of suitable H_2 hub locations.
- Location criteria: The development of transparent criteria for the location selection of H_2 hubs promotes targeted planning.
- Identification of possible H_2 hub operator models, in which local players should also be actively involved in order to strengthen regional value chains.
- Piloting: An initial H_2 hub should be piloted by 2030 in order to gather practical experience and identify optimization potential.
- Further investigation of the key aspect "hydrogen quality": How and at what cost can the purification of the hydrogen extracted from the pipeline be guaranteed (with fluctuating quality/different impurities)?
- Technology development: Further developments in hydrogen processing and compression are essential in order to achieve economies of scale.
- Grid charges: Early determination of grid charges and connection fees creates investment security.
- Holistic analyses: The investigation of the effects of pipeline supply via the H_2 network should also be extended to other areas (ecological, social, etc.).

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Author:
Carsten Beyer
NOW GmbH, Berlin
→ carsten.beyer@now-gmbh.de

Regions series: Emscher-Lippe

H_2 PRODUCTION IN THE HEART OF NRW

With one of the largest hydrogen production facilities in Europe and the refueling center in Marl, the company not only supplies local companies, but also chemical sites throughout Nordrhein-Westfalen (NRW). As the H2EL hydrogen coordinator, we keep an eye on all projects in the region and their progress and create the necessary transparency regarding the market ramp-up through our regular monitoring. Our Hydrogen Roadmap 2024 is simultaneously a progress report, an inventory and an outlook on the development of the hydrogen economy in the Emscher-Lippe region. **Author:** Marc Luckhaus

The Emscher-Lippe region, located in the heart of the northern Ruhr area in Nordrhein-Westfalen, extends south of Münsterland and is part of the administrative district of Münster. This results in close links between the region and neighboring areas, both politically and technologically. The region is also characterized by the combination of conurbations in the southern part of the region and the more rural parts in the north, forming interfaces between traditional industry and modern innovation in many places. With the independent cities of Bottrop and Gelsenkirchen and the ten towns in the district of Recklinghausen, the Emscher-Lippe region is the center of life for around one million people.

Our region is known for its industrial tradition, which has been undergoing structural change for many years now. It has over 30,000 companies, two universities and 15 vocational colleges, which have already adapted their courses specifically to the technological developments in the hydrogen sector. In addition to a well-developed road and highway network, the region also has a dense rail and canal network as well as numerous pipelines. We are also creating synergies for our future strategy with the neighboring Münsterland region and the adjacent Hellweg zone. We also work closely with the Netherlands, for example with the joint project TECH.LAND

Fig. 1: Klimahafen Gelsenkirchen [Source: Julian Schäpertöns]

H_2ERE YOU CAN EXPERIENCE THE FUTURE A unique selling point of our region is its particular suitability and experience for the hydrogen economy. Due to the well-developed pipeline infrastructure and major buyers of hydrogen, its ramp-up can take place faster and more cheaply here than in other parts of Europe. In addition to regional customers, several chemical sites (e.g. in Cologne or Leverkusen) purchase hydrogen from our region.

However, we not only cover production and use, but also comprehensively map the other important areas of the value chain. These include a large number of companies that specialize in the development and manufacture of components, as well as other companies that act as providers of technologies and innovative solutions.

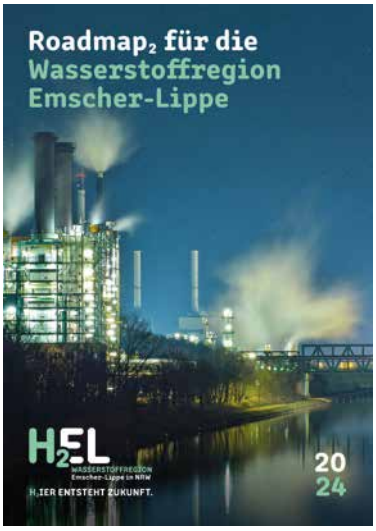


Fig. 2: Hydrogen roadmap

In our new roadmap, we provide an up-to-date overview of relevant hydrogen-related projects that are being implemented in our region or are in the planning or idea phase. In addition to the H_2 roadmap, we are continuously monitoring the projects in order to create transparency and guidance for the market ramp-up in the region.

WIDELY POSITIONED The project portfolio represents the core of our roadmap and provides information on how the H_2 requirement from 2024 to 2032 will probably develop. The projects are divided into the following five fields of action: city quarters, qualifications, research & development, industry and mobility. When we look at the total number of the projects, it turns out that we have taken significant steps in recent years. Originally 57 projects in 2021 have become over 100 in almost three years. A strong growth is recorded in particular in the implementation of the projects. While there were still 17 in 2021, it is now 53. The increase is particularly striking in the field of action industry.

LEUCHTTURM PROJECTS Our project portfolio contains all hydrogen-related projects in the region, and some of them should be emphasized. Among other things, the electrolyzer planned by Air Liquide in the Marl Chemical Park with an output of 120 MW. This will generate green hydrogen, which is to be transported to customers using remote lines or via the hydrogen core network. This is an IPCEI project that received the funding notice in July 2024.

The following two pioneering Leuchtturm projects can be found in Gelsenkirchen:

On the one hand, an entire industrial area has set off with the city harbor to become climate-neutral. For this purpose, the local companies have come together for the initiative "Klimahafen Gelsenkirchen". Process heat (around 500,000 MWh) is to no longer be generated here by natural gas, but by green hydrogen. Until the green hydrogen is available, companies will use a hydrogen-rich gas energy source.

On the other hand, the university Westfälische Hochschule is strengthening its research focus in the field of hydrogen technologies. Among other things, with "H2 Solution Lab" will appear a new laboratory building for the development of knowledge with regard to components, subsystems or total systems for research and transfer.

In Haltern am See, several energy-intensive companies plan to drastically reduce their CO_2 emissions by using green hydrogen. A combined annual hydrogen requirement of around 200,000 MWh is expected, which is to be covered by an electrolyzer, fed by local wind and solar power. Haltern am See could also in the future be connected to the nearby hydrogen core network.

In Herten, the Anwenderzentrum H2herten has existed since 2009, a communal technology center for hydrogen, which self-sufficiently supplies itself through renewable energies. The existing premises and the technical center, including the first complementary energy system (wind power with electrolysis) in Germany, companies can use for investigations of various types. With the system, components can be tested under real conditions or special load cases can be simulated. The complementary system takes on the intelligent control of components, current flow and hydrogen production. In and around the technology center have settled since its completion topic-related companies and institutions, such as the engine manufacturer Cummins Inc. or TÜV Nord.

In the immediate vicinity of the user center is a system from AGR mbH. This creates electricity and district heating to supply the adjacent residential areas by burning waste. In 2024, a 3-MW PEM electrolyzer was installed, which produces hydrogen, and a connected H_2 gas station was provided. Electricity can be obtained from the burning of waste and from own regenerative energy sources (solar and wind). The gas station, via the pressure levels 700 bar and 350 bar, is suitable for refueling cars, trucks and AGR's trash collection vehicles and is currently the largest H_2 refueling station across Europe.

The project E-BO(2)t is a demonstration project by the water board Emschergenossenschaft and some project partners in the nearby city of Bottrop. The goal is to test the feasibility of a large-scale production of green methanol (e-methanol) on a sewage treatment plant. For this purpose, biogenic CO_2, which is created in the rotting towers of the Bottrop sewage treatment plant, is split off from the sewage gas and brought together with green hydrogen produced on site in order to synthesize the electric methanol and to be able to use it as an alternative fuel. As a by-product of hydrogen production, pure oxygen is created, which is directed to nearby water resources for ecological improvement.

In addition to these Leuchtturm projects, numerous other initiatives and projects are being planned. Many of these projects focus on significantly reducing the use of fossil energy sources, especially natural gas. An important approach here is the substitution of natural gas by green hydrogen as an energy source for the generation of process heat, which is essential in many industrial processes. The aim of this changeover is of course the reduction of greenhouse gases and the associated reduction in natural gas demand.

OUTLOOK On the basis of our project portfolio and the quantity forecasts for 2032, an annual need of around 6.5 TWh hydrogen is expected in the region, which corresponds to around 200,000 tonnes per year. Although we are expected to exceed our self-placed expansion objectives for electrolysis capacity for 2032, we cannot cover our growing need for hydrogen through own production and therefore have to import hydrogen on a large scale in the future. If all known electrolysis projects are realized, the amount of domestic production will be around 40 percent. By substitution of natural gas through this green hydrogen, we can save over 1.3 million tonnes of CO_2 equivalents. •

Author:

Marc Luckhaus
WiN Emscher-Lippe Gesellschaft zur Strukturverbesserung mbH, Herten
→ marc.luckhaus@emscher-lippe.de

Simulation tool supports planners

WATER IS A CHALLENGE FOR H_2 FILLING SYSTEMS

The investment design and the operating strategies of H_2 filling units sometimes differ significantly. This can significantly influence the distribution of contaminants such as water. Therefore, a better understanding of the underlying effects is required. With the HRS-Modell, the center for fuel cell technology in Duisburg (ZBT) has developed a simulation tool that depicts thermodynamic processes in H_2 filling systems in detail.

Authors: Lukas Willmeroth, Matz Dietrich

Hydrogen filling units include gas stations for cars, buses, trucks and trains as well as refueling systems for ship containers and trailers. The decisive processes in these units are comparable in principle. The differences for investment design and operating strategies lie in the detailed specification of the application, above all in the pressure level and throughput of the system.

While small quantities of high end pressures are often given up at car refueling stations, very large quantities must be filled at bottling or transfer stations. Both the corresponding operating concept and the required hydrogen quality depend on the respective application. It shows that there is a connection between the investment design and quality.

The minimum hydrogen quality for use in fuel cells is determined by ISO 14687 (DIN EN 17124). Accordingly, 13 different substances/contaminants (exclusive of particles) with defined limit values are listed here. In practice, water has turned out to be the contaminant with the highest probability of appearance. The approved limit is currently 5 ppm, whereby it continues to be intensively discussed by the standardization bodies as well as in scientific research. Among other things, this is due to the fact that the distribution of water in filling systems changes depending on the temperature and pressure levels – and thus also its state of aggregation: it can exist in gaseous form, as condensate or in ice form.

As for practice, more and more companies and operators are reporting problems in their facilities or products. Also experimentally, the high probability of appearance of water could already be detected in numerous measurements. For this purpose, the ZBT in Duisburg (Zentrum für BrennstoffzellenTechnik Duisburg) operates an in-house laboratory with the project HyLab with measuring equipment for the full analysis of all contaminants listed in the norm.

As part of different sampling campaigns, 21 hydrogen gas stations (hydrogen refueling stations, HRSs) were examined as examples (see Fig. 1). Water could be detected in each of the measured samples. You can see that the samples of some systems have a concentration that exceeds the specification value or is near the specification value. Even in the case of further sampling campaigns as part of support projects, a clear tendency for frequent exceeding of the limit value concentration can be determined.

NORM-CONFORM AND YET CRITICAL? From a regulatory point of view, the hydrogen quality at the transfer point (e.g. interface between the injector and the vehicle) is important for operators of filling systems. If the measured H_2 contaminants are below the required ISO specifications, nothing stands in the way of the delivery.

In the systems, however, thermodynamic state changes often occur locally in a very short time. If, for example, hydrogen is removed from storage, the pressure and temperature within the storage vessel change. As a result, the properties of the water also change significantly, which leads to a unit, e.g. from the storage vessel to the transfer point, whose moisture content is heterogeneous. In numerous samplings and analyzes carried out by the ZBT, it could be shown that the water concentration within the storage is larger than at the transfer point and that this difference is once again significantly dependent on the pre-cool temperatures and mass flows.

The dew point describes the thermodynamic condition in which water is condensed from the gas phase. The dew point temperature, in turn, depends on the gas pressure and the present water concentration (see Fig. 2). The blue areas mark the dew point areas, i.e. the conditions under which water condenses. You can see that even for H_2O concentrations below the ISO limit (5 ppm), conditions or operating states could exist under which the water condenses.

The influence of different pre-cool temperatures on the measured concentrations in the samples could also be shown in experiments on the H_2 test field of the ZBT. Figure 3 shows the results of three samples that have been taken one after the other, initially without cooling, then at -40 °C pre-cool temperature and finally again without cooling. The H_2O concentration drops to under 5 ppm with cooling from almost 42 ppm.

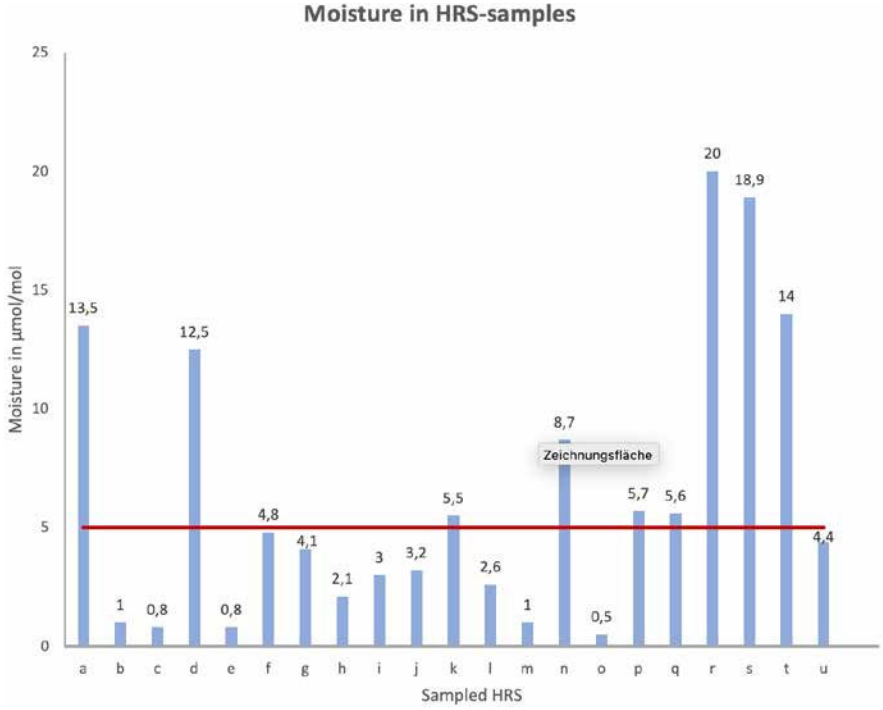


Fig. 1: Measured moisture content in 21 samples that were taken at different gas stations. Sampling and analysis were carried out by the ZBT. [Source: ZBT]

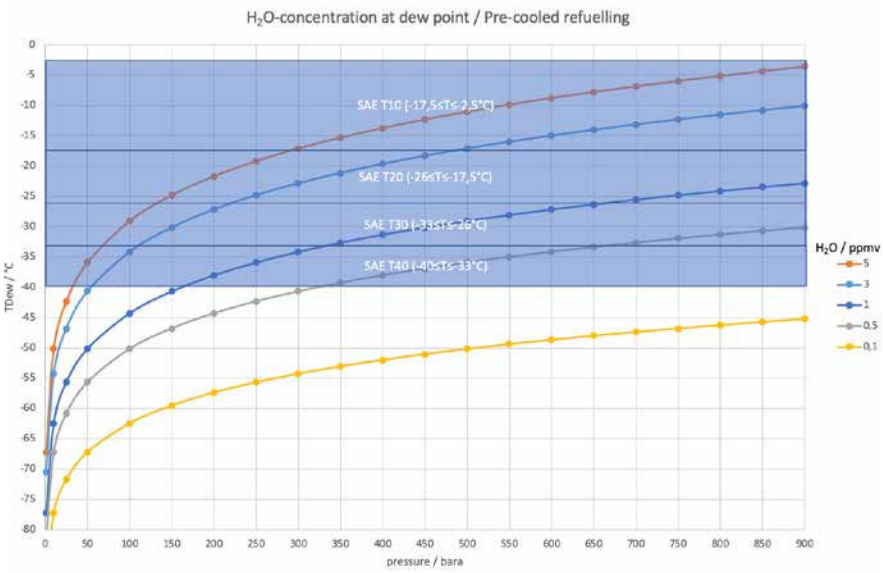


Fig. 2: Pressure-dew point curve for different H_2O concentrations (0.1; 0.5; 1; 3 and 5 ppm) [Source: ZBT]

The values very clearly document the great effect that the temperature has on the measured water load. The values determined at the transfer point can therefore deviate greatly from the values in other places in the system. At first glance, this does not seem to be disadvantageous, since the condensation leads to lower measurable concentrations at the delivery point and thus increases the likelihood of compliance with the standard specifications.

However, this may be accompanied by the negative effects for the operator that on the one hand there can be an enrichment of water in the unit and, on the other hand, the condensed water could freeze. This accumulation can have a significant impact on the operation of the units. It happens that the performance of the unit drops because pressure losses increase or components are even completely frozen over and the flow cross-section is closed.

In addition, ice particles can impair or damage them in their function due to the high flow speeds. However, due to seasonally low temperatures, the accumulation of water can occur in high-pressure storage, which can lead to the corrosion of the storage vessel and, after the winter, higher water contents. The water load is therefore a strongly safety-relevant parameter with influence on the reliability of the unit.

Compliance and detection of the standard conformity of the hydrogen quality is further made difficult by the effects described. Because if the distribution of the water in the system can change in short periods of time, the time of sampling also has a decisive influence. Seasonal effects and the previous management also play a significant role here. So the question arises: When can the sample taker take a representative sample? In addition, samples can only be removed in a few places (usually only at the delivery point). There are rarely additional points for a targeted testing of the individual containers or unit spaces.

The analysis therefore does not necessarily provide an actual knowledge of the general hydrogen quality from storage to the delivery point, but rather represents a snapshot under the prevailing framework. A comprehensive insight into the conditions of the overall system is denied. As part of the IGF funding project HRS-Modell II, the ZBT together with the chair of energy technology at the University of Duisburg-Essen will engage this topic both simulatively and experimentally.

HRS-MODELL – DESIGN AND OPERATION OPTIMIZATION Already in the now expired funding project HRS-Modell (term 2021 to 2024), the two research centers have developed a simulation tool that shows the thermodynamic processes in H_2 filling systems in detail. The tool offers the user the opportunity to map systems individually, making it easier to interpret and optimize hydrogen units. This includes, for example, the filling and emptying of storage vessels and parallel or booster refueling as well as the mapping of various operating concepts. Complex processes such as cyclical considerations and trailer change can also be simulated.

In its current version, the model is based on MATLAB Simulink and was developed with the objective to provide partners, companies and interested parties a digital test environment. A particular advantage of the model lies in its efficiency: Short computing times enable simulations even without a special simulation calculator. Results are output in real time and can be analyzed. It also enables specialized users such as component manufacturers to integrate their own components in the holistic system context and to understand the real requirements.

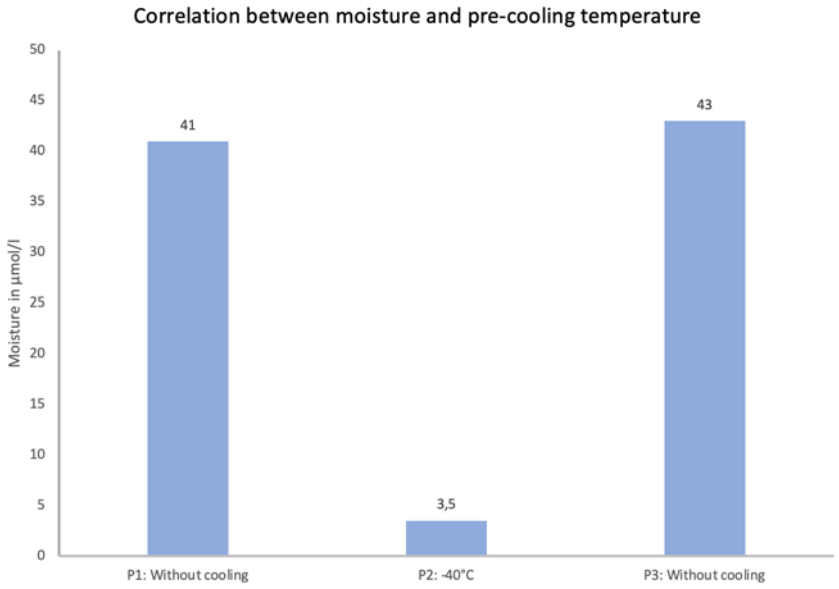


Fig. 3: Dependence of the water load on the pre-cool temperature. Three samples (P1, P2 and P3) were removed from the dispenser without cooling (P1 and P3) and with cooling (P2). With cooling switched on, significantly less water is detected than without cooling. [Source: ZBT]

The significant individual components of H_2 filling systems, such as storage vessels, compressors, cooling, pipelines and equipment, are thermodynamically integrated as individual models and the calculation methods are validated by the H_2 test field of the ZBT using the measurement data. Based on these individual models, users can build up a complete system. In the past, the HRS model has also been used for designing as part of cooperation with industrial partners.

The tool is available free of charge via its own website (hrs-modell.de/en/home-pre-en/). The aim is to share knowledge and to facilitate access to it and thus to support a better understanding of the real requirements by integrating the model into industrial and scientific applications.

FOLLOW-UP PROJECT IN THE STARTING BLOCKS In order to meet the always changing requirements, the work on and with the HRS model is now being continued in a follow-up project. The already approved project HRS-Modell II builds on the existing concept and expands it with new functions. In order to address the topic of the water load in hydrogen, a module is added to the tool that allows this very thing to be simulated in. In addition to the actual operation of the unit, the behavior of water can also be shown and analyzed. The aim is initially a better understanding of the determining effects in order to then develop recommendations for action for operators and manufacturers and thus make a contribution to better system reliability and security.

While the general processes in H_2 filling systems are comparable, the requirements and thus also the possible design and operating concepts differ. For filling systems for trailers, the large technical diversity of vehicles (different pressure levels, storage types and sizes) is an increasingly large challenge, and gas stations that have been in operation for some time have to be rebuilt or expanded in order to be able to meet current requirements. Above all, the demands for more throughput and shorter filling or withdrawal times are becoming stronger.

In order to be able to map these processes efficiently and in a targeted manner, extensive concept development and evaluation is important. As part of the HRS-Modell II project, this is addressed by adding a module to the model that can be energetic and economically efficient. The significant criteria for optimization can be set by the users. The aim is to enable users to understand the possible trade-off between capital costs (capex) and variable energy costs (opex) and to identify the specifically optimal variant for their own application. Overall, the optimization of the units already in operation and the future units can be minimized by the total costs and thus an operation optimized in economic terms can be made possible.

Experiments are carried out on the H_2 test field of the ZBT in order to map relevant system concepts and thus provide data to validate the calculation methods. The infrastructure of the test field allows the targeted approach of operating points in order to present interesting extreme scenarios for the simulation. In addition, the project structure regularly involves industry partners as part of a project support committee. As part of these and other cooperations, HRS-Modell is also validated with data from real systems.

NEW PROJECT STARTS IN APRIL HRS-Modell II is starting on April 1, 2025 and is designed for a term of 30 months. In the first year of the project, the topic of the water load is specifically focused on. The project-accompanying committee currently has 23 members. Participation in the project-accompanying committee is still possible for interested parties after the project start. In addition to sampling and analyzes of the in-house hydrogen, the ZBT is already working with partners to take samples on operated real-world units. Cooperation with partners is also actively promoted outside the HRS-Modell project, including through working in workshops, direct advice or cooperation in further research projects.

In addition to scientific use of the results obtained, care is particularly taken to make the results usable for industry. In addition to the presentation and distribution of the project results to the project-accompanying committee, industrial associations as well as national and international standardization bodies will therefore also be addressed. The model offered via the website will also be updated in the course of the project – with the clear objective that the use for all user types will remain completely free and license-free in the future.

Both projects (IGF HRS-Modell 21801 N and IGF-HRS-Modell 2_01IF23409N) were or are being funded by the German ministry of economics and climate protection on the basis of a decision by the German parliament. •

Authors:
Lukas Willmeroth
→ l.willmeroth@zbt.de

Matz Dietrich
→ m.dietrich@zbt.de
Both from ZBT GmbH, Duisburg

Hydrogen generator in the low power range

DEVELOPMENT OF A DIGITAL TWIN

With the project "Digitale Prüfplattform für die Fahrzeug- und Zulieferindustrie" (digital test platform for the automotive and supplier industry), or Digiprüfen for short, a digital twin and an AI-supported maintenance system for hydrogen generators will be used to optimize their efficiency and availability. Through sensors, machine learning and simulations, a test platform for industry is being created in the project funded by the German ministry of economics and climate protection. **Author:** Ralf Winterstein

The automotive industry is an important sector in Germany with great potential for CO_2 reduction. Unfortunately, it is one of the few sectors in Germany whose greenhouse gas emissions have not fallen as required in recent years. This is one of the reasons why an energy transition is also being sought in the automotive sector. The increasing pressure on the industry due to the threat of driving bans in cities is causing a rethink.

Some countries in Europe are already planning to say goodbye to the combustion engine between 2030 and 2040, and China is also considering the introduction of an electric car quota. The German automotive industry is also required to trade under these conditions. Two technologies are immediately available to reduce CO_2 emissions in the long term: battery electric drives and hydrogen-powered fuel cell drives. The fuel cell drive is particularly essential for the transport sector with often long distances.

A further consideration applies to the digital service based on it, which in the future can help in particular small and medium-sized companies in the vehicle and supply industry.

In order to ensure the supply of green hydrogen for the testing of corresponding components for various fuel cell systems, an H_2 generator was developed that enables users in the vehicle and supply industry to set up a virtual test environment. For this purpose, Schmidlin Labor + Service GmbH & Co. KG has equipped various hydrogen generator classes with the appropriate sensors in order to be able to map them as a virtual simulation model based on a generic model to be developed.

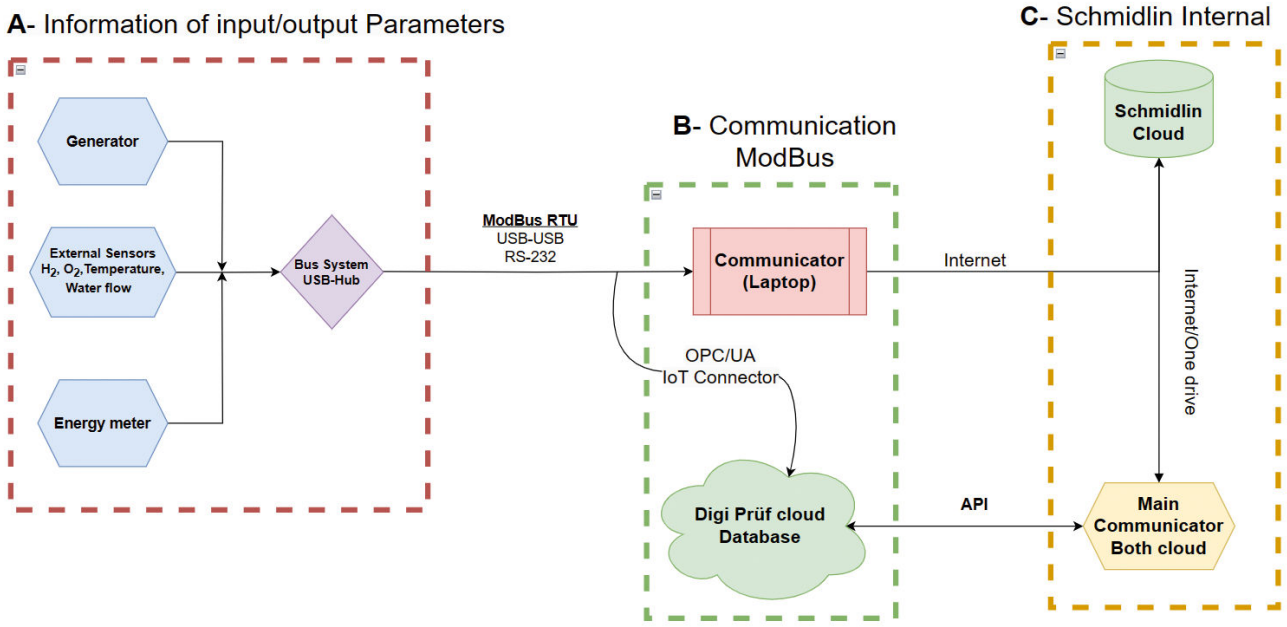


Fig. 1: A communication protocol is created by the sensors to the computer via Modbus. Using the OPC/UA IoT connector, the information can be transmitted directly to the database. [Source: Schmidlin]

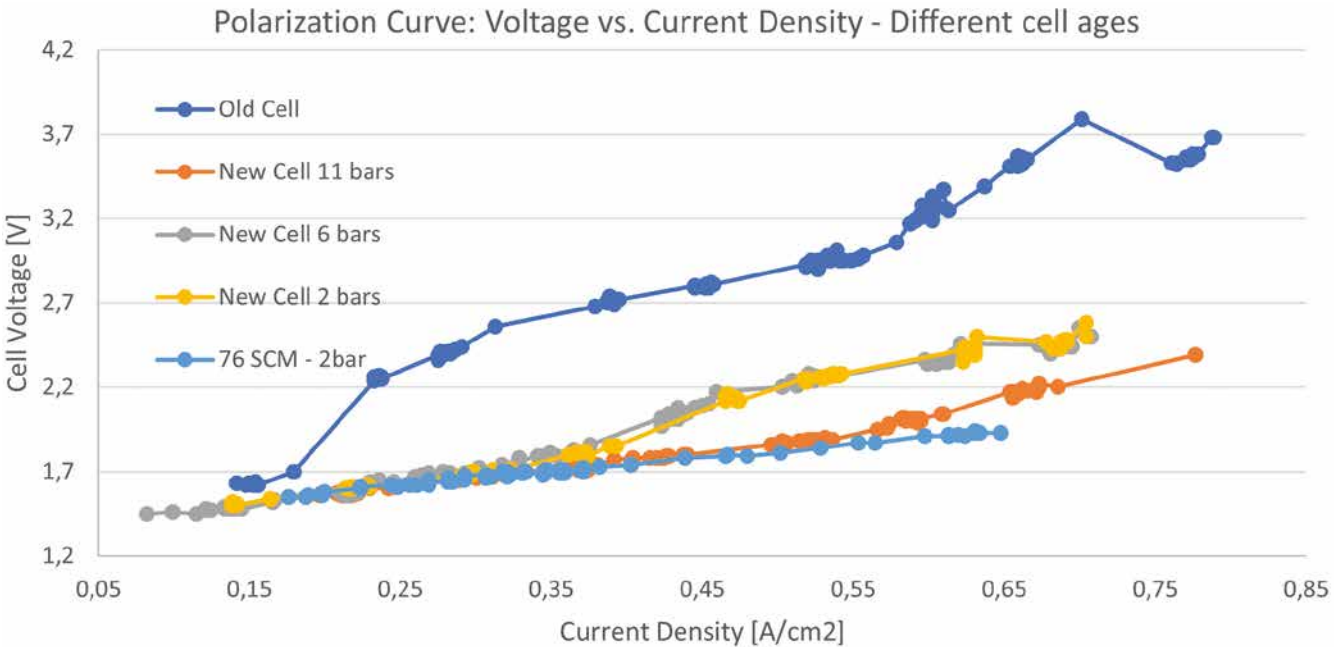


Fig. 2: To create these polarization curves, the voltage was recorded with different currents and different pressures in order to be able to map the degradation

Both algorithms and machine learning approaches are researched and developed in order to create the most accurate virtual model, that is, the digital twin. This digital twin enables different operating states and potential sources of error to be analyzed and optimized in advance. Maintenance cycles can thus be made more efficient, and the lifespan of components can be extended.

Based on this, corresponding services or microservices with regard to "Prognostics and Health Management" (PHM) are being researched and experimentally implemented. The results will be prepared as part of a common use case of the project partners. Not only is the performance of the digital twin being analyzed, but how this technology can be transferred to other industrial areas examined.

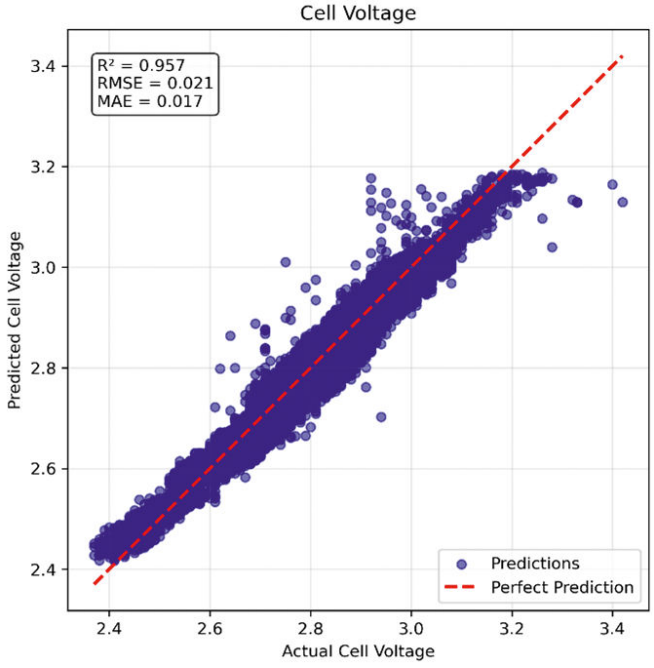


Fig. 3: Forecast of cell voltage – created with LSTM machine learning algorithms

Virtual simulation models of the test systems are required as the basis for virtual test environments. For this reason, a digital twin of H_2 gas generators in cooperation with project partners is initially developed as part of the project and as the basis for further R&D applications. The first goals are the model concept and the creation of a suitable database, which is shown in a cloud platform (see Fig. 1). Based on this, AI-based simulation models (white box and black box models) of the hydrogen generators are developed, trained and merged into an overall model (gray box model) and tested.

In addition, a "Prognostics and Health Management" system of the hydrogen generators is being researched, which gives users the opportunity to automatically monitor the condition of individual test bench components and to inform about necessary maintenance in advance (see Fig. 2). Possible failures should be recognized at an early stage so as not to affect experimental implementations. In this way, more efficient, cheaper and sustainable testing can be made possible.

First, the most important damage mechanisms and aging processes of the various H_2 generators are examined and analyzed. Corresponding and comprehensive parameter monitoring are developed and implemented on the test systems.

Subsequently, a database for the subsequent data-driven model development of the PHM system is based on these test systems. The testing, validation and optimization of the intelligent model are implemented using real experiments on the hydrogen generators (see Fig. 3). •

Author:

Ralf Winterstein
Schmidlin Labor + Service GmbH & Co. KG, Dettingen
→ ralf.winterstein@schmidlin-labor.de

System solutions for hydrogen supply and water separation

RELIABLE OPERATION OF FUEL CELLS

Fuel cell systems have much fewer components compared to other energy converters such as internal combustion engines, but even they need pumps and valves as well as the corresponding sensors. Thus, among other things, precise hydrogen dosing, safe hydrogen cut-off and precise water separation in the anode circuit of the fuel cell must be guaranteed.

Authors: Sven Geitmann, Dominik Fröhlich, Jan Beranek

Fig. 1: Robert Baustädter with the media adapter plate [Source: Proton Motor]

The basic structure of a PEM fuel cell is relatively simple (see Fig. 3). It consists of two electrodes that are separated by a membrane. On the anode side, the energy source hydrogen is supplied as fuel and on the cathode side, oxygen from the air is supplied as an oxidizer. The membrane itself is coated on both sides with catalyst material. This ensures that electrons are split off from the hydrogen molecule on the anode side. The membrane is permeable to the resulting protons, so they can pass through and make it to the cathode side, in order to be able to react there with oxygen from the air to form water.

The electrons that split off on the anode side travel to the cathode via a closed electrical circuit. Used in this are the electrical as well as thermal energy. In a vehicle, this electrical energy can then be used, for example, to charge a battery or directly for the electric drive. In the stationary area, for example for the self-sufficient energy supply of a house or building complex with electricity and heat, the fuel cell ensures emissions-free living with renewable energies. When used to secure critical infrastructures such as signal boxes or data centers, hydrogen fuel cells are used instead of diesel generators and enable the use of CO_2-neutral energy.

SAFELY DOSE HYDROGEN So that PEM fuel cells like the HyStack® 400 from Proton Motor Fuel Cell GmbH (see Fig. 2) can be operated without any problems, among other things, components for the hydrogen supply and water separation are required that meet the fluid control demands of the manufacturer and feature defined interfaces to the fuel cell stack module. Robert Baustädter (see Fig. 1), Fuel Cell Engineering division at Proton Motor, stated: "Such systems are essential for the functioning of the fuel cell, because they regulate the supply of hydrogen at the anode input and are also responsible for the safety shutdown. At the anode output, they must ensure gas purging and water separation." Only then can several of these stacks (21.3 to 49.7 kW) be connected together and in HyShelter® (see fig. on p. 4) sold to customers as a turnkey container solution.

The Bavarian company developed solutions for this together with Bürkert Fluid Control Systems, an expert for special fluidic components, whose materials are tailored to the special requirements of these areas of application and form the basis for a wide variety of system solutions. Among other things, compact blocks were developed for both anode supply and water separation, which are attached directly to the stacks

Fig. 2: The HyStack® 400 module from Proton Motor [Source: Proton Motor]

using fluidic screw connections and require little installation space (see Fig. 1). "The media adapter plates, which we have a partner produce using 3D printing, are more than just a mechanical interface. They are a multifunctional component that monitor the pressure and temperature of the individual stretches as well as ensure the proper tempering of the overarching system," reported Robert Baustädter. The fuel cells are quickly ready for operation even in sub-zero temperatures.

CONTROL VALVES IN THE ANODE BLOCK In the anode block, a servo-controlled piston valve provides safety shut-off for the hydrogen supply. An integrated pressure sensor checks for the target pressure. As a redundant safety component, a pressure switch is also installed. To increase pressure and leakage safety, the plug and core guide tube are welded together. The shape and surface quality of the housing enable maximum flow values. The coils are pressed with chemically highly resistant epoxy.

A second valve – a direct-acting proportional valve – assumes the pressure control for the hydrogen. It is, with its integrated cut-off function, likewise tightly closing. For use in fuel cell systems, suitable plug-in (cartridge) and flange housings as well as magnetic coils with automotive connectors of protection class IP6K9K are also available.

WATER AND HYDROGEN SEPARATION In fuel cell systems, the hydrogen introduced into the anode is never completely used up. In a recirculation cycle, the unused hydrogen is not wasted, but is fed back into the stack. At the anode output, the water separator with two integrated valves ensures, on the one hand, the flushing process of the fuel cell system and, on the other, the separating out of the water evolved in the stack during the chemical reaction.

For the two direct-acting plunger valves, the plug and core guide tube are welded together to increase the pressure and leakage safety. The sealing materials are adapted to the application, because the valves not only have to work precisely and reliably, but also have to be tailored to the specific area of application. With hydrogen, for example, the materials used must not become brittle and must not corrode when used with deionized water.

Robert Baustädter summarized: "For the HyStack 200 with outputs from 4 to 11 kW that is currently being developed, in principle the same fluidic systems could be used, just with smaller nominal valve sizes." •

BUSINESS OPERATIONS OF PROTON MOTOR ARE SHUTTING DOWN

At the time of going to press, it was questionable what would happen next with the Puchheim-based company. Due to financing problems, employees are currently being laid off and new investors are being sought.

Authors:
Sven Geitmann

Dominik Fröhlich
Jan Beranek
both at Bürkert Fluid Control Systems, Ingelfingen, Germany

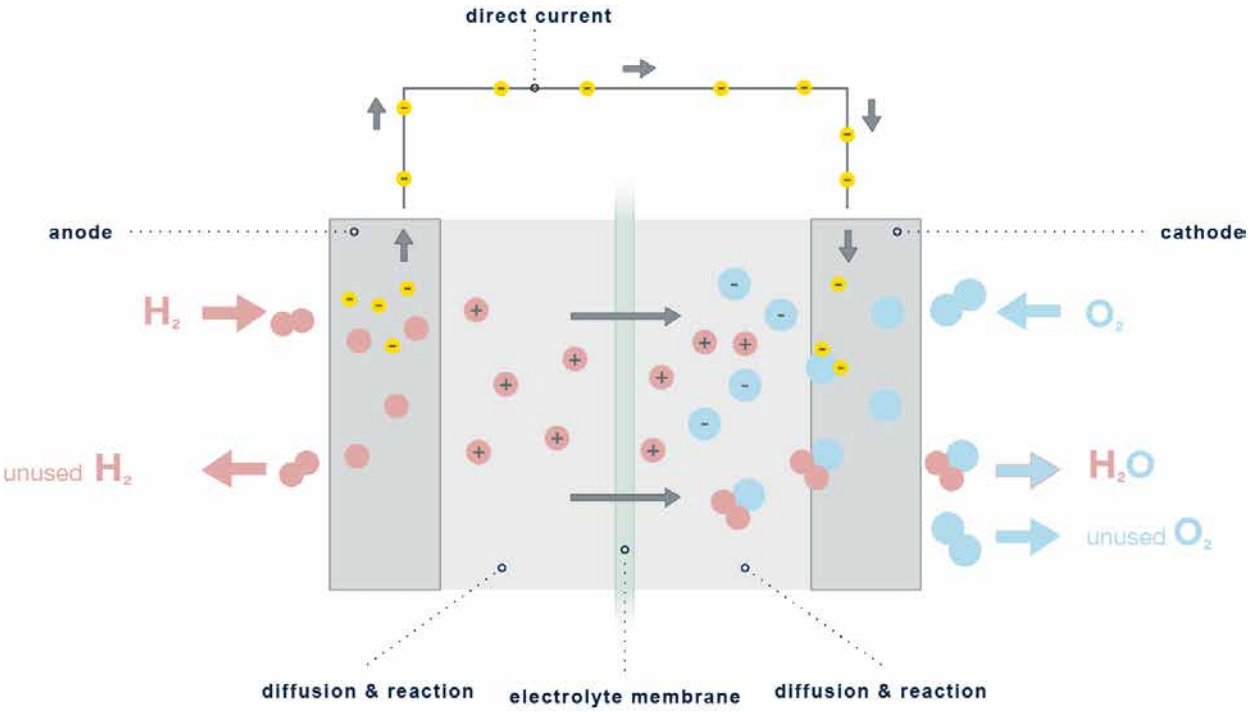


Fig. 3: Basic structure of a fuel cell [Source: Bürkert Fluid Control Systems]

MATERIAL TESTING AS A GUARANTEE OF SAFETY

For hydrogen to be able to be used as an important part of the energy transition comprehensively in industry, mobility and energy supply in Germany, new lines must be built and existing natural gas pipelines must also be upgraded for hydrogen transport. This can be challenging, as hydrogen is explosive and attacks the materials of the pipes. Professional material testing creates the necessary security regarding this. **Author:** Stephan-Lederer

With the national hydrogen strategy, the federal government is relying on hydrogen as an alternative energy source for industry, mobility and energy supply. H_2 is a promising solution to support the clean energy transition: Hydrogen has a wide range of possible applications, be it in power generation, in the operation of fuel cells for mobility applications, in industry or in heating technology. This means that hydrogen has great potential for reducing emissions; sustainability arises from the use of green hydrogen. H_2 can additionally serve as long-term storage, because it or its derivatives have a better storage capacity than electricity.

For all these areas of application, hydrogen must be transported as a gas or in liquid form: in pipelines as the backbone of an H_2 infrastructure or in tanks on the road, rail or at sea. However, ensuring the necessary security represents a technical challenge, because hydrogen is highly flammable and has a wide flammability range in which it could explode. Leaks must therefore be avoided at all costs, and materials and lines must be tight and H_2-resistant.

HYDROGEN CAN AFFECT PIPE MATERIALS This is demanding, as hydrogen reacts with other materials and influences their properties: Hydrogen embrittlement (HE) can occur when hydrogen atoms penetrate metals. H atoms diffuse into the metal structure and accumulate on lattice defects such as grain boundaries, dislocations or cavities. This reduces the strength and ductility of the metal, so its properties, leading it to plasticly deform under the load, before it gives out. This makes it more susceptible to cracks and breaks under stress.

High-strength steels and alloys (tensile strength: R_m > 1,000 MPa) are particularly affected as well as weld seams. With repeated mechanical stress, such as pressure surges like those that occur during pipeline operation, cracks can spread more quickly. Additionally, thermal-mechanical effects can be observed: At higher temperatures, hydrogen atoms can penetrate faster and deeper into the metal, and, depending on the material, another damage mechanism called HTHA (high temperature hydrogen attack) can come into play.

At higher pressure, the amount of hydrogen that can penetrate the metal increases. In humid environments, hydrogen and water can work together and accelerate corrosive attacks. Shifting temperatures and pressures then pose further challenges.

The result of these effects is a reduced service life of the transport lines: The material fatigues more quickly, cracks can occur and premature material failure can occur. That makes more frequent maintenance, inspections and the replacement of parts of the systems necessary, which leads to downtime. On top of that are safety risks such as leaks and the risk of explosion.

NATURAL GAS PIPELINES FOR H_2 TRANSPORT? Planned is the repurposing of existing natural gas pipelines for the transport of hydrogen. In parts of Germany, ten percent hydrogen is currently mixed with natural gas. The switch to 100 percent hydrogen is currently being tested in pilot projects. Many of the materials used in the natural gas pipelines are fundamentally also suitable for transporting hydrogen. However, attention must be paid to compatibility, which is why material testing is essential. This means that the material must be tested for hydrogen embrittlement and its suitability.

On the other hand, with hydrogen, whose molecules are smaller than those of methane, there is increased diffusion through seals and therefore a higher risk of leaks, which sometimes makes it necessary to replace seals and valves. In addition, better monitoring and control systems are necessary for (early) leak and situation detection.

MEASURING THE INFLUENCE OF H_2 PRESSURE ON THE INFRASTRUCTURE How hydrogen affects the materials of the infrastructure is being examined in material testing using a combination of laboratory tests, microstructure analyses, simulations and long-term field tests: In tensile tests, for example, material samples are loaded under various H_2 pressure conditions in order to measure strength, ductili-

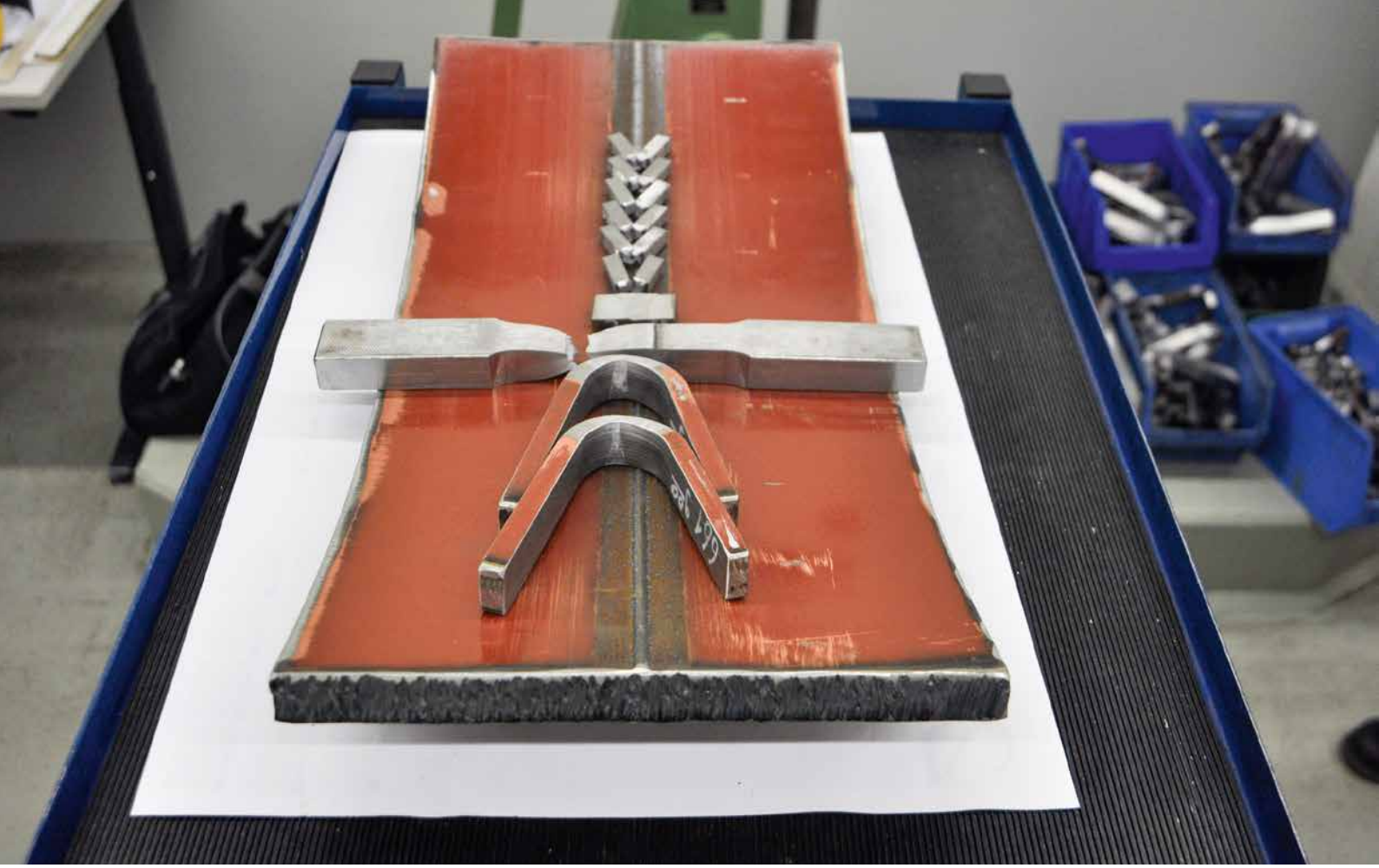


Fig.: Insight into the material testing laboratory: A part of an H_2 line with sampling according to the appropriate tests [Source: TÜV Hessen]

ty and fracture behavior. Charpy impact tests evaluate the toughness of the material and its ability to absorb energy before it breaks. Hydrogen can significantly reduce notch toughness.

During pressure and fatigue tests, materials are exposed to cyclic and different pressure conditions to investigate their fatigue strength and behavior under repeated loading. Further insights into material behavior and reliability can also be gained from field reports and data analyzes of existing hydrogen infrastructures.

Additional factors critical for assessing the suitability of materials for hydrogen pipelines include fracture toughness and crack growth behavior. They allow conclusions to be drawn about the safety, reliability and service life of the pipeline: Fracture toughness indicates how well a material can resist the propagation of a crack or defines the lowest value that a material must have in order to be considered safe for use. The tests allow precise service life predictions and, through the selection of suitable materials, longer operating times.

The quality of the pipeline welds is determined through visual inspections and non-destructive and destructive tests such as fracture mechanical analysis. International norms and standards such as ASME B31.12, ISO 11114 and others provide guidelines and minimum values that materials must meet. For example, the minimum fracture toughness is typically in the range of 50 to 100 MPa·m1/2.

Because there are still regulatory gaps, especially in national and European standards, the DIN has initiated the standardization roadmap Normungsroadmap Wasserstoff. For example, with DIN EN 13445-15 and DIN EN 13480-11 additional requirements for pressure vessels and pipelines for hydrogen applications are currently being developed.

TESTING BY ACCREDITED BODIES Material tests should be carried out by an accredited laboratory in order to meet the high quality and safety requirements. TÜV Hessen as an approved company for materials testing for example offers comprehensive testing and certification services, including non-destructive and destructive tests as well as special tests such as H_2 qualification. The accreditation in accordance with ISO/IEC 17025 certifies that the company meets the requirements of an internationally recognized standard for expertise in testing and calibration laboratories. DIN EN ISO/IEC 17025 is the globally valid standard for laboratory accreditation in the area of testing and calibration: It defines general requirements for competence, neutrality and working methods. An approved testing laboratory brings the necessary expertise through technical knowhow and experience, and guarantees independence and objectivity and compliance with international standards and thus conformity. For companies, this means increased security, risk reduction and cost savings in the long term.

SUMMARY To upgrade natural gas pipelines for the transport of hydrogen, a testing of the materials must occur. Because hydrogen embrittlement, which can arise from operation with H_2, leads to premature material fatigue and can impair safety. The necessary tests and trials should be reliably carried out by accredited testing laboratories. •

Author:
Dr. Stephan Lederer
TÜV Hessen, Darmstadt
→ mailbox@tuevhessen.de

It can still take many years until profitability

NEXT DRY SPELL FOR HYDROGEN SHARES?

Politicians have big plans, and to reduce harmful greenhouse gases, they're putting billions into the expansion of production and pipeline networks for "green" hydrogen. One of the ambitious targets is to increase its share of total energy consumption in the EU to over 20 percent by 2050 if possible. In Germany alone, they want to invest around 19 billion euros in the planned H_2 core network, which is to increase to over 9,000 kilometers across all German states by 2032. With these pipelines, hydrogen should then flow from the northern German ports to storage facilities or power plants. In the final expansion – around 60 percent of the network will be former natural gas pipes – the feed-in capacity is to be over 100 gigawatts, according to the German network agency (Bundesnetzagentur).

Author: Max Deml

In order to meet the forecast demand of 130 TWh of green hydrogen by 2030, it is estimated that around 70 percent of this will have to be imported. However, it is far from certain that the other 30 percent – despite subsidies – can be produced domestically at economically viable prices.

According to a study by the Potsdam Institute for Climate Impact Research, H_2 programs have now been implemented in over 60 countries. However, of the production capacity announced for 2023 of over 1,200 projects worldwide, only a small fraction of seven percent have been established. One reason for this is that it is still uncertain how energy prices, CO_2 taxes and state subsidies will develop in the next few years, since the global production budget of almost one trillion euros required for the expansion plans over the next six years (up to 2030) is far from being committed – and will be increasingly difficult to raise in times of increasing public debt.

In the HYPAT research project, which is developing a "global hydrogen potential atlas", the **Fraunhofer Institute for Solar Energy Systems** in Freiburg has estimated the respective costs for various locations in potential supplier countries – from Brazil to the United Arab Emirates. Depending on the power-to-X product examined (a total of five, in addition to liquid hydrogen e.g. ammonia or methanol) and storage or transport option (pipeline or ship), hydrogen prices per kilo are expected to be between 3.50 and 6.50 euros in 2030, which could fall to between 2.00 and 4.50 euros by 2050.

One of the influencing factors here is water consumption, as each kilogram of hydrogen requires up to 20 liters of water for electrolysis (incl. cooling of the systems), which in some regions can only be obtained by complex procedures such as seawater desalination.

LISTED COMPANIES IN THE H_2 SECTOR With the exception of large corporations such as the French industrial gas producer **Air Liquide SA** or **Linde plc**, in which there is only a fraction of the turnover based on hydrogen, most of the listed companies that have to do with research, production or infrastructure in the area of hydrogen have been writing losses for years. It is therefore not surprising that the shares – see key figure table for 21 companies – often fell by more than 50 percent in the twelve months from February 2024 to January 2025, with two even by 96 percent. In relation to the maximum price shares of three to four years ago, the prices are often over 90 percent lower.

Many expectations have not been met or projects have been delayed greatly. But despite increasing balance sheet losses, the stock market values are usually still significantly above the last annual sales figures.

Some smaller companies had to register bankruptcy years ago, e.g. the Canadian pressure tank manufacturer **Dynetek Industries**, the **Berlin Heliocentris Fuel Cells AG, Syngas International** or the Norwegian fuel cell manufacturer **Teco 2030,** which had planned a "gigafactory" for truck and ship drives. The non-listed **Hydrogen Emobility AG** (based in Schönbrunn Castle) was also liquidated in 2023. The stock market values of some small caps such as the Swedish **Cell Impact** or the US **Hydrogen Engine Center** have dropped to a few million euros or even less than EUR 1 million.

Other companies, such as the Danish Nel spin-off **Everfuel A/S,** which has been listed since October 2020 and whose shares were last traded at the end of 2024, were taken over. In 2023, Everfuel increased sales by 128 percent to around 5.7 million euros with around 75 employees, but the loss of almost EUR 16 million also rose to around EUR 28 million. The share price on the home exchange Oslo sank from over NOK 183 (early 2021) until May 2024 to under NOK 11 (which corresponded to a stock market value of almost 80 million euros).

At this point, a hydrogen pipeline between Denmark and Germany was planned, for which Everfuel was to supply around 10,000 tonnes of green hydrogen (RFNBO, i.e. non-biological origin) annually (which would have required an electrolyzer capacity of at least 100 MW). Now the free Everfuel shares – forcibly – hiked to a price of NOK 13 via the **Faro Bidco APS** in infrastructure investment funds that will be advised by **Swiss Life Asset Management AG.**

Still other stocks, such as that of the Canadian **Powerap Hydrogen Capital Corp.** (www.powertapcapital.com), formerly a cannabis startup, have hardly been traded after the plan to set up an H_2 gas station network in the USA and Canada could not be realized. The share price dropped from around USD 50 (2021) to below USD 0.01.

Sunk strongly from NOK 25 to under NOK 1 is also the price of **Havila Kystruten AS,** founded in 2017 and listed since 2021, which operates four hydrogen battery-powered passenger ships (mainly for tourists) along the Norwegian coast from Bergen to Kirkenes and has been making more losses every year since its launch (2023 e.g. over NOK 900 million) than turnover (approx. NOK 764 million).

In the following are details of more or less important H_2 shares – in alphabetical order:

BALLARD POWER SYSTEMS

The company, founded in 1979 (initially with the aim of researching and developing lithium batteries) and, which has been listed since 1993, has repeatedly financed losses in billions in the area of fuel cells through capital increases. **The Automotive Fuel Cell Cooperation** (AFCC), the division for automotive drives, was sold to Daimler and Ford in 2008 and dissolved again in 2018, with the majority of the machine park going back to Ballard Power. In 2018, **Weichai Power** took a stake in **Ballard Power** with around 20 percent in order to use its technology for trucks and buses in China. At the end of 2024, the fuel cell pioneer received another delivery order for 98 hydrogen engines from the railway operator **Canadian Pacific Kansas City,** which are intended to replace the diesel engines of the locomotives – for refueling, there are already the first hydrogen gas stations on the route.

BLOOM ENERGY

Bloom Energy from San Jose, California, is one of the few share price winners in 2024. The company, founded in 2002 by four former NASA employees, specializes in the production of fuel cells for stationary power supply. Despite a lower turnover of USD 330 million (-18%), the loss of USD 169 million in the previous year was reduced to less than USD 15 million in the 3rd quarter of 2024.

CERES POWER HOLDINGS PLC

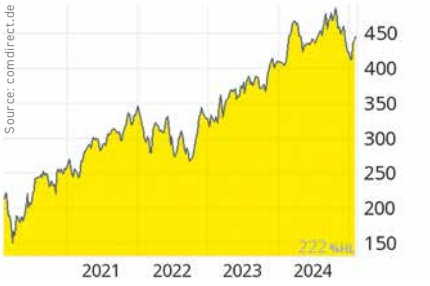
The British company, founded in 2004, develops electrolysis technologies for green hydrogen and fuel cells for electricity production in the business areas SOFC (solid oxide fuel cell) and SOEC (solid oxide electrolysis cell). It belongs to around 37 percent of the two main shareholders **Weichai Power** and **Robert Bosch GmbH.**

ENAPTER AG

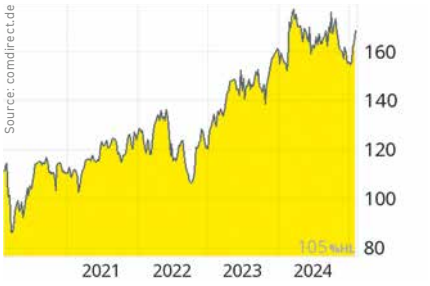
The company, headquartered in Germany with a research and production location in Italy, has developed electrolyzers in single- and multi-core systems and has now sold to over 350 customers in over 50 countries, from energy and transport to heating and telecommunications companies. After projects were delayed, management in November reduced the sales forecast for 2024 from EUR 34 million to EUR 22 to 24 million – the annual loss could reach the ten million-euro mark. Part of the order volume of around 50 million euros comes from the US subsidiary **Clean H2 Inc.** (www.cleanh2.energy), which is benefitting from the Inflation Reduction Act, including the funding of hydrogen applications.

FUELCELL ENERGY

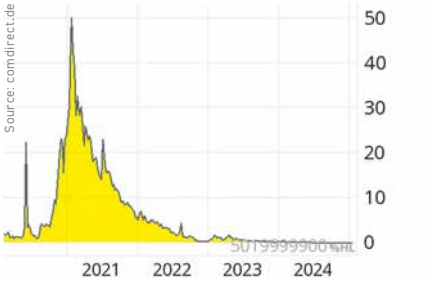
The company based in Danbury, USA, which is primarily active in the field of industrial production, was founded in 1969 and employed 591 employees at the end of the last financial year. Ja-



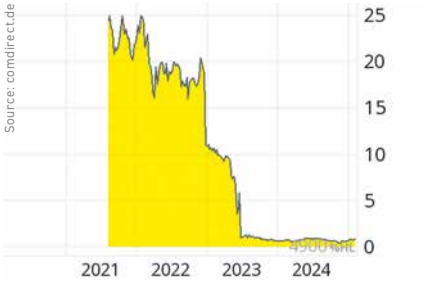
Linde plc, in USD



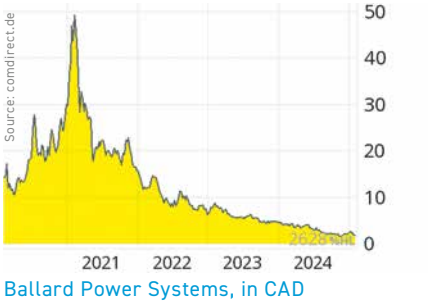
Air Liquide SA, in EUR



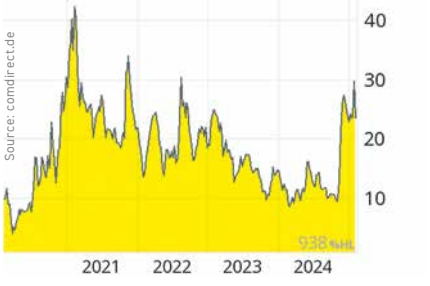
PowerTap Hydrogen Capital Corp., in USD



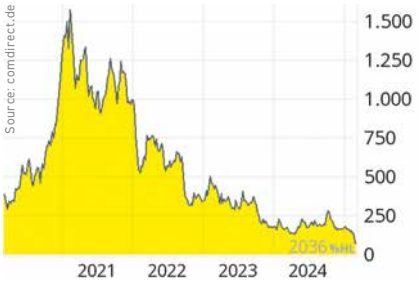
Havila Kystruten AS, in NOK



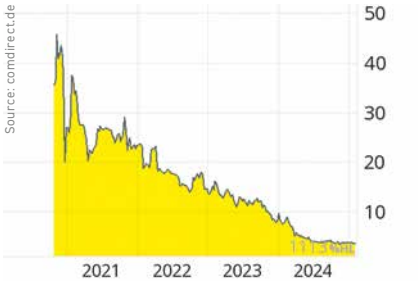
Ballard Power Systems, in CAD



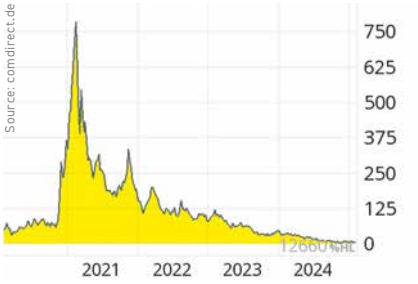
Bloom Energy, in EUR



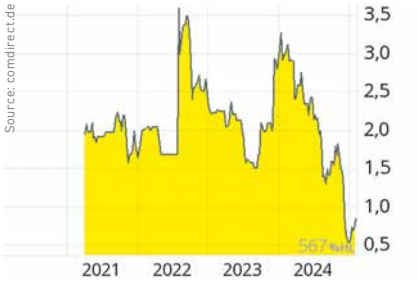
Ceres Power Holdings plc, in GBp



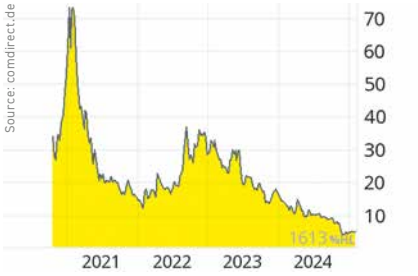
Enapter AG, in EUR



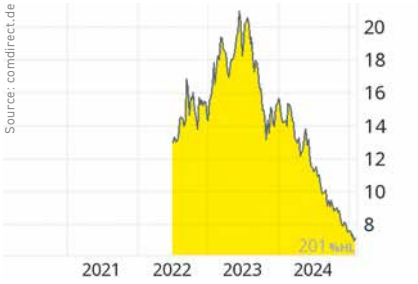
FuelCell Energy, in EUR



H2 Core AG, in EUR



Hydrogenpro ASA, in NOK



Industrie De Nora SpA, in EUR

son B. Few held the chairmanship. The largest shareholders are The Vanguard Group, Inc., BlackRock Fund Advisors and Legal & General Investment Management Ltd.

H2 CORE AG

H2 Core Systems GmbH, a spin-off of the TC Hydraulik Group, was assessed as a contribution in kind with EUR 36 million and against 10 million stocks (to the shareholders **TC Holding GmbH, World Wide Green Holding GmbH, BluGreen Company Ltd.** and **Enapter AG**) brought into **MARNA Beteiligungen AG,** which had left the previous business area (ship financing) and has been renovated to H2 Core AG. Together with the previous share of around 1.5 million stocks and a capital increase in mid-2024 (324,826 new stocks were issued at EUR 2.20 per share), there were over 11.8 million stocks at the end of 2024. In the first half of 2024, the sales of the system integrator (with customers in Europe, Asia, South America and the USA) rose by 48 percent to around EUR 3.13 million, with the loss to EUR 2.5 million. Enapter AG is the main supplier of the electrolysis blocks (stack modules) necessary for the hydrogen-based plug-and-play supply solutions from H2 Core.

HYDROGENPRO ASA

The main product of the company specializing in hydrogen and renewable energies is an alkaline high-pressure electrolyzer. Innovative coatings were developed with the acquired Danish **Advanced Surface Plating APS.** The systems can be adapted to the customer's request. The main shareholders are the Austrian plant engineer **Andritz AG** (23%) and the Japanese **Mitsubishi Heavy Industries** (17%).

INDUSTRIE DE NORA S.P.A

The Milan company, founded in 1923 (by Oronzio de Nora) and has been listed since 2022, is one of the world market leaders in the field of electrochemistry. In addition to electrodes and coatings for various industries (e.g. chlorine chemistry), electronics components, water filters and disinfection technologies, the product range also includes components for hydrogen electrolysis. De Nora is present in ten countries – there are also research centers in Italy, Japan and the USA – and after the Thyssenkrupp Group with almost 25 percent, is the second largest shareholder of the **Thyssenkrupp Nucera AG & Co. KGaA.** In 2023, sales rose only minimally to a good 856 million euros, but the profit by 158 percent to EUR 231 million. In 2022 and 2023, dividends (each 0.12 euros per share) were distributed. The equity ratio is relatively high with 68 percent recently, but the profit may have decreased considerably (estimated to be less than 80 million euros) in 2024 – as well as the share price, from over 20 euros (mid-2023) to less than 7 euros in February 2025.

ITM POWER PLC

The British company, founded in 2001 **(www.itm-power.com),** is one of the most established companies in the electrolysis industry in Europe, even if sales are still very low compared to the stock market value. ITM Power, whose three major shareholders also include **Linde,** has, among other things, founded a joint venture (50/50) with Linde: **ITM Linde Electrolysis GmbH** (ILE GmbH) wants to implement the world's largest electrolyzer system in Leuna, Germany. ITM Power offers several electrolyzer models, from Trident (2 MW) and Neptune to Poseidon (20 MW) for major projects. The share price dropped from GBP 7.17 (early 2021) by over 95 percent to less than 0.35 (February 2025), which corresponds to a market value of almost GBP 220 million, almost ten times the turnover of the last four quarters.

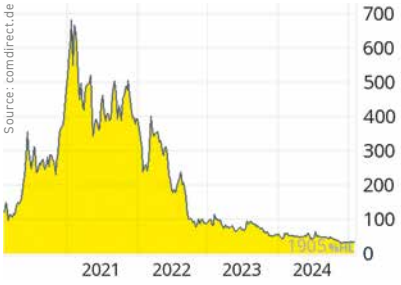
MCPHY ENERGY S.A.

The company, headquartered in Grenoble and having several subsidiaries such as **McPhy Energy Deutschland GmbH,** sees itself as "developers and manufacturers of systems for the production and distribution of carbon-free hydrogen." In addition to electrolyzers, the locations in France, Germany and Italy also offer storage containers and systems, including for the energy and transport area. The sales forecast for the financial year 2024/02/01 to 2025/01/31 was reduced from 18 to 22 million euros to EUR 11 million in autumn 2024.

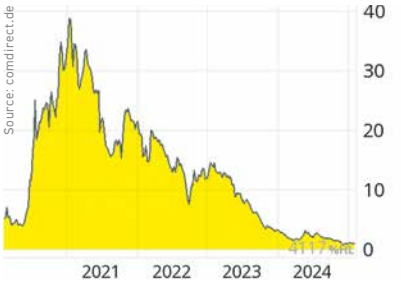
NEL ASA

After electrolysis, the Norwegian company, founded in 1927, also specialized in infrastructure (construction of hydrogen refueling stations and injector systems, mainly for transportation) and founded with **Hexagon Composites** and **PowerCell Sweden** the joint venture **Hyon** for the area of watercraft

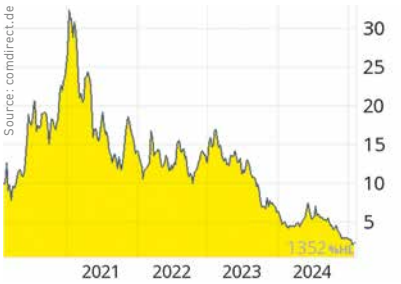
Country	Company	Share	Share Euro	MK (Mio EUR)	KUV	KGV	EK-G	Div. Return
F	**Air Liquide SA**	176.62	176.62	101,807	3.7	33	52%	1.6%
CAN	**Ballard Power**	1.75	1.16	349	3.8	neg.	92%	0.0%
USA	**Bloom Energy**	24.02	22.99	5,255	4.1	neg.	22%	0.0%
GB	**Ceres Power Holding plc**	73.80	0.89	173	6.4	neg.	88%	0.0%
D	**Enapter AG**	3.49	3.49	101	3.2	neg.	57%	0.0%
USA	**FuelCell Energy**	5.77	5.52	113	1.1	neg.	77%	0.0%
D	**H2 Core AG**	0.82	0.82	10	1.9	neg.	31%	0.0%
N	**Hydrogenpro ASA**	4.795	0.41	34	0.7	neg.	70%	0.0%
I	**Industrie De Nora SpA**	8.855	8.86	1,786	2.1	21	69%	1.4%
GB	**ITM Power plc**	29	0.35	217	10.9	neg.	52%	0.0%
GB	**Linde plc (Kurs in USD)**	445	425.94	202,814	6.5	33	51%	1.1%
F	**McPhy Energy SA**	0.94	0.94	28	1.5	neg.	54%	0.0%
N	**Nel ASA**	2.23	0.19	319	2.2	neg.	72%	0.0%
USA	**Nikola**	0.201	0.19	16	0.5	neg.	55%	0.0%
USA	**Plug Power**	1.61	1.54	1,404	1.6	neg.	59%	0.0%
S	**PowerCell Sweden AB**	32.20	2.88	167	6.0	neg.	65%	0.0%
GB	**Proton Motor Power Systems plc**	0.15	0.00	3	1.2	neg.	neg.	0.0%
D	**SFC Energy AG**	18.46	18.46	321	2.7	15	71%	0.0%
I	**Snam SpA**	4.649	4.65	15,574	3.7	14	23%	6.0%
D	**thyssenkrupp nucera AG & Co. KGaA**	8.415	8.42	1,063	1.2	97	59%	0.0%
HK	**Weichai Power**	15.28	1.88	16,414	0.6	13	34%	3.7%
	Summe / Median			**347,968**	**2.2**		**58%**	**0.0%**



ITM Power PLC, in GBp



McPhy Energy SA, in EUR



Nel ASA, in NOK

with fuel cell drives in 2017. As part of the **PosHYdon** consortium, an offshore hydrogen production system (on the oil and gas platform Q13a-A of **Neptune Energy**) is also planned. After Nel CEO Håkon Volldal in 2024 only saw "limited synergies between the business areas of refueling and electrolyzers," the refueling division under the name **Cavendish Hydrogen** was outsourced and separately brought to the stock exchange in Oslo. In 2023, Cavendish generated and announced an equally high loss with NOK 330 million turnover (+59%) and announced the releasing of around 45 percent of the employees in the 1st quarter of 2025.

NIKOLA

A tragedy is the share of the US company named after **Nikola Tesla** based in Phoenix, Arizona. Already at the presentation of the first "hydrogen-powered" truck, it turned out that the advertising video was a fake (a moving Nikola truck was shown that was not operated with hydrogen). There are collaborations with German companies and with the Norwegian Nel (for a hydrogen refueling station network in the USA). After a hype with share prices of over USD 80 (split-adjusted would have been around USD 2,000) and judicial convictions of the first CEO, the stock is now a penny stock. The stock market value has shrunk from at one time tens of billions to around USD 50 million, which is not surprising: In 2023, a record loss of over USD 864 million at not even USD 36 million turnover.

PLUG POWER

The US company is one of the world's largest buyers of liquid hydrogen, but after the takeover of **United Hydrogen** (2021) it also produces it itself. At the beginning of 2025, the US energy ministry (DOE) via the Loan Programs Office (LPO) and in accordance with the Justice40 initiative of the Biden Administration gave the green light for the requested loan guarantee of USD 1.66 billion. This is intended to finance the development, construction and ownership of up to six systems for the production of green hydrogen. A sign of hope after reducing the sales forecast for 2025 from USD 1.5 billion to 850 to 950 million at the end of 2024.

POWERCELL SWEDEN AB

The company, founded in 2008, produces fuel cell systems that can convert fossil as well as renewable energy

12 Months	www.	MA	Revenue Mio. Euro
4%	www.airliquide.com	67,800	27,610
-60%	www.ballard.com	1,200	92
165%	www.bloomenergy.com	2,400	1,276
-60%	www.cerespower.com	600	27
-52%	www.enapterag.de	200	32
-84%	www.fuelcellenergy.com	600	107
-72%	www.h2core.com	40	5
-63%	www.hydrogen-pro.com	230	49
-51%	www.denora.com	2,000	856
-48%	www.itm-power.com	360	20
8%	www.linde.com	66,300	31,443
-53%	mcphy.com	270	19
-50%	www.nelhydrogen.com	670	144
-99%	nikolamotor.com	870	34
-59%	www.plugpower.com	3,900	853
-8%	powercellgroup.com	150	28
-96%	www.protonmotor-powersystems.com	110	3
6%	sfc.com	400	118
6%	www.snam.it	3,800	4,244
-45%	www.thyssenkrupp-nucera.com	650	862
6%	www.en.weichaipower.com	47,600	29,002
-51%		**200,150**	**96,823**

Legend to the table:
Mcap = market capitalization in million euros
ER = Equity ratio
P/S = Price-to-sales ratio
P/E = Price-to-earnings ratio
DivY = dividend yield
NrE = number of employees
12-month: share price performance from March 1, 2024 to February 28, 2025
The figures refer to the most recent fiscal year (usually 2023).
Share prices in euros or home currency (on the home exchange)
CAD = 0.66546 Euro
GBp = 0.0121137 Euro
HKD = 0.1231 Euro
NOK = 0.08547 Euro
SEK = 0.08948 Euro
USD = 0.95716 Euro
(as of February 28, 2025)
[Sources: Reuters, Marketscreener, Öko-Invest, company information]

sources into hydrogen. So far, it has produced losses, with one exception in 2019: The sale of around 50 million euros was achieved by selling an exclusive production and sales license for the S3 fuel cell stack to **Robert Bosch GmbH.** In the first three quarters in 2024, sales rose by four percent to over SEK 190 million, but accrued a loss, like in the previous year's time with SEK 53 thousand, of around SEK 50 million.

PROTON MOTOR POWER SYSTEMS PLC

The British fuel cell company with the German subsidiary **Proton Motor Fuel Cell GmbH,** which also develops products in the area of hydrogen, has hardly been over annual sales of over GBP 2 million in the past seven years. In 2018 and 2019, there were only around 0.8 million pounds – with mostly higher, often double-digit million losses. The equity ratio has been negative for many years. The share price dropped from over 50 pence (early 2021) by more than 99 percent to around 0.1 pence (February 2025). In order to save costs, the management considered at the end of 2024 to take the stock off the stock exchange soon.

SFC ENERGY AG

The company (formerly SFC Smart Fuel Cell AG) offers systems and components with small fuel cells (10 to 250 watts of power) that can be used to produce electricity independently and noiselessly, for example on campsites, but also for military applications.

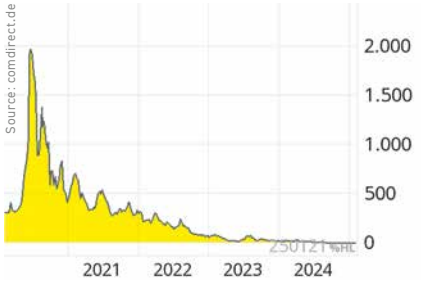
In the first three quarters in 2024, company turnover rose by 20 percent to over 105 million euros, with the profit by 35 percent to EUR 8.7 million.

SNAM S.P.A.

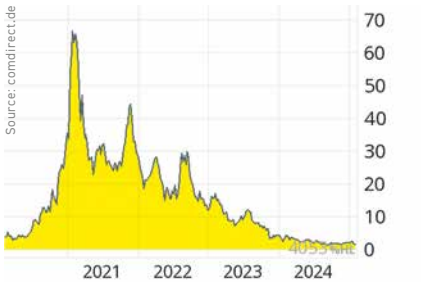
The company, which was founded by the energy corporation Eni in 2001, operates a natural gas transport network of around 38,000 km in and also outside of Italy and gas storage of 15 percent of natural gas reserves in Europe. In the hydrogen sector there is a joint venture with **Industrie De Nora S.p.A.,** and participating in the large **SouthH2 Corridor** project are Snam along with partners **Gas Connect Austria GmbH, Bayernets GmbH** and **TAG GmbH.**

THYSSENKRUPP NUCERA AG & CO. KGAA

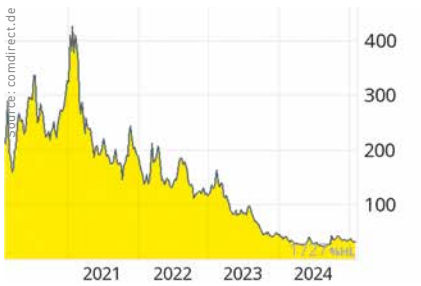
In 2024, the electrolysis company split off the Thyssenkrupp Group (Thyssenkrupp AG remained as a good 50-per-



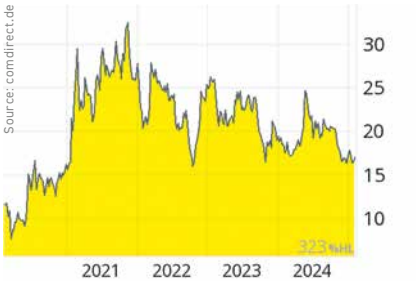
Nikola, in EUR



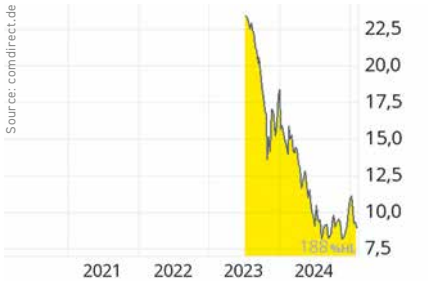
Plug Power, in EUR



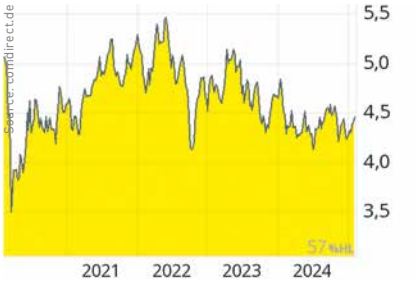
PowerCell Sweden AB, in SEK



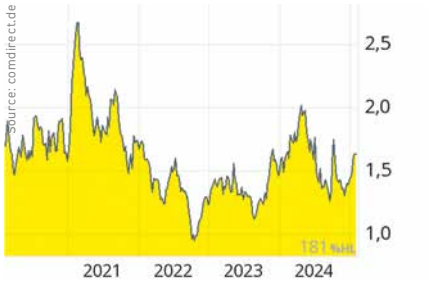
SFC Energy AG, in EUR



thyssenkrupp nucera AG & Co. KGaA, in EUR



Snam SpA, in EUR



Weichai Power, in EUR

The author Max Deml (born 1957) has been editor-in-chief of the Öko-Invest stock exchange letter since 1991 and author of the manual "Grünes Geld" (green money, 8th edition since 1990). In 1997, he developed the international nature stock index NX-25 (with 25 members) and in 2001 the solar stock index PPVX, which contains the 30 largest listed PV production, supply and operator companies.

cent main shareholder) gained Fraunhofer IKTS as a strategic partner for "highly innovative high-temperature electrolysis" (SOEC technology) – and the US energy ministry has selected Thyssenkrupp Nucera "to advance the mass production of water electrolysis cells and to build up an automated assembly line of these cells." In financial year 2023/2024 (as of 2024/09/30), an operational loss of EUR 22 million was generated with a turnover increase of 32 percent to EUR 862 million (including over 500 million euros in the area of alkaline water electrolysis).

WEICHAI POWER

This vehicle technology group, founded in 1953, was called **Weichai Diesel Engine Factory** until 1992 and still produces diesel engines in China today. With participations such as that of **Ballard Power** and **Ceres Power,** they now also deal in the production of fuel cell products or hydrogen applications. The share prices of the H_2 stocks also listed on German stock exchanges swung between 0.93 and 2.78 euros in recent years, most recently at around 1.70 euros. •

Starting torque for hydrogen as an energy carrier and raw material

WHY DOES GERMANY NEED HYDROGEN?

The synthesis report of the IPCC "Klimawandel 2023" (climate change 2023) [1] comes to the following statement under point B1: "Persistent greenhouse gas emissions will lead to increasing global warming, whereby 1.5 °C in the scenarios and modeled paths under consideration will be achieved in the near future. Every little increase in global warming will increase multiple and simultaneously occurring dangers. A profound, fast and persistent reduction in greenhouse gas emissions would lead to a detectable slowdown of global warming and furthermore within a few years to demonstrable changes in the atmospheric composition."

Authors: Reinhold Wurster, Ulrich Bünger

The past few years show that the fastest increase in generation performance with photovoltaics and wind energy can be achieved in the energy generation sector. China is the best and most impressive example. Only renewable energies enable an almost climate-neutral energy supply. Since we only have about a decade and a half of the IPCC to comply with the 2 °C target for decarbonizing the energy system, nuclear energy is excluded from having a significant contribution. The fact that China shares this insight can be read from the "China Energy Transformation Outlook 2024" (CET 2024) [2].

In addition to resource availability, climate change is the main reason for the entry into an energy system that builds on renewable electricity and hydrogen.

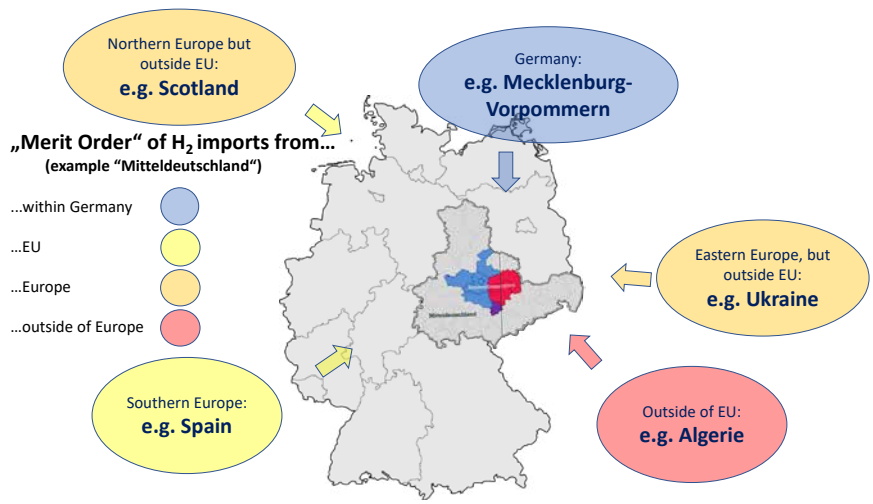


Fig. 1: Merit order of the H_2 import paths via the gas network to central Germany [Source: [5]]

The following sections shed light on the other reasons for Germany in particular to use hydrogen on a larger scale.

AVOIDING THE CURTAILMENT OF RENEWABLE ENERGY PLANTS According to the German network agency (Bundesnetzagentur, BNA), renewable energies accounted for 59% of electricity generation in Germany in 2024. The plan is to increase this proportion to 80 percent by 2030. As hydropower and biomass can no longer or hardly be expanded, only the fluctuating sources of PV and wind, both of which supply electricity, remain to increase the share. It is foreseeable that the massive expansion of the electricity grid required to transport them will not be sufficient at the transmission and distribution level.

Furthermore, the fluctuating electricity generation and the consumption can be reconciled less and less. A significant structure of large energy storage capacities is required to avoid the reset of generation plants in times of weak demand and high production. The energy stored in this way can then be used again in times of generation lulls and demand peaks. Only with chemical storage – i.e. primarily hydrogen as an energy carrier or its derivatives – is

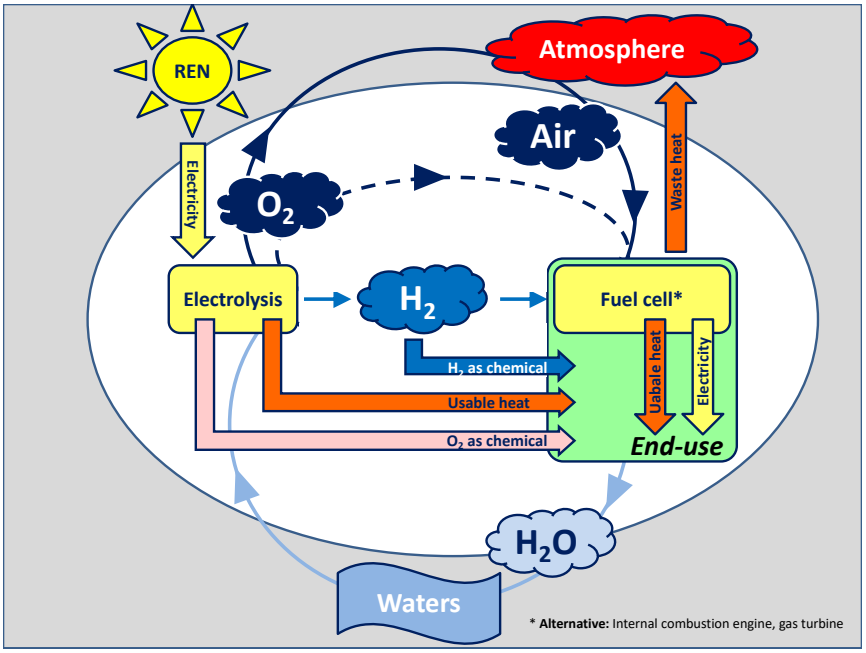


Fig. 2: Circular economy system, based on renewable energies (RE), air/oxygen (O_2) and water (H_2O) [Source: U. Bünger]

a compensation of these disparities to a sufficient extent over periods of days or weeks economically representable [3], [4], since the end customers do not have to bear the direct electricity costs (Levelized Cost of Electricity, LCOE) from wind and solar systems, but rather the costs for covering their electricity requirements (Levelized Cost of Load Coverage, LCOLC). The latter also includes the expenses for the stabilization of the electricity system using batteries and especially peak-load gas power plants (now natural gas but in future H_2 companies).

STABILIZATION OF ELECTRICITY/ENERGY SUPPLY All electricity demand peaks that are not intercepted by demand shifting (load shedding) or pumping or battery storage as short-term storage are required to use peak-load power plants. FHG-ISE [5] has a capacity of 99 to 116 GW flexible gas and hydrogen power plants in the long term to compensate for fluctuations in electricity supplies. With this approach, the so-termed "Dunkelflaute" ("dark doldrums," combination of low wind energy and low PV volume, e.g. in low-wind nights or generally in the winter half of the year) can be intercepted.

Germany has the greatest potential of underground salt formations in Europe, located in northern Germany, Central Germany and Northern Hesse, which can be used for gas storage of large volumes. With these, offerings and demand fluctuations of natural gas are already balanced seasonally, and they can also be used for the large-scale storage of hydrogen in the future. On the one hand, these storage locations can be filled with the H_2 generated from surplus current and, on the other hand, with hydrogen imported from southern Spain and North Africa via pipeline. This can then be taken out of storage as needed to cover peak loads with electricity as well as a supply for all other H_2 applications (industry, transport).

ROBUSTNESS OF THE ENERGY SYSTEM An additional gain from the need to produce hydrogen as a compensation element to avoid a curtailment of renewable electricity can consist of a further expansion of renewable energies and more production of hydrogen in Germany, which in turn leads to a reduced dependence on energy imports and thus to more security of supply. However, this also requires higher investments and, when needed, operating costs. A full increase in efficiency in the energy system would help reduce the total costs on the one hand, but on the other hand, but also the development pressure to expand renewable energy sources as a whole.

In addition to the purely economic aspects of a future energy supply, numerous other criteria of strategic importance must be taken into account: Hydrogen-specifically include the use of domestic value creation potential, political and environmental security (diversification of energy sources and strategic energy reserves) as well as the avoidance of environmental effects, e.g. unnecessary resource pressure on scarce energies or materials, for example due to imprudent transports over long distances. In Figure 1, using the example of central Germany, a "merit order" qualitatively derived from these arguments for the prioritization of the H_2 imports is depicted, in which the value of domestic H_2 production increases with decreasing transport distance.

ENERGY SYSTEM INTEGRATION A central demand for the German gas industry is a planning of the relevant energy infrastructures for electricity and gas/hydrogen in the future. This should result in sensible short or long-term storage options, taking into account the generation and consumption locations [7]. Power-to-gas (PTG) – or general PTX – is becoming increasingly a key term of the energy system [8]. According to the current national H_2 roadmap, this will also integrate transport and heating networks as part of a future system development strategy (SES) [9].

The planning task for these strategic public supply infrastructures is therefore responsible for politics, whereby the Bundesnetzagentur is in a close coordination with the responsible companies. This requirement is primarily based on the insight that

- Energy transport and storage of small amounts of energy over short distances and short periods of time are particularly efficient and economical through electrons.
- The desired storage of large fluctuating amounts of energy over longer periods of several days, weeks or sometimes also months (e.g. strategic energy reserve) and the transport of large amounts of energy, partly over large distances (e.g. energy imports), is particularly efficient and economical primarily with the help of molecules.

CIRCULAR ECONOMY Hydrogen is part of an almost perfect and simple circulatory-based energy system, including the infrastructures for water (H_2O – liquid), electricity, heat and hydrogen as well as the "natural" transport infrastructure in the form of the atmosphere for water vapor (see Fig. 2). Oxygen (O_2) can also be beneficially included in the circulation. This circulatory system is completely possible without complex carbon compounds,

which can be made synthetically from H_2 for specific needs of industry (power-to-chemicals – PtCh).

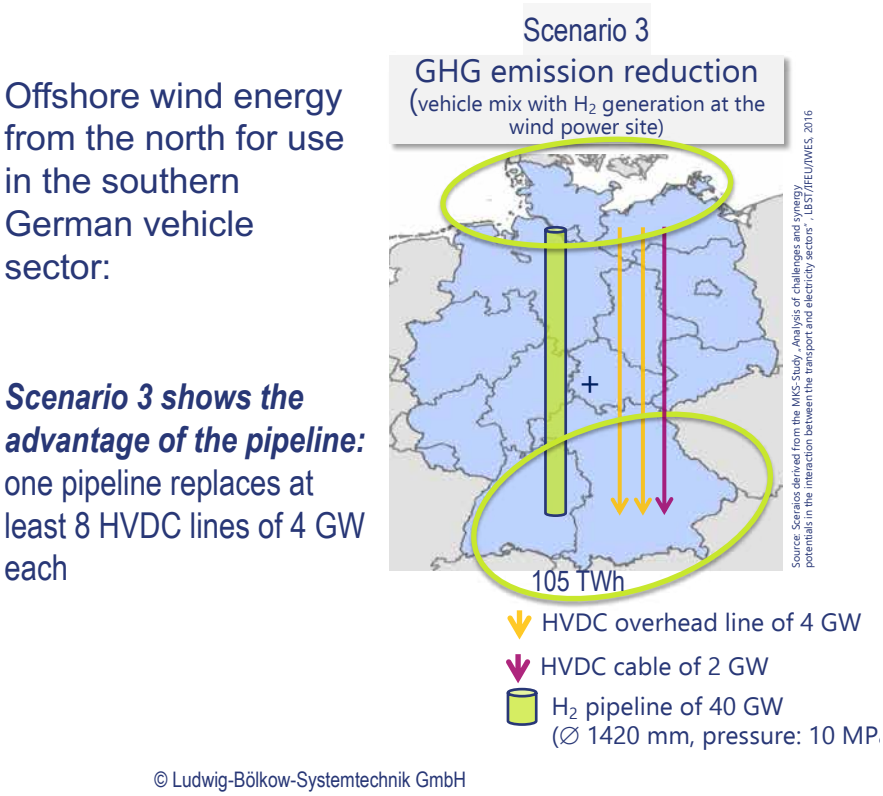
Due to the simultaneous use as an energy source and chemical raw material, an energy cycle based on hydrogen supplements the European strategy of the circular economy in an almost perfect way [10], [11].

The most environmentally friendly and sustainable method to obtain H_2 is the electrolysis in which water is used, which is again molecular as water at the end of the process chain, i.e. after an energetic implementation in fuel cells, combustion engines or gas turbines, as water (steam) is emitted into the atmosphere. Blue hydrogen, on the other hand, causes a carbon backpack, because the CO_2 has to be elaborately stored and thus disturbs the closed energy cycle. In addition, residual CO_2 emissions of the processes referred to as carbon capture and storage (CCS) cannot be avoided, which, depending on the supply option, can correspond to up to 30 percent of equivalent GHG emissions for gray hydrogen [12].

A resilient regional energy industry does not differ from a global one that relies on national transports of hydrogen. Even in the global transnational connection, a hydrogen-based energy system is still considered circulating, but the atmospheric oxygen used and the then produced water (as water vapor) are added to the atmosphere and become components of larger material cycles.

A current topic is the significance of hydrogen referred to as "geogenic" or "white," so in the form of pure molecules near the earth's surface, which should be extracted, similar to how natural gas is extracted [13], [14]. On the one hand, these analyzes are still at the very beginning and the questions open-ended. Secondly, it can be stated that white hydrogen will not replace the hydrogen produced in utilization processes based on renewable electricity using electrolyzers for load balancing of fluctuating electricity and can therefore only cover part of the global need. Thirdly, like fossil energies, it is also considered terminal and therefore not suitable for circular economies.

In addition, the extraction of geogenic hydrogen, similar to natural gas extraction, is likely to result in hydrogen slip losses, which must be prevented in any case due to its climate impact of 11.6 ±2.8 (GWP100) [15].



Scenario 3 shows the advantage of the pipeline: one pipeline replaces at least 8 HVDC lines of 4 GW each

Fig. 3: Comparison of high-voltage direct current transmission with H_2 pipeline [Source: [19]]

INFRASTRUCTURAL ADVANTAGES OF A HYDROGEN SUPPLY Final energy consumption in Germany in 2022 was supplied by 500 TWh of electricity and 1,888 TWh of fossil molecules (coal, oil, gas) [16]. Of the 500 TWh of electricity, approx. 240 TWh (48 %), but only 226 TWh (12 %) of the 1,888 TWh of molecule-based energy was generated from renewable sources. This means that at least six times as much energy must be replaced in the form of molecules as in the form of electrons for an energy supply based entirely on renewable energies.

For applications that cannot be supplied with electricity, there is a potential-limited alternative in the use of (storable) biomass. In essence, however, only green, i.e. hydrogen produced from renewable electricity, can serve as the raw material. This can be converted in a case-by-case manner and application-specific in derivatives (e.g. LOHC for cheaper storage) or synthetic follow-up products (ammonia, methanol, synthetic methane and synthetic fuels). The conversion steps required for this result in high losses and increase the climate emissions and the supply pressure of renewable primary energies in Germany compared to the consumption.

A central advantage of using molecules compared to that of electrons is that the energy transport of large amounts of energy and their long-term and seasonal storage are much more efficient. For example, a pipeline with a diameter of 1,200 mm at 35 to 85 bar pressure level can transmit about 40 GW power in the form of H_2 and thus around ten times as much as a high-voltage direct current route for 4 GW electricity (see Fig. 3). The route width of natural gas transport lines is typically 20 to 30 m, but the 380-kV free power lines 30 to 50 m [17].

Especially when hydrogen is required as the raw material or energy storage, the transport of molecules is clearly preferable to electricity transport. The decisive advantage of the H_2 pipeline transport is that the majority is carried out by existing converted natural gas lines (German H_2 core network and European Hydrogen Backbone [18]) and therefore does not require a time-consuming new construction.

EXTENSIVE USE OF EXISTING INFRASTRUCTURES As one of the selection criteria for the regional provision of hy-

Fig. 4: MAN H_2-ICE tractor unit with 70 MPa pressure hydrogen-storage module (left) and Keyou H_2-ICE truck with 35-MPa storage system [Source: R. Wurster]

drogen, the domestic value creation was also mentioned in advance under the so-termed "merit order of H_2 production." This not only includes the construction and operation of local production systems, but can also affect existing energy infrastructures – especially in the sense of an economically simplified short-term introduction of hydrogen as a new energy source.

In central Europe in particular, the existing gas industry offers its existing and well-developed natural gas network for transfer to an economically secured future as an inexpensive infrastructure solution. The decision of the European gas network companies on the conversion of the natural gas to a hydrogen network is therefore used to avoid investmently incorrect allocations (stranded assets) in the gas transport and distribution network.

Competition concepts for gas distribution in the heat market are mainly heat pumps that are supplied with the (more expensive) capacity-limited power grid or regional/local heating networks. The transport of hydrogen as an energy source and raw material within Europe, on the other hand, stands in competition with the transport of H_2 derivatives such as synthetic methane gas, hydrocarbons, methanol or ammonia by ship and further via rail and road.

With high levels of implementation efficiency in the respective process technology, hydrogen can in principle be made from fossil and renewable energies. With the mainly used steam reformation, efficiency of 80 % (lower heating value) can be realized, with the electrolysis approx. 70 % and with the gasification of biomass 70 to 75 %. By using the by-products (heat, oxygen), the utilization efficiency of the processes can be further increased. The aspect of compatibility with regard to the operational energies in the transition phase from a fossil to a renewable energy world extends the universality of H_2 as an energy source.

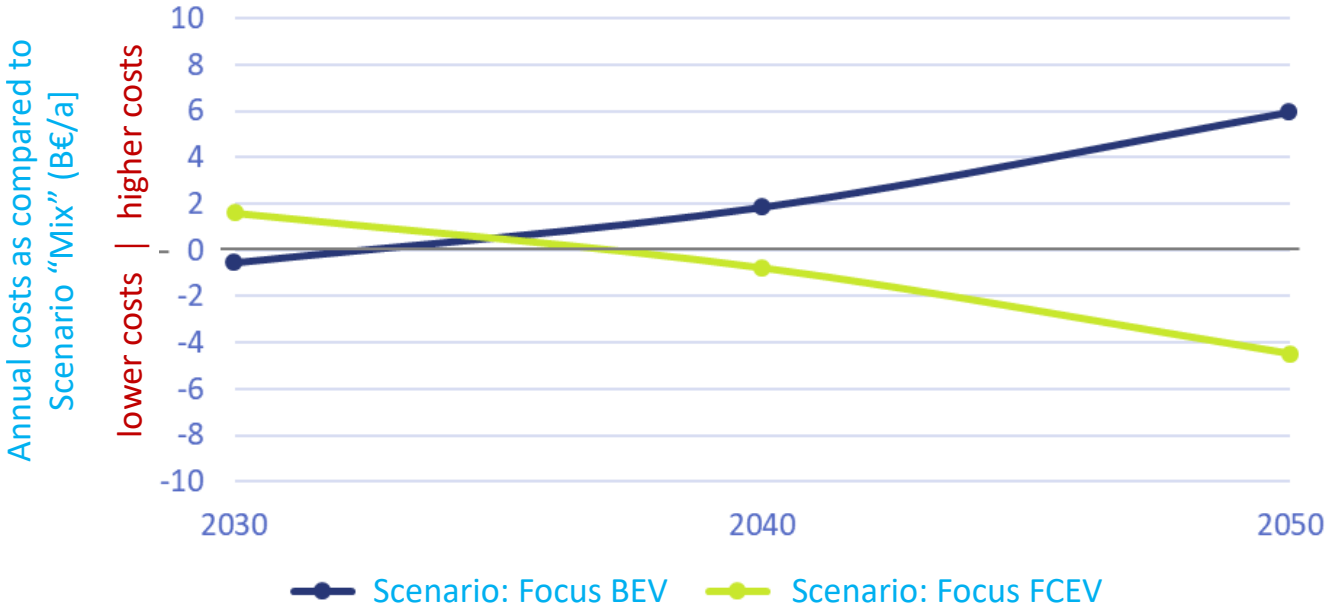


Fig. 5: Annual relative costs of the infrastructure setup for electrically operated vehicles for the scenarios "Focus BEV" and "Focus FCEV" [Source: [27]]

HYDROGEN CAVERN STORAGE The storage of hydrogen in underground salt cavern storage facilities is the most cost-effective long-term electricity storage option alongside the existing pumped-storage power plants [20]. Several analyses have shown that the hydrogen storage potential in Europe is large, with Germany playing a leading role in a European comparison, as it has the best geological structures and the corresponding know-how (e.g. HyUnder [21]).

Examples of industrial and large-scale salt cavern storage facilities can be found in the USA (three caverns in Texas), in the UK (Teesside) and soon in China. In Germany, the first small caverns are already being examined for their suitability for hydrogen and the operational boundary conditions are currently being tested in commercial operation, e.g. in Etzel in Niedersachsen [22].

The analysis results introduced in the commentary of the initiative Energie Speichern e.V. on the initial designing of the German H_2 core network show that a consistent consideration of large H_2 salt storage contributes to a more intensive use of domestic RE potential and the expansion of the H_2 core network could be pushed back to lower the investment [23].

SOCIAL AND INDUSTRIAL POLICY REASONS In contrast to battery-electric vehicles, in which China today dominates with 66 percent of vehicle production, 71 percent of Li-ion cell production and 90 percent of lithium refinement [24], the specialist skills in the sector in Europe and Germany would enable fuel cells and H_2 vehicles to be a significantly higher share of value in the development and manufacture. Germany also has first-class skills for other parts of the H_2 value chain (electrolysis, fuel cells, gas power plants, storage technologies, infrastructure components).

In order not to lose this technological tie or in some areas leadership, as with PV, batteries and wind energy, Germany must immediately start the mass production of all components and systems on the GW scale. Value creation as a criterion for Germany as a business location is a key aspect that e.g. is missing in the McKinsey analysis for the magazine Wirtschaftswoche titled "Made in Germany 2035" [25].

In addition to the existing expertise, the raw material situation is also more relaxed and Germany or Europe, unlike with PV and batteries, is less dependent on Chinese production. It is therefore necessary to immediately implement bold political measures to maintain or consolidate Germany's/Europe's economic and technological position. This will be an important prerequisite for a substantial contribution to climate protection in all energy sectors and at the same time mobilize the desired new economic upswing.

HEAVY TRANSPORTATION The sectoral analysis of energy consumption in Germany (2022) shows that the transport sector is about 95 percent dependent on fossil energies, while in year 2024, 62.7 percent of net electricity generation was covered by renewable energy sources [26].

The fastest economic use of H_2 can be made due to the high energy costs in street mobility and, together with the direct use of electricity in the transport sector, can achieve the highest CO_2 reduction effect worldwide. Diesel fuel will become more expensive in Europe in the next few years due to the rising CO_2 tax, and the economic gap to H_2 will continue to close. In the initial phase, the combustion engine H_2 truck was shown to be much cheaper for long hauls than the small number of FC trucks so far (see Fig. 4).

In addition, the structure of hydrogen refueling stations (HRSs) all over Europe is just as binding by the AFIR (Alter-

Fig. 6: Alkaline pressureless 5 MW_{el} electrolyzer, trailer refueling station in Pfeffenhausen/Bavaria, HRS in Hofolding and Solaris Urbino 12 hydrogen fuel-cell bus with green H_2 in Höhenkirchen/Bavaria [Source: R. Wurster]

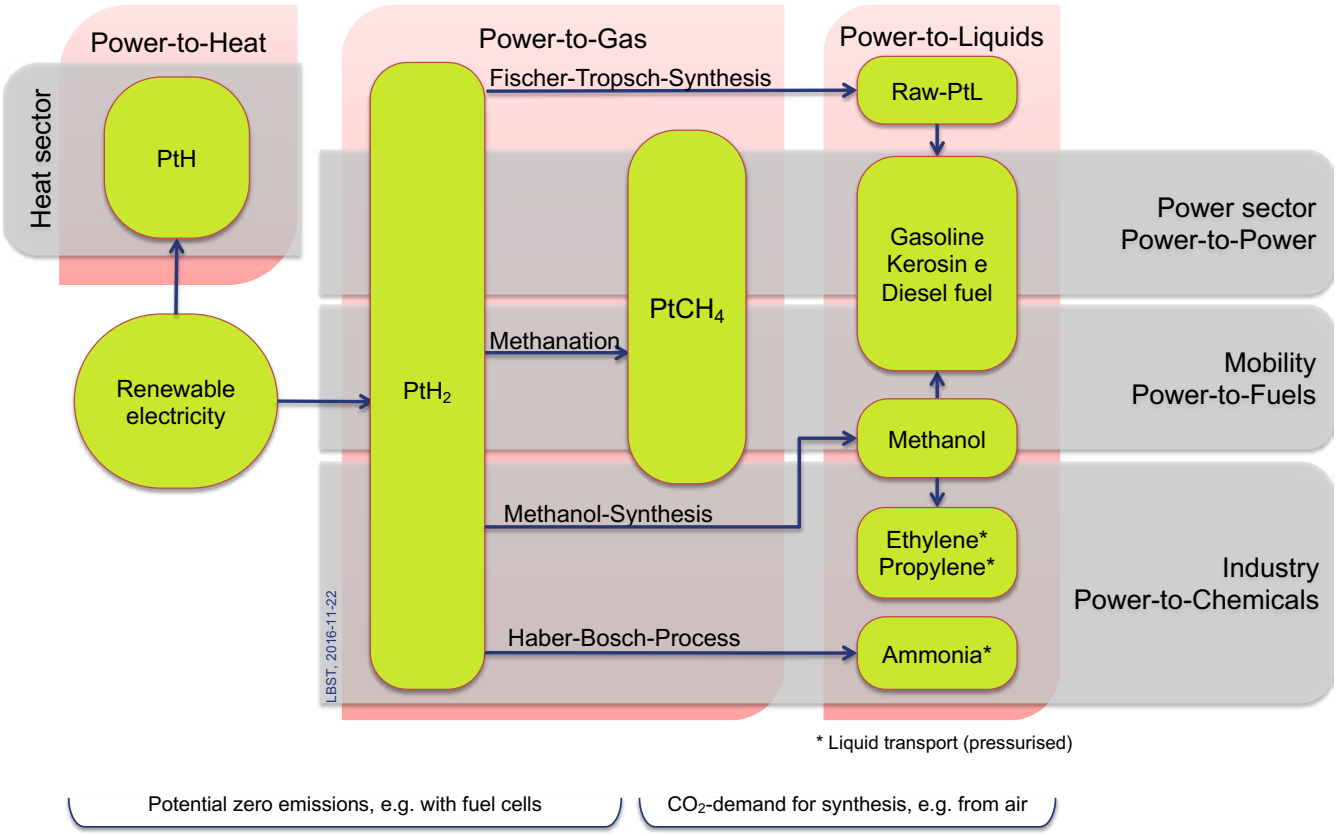


Fig. 7: Power-to-X (PtX) term taxonomy and key processes [Source: [35]]

native Fuels Infrastructure Regulation) by the end of 2030 as that of charging stations for battery vehicles – for all vehicle classes. Furthermore, various analyzes [24], [27], [28] show that the parallel structure of both infrastructures (for battery and H_2-powered vehicles) is also economically advantageous (see Fig. 5).

The charging infrastructure is initially easy to realize for a few hundred e-trucks, but exponentially complex and expensive for the final expansion, whereas it is the other way around for H_2 trucks [29]. In addition, the approach with two drive and fuel concepts is more resilient and robust. Both the use of H_2 from surplus current in Germany and the use of H_2 from PV in North Africa with double the solar radiation (solar radiation 2,200 kWh/m² instead of 1,040 kwh/m²) relativizes the frequently mentioned efficiency disadvantage of FCEVs (factor BEV/FCEV ~ 2.5).

INDUSTRIAL PRODUCTION In addition to the sensible short-term use in the mobility sector, the industrial use of hydrogen in the German national hydrogen strategy has moved to first place in demand [31]. There are various reasons: On the one hand, it turns out that the changeover of individual, regionally concentrated industrial sectors, especially the steel industry, but also the chemical industry, can achieve the largest CO_2 emission savings with the slightest infrastructure requirements. These still focus on the public gas infrastructure and are therefore the easiest way to implement it politically.

On the other hand, the industry still covers around 34 percent of its primary energy requirement with natural gas (2022), which should be substituted as soon as possible due to the political-strategic shortage of the Russia Ukraine War since 2022 and the associated cost increase. In addition, the natural gas costs will increase due to growing CO_2 taxes and specifically increasing operating costs from the dismantling of the gas grid. For this reason, hydrogen is ideal for direct substitution because of the chemical similarity with methane, with the secondary effect of growing security of the power supply using H_2 peak-load power plants and seasonal H_2 storage.

However, it is not yet clear whether the steel location Germany can be secured in the long term. The experts are still arguing. Some argue with the lack of economy of local production, others with the elimination of local value creation, the loss of workplace, the loss of quality control of the generated raw steel for critical demand sectors, the potential increase in CO_2 emissions of steel production (carbon leakage) as well as globally lower process efficiencies (without German steel expertise).

PARTIALLY REALIGNMENT OF THE ENERGY SYSTEM The decentralized use of electricity that cannot be deducted in the existing network helps to generate storable H_2 to reduce the expansion of the power distribution networks or avoid it locally and thus to cushion the network charges. This H_2 can compete in terms of price with H_2 imported via pipelines from Spain or North Africa, but its potential production quantities will never outcompete.

The combination of the objectives of a more resilient energy supply with the highest possible proportion of self-supply and an economic energy supply as possible in international competition with imports of inexpensively produced H_2 will require the strive for a regionally suitable mix of local and central RE production and use. A decentralized H_2 production base is particularly useful for a quick and less complex introduction to the establishment of a nationwide H_2 supply, combined with an immediately effective systemic contribution to relieving the electricity infrastructure in Germany.

The HyBayern project shows what such a concept of a regional H_2 production, distribution and usage chain can look like in reality (see Figure 6).

As early as 2030, hydrogen can be used with smaller electrolyzers (up to approx. 10 MW) for local users at some locations in Germany. However, an uncoordinated array could also lead to exacerbation of existing bottlenecks in the power grid, which is therefore absolutely to be avoided [33]. By 2040, an increasing number of regions could be good for the systemic use of electrolyzers both due to the connection to the H_2 core network and through the H_2 market ramp-up [34]. As a result, relief for the cost-intensive power distribution network and minimizing the expansion of electricity transport lines can be achieved by using existing pipeline and storage infrastructures.

GLOBAL TRANSFERABILITY Hydrogen is generally considered a particularly robust energy source, which on the one hand has the highest compatibility with other energy sources or chemical raw materials, like e.g. methane, methanol or ammonia. On the other hand, it is characterized by the simplest convertibility. This is made possible by the key technologies fuel cell and electrolysis. But it is also possible to burn hydrogen in air or pure oxygen, for example when using thermal burners (heating) and heat engines.

Figure 7 shows how electricity can be transferred to all other forms of energy used in everyday life under the term PtX (renewable). With the exception of power-to-heat (PtH), every one leads to the production of hydrogen molecules. Hydrogen (= molecules), paired with the use of electricity (= electrons), will play a central role in future energy systems [35].

Its systemic universality and robustness in particular is a prerequisite for the use of hydrogen in many application sectors and regions.

In addition, electrolyzers and fuel cells as well as H_2 storage can be scaled to a very far extent – from kW to the GW range.

MAKING USE OF RENEWABLE ENERGIES The solar radiation in North Africa is more than twice as high as that in Germany. Electricity can ideally be generated with PV in large power plants for € 0.02/kWh_e, compared to German PV electricity with € 0.04 to € 0.07/kWh_e (open space) or 0.06 to € 0.12/ kWh_e (roof PV) or wind power with € 0.04 to € 0.09/kWh_e (onshore) or 0.06 to € 0.11/kWh_e (offshore) [36]. This means that H_2 can be generated in North Africa for less than € 2.5/kg [37] and transported by pipeline, e.g. via the SouthH_2Corridor, for less than € 0.5/kg [38] to Central Europe.

In principle, Algeria could cover the entire energy requirement of Europe [39]. At the first ministerial conference for the southern hydrogen corridor, a declaration of intent to develop the southern hydrogen corridor was signed in Rome on January 21, 2025 by Germany, Algeria, Italy, Austria and Tunisia [40].

Analyzes for the European Commission (DG Energy) on the potential of generation of green gases have shown that the RE generation potential within Europe of around 14,000 TWh/yr for the supply of green hydrogen in addition to the demand in RE for the general electricity demand would be more than sufficient [41]. Via the European Hydrogen Backbone [42] and this contains the German H_2 core network, in principle, an efficient (energy, cost) provision of large H_2 quantities could be realized and decarbonizing of the entire industry.

CONCLUSION In order to be able to maintain a temperature goal of at least 2 °C in an energy system with primarily intermittent range of energy from PV and wind in the next 15 years by 2040, there is no way around the decarbonization of the industry and the transport sector with the help of green hydrogen. The challenge is the decarbonization of the fossil molecules in the end energy use. The transport sector could play an important role in the ramp-up of the production of green hydrogen, because the replacement of conventional energy with a focus on heavy-duty applications is the first cost-covering option there. •

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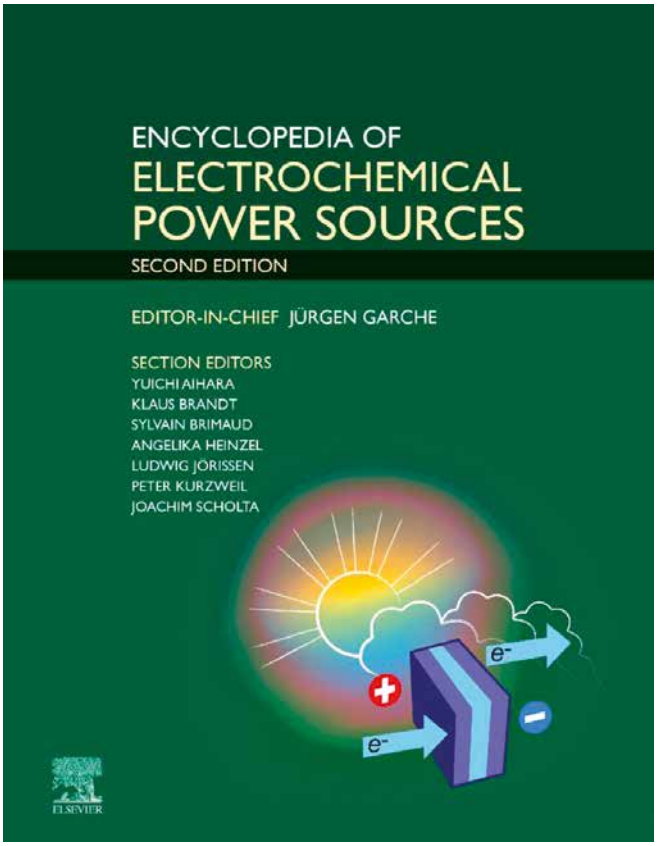
Authors:

Reinhold Wurster
→ Reinhold.Wurster@lbst.de
Ludwig-Bölkow-Systemtechnik GmbH (LBST), Ottobrunn

Dr. Ulrich Bünger
→ Ulrich.Buenger@posteo.de
Freelance consultant for hydrogen energy technology – until 2021 at LBST

NEW FUEL CELL COMPENDIUM



The Elsevier publishing house is known for its highly scientific publications. Two years ago, the British company set about reissuing its legendary fuel cell compendium "Encyclopedia of Electrochemical Power Sources." Following the first edition in 2009, this English-language doorstopper will now be published in a second edition later this year.

The editor is once again Prof. Jürgen Garche from the University of Ulm, who, together with numerous experts, presents all aspects of the ever-growing area of hydrogen and fuel cell technology in great detail and from a scientific perspective. For the seven chapters, he was able to recruit experienced specialists – from Germany, among others, Prof. Angelika Heinzel from the University of Duisburg-Essen, Ludwig Jörissen from the Center for Solar Energy and Hydrogen Research (ZSW) and Dr. Johannes Töpler from Dresden International University (DIU).

The encyclopedia is regarded as an important interdisciplinary reference work for all those working with batteries, fuel cells, electrolyzers, supercapacitors and photoelectrochemical cells. One focus is on the ecological and economic impact of electrochemical energy sources, making it an excellent resource for professionals and students – particularly those in the fields of electrochemistry and materials science as well as electrical engineering, mechanical engineering and chemistry.

This completely revised second edition takes particular account of the progress made in the field of battery and hydrogen technology over the last 10 years. However, this wealth of information also comes at a price – namely USD 4,094 for the hardcover book and eBook bundle. •

Garche, Jürgen; Encyclopedia of Electrochemical Power Sources, Elsevier, ISBN 978-0-323-95822-6

Interview with Erkam Kocakerim, CEO of Limak Cement Globall

BIGGEST CHANGE IN THE HISTORY OF THE CEMENT INDUSTRY

Together with Air Liquide, Limak Cement Group has successfully tested the first hydrogen-blended fuel supply for cement production in Ankara, Turkey. H2-international conducted an interview with Erkam Kocakerim, CEO of Limak Cement Global. **Interviewer:** Sven Geitmann

Fig. 1: Erkam Kocakerim [Source: Limak]

H2-international: Could you please start by introducing your company to our readers in a few words?

Kocakerim: Limak Cement is in the top 50 in the global cement industry with 18 million metric tons of cement production capacity through its 11 cement factories located in Turkey, Ivory Coast and Mozambique. Besides, we export to 15 countries across four continents. We have 30 RMC plants and several waste-to-fuel preparation facilities. We are the second largest in our homeland Turkey.

While our factories and facilities spread all over Turkey provide us a strong presence in the market, our distinctive structures – the R&D and Innovation Center, Center of Excellence, Center of Climate Change, and Limak Cement Academy – are the wealth of our intellectual capital and the strong transforming catalysts. Furthermore, they are the strongest boosters for shaping today's workforce.

Limak Cement is today absolutely one of the global frontrunners in regard to transforming a giant cement, concrete, and building materials holding to an excellent combination of an industry and tech enterprise.

You have stated that you want to increase the use of alternative fuels with a high biogenic content and renewable energies by 2030. Can you be more specific about this?

With almost 40 percent of its overall CO_2 emissions stemming from combustion emissions, our industry must shift fossil fuels with alternative fuels (AF) sourced from a variety of waste streams.

Today, the global cement sector and Turkey's AF usage rate have only reached 10 percent to 15 percent. The EU average is 53 percent. Limak Cement uses AF between 30 percent and 50 percent in its factories where it has switched to AF.

By 2026, all our factories will have transitioned to AF usage, and we aim to align with the EU by raising our group average to 60 percent and our facility-level maximum usage to 70 percent by 2030, with the goal of surpassing the EU average starting from that year. In increasing the AF usage rate, the role of policies and legislation in the ecosystem where the factories are located, as well as R&D and technology, is very important. Plans are in place to guarantee a sufficient supply of alternative fuels, incorporating at least 50 percent bio-waste content. However, many countries other than EU, including Turkey, do not yet have an appropriate policy framework in place, and it appears that the next few years will see the establishment of this framework.

However, Limak Cement sees the use of green hydrogen as one of the most important leverage for this purpose, aiming to maximize AF usage. Hydrogen is the key to achieving a high thermal substitution rate thanks to its high calorific value and its ignition properties.

To gain practical experience, you teamed up with the gases company Air Liquide last year (2024). Why did you choose Air Liquide as a project partner?

At the end of 2022, Limak Cement began planning studies to use green hydrogen, albeit at low rates, in its kilns, with the goal of increasing the AF rate. Within the framework of ecosystem-based growth, we required a supply and technology partner for the supply, transportation, usage safety, and practice of hydrogen. We found this opportunity with a global, strong partner such as Air Liquide. Following the completion of the project studies in June 2024, Limak Cement conducted trials with hydrogen combustion, with the aim of developing expertise in hydrogen combustion optimization and determining the optimal feeding rate required to increase the use of high biogenic content alternative fuels.

Fig. 2: Commissioning of the first Turkish H_2 demo plant [Source: Limak]

Limak Cement sees its "triple transformation" journey not just as its own journey, but also as a development journey of the ecosystem; hydrogen is exactly such a subject. We are extremely interested in all the links of the stakeholder chain, from its technology to its legal infrastructure, from the supply-demand balance to its economy, and we are one of the pioneers of the ecosystem.

Air Liquide is our global stakeholder, with which we share a common vision. This shared vision is the most significant factor contributing to this unity. The aim of the first stage of the project was the safe use of green hydrogen in cement rotary kilns, its logistics to our factories, its positive effect on the AF usage percentage and the observation of semi-finished product quality.

What is the provisional assessment of this collaboration?

Our trials have shown that we can achieve 100 percent thermal substitution of the clinker production line calciner with a mix of high biogenic content alternative fuels and hydrogen; we have also concluded that we can apply the technology to the entire production system.

We have successfully increased our AF usage rate in the region by up to 20 percent, while also substituting 3 percent of hydrogen. This situation provided us with the opportunity to experience our potential to reduce 180,000 tons of carbon dioxide emissions annually in our medium-sized cement factories.

Do you intend to continue your efforts in this direction? If so, in what way?

Our industrial trial phase 2 and phase 3 plans are ready for the next six months. Following the first phase, we successfully tested the rotary kiln calciner; we planned phase 2 and phase 3 studies, testing both the calciner and the main burner simultaneously, using oxygen-enriched combustion. After these phases, we believe the results will guide us and the global sector. As a result we are working to have a hydrogen-blended, high-biogenic-content alternative fuel mix in all our facilities. That will be the way to achieve our decarbonization targets. By applying the same fuel mix in all our facilities, the yearly CO_2 saving can reach up to 700,000 tons of CO_2 per year.

Is it correct that you want to install several electrolyzers at different locations for H_2 production?

While your acquisitions for the transportation and use of green hydrogen in liquid or gas form are proceeding at a rapid pace, our plans for on-site production of electrolyzers remain unchanged. On the one hand, we are aiming to reduce operation costs for hydrogen and on the other hand, new national and global policy trends such as CBAM and ETS will result in increased incentives for the use of low-carbon fuels. For this reason, we have prepared roadmaps to scale up these initiatives, which we initiated on a small scale, concurrently with the increase in regulations and incentives.

Planning the workforce and necessary competencies together with the advanced technologies is another crucial aspect of the subject.

Which electrolyzer manufacturer are you working with?

We are still collaborating with our business partner Air Liquide on transport-related technology and performance, as well as the planning of the first small-scale electrolyzers.

What are your medium- and long-term goals?

Our medium-term goal is to fulfill our pioneering mission that will reveal the sustainable use of hydrogen technologies in our global sector. Another medium-term goal is to carry out activities that will activate the necessary stakeholder chain for hydrogen in our ecosystem.

Our long-term goal is to attain a level of expertise and depth that enables the production of pioneering technologies on low-carbon fuels in the industry, extending beyond the cement perspective of Limak Cement.

Can you imagine using such technology in Germany as well?

Decarbonization requires a tailor-made approach. Resources, technology, legislation, weak and strong muscles, and plant-based analysis of priorities are required. German cement manufacturers undertake many global pioneering missions and are capable of creating carbon-neutral fuel mixes supported by hydrogen. Moreover legislation, AF and the hydrogen ecosystem are much more mature and suitable for establishing this structure.

Do you really think it is possible for the European cement industry, and therefore also the Turkish cement industry, to become carbon free by 2050?

The cement sector is experiencing the most important transformation in its history. This transformation requires the art of technology and legislative regulations. The most difficult part is that it requires a joint effort by all stakeholders.

As of 2025, the net zero target in the industry is still possible. I believe that the global cement sector can achieve carbon neutrality earlier. I think it is possible for the cement sector in developed countries to achieve carbon neutrality by 2040. The most important barrier is the delays and uncertainties in policy transformations that will trigger and support the green transformation.

There is a huge green premium in the cement sector. The impact of possible increases in cement costs due to decarbonization on the construction sector is extremely limited, because the share of cement in the total construction cost is between 5 to 10 percent. I think this is a sector where policymakers should give more courageous support for this science-based data. •

Sustainable energy supply based on hydrogen

MICROGRIDS FOR SOUTH AFRICA, NAMIBIA, UKRAINE

In emerging and developing countries, but also in crisis areas, there are many opportunities to use hydrogen to overcome energy poverty and establish a reliable, CO_2-neutral power supply. In this context, hydrogen-based microgrids have a decisive role to play. In this form, hydrogen-producing electrolyzers, cylinder racks for hydrogen storage and fuel cell systems for reconversion into electricity can be accommodated in the space of a shipping container. Together, they help to conserve renewable energy for later use. **Author:** Ulrike Beyer

Fig. 1: Hydrogen Tryout Area
[Sources: Referenzfabrik.H2@Fraunhofer IWU]

Hydrogen-based microgrids can be flexibly adapted to different application scenarios. They are therefore primarily used for decentralized supply in rural areas, but also in urban conurbations and to support industrial production and processes as a real alternative to CO_2-producing diesel generators. If the industrial production of microgrids can be successfully established, this will benefit manufacturers (industrial value creation), local communities (stable energy supply) and climate protection (CO_2-neutral energy production) in equal measure.

HYTRA – HYDROGEN TRYOUT AREA IN CAPE TOWN, SOUTH AFRICA The Hydrogen Tryout Area, funded by Germany's Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), is ideally suited to demonstrating the effectiveness of hydrogen for a stable, climate-neutral energy supply. Especially for regions that have surplus renewable energy and are potential exporters of hydrogen, HyTrA offers them the opportunity to use hydrogen themselves.

General conditions
South Africa's economy and energy production are heavily dependent on coal. The country is also one of the 20 largest greenhouse gas emitters in the world. Its electricity supply is very patchy: South Africa's state-owned energy company Eskom has had to ration electricity supplies for its 60 million customers for more than a decade. The outdated infrastructure results in an estimated annual power deficit of 4 gigawatts, which corresponds to the demand of around 10 million households. A stable energy supply is the basis for socially oriented economic growth and indispensable in the fight against poverty and inequality – solutions for a secure supply of renewable energy are urgently needed in South Africa.

HyTrA is installed close to industry at the company Alu-Cab, a manufacturer of car roof tents and accessories in Cape Town. Alu-Cab already has photovoltaic systems on site and can now also use the surplus energy to produce hydrogen on the premises, store it and convert it back into electricity when required. Thus the microgrid ensures that the company has a stable power supply for its production.

Solution overview
The central component of HyTrA is a robust and cost-effective microgrid specially designed for the African market by Texulting GmbH and Fraunhofer IWU. This innovative solution forms the centerpiece of a Hydrogen Tryout Area, which also has a technology showcase designed to arouse companies' interest in component manufacturing, assembly and installation. HyTrA is also integrated into a socio-economic and socio-ecological H_2 framework, which emphasizes environmental aspects through accompanying information and training offers, which fundamentally contribute to the acceptance of hydrogen and count towards the Social Development Goals (SDG) of the United Nations.

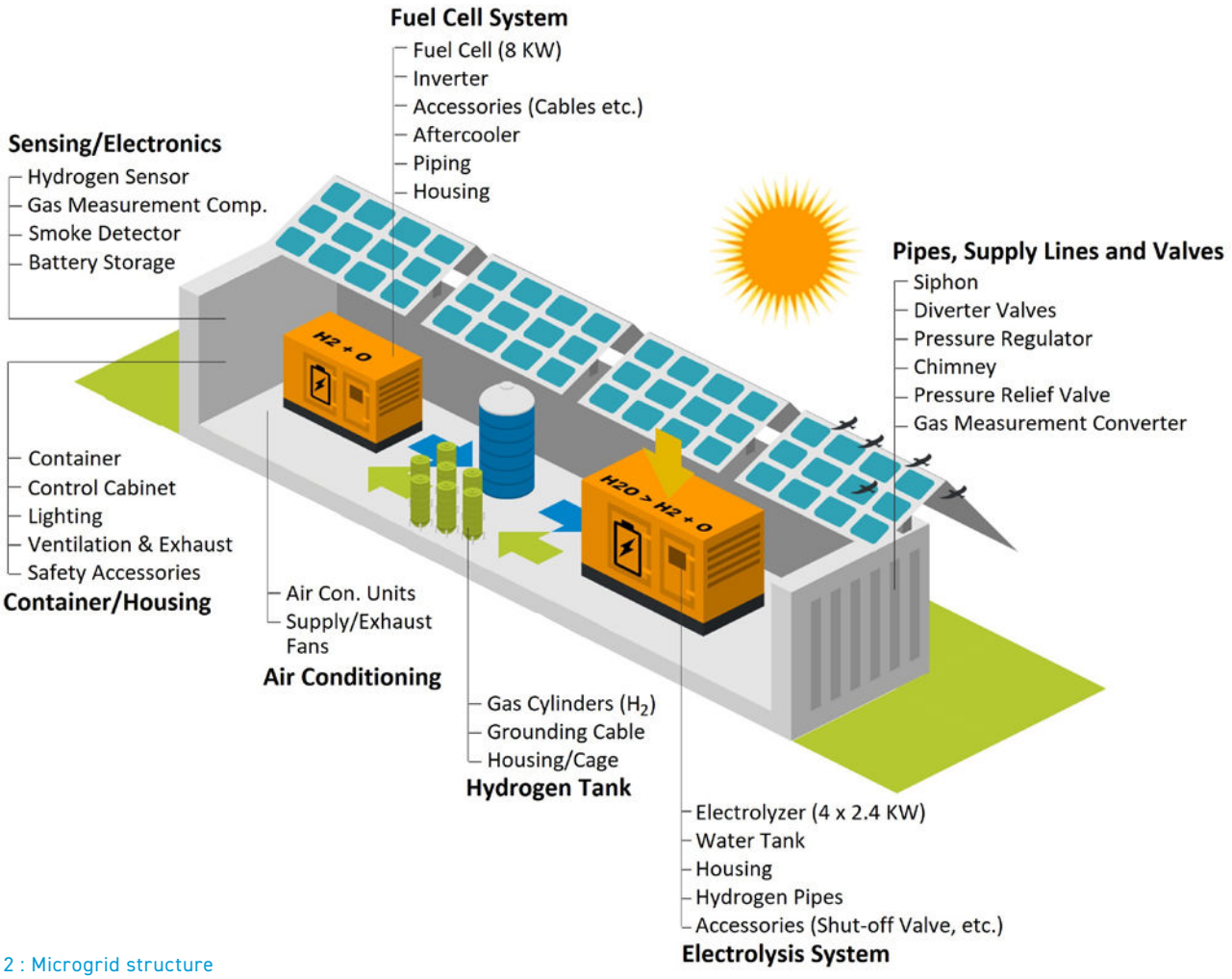


Fig. 2 : Microgrid structure

Microgrid

To this day, fossil fuel-powered generators play a central role in South Africa as emergency power generators or to support the unstable and, in some locations, inaccessible energy supply. The aim in developing and testing the compact 8-kW hydrogen microgrid was to offer an efficient and robust alternative at comparable cost. Complete power-to-power sector coupling is integrated into the compact H_2 microgrid unit. All the microgrid components required are contained in a transportable housing. The electricity generated by solar cells is used to split water into hydrogen and oxygen in the electrolyzer. The hydrogen is compressed and stored in suitable gas cylinders. If electricity is required, the hydrogen can be converted back into electricity via a fuel cell stack through the introduction of ambient air (oxygen). The waste product is water, which is stored in a tank and made available for electrolysis as required. This creates a closed water cycle for which water only has to be provided at the beginning and which subsequently operates almost loss-free.

The microgrid thus integrates and links various components that ensure hydrogen production, storage and reconversion resulting in a decentralized power supply independent of the changing availability of renewable energies and enabling seasonal storage of green energy. The key here is a modular, closed structure that allows for a largely maintenance-free, flexibly scalable and easily adaptable system.

The microgrid developed as part of HyTrA is a self-sufficient energy network in a small and compact format. What makes it unique is that it is perfectly adapted to the specific requirements of the African market. With a service life of over 60,000 operating hours (more than 10 years), it represents a robust and safe technological solution. The system offers new possibilities in terms of storage density, safety, user-friendliness, maintenance-free operation and energy self-sufficiency. Based exclusively on renewable energies, the system is the key to a decentralized power supply that also covers off-grid and hard-to-access areas.

Technology showcase

The hydrogen technology showcase makes the microgrid transparent as a virtual reference grid. The digital image shows how the physical system works, what advantages it offers, which system components it comprises and how they are integrated. It also serves to market HyTrA across regions. It allows access to functional data from Germany and thus ensures a continuous exchange of information and increased cooperation.

Specific tests and field trials with the microgrid components deployed provide results that serve as a basis for further development. The aim is to successively improve the robustness of the system and optimize its use in climatically and socio-economically challenging areas. Component manufacturers in Germany can use data to adapt their products for use in the African market and refine standards. This makes risk-minimized expansion possible.

Extended framework

The broad framework also expands HyTrA's scope. For example, joint ventures have been initiated between German and African companies. The establishment of regional supply chains has also been promoted. Needs-oriented support ser-

vices and information offerings make it easier for German companies to tap into the African market, and local companies interested in a secure energy supply and the integration of hydrogen into their processes can make use of the services of German companies.

Marketing, consulting, sales and customer support are aimed at establishing the microgrid as a climate-neutral alternative to fossil-fueled generators. The exchange of scientific ideas relating to hydrogen is also being encouraged. The development of the microgrid therefore provides starting points for research cooperation, particularly on technological and economic aspects.

Last but not least, the transfer of knowledge is of central importance so that local communities can use the new technologies sustainably and independently. For example, cooperation with the d-school of the Hasso Plattner Institute in Cape Town has been continuously extended. In particular, a design thinking challenge has aimed to improve access to clean energy for rural farming communities. Over a period of 10 weeks, students developed innovative prototypes and solutions for the specific challenges faced by these communities.

Commissioning and accompanying measures

On July 13, 2023, HyTrA was ceremoniously put into operation in Cape Town in the presence of the Mayoral Committee Members for Energy in the City of Cape Town, representatives of NOW and Z.U.G. and supported by a greeting from the BMUV. The project team from Fraunhofer IWU, Texulting GmbH, Alu-Cab, Stellenbosch University and Umstro GmbH produced the first hydrogen on African soil, which was then converted back into electricity for a specific industrial application at Alu-Cab.

HyTrA is an important cornerstone for building a bridge between Africa and Europe with hydrogen. Unlike the megawatt and gigawatt projects of large investors, this project is designed for the use of hydrogen in Africa. An equal partnership approach will create long-term benefits for both sides.

The initiative will make use of systems and expertise from Germany. The participating SMEs and scientific partners in particular can gain important experience as well as gather usage data for further developments by using the system in practice. The microgrid also provides a basis for the applied training of urgently needed specialists. It is currently undergoing a long-term test, which is providing valuable data on service life and performance. This data will help to improve the next generation of components.

With appropriate scaling on both sides, hydrogen will become an export commodity for Africa and play a major role in supporting Germany's energy transition.

Fig. 3: Governor Neville Andre (Erongo District, Namibia) – with Dr. Ulrike Beyer on his right

HYGO – WATER TREATMENT IN NAMIBIA HygO is another pioneering H_2 project in the starting blocks. In addition to the functionalities of the HyTrA system, the project, which is likewise funded by the BMUV, will also use the oxygen produced during electrolysis. The plan is to use this for the treatment of wastewater. Other industrial partners have been involved in the project. Haver & Boecker OHG and Krenkel Abwassertechnik GmbH join Texulting GmbH and Fraunhofer IWU as new members of the project team. The microgrid is currently being set up at Fraunhofer IWU. The intention is to put it into operation in a remote area in the Erongo region of Namibia from June.

HYGRID FOR THE RECONSTRUCTION OF UKRAINE With HyGrid, the Fraunhofer-Gesellschaft is promoting a cost-effective and robust microgrid based on the hydrogen system solutions HyVentus (electrolyzer) and HyVictus (fuel cell) developed at the Fraunhofer IWU Chemnitz. The aim is to create a particularly economical demonstrator microgrid as a blueprint for the industrial series production of such systems. These hydrogen-based microgrids will be used in the reconstruction of Ukraine and will stabilize the power supply, which has been severely damaged by the war. Thanks to the scaled plug-and-play design, they can cover the range from a few to several hundred kW – ideal for the needs of hospitals, businesses, schools or remote rural areas. The core task of these microgrids is also to store renewable energy over a longer period of time and to convert immediate energy surpluses into hydrogen so that the latter can be converted back into electricity during periods when there is little sun or wind. HyGrids will contribute to the energy supply next winter.

HYDROGEN-BASED MICROGRIDS ALSO APPEALING TO GERMANY The visibility of the African activities of Fraunhofer IWU and its participating industrial partners has also led to numerous inquiries about the use of hydrogen-based microgrids in Germany. In particular, the option to use the oxygen produced during electrolysis for water treatment represents a unique selling point. For example, many requests for decarbonization come from sports centers that want to reconvert the hydrogen produced during the day into electricity for the operation of floodlights. The oxygen obtained could be used to purify or disinfect water and utilized in swimming pools or to irrigate field hockey pitches. The waste heat from the microgrids could also be used to heat utility buildings, for example.

Hydrogen-based microgrids are suitable for numerous decentralized energy supply applications and also offer other advantages that further increase their effectiveness. They represent considerable value creation potential for the German economy, both directly in the production of the required system components and in terms of cooperation with Africa in the future. •

Author:
Dr. Ulrike Beyer, Referenzfabrik.H2 at the Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz
→ Ulrike.Beyer@iwu.fraunhofer.de

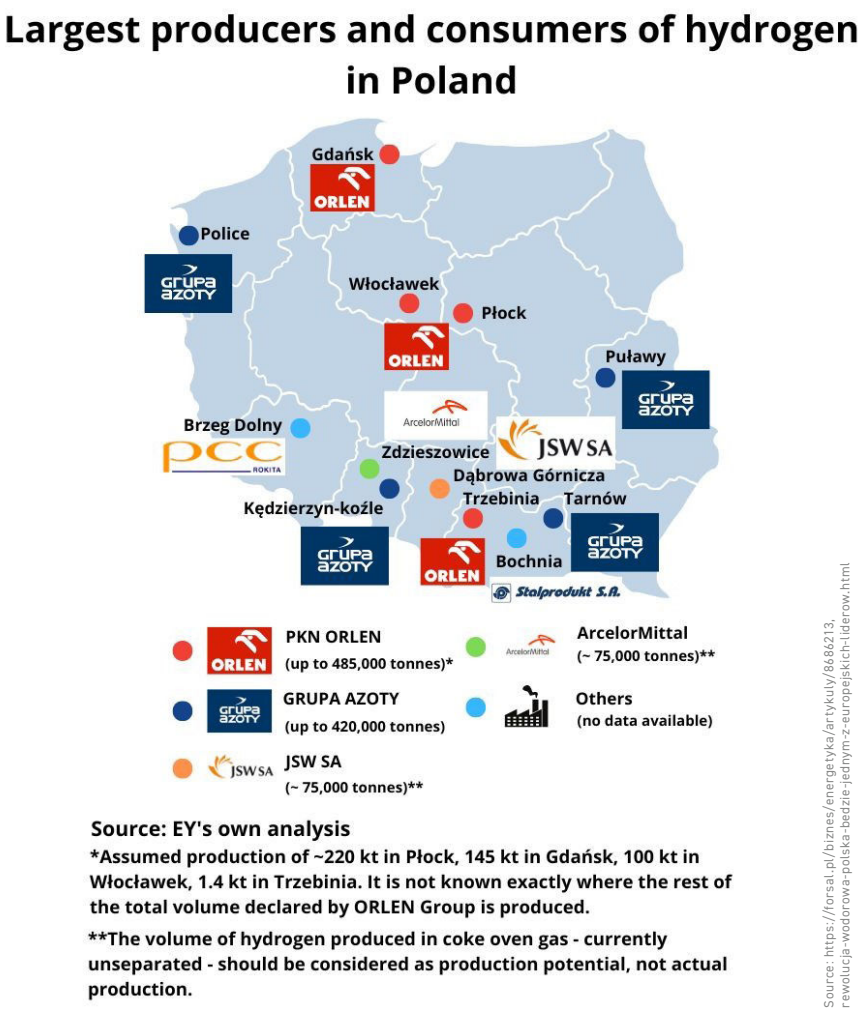
Green hydrogen in Poland

POLAND'S ROLE IN EUROPE INCREASINGLY IMPORTANT

Wind and photovoltaic energy developed in our eastern neighbors with a lag of several years compared to the German market. However, this has not disturbed the fact that more than 20 GW of photovoltaics and more than 10 GW of wind power plants are currently installed across the river Oder. Around 50 GW of renewable energy projects are currently in the pipeline with grid connection approvals. The growth rate of renewable energy is impressive, with 5 GW of new capacity installed in the last 12 months alone. The average age of wind turbines is less than 5 years and photovoltaic farms 3 years. The green hydrogen market is only just taking off. So, will Poland, as in the case of wind and solar, take advantage of the "latecomer bonus" and be an equally attractive market? **Author:** Piotr Rudyszyn

HYDROGEN MARKET IN POLAND What you may not have known until now is that Poland is a leader in hydrogen production and consumption, not only in Europe, but also in the world. Annual production and consumption of hydrogen in Poland amounted to more than 1.3 million tonnes in 2023. Hydrogen production takes place mainly in large industrial plants in the process of steam reforming of hydrocarbons, where hydrogen is used in industrial processes. The specific nature of the Polish market assumes that the demand for this element is completely covered by domestic production and independence from imports. This is also due to the fact that so far hydrogen has mostly been produced as a semi-finished product in other production processes, such as the production of mineral fertilizers, metallurgy or the fuel industry. Grupa Azoty S.A. alone, as a supplier of, among other things, fertilizers for agriculture, produces approximately 420,000 tonnes of this raw material annually. The fuel corporation Orlen simultaneously produces and consumes around 150,000 tonnes of hydrogen. The four largest players hold more than 60% of the market. So if we count production of hydrogen, not its consumption, Poland is ahead of the Netherlands in this ranking and is the second largest producer of hydrogen in Europe, after Germany, and the fifth largest producer in the world. This is mainly due to the lack of exports and imports of this raw material. Germany and the Netherlands rely heavily on imports of this compound, which puts them two places ahead of Poland in consumption statistics. Unfortunately, this is not yet green hydrogen, and hydrogen production by hydrolysis and using RES (renewable energy sources) is limited to a few test and experimental facilities. However, the enormous potential and experience of the Polish people can be seen. It can also be assumed with a very high degree of probability that current hydrogen consumers will be the pioneers of change and will be among the first to start replacing gray hydrogen with green hydrogen. This will be due to two factors: legal and economic. It is no secret that Grupa Azoty is currently in a difficult financial situation and is starting to look for savings by, among other things, planning to reduce CO_2 emissions. Currently, 1 tonne of gray hydrogen emits about 17 tonnes of CO_2. This means that Polish farmers are significantly affected by CO_2 charges and the high cost of gas in the price of fertilizer. This reduces demand. The second factor will be the falling costs of producing hydrogen from hydrolysis. A Bloomberg Agency report assumes that in Poland the price of green hydrogen will be lower than gray hydrogen as early as 2029. If investors want to be ready with green hydrogen production in Poland by that time, they must already start building green hydrogen factories. It is worth adding here that the Polish hydrogen strategy 2030 with an outlook to 2040 is only a few weeks younger than the German one.

Poland is the leader of the chemical industry in Europe. Poland has excellent and young professionals. Thanks to the cooperation between the Polish research center and German universities, technology transfer is very fast. We wrote about



Source: https://forsal.pl/biznes/energetyka/artykuly/8686213,rewolucja-wodorowa-polska-bedzie-jednym-z-europejskich-liderow.html

Fig. 1: The largest producers and consumers of hydrogen in Poland

the Hydrogen Study (Wasserstoff-Studium) in the previous issue of H2-international (October 2024). Participants in the Study visit hydrogen facilities in Germany, gain knowledge not only from German professors and practitioners, but also make international connections through the university's alumni forum. The Hydrogen Study utilizes German know-how and trains company employees, and is also a distributor of software for designing hydrogen facilities. The study program works in Polish and German and provides, thanks to its qualified staff, advisory services for domestic and foreign players that want to invest in the hydrogen industry in Poland. One of Poland's largest fuel and energy companies, ORLEN, in its report "Hydrogen Market in Poland and the Baltic States: Forecast to 2040" reported, "In 2030, the demand for green hydrogen in Poland will be at least ~260,000 tonnes, and in 2035 this amount will increase to ~515,000 tonnes." An additional piece of information from the above report is the link between the Polish market and the Baltic countries. This is mainly due to foreign investments of large Polish companies in Lithuania and other neighboring countries. The Czech Republic, Latvia, Lithuania and Ukraine are places where Polish companies invest a lot and their trade relations are very strong. Poland is, in a way, a window to these markets for investors.

ELECTRICITY MARKET IN POLAND When Poland, along with nine other countries, joined the European Union in 2004, almost 98% of electricity came from black and brown coal. The total installed capacity of power plants and combined heat and power plants was almost 40 GW. A few percent of the energy came from dozens of old hydroelectric power plants that often remember the early 20th century. Added to this were several large Communist-era power stations visible on the largest rivers. All of this infrastructure remained in a terrible state of repair. Thanks to the introduction of European relations, in less than 20 years the installed capacity of renewables has amounted to more than 30 GW in business installations and around 11 GW of home installations. Thus, the installed capacity of renewables exceeds that of coal, whose days are numbered.

HIGH VOLTAGE – POLAND'S RELATIVE ENERGY CONSUMPTION Despite huge investments in transmission and distribution networks and infrastructure, investments by the large operators have not kept pace with the development of energy sources. In addition, the largest operators remain under state control and are not quite coping with the new reality. One of the biggest barriers to market entry by energy producers is precisely the limited possibilities of connecting to the grid. At the end of this year, Poland's largest transmission system operator PSE S.A. showed in its report that the amount of spare capacity in the system is 0 MW (in other words zero)

However, the market abhors a vacuum. The hitherto state-dominated energy sector is being "privatized" without selling assets. This is happening thanks to the increasing participation of private and foreign companies in the electricity market. This is also happening thanks to market liberalization. In Poland, it is quite easy to set up a distribution company to manage medium- and high-voltage networks. This makes it possible to break the monopolies of existing operators. It is even easier to set up an electricity, gas, hydrogen and fuel trading company. Safety and customer protection systems work reasonably well, and there have been no bankruptcies or failures of companies in this industry for many years. Companies are increasingly building direct connections from the energy producer to the consumer for small and medium-sized installations. More and more PPAs are being concluded. There are several medium-sized energy trading companies active in the market, which compete effectively with the state-owned giants. In general, dozens of energy trading companies are active. In addition, there are dozens of grid operators. This means that hydrogen installations are not condemned to state monopolies. There are also a lot of ready-made wind and photovoltaic farm projects on the market that have not been given permission to connect to the grid. PSE estimates that there were a total of around 83.6 GW of such projects in 2023 alone.

All these companies are counting on contracts with hydrogen produc-

ers and the construction of direct connections or PPAs. A solution to the shortage of power grids is therefore on the horizon, as this is the biggest issue facing the energy market in Poland.

POLITICAL CHANGES Most of the troubles plaguing the Polish market were caused by the economic policies of the populist-right-wing Law and Justice Party (PiS), which ruled from 2015 to 2023. Fear of change, flirting with trade unions, building political capital on the fight against wind energy, deepening the role of the state and rebuilding the monopolies of state-owned companies stopped the development of renewable energy. The main market players quickly put wind power plans on hold and focused on photovoltaics. Geothermal and biogas plants, which were promoted and favored by those in power, lost the economic competition. Poland has become one of the fastest growing photovoltaic markets in Europe. However, when confronted with the ever-demanding grid upgrades, the system began to "choke" on excess energy from the sun. In 2024 alone, solar power producers had to switch off their installations more than 60 times. Despite this, coal-fired power plants as the backbone of the system were pushing up energy prices to some of the highest in Europe. Buying the support of mining unions resulted in populist laws on energy price subsidies for individual consumers instead of renewables. When, after the COVID pandemic, almost the whole of Europe embarked on a recovery and a massive modernization program, Poland was one of the few countries not to receive aid measures due to numerous political disputes over, among other things, the rule of law.

However, in October 2023, a coalition of centrist and left-wing parties led by Donald Tusk, who is well-known and popular in Europe, returned to power. Virtually immediately, the process of returning the country to the path of a transformational leader and a modern state began. After just a few weeks, EU aid funds were unblocked. The 10H rule effectively blocking the development of wind energy was also abolished. Poland's role in Europe is steadily growing. Poland is becoming a country that plays a very important role in the European Union. The new coalition is also aware of the challenges facing the modern economy. The minister for industry, Marzena Czarnecka, has moved her office to Upper Silesia, to Katowice, where mining, metallurgy and heavy industry dominated in Communist times, and where today the region is looking for its opportunity in new and clean technologies and where specialists are finding new jobs. It is green hydrogen that is supposed to be this "coal of the future," and this is a good omen for the future.

FUNDS AND FINANCE One of the problems facing the green hydrogen industry is the lack of takers for the more expensive green hydrogen. Most entrepreneurs realize that the test phase of the first projects is over several years before the moment when electrolyzer efficiency and energy prices will allow green hydrogen to make money. They expect countries to find aid funding to accelerate up to this moment. However, in most countries that have so far actively financially supported hydrogen projects, they now either do not have the funds to do so or have other problems. It turns out that one of the few countries that has these funds and wants to invest in hydrogen projects is Poland. This is where, over the next few years, around EUR 30 billion will be earmarked for loans and grants for investments in the construction of energy networks, energy transition, green hydrogen and energy storage. The KPO, or National Recovery Plan, may be the best bridge during the development of hydrogen technologies to their full viability.

LATECOMER'S BONUS Anyone who has been to Poland recently has noticed that IT and telecommunications services there are at one of the highest levels in Europe. Every Pole has an "m-citizen" app on their phone, thanks to which they always have with them: their identity card, driving license, car insurance, prescriptions for the pharmacy, information on traffic penalty points, vaccination certificate, school or student card and transport tickets, among other things. Al-

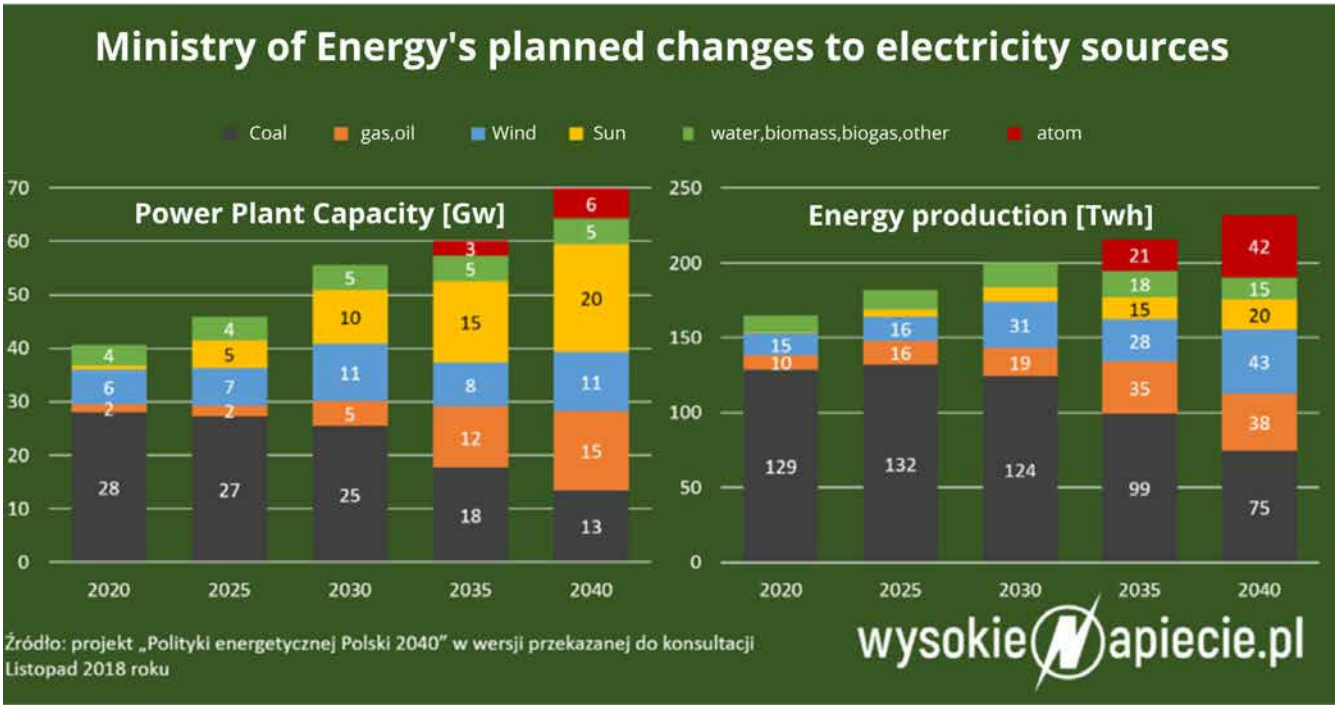


Fig. 2: Polish ministry of energy's planned changes to electricity sources [Source: wysokienapiecie.pl]

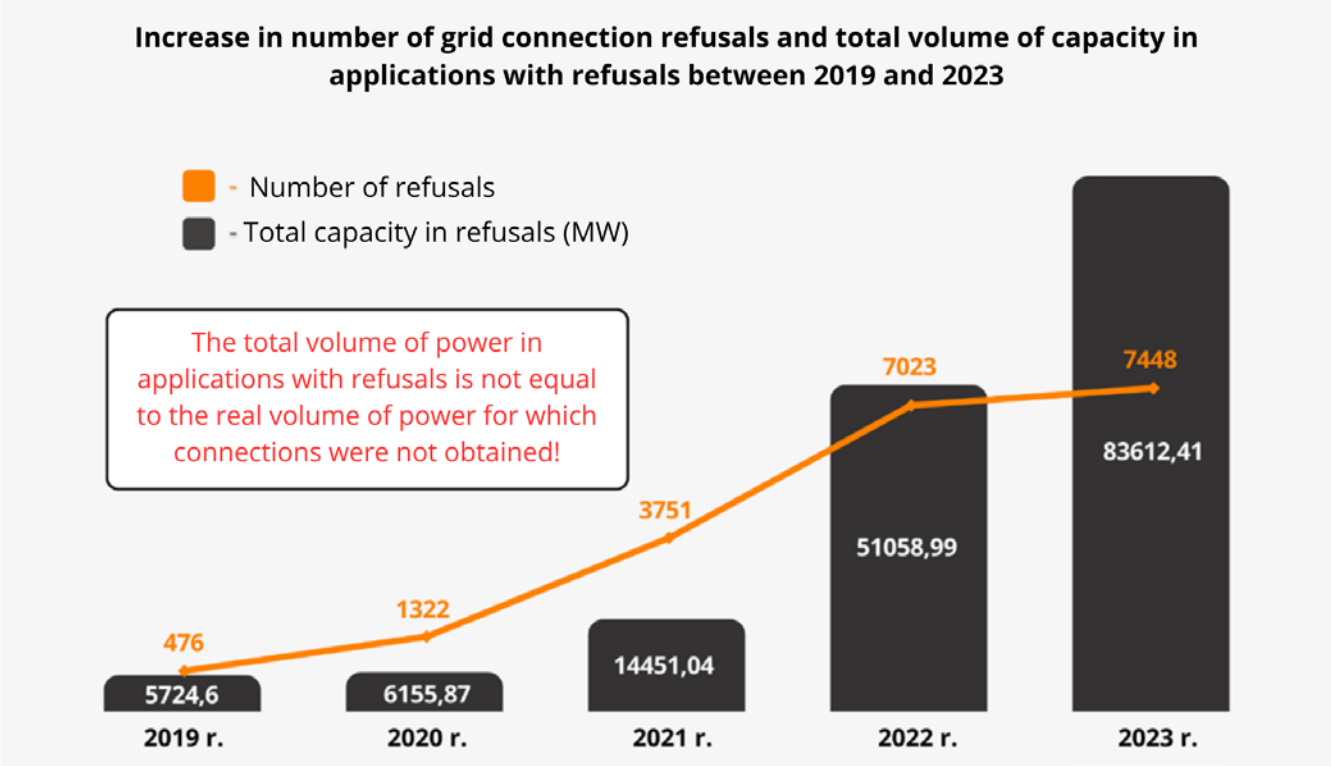


Fig. 3: URE – Number of refusals issued and power of projects that did not get connected to the grid

most all administrative and tax matters can be handled with this app. You can sign documents or applications with an electronic signature. The app is linked to your bank account and our bank's app, and with it you can pay taxes, fines or apply for benefits. Long before the COVID pandemic, phone payments were the majority for individual purchases.

As most companies and individuals have their bank accounts linked to their telephone numbers, all company bills are paid online. Hardly anyone remembers that there is an obligation to pay by bank transfer above €10,000, because everyone pays most bills online anyway. Companies only settle accounts with the tax authorities online, and tax returns are an electronic summary of all cost and income invoices. In practice, it is the office's software that calculates the tax. Tax office inspections are rare, as all documents are online and there is no need to visit the company and its contractors to inspect them. Despite seemingly less state interference in the lives of citizens, tax revenues have increased, the shadow economy has decreased and the mythical VAT gap (sales tax fraud) has been virtually eliminated. Companies and partnerships are set up online. Limited liability companies are established in 24 hours. The competent court easily places the company in the registers within one day, and does so automatically. There is LTE internet in every, even the smallest, village, and increasingly 5G. Charges for unmetered internet on the phone or at home can be found from €5 per month.

I know that there are certainly several countries in the world that are doing even better in this area, but I want to show that the "latecomer's premium" has resulted in solutions that were adopted in Poland later on being much more modern and convenient than in other countries. I believe that thanks to the fact that Poland's green hydrogen economy is developing a few years behind Germany or the Netherlands, it will avoid a few beginner's mistakes and benefit from the best experiences. Combined with delays in the disbursement of aid funds from the "Reconstruction Funds" intended mainly for the energy transition, Poland has a chance to become one of the best investment markets in Europe in the next few years. Let us not forget that Poland has been on a consistently strong growth path since the early 1990s. Since then, there has not been a single recession and growth rates of up to 6 percent have not been rare. During this time, gross domestic product has tripled, and this is probably the best result in the world. Poland is now the fifth largest market in the European Union and continues to grow dynamically. Despite the country's very difficult situation at the beginning of the 1990s, thanks to consistent reforms and financial and economic policies, our eastern neighbor is making excellent use of its opportunities.

In summary it should be said that:

- Poland has a very high demand for hydrogen and great potential for replacing gray hydrogen with green hydrogen
- Poland has young and good managers and proven O&M companies
- Poland's RES market is growing rapidly and has great potential
- Regulations encourage the development of green hydrogen
- The political situation in Poland is good and favorable for hydrogen investments
- Poland will receive a huge amount of funds from the national program for hydrogen investments in the coming years •

Author:

Piotr Rudyszyn
J. Czochralski Holding Sp z o.o., Warschau
→ pr@czochralski.com

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Phone +49-4497-9269-90, Fax -18,
www.maceas.com

Resato International B.V., H_2-Pressure Testing, H_2 gas booster for refueling stations, high pressure technology, Duitslandlaan 1, 9400 AZ Assen, Netherlands, Phone +31-(0)501-6877, *h2sales@resato.com, www.resato.com*

Sonplas GmbH, H_2 test stand, Testing of hydrogen-carrying components with real fuel, Sachsenring 57, 94315 Straubing, Germany, Phone +49-9421-9275-0, *info@sonplas.de, www.sonplas.com*

Zeltwanger, Leak and Functional Testing, Automated Lines for Laser Applications and Assembly Tasks, Maltschachstr. 32, 72144 Dußlingen, Germany, Phone +49-7071-3663-106, *e-mobility@zeltwanger.com, www.zeltwanger.de*

TEST STANDS

AIP Automotive GmbH & Co. KG, Hojen 30, 87490 Haldenwang, Germany, Phone +49-8374-24090, *info@aip-automotive.de, www.aip-automotive.de*

EVENTS

More events at www.h2-international.com/events

MARCH

Hannover Messe 2025
March 31 – April 4, 2025
Messegelände Hannover
www.hannovermesse.de/de/hannover-messe-2025/

MAY

The smarter E Europe
May 7 – 9, 2025
Messe München
www.thesmartere.de/messe-kompakt

Innovationsforum Energie
May 15 – 16, 2025
Zürich Marriott Hotel
www.innovationsforum-energie.ch

JUNE

Wasserstoff und Brennstoffzelle
Nur Speicher und Kraftstoff oder mehr?
June 3 – 5, 2025
Haus der Technik
www.hdt.de

ENA2025 – Electrolysis North America
June 16 –17, 2025
Toronto
www.redcabin.de/summits/electrolyzers-north-america/

JULY

Innovationsforum Mobility
July 3 – 4, 2025
GDI Gottlieb Duttweiler Institute
www.innovationsforum-mobility.ch

AUGUST

ICE 2025 | International Conference on Electrolysis
August 25 – 29, 2025
University of Freiburg
www.ice2025.eu

SEPTEMBER

New Energy Investor Summit
September 25 – 26, 2025
Swiss Re Centre for Global Dialogue
www.investorsummit.ch/de

OCTOBER

hy-fcell
October 7 – 8, 2025
Landesmesse Stuttgart
www.messe-stuttgart.de/hy-fcell/

LEGAL NOTICE

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Legally Responsible for Content Dipl.-Ing. Sven Geitmann
Phone +49 (0)33055 21322
Email info@h2-international.com
Web www.hydrogeit-verlag.de, www.h2-international.com

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Eva Augsten, Max Deml, Sven Geitmann,
Niels Hendrik Petersen, Jens Peter Meyer

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Cover image: Such iron nuggets can release hydrogen on site [Source: Ambartec]
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