THE HYDROGEN MAGAZINE

01 . 26th Year 2026 . 14391
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E-fuels:
Energy imports from the desert

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New projects and new electrodes

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Hydrogen stocks

Who were the few winners in 2025?


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The transformation is in full swing

One sign that an industry is maturing is when the first prototypes or their replicas end up in a museum – like the 30-year-old Necar 1, the first car with a fuel cell drive. It is a van whose cargo space is almost entirely filled with the fuel cell system, hydrogen tank and accessories. The original is on display at the Cellcentric factory in Esslingen. Also exhibited at the site are the fuel cell module generations developed by the company itself. Each new generation is visibly more compact and delivers more power in the same space.

"More power" is also increasingly evident in Germany's electrolysis plants, which now more and more frequently have two- or three-digit megawatt capacities. Although progress is slower than hoped a few years ago, over one gigawatt of electrolysis capacity is now under construction, as HZwei author Niels Hendrik Petersen reports.

And despite what the headlines might sometimes suggest, Germany is not walking the hydrogen path alone. There is the EU, which is pushing on climate protection – even if in the hydrogen sector it is best known for its unpopular Delegated Act on the temporal correlation between electricity consumption and production.

In German power plant planning, EU competition authorities made it clear to the Federal Ministry for Economic Affairs that no money would be distributed to power plant operators without a clear pathway to climate neutrality – in other words, hydrogen. And for the first time, hydrogen pipelines are now officially included in European grid planning.

In hydrogen nation Japan, Fukushima Prefecture in particular has been pushing hard for green energy since the nuclear disaster in 2011 – there are now even hydrogen-powered bicycles there. My colleague Monika Rößiger learned this at a presentation by Masao Uchibori, the Governor of Fukushima.

Oman has also begun its hydrogen ramp-up – with the prospect of selling green gas to Europe and Germany in particular. But the memoranda of understanding once signed are no longer being taken so seriously in Germany. The Omanis are not amused, as our freelance author Natascha Plankermann reports after her recent trip. One can only hope that Germany does not earn an international reputation as one of those customers who first have a list of special requests and then end up buying nothing. That would backfire – and not just for the hydrogen industry.

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19 Global perspectives on hydrogen

Hydrogen ramp-up around the globe: Our focus section highlights progress in Europe, Japan's Fukushima Prefecture and Oman.

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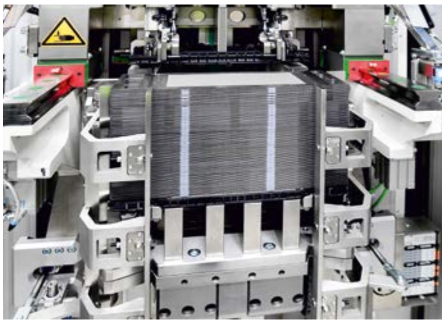
The Gulf state has major export plans but is also using hydrogen domestically.



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Cellcentric is upgrading its production for the new fuel cell unit.

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What's up, Hyfindr?

HYDROGEN IS NOT GOLD

Hyfindr Managing Director Dr. Björn Lüssow shares insights and encounters from the international hydrogen community.

The current gold rush is an alarm signal – record prices point to dwindling confidence in the international financial system. The USA, for example, is groaning under 38 trillion US dollars in debt. In 2025 alone, more than 1,000 billion was spent on debt interest – more than on the entire US military! Although the USA needs ever more money, central banks are reducing their holdings of US bonds and building up their gold reserves. It is unclear how this shift away from the dollar will play out. What is certain is that financial risks are rising. Anyone in industry hoping for "top priority" government hydrogen funding is also ignoring geopolitical realities – politicians have bigger concerns these days.

What is to be done? Take action, don't just wait and see!

Since the financial crisis in 2008, stress tests have been mandatory for European banks. There are lessons to be learned from this. Business leaders would be well advised to ask themselves the radical question now: would their business model survive without a single cent of funding? If the answer is no, they are not running a viable business, but a political project.

In a world of volatile capital, hydrogen must shine through technical excellence and return prospects, not subsidy approvals.

In my view, the question must be: how do we become innovative enough that capital flows increasingly into hydrogen rather than gold or AI?

Sovereignty does not come from state life support, but from commercial viability. In the past, we have delivered solutions that were convincing both technically and financially. Pursuing this path with courage and independence is the order of the day. If policymakers would then allow compelling innovations and products to flourish, the stress on business models would ease.

This will not turn hydrogen into gold. But it could then attract capital. ○

Hydrogen storage for emerging markets wins award

Helmut Schmidt University and the Helmholtz-Zentrum Hereon have been awarded the German Renewables Award 2025 in the "Hydrogen Innovation of the Year" category. The prize was given for a mobile, sector-coupled hydrogen system designed for international use. The jury recognised the "Smart Energy Transform Box," a compact, mobile hydrogen-based energy system.

The system enables the coupling of different energy sectors in a single unit, balancing energy supply and demand. It is designed specifically for use in developing and emerging countries. "Climate is not a national issue, but an international one," said Julian Jepsen, Professor at Helmut Schmidt University and researcher at Helmholtz-Zentrum Hereon. The box is "highly suitable" for deployment in these regions.

The award was presented as part of the annual German Renewables Awards organised by the Renewable Energy Hamburg Cluster (EEHH). The prize aims to highlight technological innovations that contribute to the transformation of the energy system.

Five projects competed in the "Hydrogen Innovation of the Year" category. In addition to the Smart Energy Transform Box, entries included a hydrogen project in Bremerhaven and a hydrogen-powered baggage tractor at Hamburg Airport (the latter project was covered in H2int. issue 5/2025). ○

Great joy among the winners of the German Renewables Award 2025

Hydrogen veteran David Bow joins Power to Hydrogen

David Bow, Chief Strategy Officer © Power to Hydrogen

Power to Hydrogen, a US developer of industrial electrolysers based on anion exchange membrane (AEM), has appointed David Bow as Chief Strategy Officer. Bow is to lead the company's strategy and market expansion in North America and Europe. His responsibilities include building strategic partnerships, market segmentation, commercial scaling, and aligning product development with customer and financing requirements.

Bow has over 25 years of leadership experience in the hydrogen and energy industry. Most recently, he led the electrolyser solutions division at Plug Power. Previous positions included Verdagy, Nel Hydrogen, and Proton OnSite. According to the company, Bow was involved in the marketing of more than 2 GW of electrolyser projects in 85 countries. He began his career at Dow Chemical in Columbus, Ohio, where he developed electrolysers for biochemical applications. He is currently also advising the Swedish investment company EQT Group on hydrogen, low-carbon fuels, and chemicals.

Power to Hydrogen develops AEM electrolysers, which the company claims to be a cost-effective alternative to conventional PEM systems. The technology combines dynamic operational capability and efficiency with a scalable material concept that avoids the use of precious metals like iridium. The hybrid cell architecture is designed for longevity under fluctuating renewable power supply and aims to enable reliable and financeable use on an industrial scale.

"Electrolysis is at a turning point. Customers no longer buy technology stories, but bankable assets that they can operate with confidence," says Bow. "My goal is to strengthen this confidence through suitable partnerships, credible validation, and disciplined implementation – in line with the procurement processes of industrial customers." Paul Matter, CEO of Power to Hydrogen, says: "David has spent his career guiding energy and industrial technology companies from technical capability to repeatable commercial implementation. As we move from pilot projects to scaled implementation, strategy becomes a matter of disciplined decisions: where do we play, how do we create customer value, and how do we build the partnerships that enable acceptance." ○

EU and Germany reach agreement in principle on power plant strategy

Germany's Federal Ministry for Economic Affairs and Energy (BMWE) has reached an agreement in principle with the European Commission on key points for the country's power plant strategy. This clears a major hurdle. The new power plants are to be hydrogen-ready.

A tender for 12 GW of dispatchable capacity is to be launched this year. Of this, 10 GW must be able to provide output for a longer minimum duration. These are to be "for example, but not exclusively" modern gas-fired power plants. Federal Minister Katherina Reiche now speaks of a "technology-neutral capacity market" intended to incentivise the addition of "further power plants and other flexible capacities."

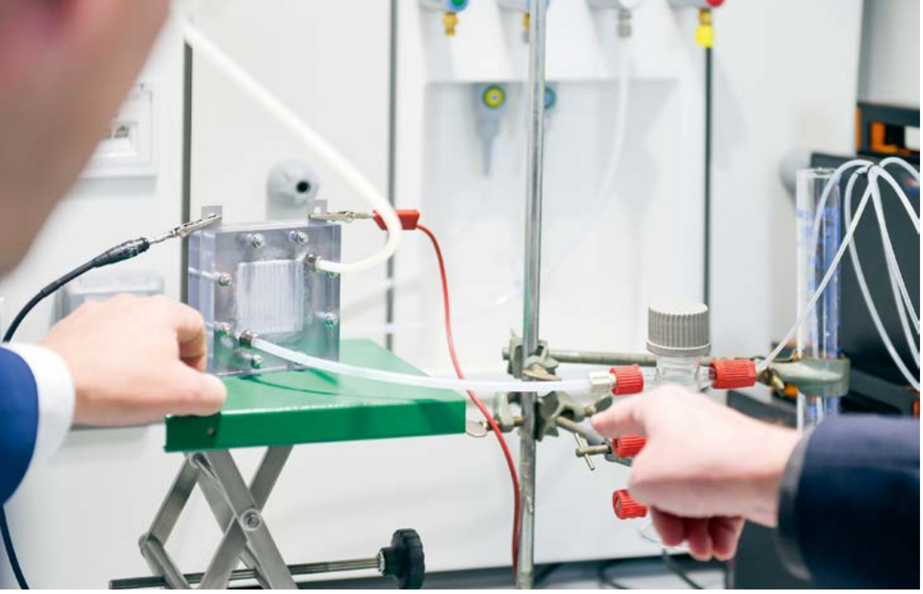
The capacities to be tendered this year are to come online by 2031 at the latest. Further tenders for dispatchable capacity are to follow in 2027 and 2029/2030. These tenders are also to be open to existing plants. Whether the tenders will total the capacity of just over 20 GW initially mentioned by the BMWE remains unclear at this point.

All power plants built under the power plant strategy are to be hydrogen-capable and fully decarbonise by 2045 at the latest. Additional measures are to be introduced to incentivise early switching to hydrogen at all power plants. The target is to convert the first 2 GW by 2040 and a further 2 GW by 2043. The instrument for this is to be contracts for difference, which are to be tendered from 2027. A legal framework for this still needs to be established.

The EU's involvement is due to the strict regulation of state aid under EU competition law. Even with this agreement, the state aid procedure is not yet complete. The ball is now back in the Ministry's court to draft a new version of the legislation. Once the law is passed by the Bundestag, Germany's federal parliament, official state aid approval can be granted. A legally sound tender can then be launched.

The German Association of Energy and Water Industries (BDEW) welcomes the agreement. Kerstin Andreae, Chair of the BDEW Executive Board, praised the key points: "It is a positive step that technology-neutral tenders for new and existing plants in 2027 and 2029 for the target year 2031 will be introduced alongside the tenders for new plants in 2026. These address the total demand for dispatchable capacity for 2031."

Incentivising the switch to hydrogen for gas-fired power plants through separate tenders from 2027 is also seen as a sensible approach. This reduces the investment risk that a fixed hydrogen conversion date would pose for companies. The BMWE must now act quickly so that the legislation can pass through parliament by summer if possible. ○



ABOVE: The Ammonia2H2 project is researching how hydrogen can be extracted from ammonia.

New research platform for hydrogen systems

The University of Stuttgart has launched the WAVE-H2 research platform for new hydrogen technologies. The aim is to develop solutions for decarbonising industry and mobility. The platform is to research new hydrogen technologies along the entire value chain – from production to application in industry and energy systems. Germany's Federal Ministry for Research, Technology and Space (BMFTR) is funding the project with around €36 million.

The Vaihingen campus serves as the main experimental site. A second location in Freudenstadt is to follow in summer 2026, where the technologies developed will be tested at industrial scale.

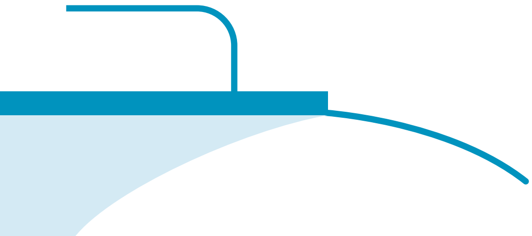
Research at the WAVE-H2 campus focuses not only on electrolysis but also on conversion into energy carriers such as methanol or ammonia, as well as the recovery of hydrogen from ammonia. The latter is considered a promising approach for transporting hydrogen.

A fuel cell test rig also enables research into the conversion of hydrogen into electricity and heat. Further projects address the production of aviation fuel from biogas and the manufacture of basic chemicals from waste using pyrolysis.

The platform is operated by the Institute for Energy Efficiency in Production (EEP) and the Chair of Electrical Energy Storage Systems at the Institute for Photovoltaics (ipv). Project leader Alexander Sauer, Director of the EEP, emphasises: "With our platform, we are making a strong contribution at regional, state and national level to innovative and flexible hydrogen solutions and to the decarbonisation of industry."

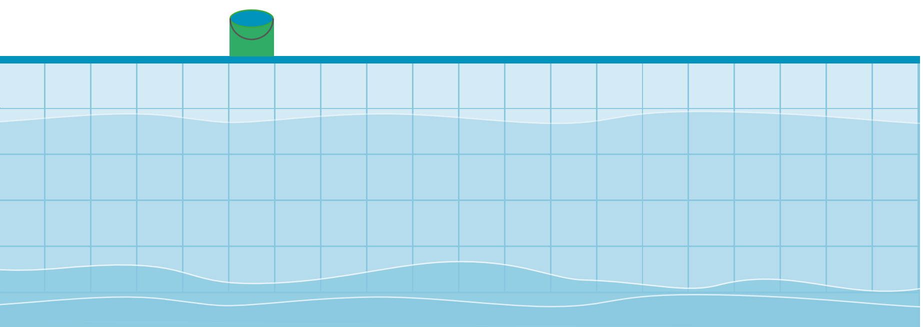
RIGHT: Prof. Alexander Sauer and Prof. Kai Peter Birke at the fuel cell test rig in the WAVE-H2 laboratory

The research is closely linked to industrial practice. The Vaihingen site is located in close proximity to the ARENA2036 research factory. WAVE-H2 also cooperates with the CHEMampere initiative, which is working on CO2-neutral processes for chemical production. ○



According to the IEA Global Hydrogen Review 2024/25, just under 1 million tonnes of hydrogen were produced worldwide using low-emission technologies – barely 1 percent of the 100 million tonnes of hydrogen in total. That is equivalent to a bucket of water in an Olympic swimming pool. For comparison: photovoltaics in Germany exceeded a 1 percent share of electricity generation in 2009. By 2025, it had reached 18 percent, surpassing both lignite and natural gas.

= 1 MILLION TONNES OF HYDROGEN



Freiberg uses Danish e-methanol for nearly climate-neutral gasoline

E-methanol production plant in Kassø, Denmark © Jacob Hartwig Larsen

The TU Bergakademie Freiberg and the company CAC Engineering have processed industrially produced e-methanol from Denmark into synthetic gasoline for the first time as part of the DeCarTrans project funded by the Federal Ministry of Transport. The e-methanol comes from the large-scale plant in Kassø, Denmark, a joint venture of European Energy and Mitsui.

In the sixth test campaign from November to December 2025, around 23,000 litres of nearly climate-neutral gasoline were produced in the Freiberg large-scale test facility. The e-methanol used is based on biogenic CO2 and green hydrogen, which was generated with renewable electricity.

“The first use of e-methanol in our large-scale test facility is a pioneering milestone in preparation for a first industrial plant,” says Martin Gräbner, Professor of Process Energy Engineering at TU Freiberg. “We succeeded in demonstrating the entire process chain from biogenic CO2 and green hydrogen to high-performance synthetic gasoline.”

According to Gräbner, the new input product enables more efficient process management. The CO2 savings compared to fossil gasoline can be up to 90 percent.

CAC Engineering also sees this step as an important foundation for the planned industrial plant "German eFuel One" in Lower Saxony. “Our cooperation with Kassø shows that our process engineering Methafuel process is now fully based on an industrially available, electricity-based carbon carrier,” says Mario Kuschel, Head of Research and Development at CAC Engineering.

Freiberg demonstration plant is the first and largest of its kind in Europe The demonstration plant in Freiberg was established in 2009 and is the largest of its kind in Europe. Since the start of the project, 253,700 litres of regenerative fuel have already been produced there. The e-fuels produced are used, among other things, for engine and vehicle tests as well as in motorsport.

Another test campaign with e-methanol is planned for the second quarter of 2026. The aim of the project is to demonstrate the continuous operational capability of the technology under real conditions by the end of 2026.

The DeCarTrans project is funded with a total of 14.93 million euros by the Federal Ministry of Transport. In addition to TU Freiberg and CAC Engineering, project partners include FEV Europe, Coryton Advanced Fuels Deutschland, and the Forschungszentrum Jülich.

The synthetic gasoline meets the requirements of the DIN EN 228 standard, is drop-in capable as an E10 blend, and is registered under REACH. According to project information, production costs of about one euro per litre could be achieved in industrial plants. ○

Resilience as a catalyst

Critical infrastructure is moving to the centre of defence capability. As a resilient energy carrier, hydrogen can make a major contribution here – while also accelerating the transformation.

The hydrogen debate has been shaped largely by industrial, climate and innovation policy; its relevance for security is now becoming increasingly clear. Hydrogen technologies could make armed forces and security-relevant infrastructure significantly less dependent on fossil fuel imports. NATO has already explicitly recognised hydrogen as a strategic building block for the energy transition in the defence sector.

What are the application areas for the defence industry?

- **Mobile energy supply and logistics:** Hydrogen fuel cells offer quiet, low-maintenance and climate-neutral power supply – even away from conventional supply grids. Mobile hydrogen generators can operate field camps, sensor systems or communication units autonomously and offer advantages over diesel infrastructure in terms of transport, logistics and maintenance.
- **Alternative fuels and vehicles:** E-fuels enable the decarbonisation of existing fleets – crucial for air forces, navies and armies. Hydrogen-powered utility and special-purpose vehicles reduce dependence on conventional fuel supply chains, extend range and enable autonomous energy supply even in emergencies.
- **Protection of critical infrastructure:** Power outages and sabotage threaten the operational capability and supply of armed forces. Hydrogen-based emergency power supply with fuel cells as backup enables redundancy and security of supply – independent of diesel reserves and supply chain risks.

STEFAN KAUFMANN
Dr Stefan Kaufmann is a lawyer who advises companies and investors in the hydrogen economy nationally and internationally. He served in the Bundestag, the Federal Parliament of Germany, from 2009 to 2021 and from 2024 to 2025. From 2020 to 2022, he was the Federal Government's Innovation Commissioner for Green Hydrogen at the Federal Ministry of Education and Research. For H2int., he regularly reports on current developments in the energy carrier of the future.

Opportunities for the hydrogen ramp-up The defence industry is predestined to lend momentum to the hydrogen ramp-up as an early adopter, innovation driver and critical large-scale customer. It can provide incentives for scaling through demand aggregation and government investment. Initial pilot projects are already underway at the Bundeswehr, Germany's armed forces, including hydrogen-powered emergency power systems, H2 special-purpose vehicles and mobile refuelling stations.

However, it is also clear that military applications or increased Bundeswehr engagement in the hydrogen sector will support the ramp-up less through corresponding volume demand than by helping to build infrastructure. The Bundeswehr's actual fuel consumption as a share of total fuel consumption in Germany is likely to be well below one percent (i.e. well below one billion litres or 0.9 million tonnes).

The large budgets now released by the Federal Government for the defence sector give hope that some of this will also boost the hydrogen ramp-up. One example is support for building decentralised supply infrastructures for e-fuels – such as those now being developed by Rheinmetall. Considerations such as quotas for green steel in armoured vehicles could also indirectly incentivise the hydrogen ramp-up. Successful pilot applications in military technology can become a blueprint for accelerated market penetration in the civilian sector.

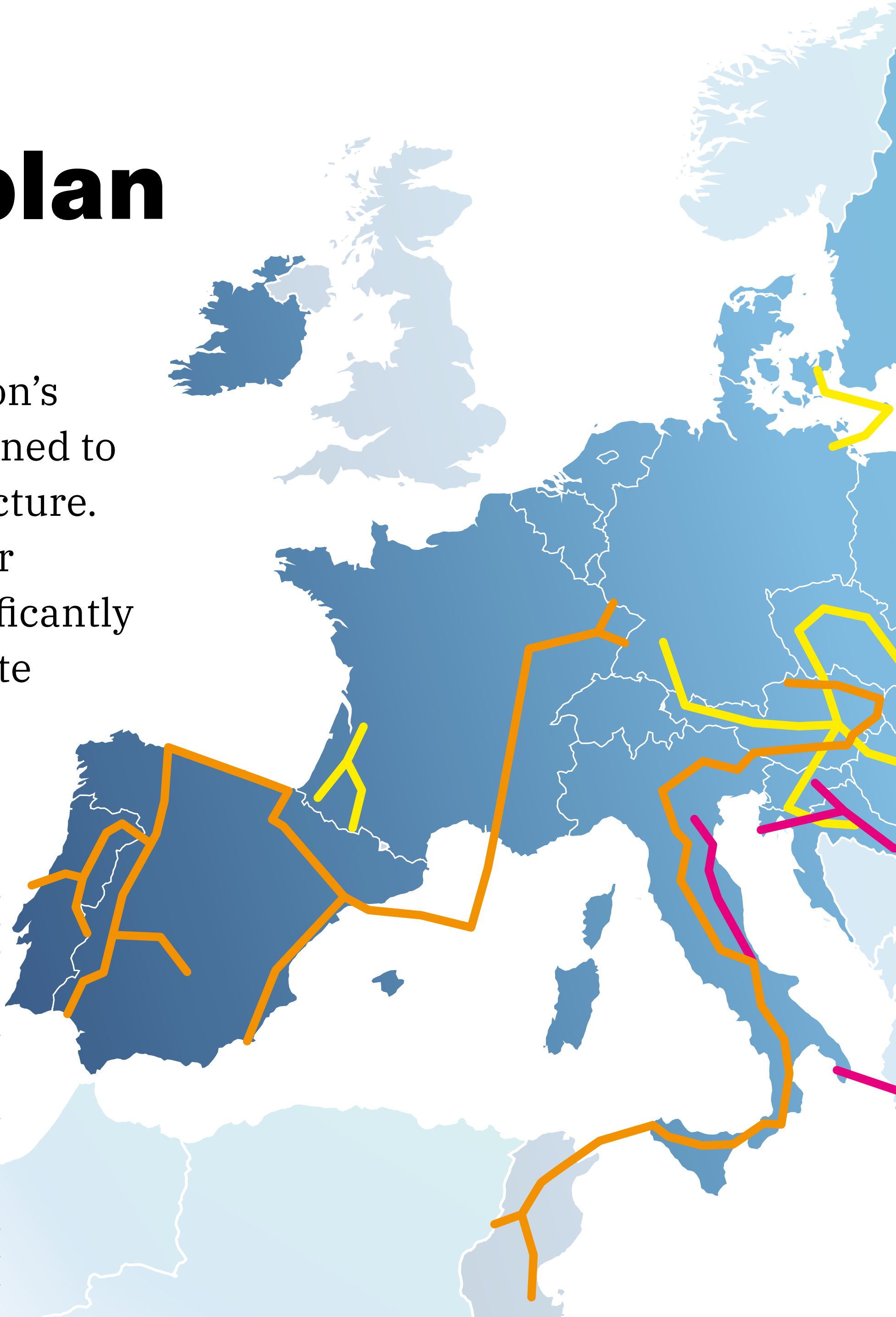
In this way, resilience can become not only a premise of modern security policy – but a driving force behind the hydrogen ramp-up. ○

European energy networks

Hydrogen joins the plan

By Eva Augsten

The European Commission's new grid package is designed to boost hydrogen infrastructure. It promises not only faster permitting, but also significantly more funding and concrete pipeline corridors.



On 10 December 2025, the European Commission presented proposals for the joint modernisation and expansion of energy infrastructure. These cover electricity, natural gas and hydrogen networks, as well as energy storage and charging infrastructure for electric mobility. To accelerate progress, the package aims to simplify planning, permitting and financing through improved coordination, more transparent cost-sharing models and the use of joint financing tools such as special purpose vehicles.

A seat at the planning table Much like Germany's grid development plans, which are coordinated between operators and the responsible authority, a similar process takes place at EU level – until now covering natural gas and electricity. With the new grid package, the European Commission is now anchoring hydrogen in European network planning.

Going forward, a central EU scenario for electricity, gas and hydrogen will be drawn up every four years. This will serve as the basis for the Ten Year Network Development Plans (TYNDPs) and the European infrastructure needs assessment. The associations representing the respective network operators play a key role in this process. Until now, these have primarily been the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSO-G). The latter has also been responsible for hydrogen matters to date. That is set to change. The European Network of Network Operators for Hydrogen (ENNOH), founded in June 2025, will now participate on an equal footing and take responsibility for hydrogen networks. For 2026, however, responsibility will remain with ENTSO-G on a transitional basis. Existing natural gas infrastructure is also to be more rigorously assessed for potential conversion to hydrogen use.

The Commission expects these measures to improve integration across sectors. The hydrogen association Hydrogen Europe expressly welcomes this. However, ENNOH remains excluded from the Offshore Network Development Plan – a point of criticism from Hydrogen Europe, given that it also contains targets and plans for hydrogen infrastructure.

Legend
Hydrogen
Electricity
Gas

© Source: European Commission, graphic: NEONBOLD

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Mapping the route The Commission not only outlines future planning processes but also identifies eight specific network expansion projects, known as Energy Highways, that are of particular strategic importance. Two of these are hydrogen pipelines.

The South H2 Corridor is to involve Tunisia, Italy, Austria and Germany, while the South-Western Hydrogen Corridor will run from Portugal to Germany.

In addition, three priority corridors for hydrogen and electrolysers have been designated: Hydrogen Infrastructure in Western Europe (HI West), Hydrogen Infrastructure in Central Eastern and South Eastern Europe (HI East) and Baltic Energy Market Interconnection Plan in Hydrogen (BEMIP Hydrogen). These are intended to create cross-border connections, resolve bottlenecks and link import corridors with industrial consumption centres. In doing so, they are to form the backbone of a future EU hydrogen network.

According to the German Association of Energy and Water Industries (BDEW), this marks the first time the European Commission has included hydrogen projects in its core energy infrastructure corridors. This demonstrates that the Commission now views hydrogen pipelines as systemically important components of the European energy system.

Significantly more funding The Commission estimates that around €240 billion will be needed for hydrogen networks by 2040. Compared to the €1.2 trillion required for electricity grids, this is a considerably smaller but still significant amount. To avoid passing all these costs on to consumers through network charges, the Commission intends to commit more of its own funds. The current long-term EU budget (2021–2027) allocates €5.8 billion under the Connecting Europe Facility for cross-border energy projects. For the next budget period, from 2028 to 2032, the Commission plans to increase this fivefold to €29.91 billion.

Hydrogen Europe welcomes the Commission's willingness to assume part of the economic risk through public funding and to spread costs over time. These principles are similar to those underpinning the financing of Germany's core hydrogen network.

Exactly how the funding for EU hydrogen infrastructure will be distributed remains unclear. Direct grants are apparently not envisaged. The Commission intends to explore contracts for difference, among other options. The European Investment Bank (EIB) is also providing a counter-guarantee of €1.5 billion for network components. Industry is invited to submit concrete proposals, which will be discussed at the Energy Infrastructure Forum – an annual event organised by the Commission's Directorate-General for Energy in Copenhagen each summer. Hydrogen Europe has indicated its intention to contribute. The Commission plans to set out how it intends to convince private investors to invest in network expansion in its Clean Energy Investment Strategy for Europe, due to be published next year.

Hydrogen pipeline and electrolyser projects will also continue to be eligible for designation as Projects of Common Interest (PCI) or Projects of Mutual Interest (PMI). This status brings streamlined permitting, higher political priority and improved access to EU funding.

Fast-track permitting for pipelines – storage takes longer Hydrogen Europe also welcomes the permitting acceleration directive included in the grid package, which is explicitly intended to streamline processes for hydrogen infrastructure. According to the association, however, this does not apply to the same extent as for electricity networks.

Hydrogen storage facilities are expressly excluded from accelerated permitting and simplified procedures – a significant obstacle for projects, according to Hydrogen Europe. The BDEW also emphasises that, given the long development timelines, storage must be included in the simplification measures.

Overall, both Hydrogen Europe and the BDEW see the grid package as a major boost for hydrogen infrastructure – with points deducted for the omission of hydrogen storage and the lack of integration into offshore planning.

"Network operators need an appropriate financial and regulatory framework to invest in grid expansion and digitalisation," says Kerstin Andreae, Chair of the BDEW Executive Board. However, she considers the intervention in planning to go too far. The focus should be "on stronger European coordination rather than centralised planning." She regards the hydrogen corridor from Portugal to Germany as particularly important for Germany.

The grid package is now in the regular legislative process. The Council and the European Parliament will deliberate on and amend the proposals during 2026. In parallel, technical groundwork is beginning for the next round of European network development planning, in which hydrogen will be systematically incorporated into scenarios and needs assessments for the first time. The concrete design of the financing mechanisms – such as the use of contracts for difference or additional EU guarantees – will be specified by the Commission in its announced Clean Energy Investment Strategy during 2026. At that point, it will become clear whether the planned hydrogen corridors will swiftly become reality or remain planning projects for the time being. ○

Nuclear power? No thanks!

By Monika Rößiger

In the wake of the triple disaster in Fukushima, the region in northeastern Japan has taken a unique approach to energy policy: it is relying entirely on solar and wind energy, biomass, and hydrogen.

Masao Uchibori refers to the province of Fukushima as a “treasure chest of nature” when he addresses around 70 experts in renewable energy and hydrogen in Hamburg. “Beautiful landscapes, castles, ramen, and our world-famous sake,” continues the governor of the prefecture. “Fukushima was so magnificent and so peaceful. And then came March 2011.” The regret is still audible in his voice.

Fifteen years after the devastating meltdown in three reactors at the Fukushima Daiichi nuclear power plant, Japan presents a divided picture in terms of energy policy: while the country continues to rely on nuclear power and reactivated two reactor units of the 8.2-gigawatt Kashiwazaki-Kariwa nuclear power plant in early 2026, the Fukushima region is steadfastly committed to renewable energy and hydrogen.

This has led to the curious situation that two energy-related superlatives are located just about 150 kilometers apart as the crow flies: the largest nuclear complex in the world and one of the world’s largest facilities for the production of green hydrogen.

“Fukushima has truly undergone an energy revolution,” says Katharina Fegebank, Second Mayor of the Hanseatic City, in welcoming the representatives from business, science, and politics who are attending an economic seminar in Hamburg. This is intended to further deepen the partnership between Hamburg and Fukushima, with a focus on scientific exchange and sector coupling. Previously, Hamburg’s First Mayor Peter Tschentscher had welcomed the high-ranking delegation from Japan at City Hall, where he and Governor Uchibori ceremoniously extended the cooperation, particularly in the field of hydrogen technology.

Since 2018, the city-state and the Japanese region, each with around 1.8 million inhabitants, have been cooperating on the basis of a Memorandum of Understanding. They support companies in entering each other’s markets and implement joint research projects. Both partners also share the highly ambitious goal – especially for industrial regions – of becoming climate neutral by 2040.

Fukushima already generates 60% of its electricity needs from renewable energy sources – equivalent to the share of renewables in Germany as a whole. The province aims to become a model region for a hydrogen-based society, while the central government in Tokyo continues to rely on nuclear energy. Japan is not aiming for climate neutrality until 2050.

Reconstruction with renewables and hydrogen

“Our experiences have taught us that it is better not to depend on nuclear power,” explains Uchibori. Electrolyzers and wind turbines from Germany are also contributing to this independence. German technology and expertise are of great interest: “We even have a German electrolyzer installed in a school as a demonstration and teaching tool,” says the govenor.

The prefecture, whose name will forever be associated with one of the worst nuclear disasters in history, is now one of the leading and politically most important regions for hydrogen-based mobility in Japan. This applies in particular to fuel cell-powered commercial vehicles, whether trucks or buses, police or ambulances.

“Even hydrogen-powered bicycles are part of everyday life for us,” says Uchibori. Stationary fuel cell systems supply the city hall, residential buildings, and an Olympic sports facility in the city of Fukushima with electricity and heat. The local industry uses electrolytic hydrogen, for example, in afterburner furnaces, in a semiconductor glass factory, and at the Falken/Sumitomo tire plant in Shirakawa.

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Governor Masao Uchibori explains what the future of Fukushima Prefecture looks like with green hydrogen to representatives from business, science, and politics in Hamburg.

© Monika Rößiger

There, it is used to produce climate-neutral tires. In the past, this factory already used grey H2 in the vulcanization process. Fukushima not only has its own hydrogen strategy (in addition to the national one from 2017, which made Japan the first country in the world to adopt such a strategy).

With the Fukushima Hydrogen Energy Research Field (FH2R), the region is home to one of the world's largest demonstration facilities for the production and research of green hydrogen.

H2 research is further strengthened by the Hydrogen Energy Research Institute at the University of Fukushima. The Fukushima Renewable Energy Institute (FREA), one of the country's most important research institutions, is also located there – and maintains close exchange with H2 specialists from Germany.

"On our campus, we have demonstration and pilot plants for electrolysis, ammonia synthesis, and the use of ammonia and hydrogen in engines, turbines, and CHP systems," explains Hirohide Furutani, Director General of FREA. "Storage, catalyst development, and load-following operation under fluctuating power generation also play a major role for us."

Pioneer in hydrogen research FREA is researching hydrogen and ammonia engines for stationary energy applications and is working with partners from industry and plant engineering. "In April 2018, we commissioned a pilot plant for green ammonia with a capacity of around 20 kilograms of ammonia per day," Furutani continues.

"The goal is flexible ammonia synthesis from electrolytically produced hydrogen." It is considered one of the world's first ammonia pilot plants of this kind to be operated entirely with renewable electricity. In April 2024, the University of Fukushima established the Hydrogen Energy Research Institute (HERI), which pursues an integrated research approach along the entire value chain.

Hydrogen from biomass and circular economy Particular attention is being paid to a joint project with the prefecture of Fukushima, in which a novel process is being developed to simultaneously extract hydrogen and carbon from forest biomass.

"The goal is to establish a regional circular system for decarbonization that utilizes local resources and contributes to the sustainable development of the region," explains Tsukasa Matsuda, Executive Director of the university. The project is part of a comprehensive biomass-hydrogen research initiative that combines technological innovation with regional value creation.

The fact that the implementation of the hydrogen society in Fukushima, but also in other parts of the country, is progressing so well is also due to "cultural differences," summarizes Jan Rispens, head of the EEHH cluster of the Hamburg Ministry of Economic Affairs and co-organizer of the seminar. Japan's Ministry of Economy, Trade and Industry (METI) is managing the various areas of the hydrogen economy with military precision.

Europe: simply too complicated The economy there understands that this is a long journey and requires extensive research and development investment.

"In Germany and Europe, on the other hand, we are trying to use overly complex regulations to encourage the economy to invest in something that simply isn't profitable at the moment. The rules for the production of green hydrogen are just too complicated." ○

Hydrogen from Oman

Green iron, clear direction

By Natascha Plankermann

Oman is known as an ambitious hydrogen player. After the hype, the Gulf state is now taking a deliberately sober approach. It is seeking benefits for its own country while also serving European customers – particularly the German steel industry.

"We are experiencing what every energy transition brings: delays," says Oman's Energy Minister Salim Al Aufi. He compares the current situation to that of the British Navy, which only managed the switch from coal to oil for powering its ships after a lengthy transition. The minister is not trying to conjure up a heroic myth, but rather to recall what transformations are all about: the right pace, a gradual build-up of infrastructure – and perseverance. For Oman, this currently means acknowledging that certifications and regulations for producing and transporting green hydrogen are complex. They also need to correct illusions about demand. Europe is not honouring the commitments made in joint declarations of intent regarding the offtake of green hydrogen. This has led to a change of course that was palpable at the Green Hydrogen Summit, where EU representatives and Omani decision-makers met in the capital Muscat. The tenor of the meeting: away from mere promises of molecules, towards applications that create value in the country while also stabilising European supply chains.

Export products aligned with CBAM The target remains clear: by 2030, Oman aims to produce one million tonnes of green hydrogen per year, rising to eight million tonnes by 2050. This should enable producers in the country to largely switch to green hydrogen – a plan that fits with the sustainability objectives of the country's Vision 2040. The green molecules are not to be considered in isolation, but integrated into industrial processes. They are intended to create jobs and deliver export products compatible with the CBAM mechanism (Carbon Border Adjustment Mechanism). This refers to EU import duties based on carbon footprint. Here lies the connection between Omani industrial policy and European climate regimes: CBAM defines the rules of the game by which production and investments can be aligned.

"Oman does not see the EU's plans for this carbon border adjustment mechanism as a threat, but as an opportunity to build a competitive green industry and thus create jobs," says Dawud Ansari, President of the Majan Council think tank in the country and author of the Oman Clean Energy Strategic Outlook.

In this context, potential transport routes to Europe and especially to Germany are becoming increasingly important. "The India-Middle East-Europe Economic Corridor (IMEC) can become a lifeline for Europe's industry," says Jorgo Chatzimarkakis, CEO of Hydrogen Europe. This is not a romantic notion of new Silk Roads, but a logic of connectivity. This can apply to crude steel products as well as ammonia deliveries. For ammonia, Chatzimarkakis cites the ACME Group as an example: the Indian energy company is building a plant there that is due to start up at the end of 2026; the first ammonia shipments to Europe are scheduled for early 2027. In the first phase, around 100,000 tonnes of green ammonia per year are planned, potentially rising to almost one million. Initially, ACME intends to use electrolysers from Asian manufacturers, but in the medium term also plans to cooperate with European technology partners such as Thyssenkrupp Nucera. ▻

Desalinated seawater is needed for the production of green hydrogen – as supplied by numerous plants along the Omani coast, including the desalination plant in Barka, around an hour west of Muscat.

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Abdullah Al Abri, until recently Oman's representative at the International Energy Agency and now responsible for sustainability and hydrogen at the Port of Sohar, explains the country's current situation in the field of green hydrogen at the Green Hydrogen Summit in Muscat.

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At the new hydrogen filling station in Muscat, Sharik waits for customers with the fuel nozzle.

© Natascha Plankermann

Those who produce green molecules in Oman and convert them into products that can be used directly in Europe reduce transformation risks on both sides. This explains why projects in Oman's port city of Duqm are not only targeting ammonia, but also fertilisers and the interface with the steel industry.

Intermediate products for the steel industry from Duqm This is why further industrial plants are being built in Duqm that view hydrogen not as an end in itself, but as a means to an end. Indian steel group Jindal is preparing a plant that is due to start operations in 2027. "It will start production with natural gas and gradually switch to hydrogen," says Dr Firas Al Abduwani. This path of gradual substitution may seem unspectacular, but it is realistic. It allows operating models to be tested and the hydrogen share to be increased as volumes rise and prices fall. The plan is to supply the European market, particularly Germany, with lower-carbon intermediate products. Interestingly, Jindal Steel International has made a purchase offer for Thyssenkrupp's steel division (Thyssenkrupp Steel, TKSE). At the time of going to press (mid-January 2026), negotiations were underway regarding a possible gradual takeover.

Singapore-based company Meranti Green Steel is also pursuing the idea of supplying steel intermediate products from Oman – in a form that directly addresses European bottlenecks. "Europe needs such green intermediate products to remain competitive – and politically stable partners like Oman that can deliver," says Sebastian Langendorf, CEO of Meranti Green Steel and a native of Freiburg in Germany. In Duqm, his company is building a direct reduction plant with a growing share of green hydrogen. The product is HBI, hot briquetted iron, which can be further processed in Europe. The groundwork has been done: gas is allocated by Oman Integrated Gas Company, preliminary investment approval from Oman Invest is in place, as is a banking mandate with KfW IPEX-Bank. The hydrogen partner is Amnah Energy, with a majority stake held by Copenhagen Infrastructure Partners. Construction is scheduled to begin at the end of 2026, with operations due to start in mid-2029. Offtakers of the pig iron include Thyssenkrupp Materials Trading. The transport chain is outlined: via Rotterdam or Antwerp. Duqm reduces, Duisburg refines – CBAM-compatible.

What matters in this phase is not the grand promise of switching everything to hydrogen – rather, benefits and scalability must be properly aligned. This was precisely what experts discussed during a masterclass held by the Fraunhofer Institute for Surface Engineering and Thin Films IST during the summit in Muscat. "So-called sponge iron is the key to low-carbon steel production. Although three direct reduction plants have been commissioned in Germany – in Duisburg, in the Saarland and in Salzgitter – the complete switch to hydrogen remains difficult as long as the costs of green hydrogen do not fall significantly and cheap imports fail to materialise. In this context, Oman can play a central role in Germany's energy transition and in the market ramp-up of green steel in Europe," said Florian Scheffler. This is not a rejection of domestic production, but a plea for transitions that work. ○

OMAN

- **Population: approx. 4.6 million inhabitants**
- **Labour market and Vision 2040: The Majan Council think tank estimates that more than 20,000 new jobs can be created through hydrogen and green steel projects.**
- **Current economic structure: Oil and gas contribute around 37 percent to GDP, with 65 percent of exports and 72 percent of government revenues coming from this sector (2023, GTAI).**
- **Land potential: 50,000 km² for hydrogen zones.**
- **Production targets: one million tonnes of green hydrogen per year by 2030, eight million tonnes by 2050.**

Hydrogen stocks

Few winners, many losers in 2025

By Max Deml

Hydrogen stocks experienced a hype in 2021. Since then, share prices have fallen for many companies, but some saw strong gains in 2025. Financial expert Max Deml summarizes the past year for H2international.

COUNTRY	COMPANY	PRICE	PRICE €	MCap (MIO €)	P/S	P/E
CAN	BALLARD POWER	3.50	2.17	653	11.0	neg.
USA	BLOOM ENERGY	86.89	73.86	17,468	13.9	neg.
GB	CERES POWER HOLDING PLC	212.80	3.12	608	8.0	neg.
D	ENAPTER AG	1.70	1.70	55	2.2	neg.
D/L	H2APEX GROUP SCA	1.16	1.16	58	2.0	neg.
D	H2 CORE AG	0.615	0.62	7	7.3	neg.
N	HYDROGENPRO ASA	1.96	0.17	16	1.0	neg.
I	INDUSTRIE DE NORA SPA	7.29	7.29	352	0.4	4
GB	ITM POWER PLC	62.30	0.91	565	14.8	neg.
N	NEL ASA	2.232	0.19	348	2.9	neg.
D	PATH2 HYDROGEN AG	0.454	0.45	51	50.6	neg.
USA	PLUG POWER	1.970	1.67	2,328	4.4	neg.
S	POWERCELL SWEDEN AB	29.94	2.74	159	5.2	neg.
I	SNAM SPA	5.656	5.66	18,948	5.3	15
D	THYSSENKRUPP NUCERA AG & CO. KGAA	8.88	8.88	1,122	1.3	224
HK	WEICHAI POWER	18.85	1.74	15,216	0.7	13
	SUM / MEDIAN			**57,951**	**4.8**	

Of the more than 20 companies discussed in the article "Further dry spell for hydrogen stocks?" (HZwei 2/2025), several are missing here. Reasons include insolvency or a switch from hydrogen to natural gas, as in the case of fuel cell company FuelCell Energy. Also no longer included are **McPhy Energy SA**, **Nikola**, **Proton** and **Motor Power Systems plc**, as well as the two major industrial gas producers **Air Liquide SA** and **Linde plc**, which generate only a fraction of their revenues in the hydrogen sector. Some stocks such as **Bloom Energy** rose by well over 200 percent in 2025 – at times even by more than 500 percent. Others lost more than 50 percent. The 16 companies from Europe, the USA and Asia listed in the key figures table, with a combined workforce of around 112,000 employees, most recently achieved annual revenues of around €29 billion and a market capitalisation of around €58 billion. Only four of these companies are profitable, with China's Weichai Power accounting for by far the largest share of both revenues (around 74%) and employees (around 87%).

In the "P/S" (price-to-sales ratio) column, eight of the 16 companies show figures ranging from five to 50, meaning their market capitalisation is five to 50 times higher than their most recent annual revenues. However, a stock generally appears more attractive the lower its P/S ratio. When annual revenues rise subsequently, earnings and thus share prices usually increase as well. The following section provides details – in alphabetical order – on hydrogen stocks of varying significance.

KEY TO TABLE
MCap = Market capitalization in millions of euros
E/A = equity-to-asset ratio
P/S = Price/sales ratio
P/E = Price/earnings ratio
Div.-yield = Dividend yield
HC = Headcount

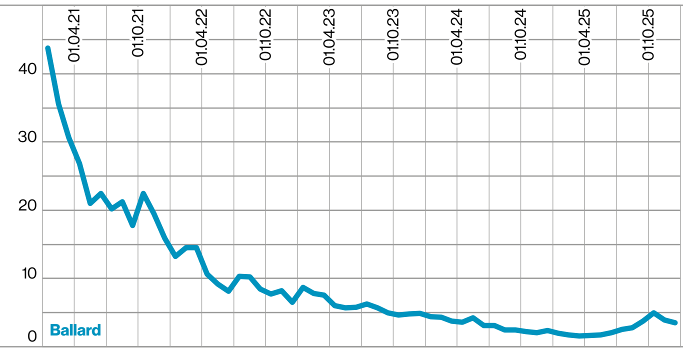
YTD (year-to-date):
Share price performance from January 1, 2025 to December 31, 2025.
The figures refer to the last financial year (usually 2024).
Share prices in euros or currency on the home stock exchange.

EXCHANGE RATES
CAD = 0.6208 Euro
GBP = 0.01468 Euro
HKD = 0.0925 Euro
NOK = 0.08463 Euro
SEK = 0.09148 Euro
USD = 0.85000 Euro
As of December 31, 2025

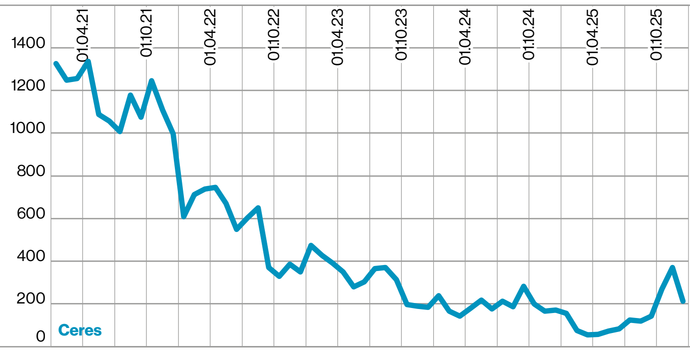
Sources: Reuters, Marketscreener, Öko-Invest, company information

Author Max Deml (born in 1957) has been editor-in-chief of the stock market newsletter Öko-Invest (www.oeko-invest.net) since 1991 and is the author of the handbook 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 includes the 30 largest publicly traded PV production, supply, and operating companies worldwide.

E/A	DIV-R.	YTD	WWW.	HC	SALES (MIO €)	PRICE ULT. 24
87 %	0.0 %	46 %	www.ballard.com	890	59	2.39
22 %	0.0 %	291 %	www.bloomenergy.com	2,130	1,253	22.21
85 %	0.0 %	24 %	www.cerespower.com	480	76	171
43 %	0.0 %	–58 %	www.enapterag.de	200	25	4.0745
33 %	0.0 %	–79 %	www.h2apex.com	160	30	5.6
20 %	0.0 %	–7 %	www.h2core.com	40	1	0.66
60 %	0.0 %	–62 %	www.hydrogen-pro.com	150	17	5.1
67 %	1.4 %	–4 %	www.denora.com	2,080	863	7.57
66 %	0.0 %	75 %	www.itm-power.com	310	38	35.7
73 %	0.0 %	–17 %	www.nelhydrogen.com	410	118	2.704
53 %	0.0 %	–52 %	www.path2hydrogen.com	30	1	0.94
50 %	0.0 %	–8 %	www.plugpower.com	3,220	534	2.13
62 %	0.0 %	–16 %	www.powercellgroup.com	140	31	35.46
22 %	3.0 %	32 %	www.snam.it	3,830	3,548	4.277
59 %	0.0 %	–16 %	www.thyssenkrupp-nucera.com	650	845	10.6
35 %	4.2 %	59 %	www.en.weichaipower.com	97,300	21,610	11.88
56 %	**0.0 %**	**–7 %**		**112,020**	**29,048**	



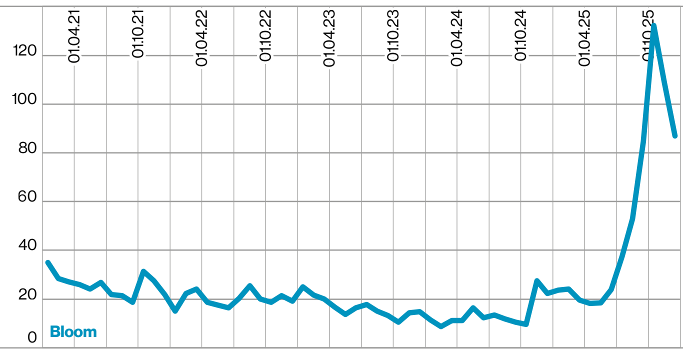
Ballard Power Systems Founded in 1979 (initially to research and develop lithium batteries), the company has been publicly traded since 1993 and has repeatedly financed its billions in losses in the fuel cell sector through capital increases over more than 30 years. In 2018, Weichai Power acquired a 20 percent stake in Ballard Power in order to use the technology for trucks and buses in China. The year 2024 was also heavily in deficit: the loss was 4.6 times higher than the revenue of just under 60 million euros. In the third quarter of 2025, sales rose by 120 percent to around USD 32.5 million, mainly due to more rail orders, while losses fell sharply to around USD 28.1 million.



Ceres Power Holdings plc Founded in 2004, the British company, in which the main shareholder **Weichai Power** holds a 20 percent stake, develops electrolysis technologies and high-temperature fuel cells: solid oxide fuel cells (SOFC) and hydrogen solid oxide electrolysis (SOEC).

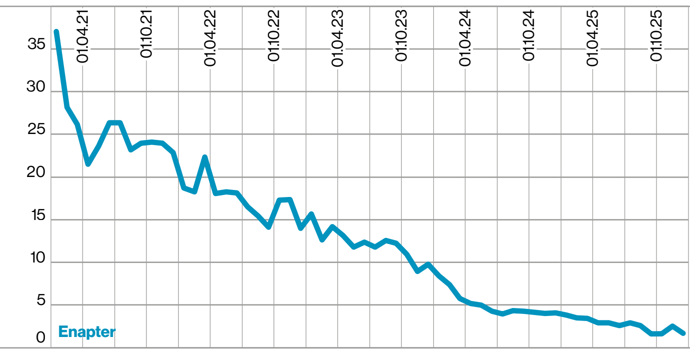
In 2024, revenue rose by over 130 percent to around £52 million, while losses were almost halved to around £28 million. In the first half of 2025, revenue fell by 26 percent to around £21.1 million, while losses fell by a good 30 percent to around £19.6 million.

In December 2025, short selling and price turbulence ensued after **Grizzly Research** claimed in a report that Ceres Power had misled investors with its high revenue expectations.



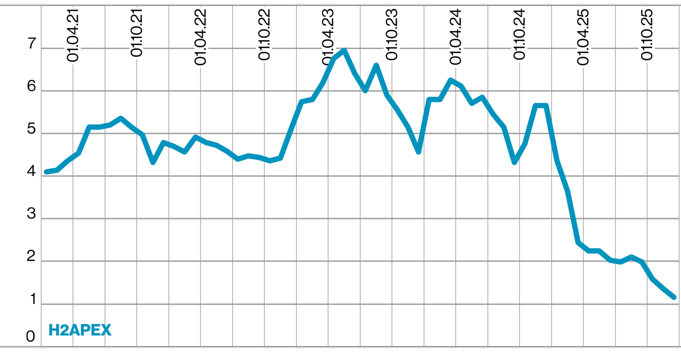
Bloom Energy As in 2024, the California-based company, founded in 2002, was one of the few stock market winners in 2025. The manufacturer of fuel cells for stationary power supply is benefiting from the growing demand for data centers in the wake of the AI boom. In 2024, sales rose by a good ten percent to over $1.25 billion, while losses were significantly reduced from over $300 million to less than $30 million.

In the third quarter of 2025, sales rose by 57 percent to around $519 million, but losses also rose by 57 percent to around $23.1 million. At the end of 2025, Bloom Energy placed a billion-dollar convertible bond with a very high conversion price of around $195. Despite a decline in the share price towards the end of the year, the stock was by far the best performer in the table in 2025, with a gain of over 250 percent.



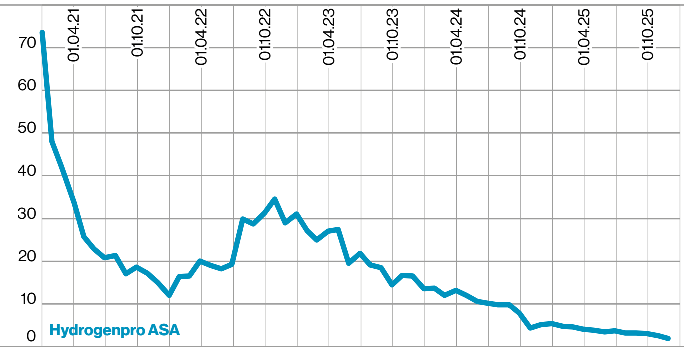
Enapter AG The company, headquartered in Germany with a research and production site in Italy, has developed electrolysers in single-core and multi-core systems. Its approximately 400 customers in over 50 countries include companies from the energy, transport, heating and telecommunications sectors.

In 2024, sales fell by around a third to €21.4 million, while losses almost tripled to €20.7 million. In the first half of 2025, sales fell by 32 percent to around €5.6 million, while losses rose by over 70 percent to around €13.7 million.

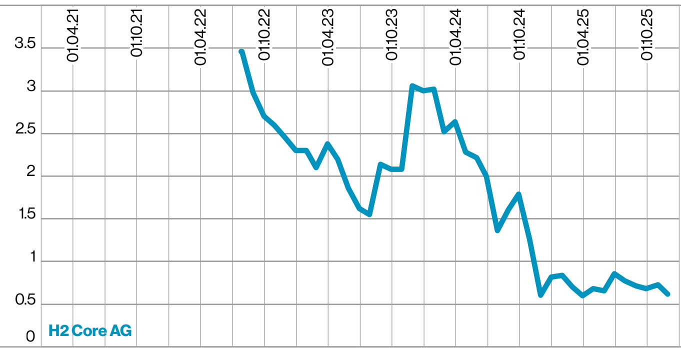


H2APEX Group SCA Founded in 2000 and based in Rostock, the company (formerly **exceet Group**) specializes in the "development, planning, and construction of hydrogen-producing plants." In the first nine months of 2025, revenue fell from €25.2 million to €5.2 million, while losses rose from €18.9 million to €28.1 million. Chief Financial Officer Bert Althaus is nevertheless satisfied in view of the "challenging environment" and has raised the sales forecast for 2025 from €6–8 million to €9–10 million.

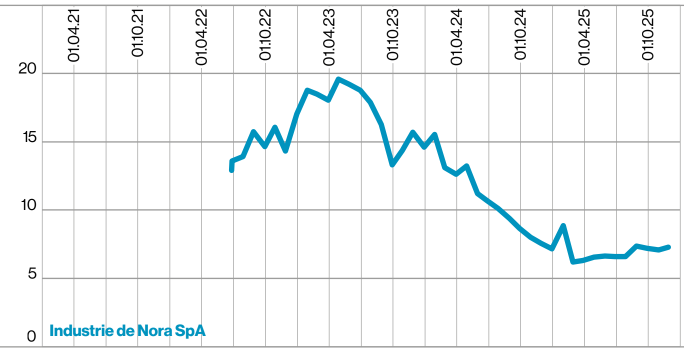
In mid-2025, the insolvent **HH2E Lubmin** was taken over, creating a second location for hydrogen production in Lubmin. In addition, there was a capital increase of €30 million. At the end of 2025, the (often overly optimistic) analyst Karsten von Blumenthal of First Berlin Equity Research continued to recommend the stock as a buy, but lowered the price target from €3.70 to €3.30.



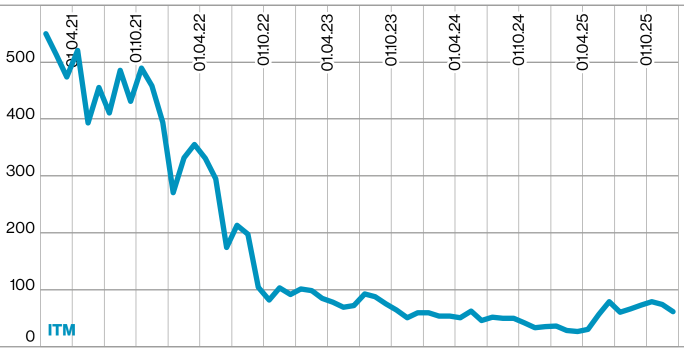
Hydrogenpro ASA An alkaline high-pressure electrolyzer is the main product of the company, which specializes in hydrogen and renewable energies. Its main shareholders are Austria's **Andritz AG** and **Mitsubishi Heavy Industries** from Japan. In 2024, losses amounted to around NOK 196 million, which was just as high as sales, which had been NOK 568 million a year earlier. In the first three quarters of 2025, revenue fell by 44 percent to around NOK 70.1 million, while the loss for shareholders rose by 27 percent to around NOK 194 million.

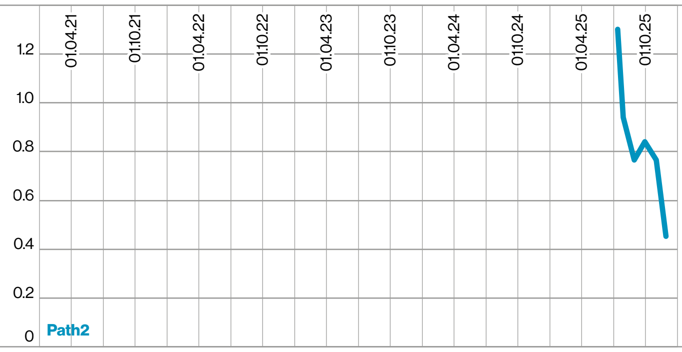


H2 Core AG which emerged from **Marna Beteiligungen AG**, offers H2-based "plug-and-play energy supply solutions" using electrolysis stacks, which are mainly supplied by **Enapter AG**. In mid-2024, around 325,000 new shares in H2 Core AG were issued at €2.20 each. The share price is now around 70 percent lower. The company fell behind schedule with the publication of its sales figures in 2025 and continues to post losses in the millions.



Industrie De Nora SpA Founded in 1923 and listed on the stock exchange since 2022, the Milan-based company is one of the world market leaders in the field of electrochemistry. Its product range includes components for water electrolysis, electrodes and coatings for various industries, such as chlorine chemistry, as well as electronic components, water filters and disinfection technologies. Industrie De Nora is the second-largest shareholder in **Thyssenkrupp Nucera AG & Co. KGaA** after the Thyssenkrupp Group. In 2024, sales of €863 million (+1 percent) generated a profit of €83.4 million (-64 percent). In the first nine months of 2025, sales rose by 5 percent to around €631 million, while profit increased by 15 percent to around €60 million.

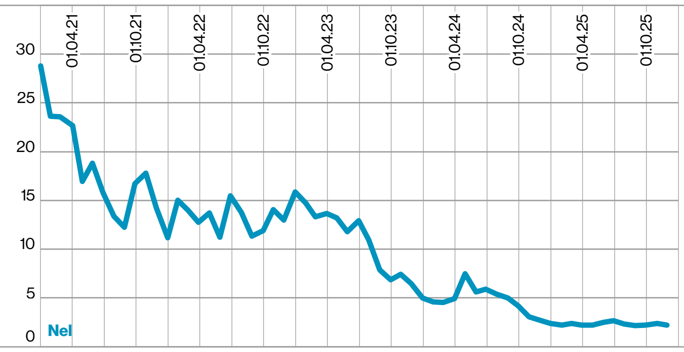


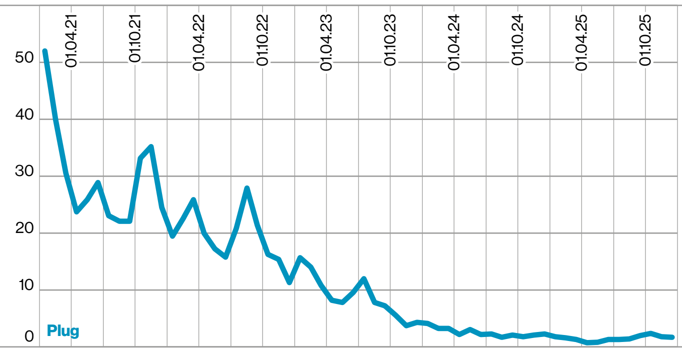


ITM Power PLC Founded in 2001, the British company has major shareholders such as **Linde** and is one of the best-established companies in the European electrolysis industry. However, in the 2024/25 financial year, losses of £45.5 million were once again far higher than revenues of £26 million. Although revenue rose by 28 percent to around £18 million in the first half of 2025/26 (as of October 31, 2025), the company still incurred a double-digit million loss. Hopes are pinned on the new, highly scaled 50 MW PEM electrolyzer “ALPHA 50” for industrial applications.

Path2 Hydrogen AG Founded in 2001 as **H5 B5 Media AG**, the company has since been renamed five times and was most recently called **Philomaxcap AG**. One of the company’s holdings, the **Swiss AmeriMark Group AG**, was listed in Vienna until 2021 and was active in the trade and leasing of used cars for subprime customers through **Rymark Inc**. in the US. In terms of the balance sheet, this investment (48.5 percent) is still a large item, but its value depends on a legal dispute over ownership rights in the US.

The holding company, renamed **Path2 Hydrogen AG** in 2025 and with **Josh McMorrow** as its new CEO, intends to develop and market “hydrogen liquefaction and storage facilities” with its US subsidiary **GenH2** (www.genh2.com), which was contributed as a non-cash contribution with around 95 million shares. GenH2 generated revenues of US$0.7 million and US$0.8 million in 2023 and 2024, respectively, while posting losses of US$12.4 million and US$9.6 million. Now, Canadian company **ProtonH2**, which has developed a technology for H2 production from former oil and natural gas storage sites, is also to be acquired.

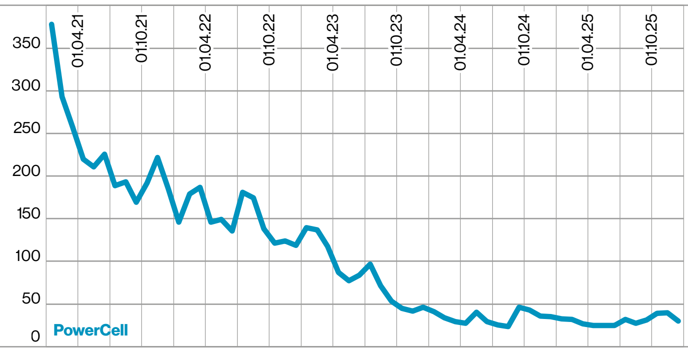




Nel ASA Founded in 1927, the Norwegian company specializes in electrolysis and transport infrastructure, and is involved in the construction of H2 filling stations and refueling systems, among other things. In 2017, it merged with **Hexagon Composite** (hydrogen storage) and **PowerCell Sweden AB** (fuel cells) to form the joint venture **Hyon**, with the aim of supplying the maritime sector with FC drives.

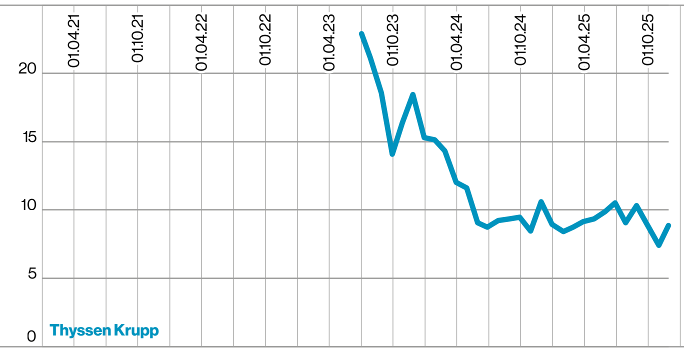
Nel generated revenue of just under NOK 1.4 billion (-17 percent) in 2024 and a loss of NOK 258 million (after NOK 855 million in the previous year). In the third quarter of 2025, it posted a loss of NOK 85 million on sales of NOK 349 million. Due to “limited synergies between the refueling and electrolyzer businesses,” the refueling division was spun off in 2024 under the name **Cavendish Hydrogen** and listed separately on the Oslo Stock Exchange. In 2024, Cavendish generated revenue of NOK 361 million (+9 percent) with around 250 employees, posting a loss of NOK 265 million (-20 percent).

Plug Power The US company is one of the world’s largest buyers of liquid hydrogen. However, since acquiring **United Hydrogen** (2021), it has also been producing it itself. In 2023 and 2024, revenues of $891 million and $629 million respectively resulted in losses of $1.37 billion and $2.10 billion. In the first three quarters of 2025, revenue rose to $485 million (+11 percent), while losses increased to $786 million (+2 percent).



PowerCell Sweden AB Founded in 2008, the company manufactures fuel cell systems that can convert both fossil fuels and renewable energy sources into hydrogen. It has consistently generated losses to date, with one exception in 2019: that year, the sale of an exclusive production and distribution license for the "PowerCell S3 fuel cell stack" to **Robert Bosch GmbH** generated proceeds of around €50 million.

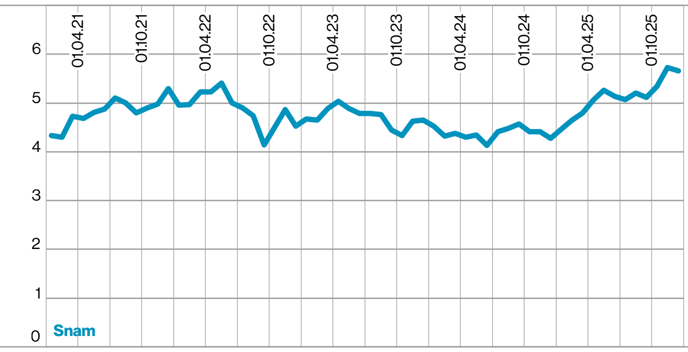
From January to September 2025, sales rose by 52 percent to over SEK 290 million. Losses fell from around SEK 50 million to less than SEK 9 million. In December 2025, CEO **Richard Berkling** announced that the operator of a data center in the US wants to lease two "PowerCell PS190" fuel cell systems. This will be done on a trial basis for six to twelve months under a leasing agreement in order to achieve "reliability, scalability, and emission-free operation."



thyssenkrupp nucera AG & Co. KGaA In 2024, the electrolysis company spun off from **thyssenkrupp AG** gained Fraunhofer IKTS as a strategic partner. In May 2025, the two companies opened an SOEC pilot production plant for high-temperature electrolysis stacks in Arnstadt, Thuringia.

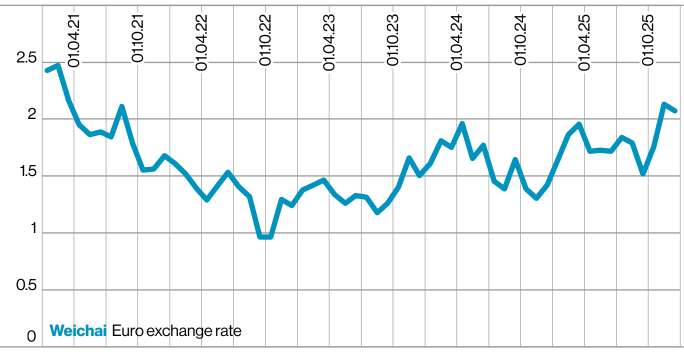
In the 2024/25 fiscal year (as of September 30, 2024), the company acquired the Danish high-pressure electrolysis company **Green Hydrogen Systems** and generated a profit of around €5 million on sales of €845 million (down two percent).

In the previous year, the figure was €11 million, but due to lower interest income, the financial result fell from €26 million to €17 million. In the Green Hydrogen segment, CEO **Dr. Werner Ponikwar** expects annual sales to more than halve: from €459 million to €150–220 million.



Snam SpA The company, which was spun off from the energy group **Eni** in 2001, operates a natural gas transport network of around 38,000 km within and outside Italy, as well as gas storage facilities accounting for around 15 percent of European natural gas reserves. In the hydrogen sector, it has a joint venture with the company **Industrie De Nora Spa**, and in the major "SouthH2 Corridor" project, **Snam** is a partner of **Gas Connect Austria GmbH**, **bayernets GmbH**, and **TAG GmbH**.

In the third quarter of 2025, revenue rose by seven percent to €2.85 billion, partly due to higher LNG imports, while adjusted profit rose by ten percent to €1.1 billion. In 2025, **Snam** sold its six percent stake in **Adnoc Gas Pipelines**. The plan to acquire just under 25 percent of Essen-based **Open Grid Europe GmbH**, which operates Germany's largest gas transmission network with a length of around 12,000 km, failed in November 2025 due to concerns on the part of the German authorities regarding security of supply (the State Grid Corporation of China has an indirect stake in Snam).



Weichai Power Founded in 1953, the automotive engineering group was known as **Weichai Diesel Engine Factory** until 1992 and still manufactures diesel engines in China today. However, through its investments in **Ballard Power** and **Ceres Power**, Weichai Power is now also involved in hydrogen applications. The prices of H shares, which are also listed on German stock exchanges, have fluctuated between €0.93 and €2.78 in recent years, most recently at around €2.10.

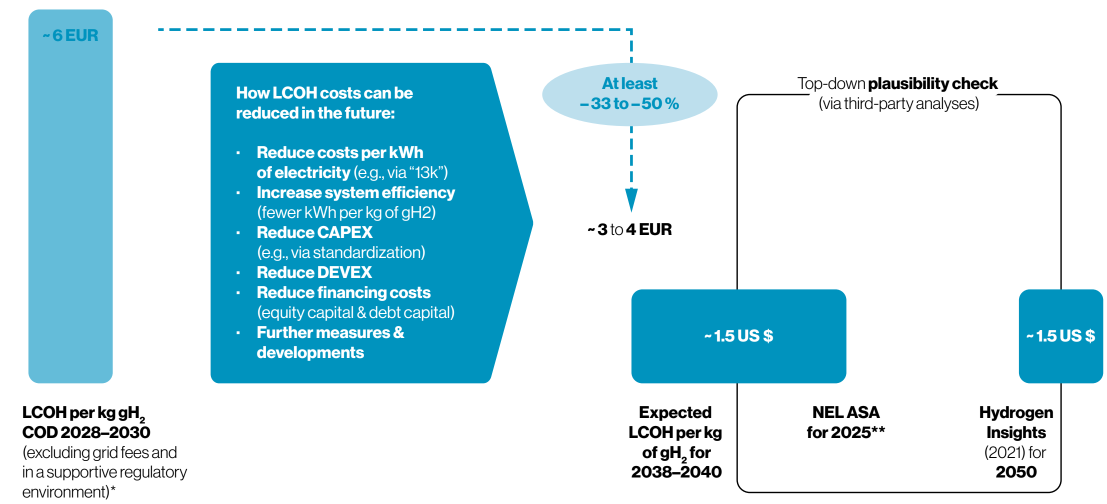
In the first three quarters of 2025, revenue rose by 5.3 percent to over 170.6 billion renminbi (RMB), while profit rose by 5.7 percent to 8.9 billion RMB. Weichai Power is by far the largest of the 16 companies in the table, ranks among the top three in terms of share price growth in 2025, and has attractive key figures. However, the hydrogen sector is not the group's main source of revenue.

Breaking the four-euro threshold

By Moritz Schwencke

Technological advances in electrolysis and the production of hydrogen, scaling effects, lower electricity and interest rates, and improved electrolyser utilisation could significantly cut hydrogen costs. Guest author Moritz Schwencke explains how.

By 2038/40, Eternal Power expects a reduction in gH2 production costs of at least 33 to 50%.



* Without the cost-increasing effect of additionality, as well as spatial and temporal correlation.
** Q1 2021 presentation by NEL ASA, page 15, dated May 4, 2021

Forecast of the LCOH for green hydrogen. © Moritz Schwencke / NEONBOLD

Electrolytic hydrogen is often considered too expensive and inefficient. But that is a sweeping generalization. Since the market is still in its infancy, it would be more accurate to say that the production of green hydrogen is currently still too expensive. However, industrial-scale projects such as those in Lingen (RWE), Emden (EWE), or Hamburg-Moorburg (Hamburger Energiewerke, Luxcara) are already under construction.

Renewables as a model for cost decreases Past experience with solar- and wind energy shows that production costs often appear prohibitively high at the beginning of market ramp-up. However, in the early stages of mass production, they tend to fall disproportionately and then level off as the technology matures. In the case of photovoltaics, the levelized cost of electricity (LCOE) in Germany at the start of the Renewable Energy Sources Act (EEG) in the early 2000s was around 80 cents and has since fallen by about 95 percent (for ground-mounted PV in southern Germany).

Even committed pioneers did not foresee or consider such a massive cost reduction possible, which was mainly driven by economies of scale and efficiency improvements. For onshore wind energy, the LCOE in Germany has dropped from 25 cents per kWh in 1990 to around five cents per kWh today at good wind sites – a reduction of about 80 percent.

Green hydrogen (gH2) produced via electrolysis is considered competitive with fossil fuels at a cost of three to four euros per kilogram – especially in light of future increases in CO2 emission prices. For the first industrial gH2 projects scheduled to go into operation between 2028 and 2030, production costs for green hydrogen are still around ten euros per kilogram (excluding grid fees). Of this, approximately two euros are attributable to cost-driving EU regulations (RED III: additionality, temporal correlation).

A further two euros could be saved through "early optimizations" (see, for example, the "position paper" by RWE from December 2025). This would bring production costs down to around six euros per kilogram for projects commissioned from 2028/2030 onwards, assuming a supportive regulatory environment and no grid fees, and after initial cost optimizations.

Use surplus power The largest cost component for green hydrogen is, as is well known, green electricity, accounting for around 65 percent. A first step would be to make greater use of surplus green electricity for electrolysis instead of shutting down plants in the event of potential grid congestion. According to the Federal Network Agency of Germany, more than nine TWh of wind and solar power were curtailed in 2024. In addition to using green electricity with negative prices, restructuring the energy system in favor of renewables, combined with battery storage, will also reduce production costs in the future.

Another important factor in cost reduction is the efficiency of the electrolyzer and the overall system. Currently, depending on the technology and manufacturer (PEM, alkaline), an electrolyzer requires about 45 to 55 kWh of electricity to produce one kilogram of hydrogen. However, the theoretical value is around 35 kWh/kg. This means that inefficiencies can be minimized in the future.

As with the examples of PV and wind power, efficiency levels can increase significantly. Considering efficiency improvements alone, with an LCOE of five cents per kWh, a low electricity demand of only 45 kWh/kg, and electricity accounting for 65 percent of total costs, the levelized cost of hydrogen (LCOH) could reach approximately 3.50 euros per kilogram.

Further savings are also expected in capital expenditures (CAPEX). Scaling up production and achieving economies of scale in electrolyzer manufacturing reduce the unit cost per megawatt (MW) of capacity. Standardizing production and modularizing electrolyzers and plants (e.g. using 50 MW modules such as "Alpha 50" from ITM Power) can significantly reduce investment costs per MW and thus the LCOH.

The use of necessary materials (e.g. precious metals) can also be reduced. Production processes for electrolyzers are being further developed, including through innovation. The combination of scaling, standardization, and technological innovation will also reduce the cost of plant equipment (balance of plant, BoP) in the future – that is, all components of a hydrogen production facility apart from the electrolyzer itself (e.g. power supply systems, water management, gas purification, compressors, cooling systems).

Further cost reduction potent Project development costs (Development Expenses, DEVEX) can also be reduced by standardizing and simplifying project development processes and permitting procedures (e.g. the German Hydrogen Acceleration Act). The FEED phase (Front-End Engineering and Design) also offers potential for savings. Additional cost reductions can be achieved in operations and management (O&M) from the time the plant is commissioned, as well as through higher production volumes. Moreover, certain monitoring tasks can be centralized through remote monitoring.

Finally, project financing costs can also be reduced in the future, including through the following measures:

- Lower interest rates for debt capital (although interest rates are an external factor, they can be leveraged by the hydrogen industry through timing).
- Lower risk and margin premiums required by equity and debt investors, for example due to increasing market maturity, financing standards, and potential guarantees that reduce risk premiums.
- Longer financial model durations of more than 20 years (as is common in projects in the Middle East Region), for example with repowering after 15 years instead of a 20-year term with a residual value.

Conclusion Assuming production costs of around six euros per kilogram in 2028/2030 in a supportive regulatory environment and without grid fees, I expect that the combination of the levers, measures, and developments outlined above will reduce the LCOH for new plants to at least three to four euros per kilogram by 2038/40. This corresponds to a cost reduction of 33 to 50 percent. As a result, production costs would finally reach parity with fossil fuels. ○

Dr. Moritz Schwencke
Co-founder & CEO,
Eternal Power

German municipalities continue to invest in hydrogen

By Leonhard Fromm

Across Germany, municipalities and municipal enterprises are driving the expansion of hydrogen infrastructure. But they are calling for greater planning certainty – including a statutory hydrogen quota.

Filling station operator H2 Mobility is now focusing on hydrogen trucks and buses in Germany; several passenger car filling stations are being closed. © H2Mobility

Across Germany, federal states and municipalities are investing heavily in green hydrogen, whether through funding programmes or via publicly owned companies. In the south, the Federal State of Baden-Württemberg is supporting the purchase of an electrolyser that the municipal utilities of Ulm and Neu-Ulm plan to operate near the A8 motorway from mid-2029. Green Hydrogen Esslingen, in which the Esslingen municipal utility holds a stake, and VK Energie in Munich are jointly organising the energy supply for the "Neue Weststadt" urban district in Esslingen, with an electrolyser at its heart. In the north, EWE in Oldenburg – 74 percent owned by 21 cities and districts in the Federal State of Lower Saxony – is investing one billion euros in its hydrogen strategy, including a 320 MW electrolyser in Emden. And in Hamburg Moorburg, where a coal-fired power plant was dismantled in 2021, a 100 MW electrolyser is being built along with a 40-kilometre hydrogen pipeline to the industrial port area of Hamburg (see detailed report in HZwei 5/2025).

Setbacks prompt criticism of funding

However, such success stories are tempered by news that Berlin-based operator H2 Mobility closed 14 filling stations nationwide at the end of the year, mainly in North Rhine-Westphalia and Lower Saxony, but also in Wendlingen in Baden-Württemberg. This is not only frustrating for users like Frank Stuckstedte from Rheda-Wiedenbrück, who launched a petition to the Federal Ministry of Transport on 6 December that needs 30,000 signatures by June to remain online (as of 8 January, 432 had signed). Stuckstedte also criticises the fact that the filling station in his town alone received €600,000 in state funding in 2019. In Bielefeld, where seven refuse collection vehicles have been running on hydrogen for years, refuelling options have also disappeared. One oddity: there is another hydrogen filling station in front of the MHKW waste incineration plant. This too received state funding – but from different sources. As a result, the municipal trucks have so far not been permitted to refuel there.

What at first glance looks like a bureaucratic absurdity can be explained by H2 Mobility CEO Martin Jüngel. While the first filling stations were primarily designed for passenger cars and 700-bar tank systems, trucks, buses and other heavy-duty vehicles are now increasingly running on hydrogen. This requires more powerful facilities with greater hydrogen capacity, more dispensers and a 350-bar tank system that limits the refuelling process to a maximum of 15 minutes.

Cooperation advances hydrogen Such disruptions create uncertainty. But with every step forward, predictability improves. In December, H2 Mobility opened its fifth new-generation filling station in Ludwigshafen. And with major business partners such as Hylane, Germany's largest lessor of carbon-neutral trucks, H2 Mobility has negotiated a price of €8 per kilogram of hydrogen for its customers. These customers include Rewe, Schenker, GLS, Hermes and haulage associations such as the one in Stuttgart, which now offers its members a hydrogen truck for quarterly test use. This dovetails with the hydrogen expansion strategies of the municipal utilities in Ulm, Stuttgart and Esslingen.

Predictability grows, quota desired The Rems-Murr waste management authority (AWRM) is currently considering building two five-megawatt electrolysers in Winnenden for €38 million, which could produce 850 tonnes of hydrogen annually from solar power generated on former landfill sites. The Federal State of Baden-Württemberg, which has been led by the Green party since 2011 and has put together a €100 million funding package for hydrogen expansion, would subsidise the project with €10 million.

Before the district council makes a decision, AWRM is researching regional hydrogen demand and specific off-takers – as is every potential operator across Germany. The cost per kilogram, which all those surveyed discuss only rarely and vaguely, plays a central role. This lack of price transparency is grist to the mill of hydrogen critics.

Any step that brings greater predictability is therefore welcome, including with regard to grid expansion and availability, which is gradually improving. At the turn of the year, the Federal Network Agency (BNetzA) set the prices for transporting hydrogen through the grid, closely aligned with natural gas costs. The physical completion of the first pipelines – such as the 400 km from Lubmin to Bobbau – also provides a degree of certainty. This is essential, as users need to be able to plan their requirements and infrastructure based on trailer deliveries or grid connections.

For all investments, proponents and operators argue, legally mandated quotas for a green hydrogen share in the energy mix would therefore be important on a transitional basis – to stimulate and secure demand and baseline utilisation of electrolysers and grids.

EU taxonomy channels capital into green hydrogen At the same time, the EU taxonomy, which requires major capital market players to align their portfolios with sustainability criteria, means that sufficient capital is fundamentally available. This is evident, for example, in the Axa Group's stake in EWE in Oldenburg, or in the shareholder structure of the French, publicly listed hydrogen producer Lhyfe, which commissioned a €30 million plant in Schwäbisch Gmünd as recently as October. "We expect the hydrogen economy to ramp up in the coming years, followed by falling hydrogen prices," says Alexander Hauk, press spokesperson for the Association of Municipal Enterprises (VKU) in Berlin.

Billion-euro investments and off-the-record criticism One of the largest municipal hydrogen players is EWE from Oldenburg. "Hydrogen is a building block of the energy transition for us, particularly where direct electrification reaches its limits – for example in industry or in certain systemic applications," says CEO Stefan Dohler. With 10,900 employees, annual revenues of €8.7 billion and 1.4 million energy customers, EWE is one of Germany's major energy companies, although these figures include its communications and IT business. The group is 74 percent owned by 21 cities and districts along the Weser, Elbe and Ems rivers, and 26 percent by Axa's investment arm Ardian.

In total, EWE plans to invest one billion euros in its hydrogen strategy. This includes building a 320 MW hydrogen production facility in Emden, converting a large-scale natural gas cavern in Huntorf for hydrogen storage, and developing pipeline infrastructure through new construction and conversion of several pipeline sections in the northwest. EWE is receiving €350 million in funding from the federal government and a further €150 million from the Federal State of Lower Saxony.

These high subsidy amounts, in the context of strained public finances, are repeatedly criticised by municipal utility directors who believe the money could be invested more efficiently elsewhere. However, no one is willing to be quoted publicly with such statements.

Southern German players push for reliability At the Stuttgart municipal utility and the Stuttgart Region Association (VRS), the alliance of the state capital with the five surrounding districts, the message is that words must be followed by action – whether it is the Southern German Natural Gas Pipeline (SEL) transporting hydrogen from 2030, the city of Stuttgart aiming for climate neutrality by 2035, or the EU-wide hydrogen network being in place by 2050. Companies, property owners and municipal utilities need this reliability, because without trust there will be no investment.

The Stuttgart municipal utility and the VRS plan to commission a 9 MW electrolyser at the Neckar harbour by the end of 2026 as part of the H2-GeNeSiS project. The hydrogen is to be purchased by the SSB public transport operator, Daimler Truck, Neckar river vessels and residential developments. Two thirds of the €18.6 million cost will be borne by the federal state and the EU.

The electrolyser is to be powered by surplus solar electricity that cannot be used directly, including from the roofs of state-owned buildings. A programme for these solar installations has been in place for years.

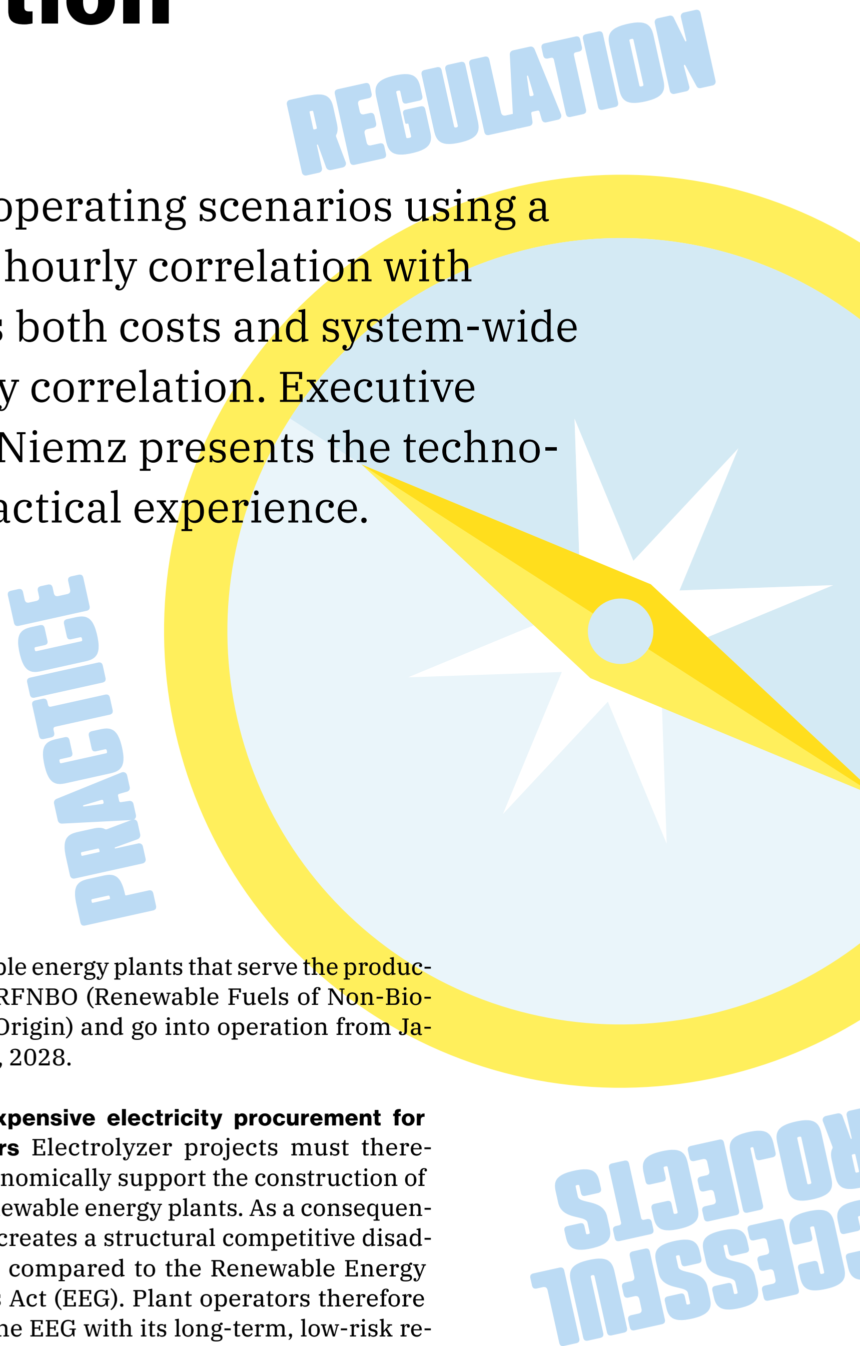
The investment is considered money well spent. It amounts to economic development, as hydrogen is needed for fuel cell research and test stands for hydrogen combustion engines, as well as for process heat in steel and cement production and the chemical industry. Felix Mayer, Managing Director of Green Hydrogen Esslingen GmbH, which operates the energy concept in Esslingen's "Neue Weststadt" district, says: "Hydrogen is the ideal medium for buffering electricity surpluses or shortfalls and for linking the individual sectors." ○

Leonhard Fromm
Freelance journalist

Hourly correlation hampers climate protection

By Tobias Bischof-Niemz

Enertrag has analyzed various operating scenarios using a 10 MW electrolyzer. The result: hourly correlation with electricity generation increases both costs and system-wide emissions compared to monthly correlation. Executive Board member Tobias Bischof-Niemz presents the techno-economic analysis based on practical experience.



The Delegated Act of the European Union on renewable hydrogen (RFNBO) is facing a crucial test. The well-intentioned criteria for “additionality” and “hourly correlation” lead, in the analyzed reference scenario, to additional costs of around €1.90/kg of hydrogen. At the same time, the results show no improvement in the systemic CO2 impact. In fact, hourly correlation even worsens it compared to monthly correlation.

The current situation presents a paradox While the EU’s climate targets remain ambitious, the implementation level significantly complicates their realization. The hydrogen ramp-up is in a critical phase: on the one hand, pilot projects are emerging across Europe and initial investment decisions are being made. On the other hand, the regulatory framework threatens to become a stumbling block. However, Enertrag is convinced that the hydrogen ramp-up works in practice. The key now is to remove these obstacles and allow for more flexibility in the system.

As is well known, the additionality criterion requires that the electricity used for electrolysis must come from new, unsubsidized renewable energy plants that serve the production of RFNBO (Renewable Fuels of Non-Biological Origin) and go into operation from January 1, 2028.

More expensive electricity procurement for operators Electrolyzer projects must therefore economically support the construction of new renewable energy plants. As a consequence, this creates a structural competitive disadvantage compared to the Renewable Energy Sources Act (EEG). Plant operators therefore prefer the EEG with its long-term, low-risk revenues. This increases the cost of electricity procurement for electrolyzers.

The criterion of non-subsidization means that even unsubsidized electricity from an EEG plant may not be used. This makes it impossible to use part of the electricity generated by renewable energy plants with a subsidized tariff in a system-friendly way. If a wind turbine produces more than its subsidized amount in certain hours or feeds in during hours with negative prices, this electricity remains off-limits for hydrogen production. Without the criteria of additionality and non-subsidization, existing plants (especially post-

hourly correlation	electricity costs without additionality [€/kg]	electricity costs with additionality [€/kg]	CO2 intensity [g/kWh]
none (electricity price led)	2.83	—	275
monthly	2.88	4.18	275
hourly	3.49	4.79	300

EEG plants) could be used, opening up a new market for de-subsidized plants. The resulting cost savings would amount to approximately €1.30/kg of hydrogen.

Even more complicated in the future From 2030 onward, the Delegated Act requires an hourly correlation between renewable electricity generation and the electricity consumption of an electrolyzer. This means that the electrolyzer may not consume more electricity per hour than the assigned renewable energy plants generate.

This prevents an electricity price-driven operation of the electrolyzer and leads to fewer full-load hours or more frequent part-load operation. The portfolio effect of the national renewable energy mix is lost. This is particularly unfavorable for the energy system as a whole, because the electrolyzer is then operated more frequently during hours with higher CO2 intensity.

measure	Savings in H_2 costs
Elimination of the additionality criterion (use of post-EEG installations)	≈ 1.30 €/kg
Remove hourly correlation (electricity price-driven operation, higher full load)	≈ 0.60 €/kg
overall potential	**≈ 1.90 €/kg**

Reality-based facts Enertrag analyzed various operating scenarios based on a 10 MW electrolyzer with flexible hydrogen sales, a wind farm with approximately 2.5 times the capacity, and a direct line to the electrolyzer. The reference year was 10/2024 bis 09/2025. As the first table shows, the additionality criterion is the biggest cost driver. And the hourly correlation worsens both the costs and the systemic CO2 impact.

Absurd: costs and emissions rise In addition, hourly correlation leads to a systemic emission impact that is around 25 g CO2/kWh higher than monthly correlation. This contradicts the actual objective of the regulation and also leads to an increase in price of €0.60/kg of hydrogen.

Enertrag has been operating an electrolysis plant in the Uckermark region since 2011. This hydrogen plant is part of the Enertrag Verbundkraftwerk®. It impressively demonstrates how sector coupling works in practice: with around 600 MW of installed capacity from wind and solar power, we operate several hundred interconnected plants within a 25-kilometer radius. A battery storage system in Cremzow with 22 MW / 34.8 MWh is used for peak load coverage. The hybrid power plant is capable of taking over key system functions of a conventional power plant.

The hydrogen ramp-up works Due to increasing demand, Enertrag is planning to build additional electrolysis capacity at two sites in the Federal States of Mecklenburg-Western Pomerania and Brandenburg, with a total capacity of around 185 megawatts.

Based on our many years of practical experience, we call for the abolition of the additionality and non-subsidization criteria at the EU level. Opening up to post-EEG plants would create new markets without competing with the EEG. In addition, the temporal requirements should be made more flexible to allow for monthly instead of hourly correlation.

A better way forward As the second table shows, it makes a lot of sense to eliminate the criteria in favor of a price-driven and system-friendly operation. At the national level, the exemption from levies (offshore grid levy, CHP levy) should be extended to all plants commissioned after 2030. The price-setting criteria of §13k of the German Energy Industry Act (EnWG) ("use instead of curtailment") should be revised to enable attractive market participation.

Accelerating the hydrogen ramp-up What is needed now above all is reliability from policymakers. A retreat from the expansion targets for renewable energy or hydrogen would jeopardize the entire value chain. It is crucial to remove obstacles in market design. More flexibility in the system would already enable cost-efficient hydrogen production. ○

Dr. Tobias Bischof-Niemz
Member of the Executive Board for International Projects & Technology at Enertrag

TOP: The facts from practice

MIDDLE: Overview savings potential

Factory in transition

By Eva Augsten

In April, Cellcentric plans to unveil the next generation of its fuel cell power unit. Conversion work is underway at the pilot production facility in Esslingen. The H2int. editorial team was given a look inside the factory halls.

Almost finished: the final station in the production of the drive systems still requires a lot of manual work in the pilot facility © Cellcentric

During coating, the membrane runs over several rollers

© Cellcentric

The diesel engine is the benchmark. That much was clear when Cellcentric set out in 2020 to develop a fuel cell power unit for long-haul heavy-duty transport. That, the company had determined, is the sweet spot for fuel cells. Last-mile deliveries in urban areas can be handled well by battery electric vehicles. For heavier vehicles covering a few hundred kilometres – refuse collection, for example – hydrogen combustion engines score with their comparatively low acquisition costs. It is only on long-haul routes, where the kilometres are limited only by drivers' mandatory rest breaks, that fuel cells really come into their own. That is because fuel costs become more significant relative to the initial investment, explains Joachim Ladra, Head of Sales, Marketing and Communications, outlining the strategy.

Today, more than 500 people at Cellcentric are working on this single product: a fuel cell power unit designed to replace a diesel engine. The unit is intended to fit precisely into the installation space occupied by a 13-litre, six-cylinder diesel engine. It should deliver comparable performance and achieve similar range. And with the next generation, which Cellcentric plans to present at Hannover Messe 2026, that goal could be within reach.

The road to this point has been long, and strictly speaking began in the 1990s. Standing in the pilot production hall in Esslingen is the first fuel cell vehicle ever to take to public roads – the Necar1 from Mercedes-Benz. The entire cargo area of the van is filled with tanks, pipes and valves, and yet it trundled along the motorways at a top speed of 80 km/h with its 30 kW output.

From Necar1 to next generation Today's state of the art is many miles removed from those beginnings. For several years now, it has been possible to have a truck converted to fuel cell drive by commercial specialists. But this is a highly bespoke undertaking, with specialists having to find the best location in the vehicle for each component. On buses, the tank usually goes on the roof; on trucks, behind the cab. Competitor Hyundai introduced the first series-production hydrogen trucks in 2020. The latest variant from 2025 achieves ranges of over 700 km. However, the fuel cell power unit delivers 180 kW – considerably less than the 350 kW electric motor installed. Full motor power can therefore only be called upon if the fuel cell has charged a buffer battery in advance.

Cellcentric, too, has most recently been producing fuel cell units with an output of 150 kW. Two of these units in Daimler Truck vehicles have demonstrated publicly that, with predictive battery management, this output is enough to cross the Alps.

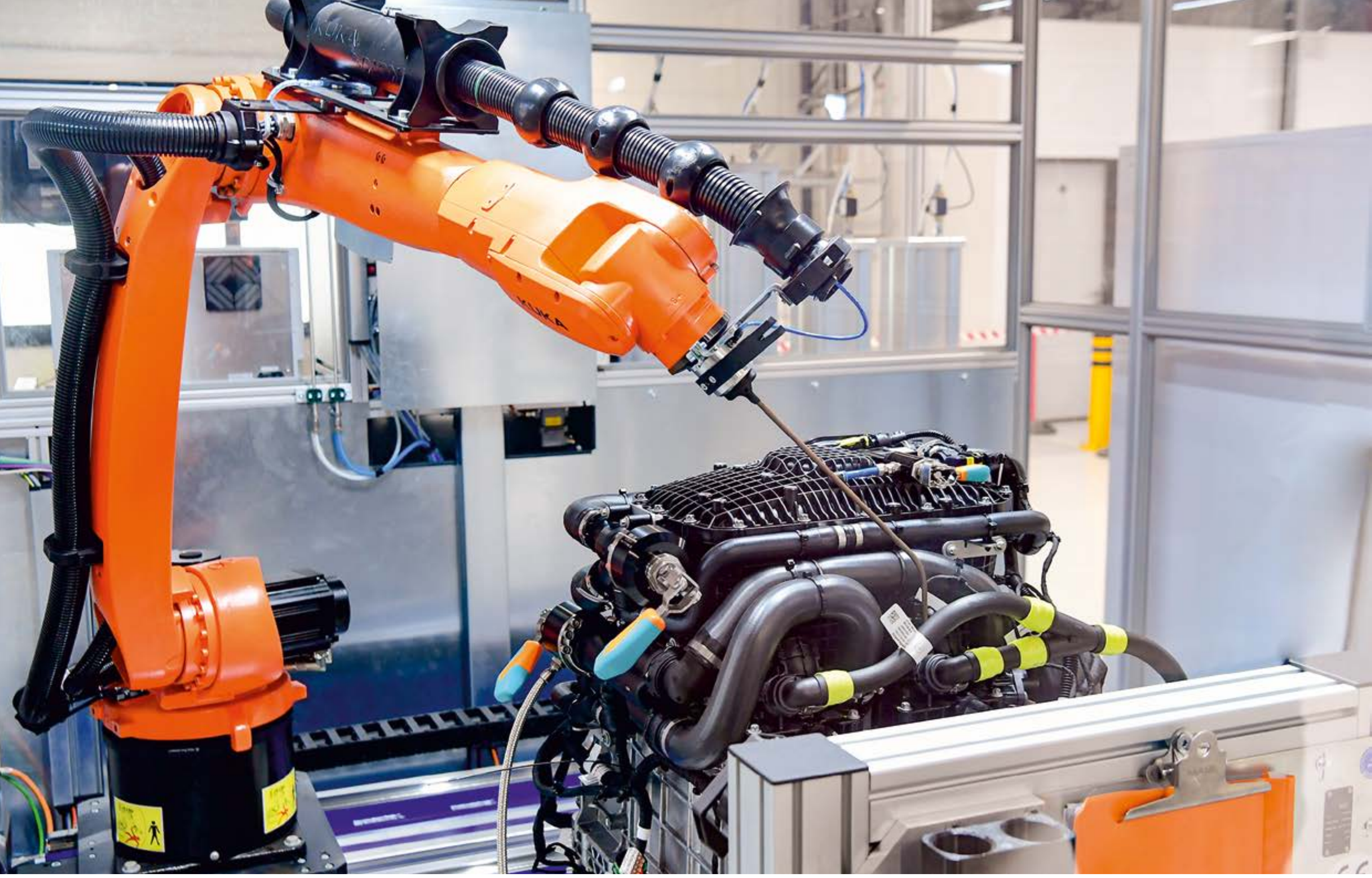
But the new generation is set to make the leap to up to 375 kW – in the same installation space, of course. Cellcentric put this figure on record in a paper at the Vienna Motor Symposium – and will be held to it in April. The fuel cell should then be able to supply the electric motor continuously at full power.

The second improvement lies in efficiency – or, put another way, in fuel consumption. This is set to fall by 20 percent compared with the predecessor model. "At hydrogen prices below €8, the total cost of ownership also becomes attractive," says Ladra.

The third critical point is cooling. If the cells overheat for extended periods, they degrade. Cooling is not technically difficult, but it requires space and costs money. The hydrogen trucks from Daimler Truck fitted with the previous fuel cell generation therefore have an extended tractor unit to accommodate the cooling system. Since overall length is limited by regulations, this comes at the expense of cargo capacity. The new generation has a 40 percent lower cooling load, the company says, partly because it tolerates significantly higher temperatures. This allows the cooling system to fit within the vehicle's standard installation space.

A key factor behind several of these improvements is that Cellcentric is now using a single fuel cell system with larger cells. The three stacks it contains operate at a higher voltage, which at the same power output means lower current and thus fewer losses in the form of heat. The catalyst composition has also been refined.

Factory undergoing conversion Cellcentric is now transferring all these improvements to the pilot production facility in Esslingen, which is currently in the midst of conversion. Some stations are already complete; others are still ▷



The sniffer robot uses its trunk-like sensor to search for leaks in the system
© Cellcentric

under construction. At the start of the production line stands the "big kitchen mixer," as Ladra jokingly calls the metal tank. It holds 100 litres. This is where Cellcentric mixes its ink for the cathode and anode coatings. It contains platinum, iridium and solvents. Beyond that, Ladra reveals little. "That's our Coca-Cola recipe. Only a handful of people know it. It's so secret that we haven't even filed a patent for it," he says.

What is no secret is that the tank containing this magic potion is transported to the next station in the pilot facility by an ordinary forklift. "We're developing the individual production steps here, not the transport. We'll deal with that when we later set up series production for larger volumes."

The development work can be observed at the next station. There, the ink is applied to long foil webs in a roll-to-roll process to produce anodes and cathodes. The webs run over several guide rollers. Before the valuable ink comes into contact with them, they are cleaned, dried and carefully inspected. From the coating unit, the web passes seamlessly into the drying oven – one of the largest machines in the hall. After the oven, the web with its electrode layers winds back onto a roll.

Ultimately, all inspections will of course be carried out inline and automatically. Today, two men with measuring instruments and laptops are stationed here. They are in the process of commissioning the system following its conversion for the new generation. In recent weeks, they have invested considerable time and effort to get all the parameters right. Now, at last, everything is working. Apart from safety glasses and safety shoes, they wear no special clothing, as there are no cleanrooms in the factory. Each section of the equipment is enclosed and set to the required cleanliness level – in its own mini-cleanroom, so to speak.

Sandwich from the roll In the subsequent production steps, where the layers are assembled, Cellcentric also works with rolls. First, the anode and cathode webs are brought together; then the delicate and comparatively expensive membrane is inserted between them. The result is a catalyst coated membrane, or CCM.

At the next station, this membrane sandwich is first supplemented with three more layers. To distribute the reaction gases evenly, a gas diffusion layer (GDL) made of a conductive carbon material is still needed on each side. And to give the unit stability, frames are required. These also come from a roll. Only when all layers are neatly aligned is the sandwich cut, positioned, bonded and singulated. The framed membrane electrode assembly is now complete (membrane electrode frame assembly, MEFA). At a further station, this is sealed by injection moulding to become a sealed membrane electrode frame assembly, or SMEFA.

Now the bipolar plate is still missing. This is one of the few parts that Cellcentric does not manufacture itself. "We use graphite bipo-

Here, the framed membrane and electrode unit is sealed to become a sealed membrane electrode assembly (SMEFA)

© Cellcentric

lar plates. Metal would be easier to handle, but tends to undergo chemical reactions at high temperatures. That means we would have to be more cautious in operation and could only use the cell's maximum power briefly, for example," Ladra explains. With graphite bipolar plates, by contrast, the stated maximum power of the fuel cell modules is identical to the continuous power. The individual cell is now complete.

Stack with bolted connections Next comes stacking. To connect the cells into a stack, Cellcentric relies exclusively on bolted connections. This is not the cheapest solution, but it offers the assurance that any cell can be replaced in the event of a defect. Since the entire stack is worth roughly as much as an upper mid-range car, this safeguard pays off. The stack becomes sealed during the subsequent compression – and visibly shrinks at the same time. The heart of the power unit is now complete.

At a final station, everything needed for the fuel cell to function is assembled – from sensors and the coolant pump to the compressor and the DC/DC converter. In the pilot factory, this is largely done by hand by a single person.

Before leaving the factory, the finished power unit must pass three tests. First comes the leak test. A sniffer robot moves its trunk-like sensor unit over all the points where hydrogen might escape. Next, the unit must prove in a high-voltage test that voltage and current are correct. In the end-of-line test, it then has to run through simulated driving cycles for three and a half hours – so it has already practised for the Alpine crossing before it even goes into a vehicle. ○

Range-Extender and E-Methanol

By Werner Tillmetz

Many vehicle manufacturers are focusing on purely battery-electric drives, but domestic green electricity generation is limited. With e-fuels, on the other hand, abundant green energy can be imported from the desert.

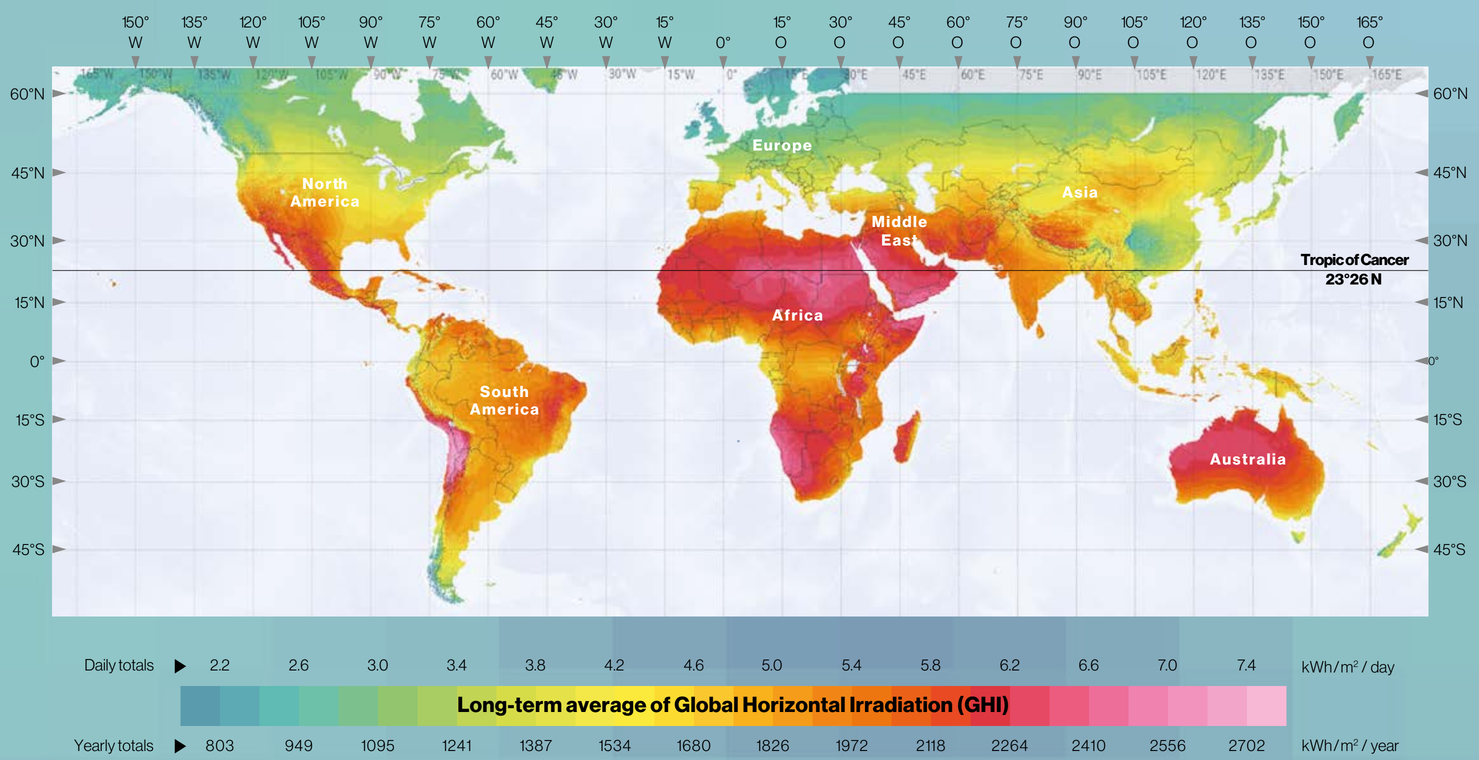


FIGURE 1: Global solar radiation. In sunny regions, up to three times more electricity can be harvested with the same solar module compared to Central Europe. © Arno Evers, Sunny Houses Samal Island

Germany's transport sector currently consumes around 700 terawatt hours (TWh) of fossil fuels, all of which must be imported, according to the German Environment Agency. The share of domestically generated solar and wind power in Germany's total primary energy consumption of just under 3,000 TWh is currently only seven percent. This is significant because only solar and wind energy can provide the scalability required for the energy transition. Further expansion of hydropower and biomass is only possible to a very limited extent. Against this backdrop, it seems highly questionable how green electricity for future e-mobility is to be made available in sufficient quantities, at all times of day and year – and at an affordable price.

Energy demand in the transport sector requires new perspectives That is why I would like to outline the role that hydrogen and its derivatives (e-fuels) could play in the transformation of the transport sector. According to current media

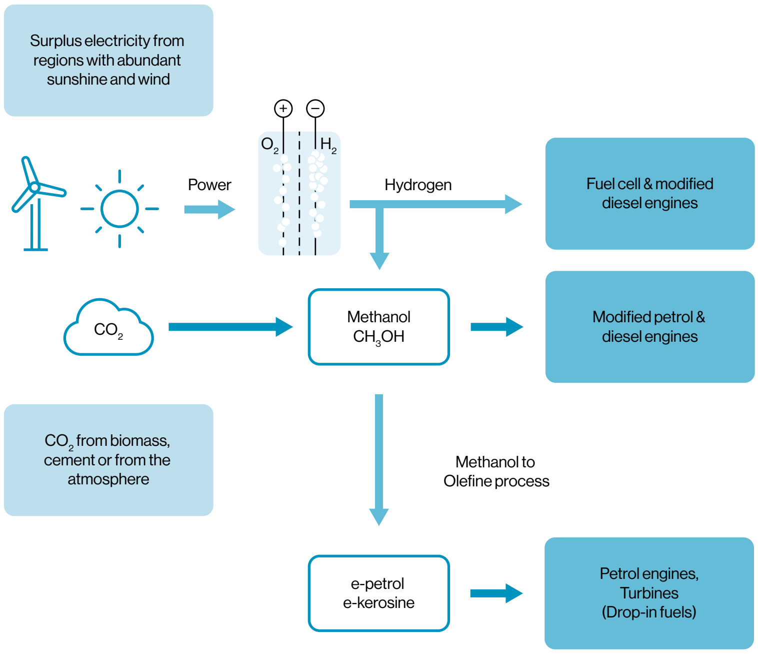


FIGURE 2: Principle of e-fuel production © Werner Tillmetz / NEONBOLD

ture, DAC). The second generation of DAC technologies, with significantly reduced energy requirements, is currently under development worldwide, especially in the USA and China. Some companies are also extracting water from the air in addition to carbon dioxide for hydrogen production. In the German-speaking region, for example, Phlair and Obrist are doing this. All other technologies, such as water electrolysis, methanol synthesis or the methanol-to-olefin process for producing e-gasoline or e-kerosene, are industrially established processes.

In recent years, activities related to the production of e-fuels have developed very dynamically. International shipping has become the largest customer for e-methanol. New ships are being equipped with dual-fuel engines. These can initially run on relatively clean marine diesel and then switch to e-methanol as soon as it becomes available or required.

coverage, e-fuels are often portrayed as "the devil's work": too expensive and inefficient to produce. Only air travel and maritime shipping are accepted as unavoidable exceptions. However, the energy system of the future, including road transport, must be considered as a whole. This is rarely done, nor is there a time-resolved analysis.

A holistic approach was taken, for example, by the German Institute for Economic Research (DIW) in 2021: In an energy system based 100 percent on renewable energy, Germany would need around 80 gigawatts (GW) of electrolysers for hydrogen production and 100 GW of flexible hydrogen gas turbines for electricity generation, including for charging electric vehicles. For comparison: today, around 30 GW of flexible natural gas power plants are installed.

However, if green energy were imported in the form of hydrogen or e-fuels from regions with abundant sun and wind, the need for grid expansion could be drastically reduced.

E-fuels from the desert: production and potential Climate-neutral fuels are produced from CO2, water and sunlight. In the future, their production will increasingly take place in the desert regions of the world. In these largely uninhabited areas are hardly any consumers for electricty from solar and wind (Fig. 1). As a result, there is no competition with other applications.

This electricity is used to produce hydrogen via electrolysis, which is then combined with CO2 through catalytic processes to produce methanol (Fig. 2). This methanol can be further processed into e-gasoline or e-kerosene (SAF) and used directly in today's engines or turbines (drop-in fuels).

Hydrogen and e-methanol can also be used directly in specially adapted engines. The CO2 required for production currently comes mostly from biomass (e.g. from biogas or ethanol production). Industrial CO2 sources, such as from cement production or waste incineration, are also well suited for the production of e-fuels.

The largest potential in terms of volume lies in the absorption of CO2 from the atmosphere (Direct Air Cap-

Many production plants for green methanol are currently being built around the world In addition to Chinese companies, Danish firms such as Maersk and European Energy are playing a key role. The Arabian Peninsula is also developing into a hotspot for the production of H2 derivatives such as e-methanol and e-ammonia.

The largest plant, with a capacity of 1.4 million tonnes, is currently being built by Beijing-based company Goldwing in Inner Mongolia. In China, around 50,000 passenger cars are already running on methanol. The use of synthetic fuels in electric vehicles with range extenders (Extended Range Electric Vehicles, EREV) is particularly interesting. In 2024, one million of these efficient vehicles, still powered by ▷

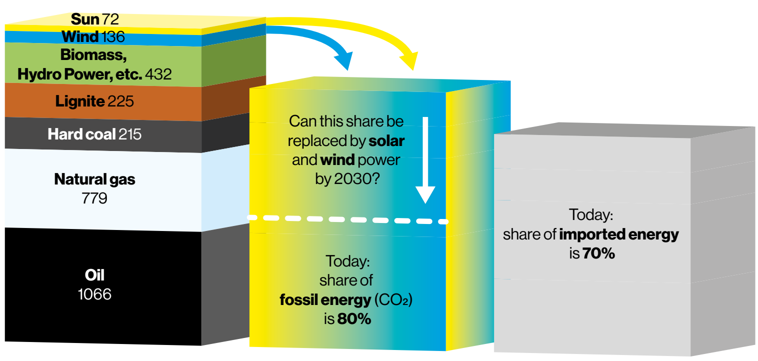
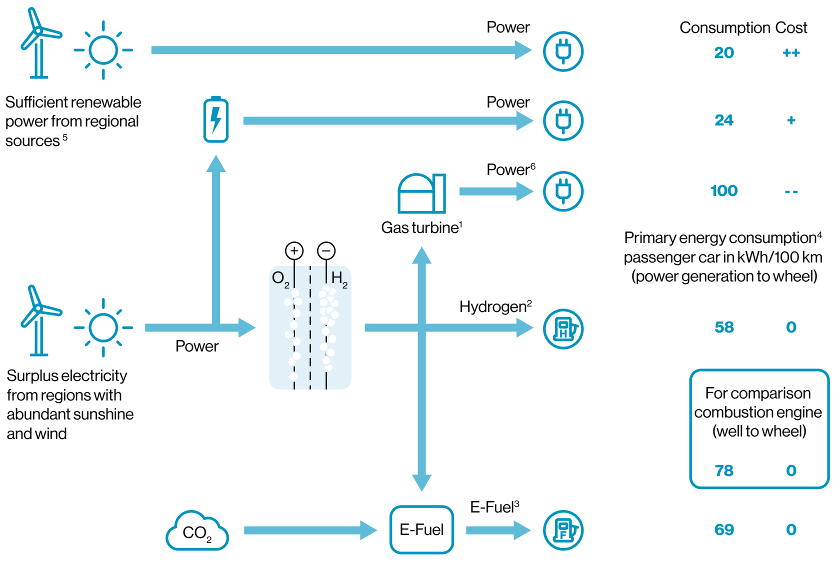


FIGURE 3: Primary energy consumption in Germany in 2024, share of fossil energy with reduction target for 2030, and share of imported energy.

(Source of figures: German Environment Agency) © NEONBOLD



1: Efficiency open gas turbine (peaker) 40%; **2**: Hydrogen via pipeline oder regional production;
3: Imported e-Fuel und Range Extender e-vehicle; **4**: Energy consumption vehicle (WLTP) in kWh: BEV 17; FCEV/Plug-in 25; EREV 24; **5**: In Germany less than 20% of the time in a year;
6: This path dominates the overall balance of battery electric vehicles (BEV)

FIGURE 4: **Holistic analysis (from electricity generation to wheel) of efficiencies and costs for the various options of electric vehicles and green fuels.** © Werner Tillmetz / NEONBOLD

fossil fuels, were registered in China. VW plans to launch its first electric SUV with a range extender on the Chinese market this year – aiming to break the 1,000-kilometre range barrier.

This year, Formula 1 is switching to climate-neutral fuels such as e-gasoline. The simultaneously required hybridisation of these powertrains reduces fuel consumption by 25 percent. The e-gasoline is produced by Saudi Aramco. For large-scale production, both Saudi Aramco and some study authors estimate production costs of 80 cents per litre.

Our current energy system is based on oil, coal and natural gas for about 80 percent In Germany as well as globally. These are responsible for the still rising CO2 emissions of around 40 billion tonnes per year (Statista). The infrastructure required for fossil energy – from pipelines to filling stations – has been built and optimised over decades and is still fully operational today.

Oil, coal and natural gas are the most important economic factor worldwide, with revenues of more than six billion dollars per day from crude oil alone. Refining crude oil into everyday fuels triples this revenue.

Since 96 percent of all passenger cars and more than 99 percent of all commercial vehicles on Germany's roads still run on fossil fuels, a complete transition to climate-neutral energy carriers (electricity, hydrogen, e-fuels) requires a well-thought-out and long-term strategy. Despite their enormous growth in recent years, solar and wind energy currently account for only seven percent of Germany's primary energy demand.

It will remain extremly challenging for them to take on a dominant role in future energy supply. In addition, their volatile generation remains a major challenge. According to the German Weather Service, there are only about 1,800 hours of sunshine per year in Germany, or about 130 sunny days. In the deserts, by contrast, there are 360 sunny days (Fig. 1).

During the remaining 7,000 hours (almost 80 percent of the time), solar power will continue to be unavailable in Germany. Wind is also only available to a limited extent, as high-pressure weather systems can result in little wind power generation for many days or even weeks.

Batteries are only suitable as short-term storage and to buffer temporary high power demand during fast charging. In addition, a regular supply of green electricity is needed to recharge battery storage systems. Most of the time, power plants must meet electricity demand – currently fossil-fuelled, and in the future powered by hydrogen – both for today's electricity consumption and, increasingly, for charging battery-electric vehicles (Fig. 3).

The currently installed 200 GW of photovoltaic and wind power capacity also lead to temporary electricity surpluses, which, despite very low or even negative prices, find no buyers and must be curtailed. Storing this surplus electricity in the form of hydrogen will be an essential component of the future energy system, as calculated by the German Institute for Economic Research.

What does this mean for the energy supply of tomorrow's transport sector? The solar and wind energy potential available on Earth exceeds today's global energy demand many times over. The deserts in the sunbelt and the long, windy coastlines offer the possibility of generating vast amounts of green electricity (Fig. 1). In these mostly uninhabited regions, it can hardly be used unless liquid fuels are produced there. These can then be transported by ship, rail or truck to consumers in the densely populated areas of the world.

E-methanol is one of the most attractive energy carriers for this purpose. It can be used directly in slightly modified engines or further refined into established fuels such as gasoline or kerosene (Fig. 2). If a solar module in sun-rich regions produces two to three times as much electricity as in Germany, but cannot be used locally, then the popular discussion about efficiency becomes irrelevant (Fig. 4). What matters are the costs of producing and transporting the fuel. And don't forget: the storage issue is already solved for these energy carriers.

The wide range of efficient electric powertrains In public discourse, the term "electric vehicle" is automatically equated with battery-electric powertrains. However, there are many variants of electric drives. Pure battery-electric vehicles (Battery Electric Vehicles, BEV) store the required energy in batteries, which weigh up to 800 kilograms in passenger cars and often more than 5,000 kilograms in trucks and buses.

In fuel cell powertrains (Fuel Cell Electric Vehicles, FCEV), electricity for driving is generated on board from hydrogen. In combination with a much smaller battery that enables regenerative braking, this results in an efficient, emission-free drive that is particularly advantageous for vehicles with high energy consumption and long driving ranges (short refuelling times and lower overall weight). In electric vehicles with a range extender (Extended Range Electric Vehicle, EREV), a small battery

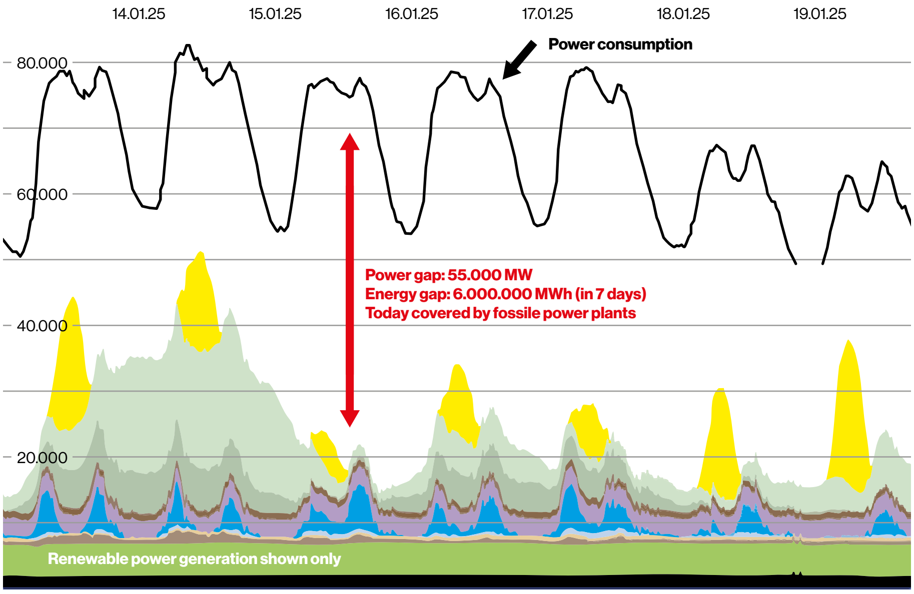


FIGURE 5: Electricity generation and consumption during a typical winter week. Despite increasing installed capacities, only limited green electricity will be available temporarily in the future. The load will increase significantly with the further expansion of battery-electric mobility.

© Fraunhofer ISE, Energy-Charts / NEONBOLD

(around 20 kWh in passenger cars) is recharged on board by a generator powered by a combustion engine when needed. The engine of the generator operates at a fixed point (speed and power) with high efficiency of more than 40 percent and minimal pollutant emissions.

Refuelling with liquid fuels (e-fuels) works just like in conventional vehicles. In the omnipresent discussion about efficiency, either only the vehicle's efficiency (from tank to wheel) is considered, or it is assumed that sufficient green electricity is always available for direct charging (Fig. 4, upper path).

However, this is relatively rare – for example, at midday on sunny summer days or during stormy weather. Intermediate storage in batteries is also only possible to a limited extent. Most of the time, the electricity needed to charge vehicles comes from a thermal power plant with an efficiency of no more than 40 percent. This reduces the overall efficiency from electricity generation to the wheel to below that of combustion engines.

Yet this perspective is almost never considered. The direct use of hydrogen in fuel cell powertrains is even more efficient than a BEV whose electricity comes from a power plant. In the Earth's sunbelt, solar power is now generated for one cent per kilowatt hour. This can then be used to produce hydrogen very cost-effectively and further processed into e-fuels (Fig. 2).

This is relatively efficient when viewed holistically, and due to the very low electricity prices, it is above all cost-effective. For e-fuels, production costs of eight cents per kWh are expected in large-scale production. That is about twice as much as fossil gasoline costs today.

Thanks to the efficient range extender, consumption would be halved and the cost per kilometre would remain the same. Compared to an electricity price of 80 cents per kilowatt hour at a fast-charging station, this is very inexpensive – even when converted to cost per kilometre. Today, e-fuels are only available in limited quantities, which is why there are no market prices yet. However, these are developing within an already established overall system.

Conclusion From a holistic perspective, e-fuels are an attractive option, especially for efficient range extender electric powertrains. The existing infrastructure for liquid fuels saves investment and enjoys high user acceptance. The extremely costly expansion of charging infrastructure and the power grid, as well as investments in peak-load power plants for demand-driven electricity generation, could then be avoided. Fuel cells, electrolysers and range extenders offer high potential for domestic value creation. They could become a key component of the energy transition, which can only succeed through technological diversity. ○

PROF. DR. WERNER TILLMETZ
worked in the automotive and chemical industries for 20 years. At DaimlerBenz and Ballard Power Systems, he led fuel cell development for vehicles until 2002. The electrochemist with a doctorate was a member of numerous committees, including the National Platform for Electric Mobility and the National Organization for Hydrogen and Fuel Cell Technology (NOW) of the German Federal Government. To this day, he remains a member of the Science Council of TotalEnergies (Paris) and the Advisory Council of Emerald Technology Ventures (Zurich).

Financing remains the key hurdle

By Niels Hendrik Petersen

By 2030, electrolysers with a capacity of up to 6.6 gigawatts could be built in Germany – provided financing is secured. Many projects are competing for limited funds in tenders, while larger plants could be better supported through long-term power purchase agreements.

Tour of the new electrolysis plant

© BASF SE

Since the publication of the National Hydrogen Strategy in 2020, installed electrolyser capacity in Germany has almost quintupled – from 33 megawatts (MW) in 2020 to 114 MW at the end of 2024. A notable achievement. Yet the market is in a transitional phase: while smaller plants have dominated so far, projects with two- to three-digit MW capacity are set to be implemented in greater numbers going forward. This is the finding of a recent analysis by the German Energy Agency (Dena). According to the agency, 185 megawatts of electrolyser capacity are currently in operation in Germany. A further 1.1 GW are under construction – roughly half of which are expected to come online shortly, based on project data.

At BASF's site in Ludwigshafen, Germany's largest PEM electrolyser has been operating

since March 2025 – following around two years of construction. The plant produces up to one tonne of green hydrogen (H2) per hour. Built in partnership with Siemens Energy, the electrolyser comprises 72 stacks and has the potential to reduce greenhouse gas emissions at BASF's main site by up to 72,000 tonnes per year.

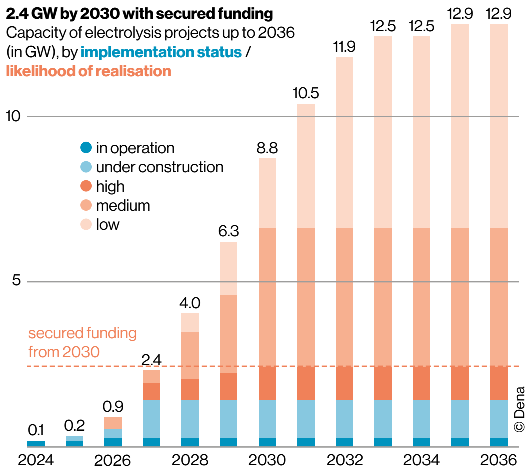
The hydrogen is fed into the site's H2 network and supplied to production facilities as a feedstock. In addition to using it as a raw material for chemical products, the chemical company plans to supply hydrogen for H2 buses in the Rhine-Neckar metropolitan region, supporting the development of a regional hydrogen economy.

Rhineland-Palatinate supports Hy4Chem Construction of the plant was funded by the Federal Ministry for Economic Affairs and Climate Action and the Federal State of Rhineland-Palatinate with 124.3 million EUR. BASF's investment amounts to around 25 million EUR. The project, titled "Hy4Chem," was selected as an Important Project of Common European Interest (IPCEI) for hydrogen and later received funding as an individual project. "As a state government, we are supporting this process with up to 37.3 million EUR because we are convinced that hydrogen plays a key role in decarbonisation and in safeguarding industrial jobs," emphasises Alexander Schweitzer, Minister-President of Rhineland-Palatinate.

According to the Dena database, projects with a total capacity of 8.8 GW could be realised by 2030. However, given the early stage of the market, Dena expects only 2.4 to 6.6 GW to actually be implemented. Secured financing is decisive for realisation – demonstrated, for example, by a final investment decision (FID), a funding approval or other financial commitments.

Long-term PPAs are key Discussions with project developers reveal that long-term offtake agreements – commonly known as PPAs – for hydrogen are critical for investment decisions. Contract terms of ten to fifteen years are considered ideal. Project developers are therefore calling for swift transposition of the revised Renewable Energy Directive (RED III) into national law. This directive sets binding quotas for the use of hydrogen and its derivatives in the industrial and transport sectors. At the same time, developers criticise the strict EU requirements for green hydrogen, arguing that these increase production costs and thus undermine project viability.

As of the end of 2025, the Dena database covers around 250 electrolysis projects with planned or completed commissioning since 2007. According to Dena, more than 80 percent of electrolysers currently in operation are publicly funded. Around 40 percent of installed capacity is accounted for by projects under the



IPCEI Hydrogen initiative and the Reallabore der Energiewende (real-world laboratories for the energy transition). The share of Reallabore is expected to decline by 2030, however, as they primarily support smaller demonstration projects.

Funding central to market ramp-up One third of the capacity planned for 2030 is currently backed by national or European funding programmes. However, many projects are competing for limited funds in tenders. In the first auction round of the European Hydrogen Bank, German projects were unsuccessful due to higher bid prices.

In the second round, two projects initially received awards but withdrew their bids before the funding agreement was finalised. Dena experts expect national projects to become more competitive as the market matures and demand grows. Nevertheless, targeted funding programmes remain necessary to support the market ramp-up.

The strategic importance of European electrolyser technology is growing overall. The year 2025 was also marked by geopolitical tensions and fragile trade dependencies. In this environment, resilience, industrial strength and technological sovereignty are increasingly coming into focus. Green hydrogen plays a central role here: as a locally producible energy carrier, it enables greater independence.

Strengthening competitiveness in Europe Installed electrolyser capacity in Europe will rise by around 50 percent year on year in 2025, reaching approximately 600 MW, while annual electrolyser manufacturing capacity will exceed ten gigawatts for the first time. Electrolyser companies have done their homework and established manufacturing capacity in Europe, says Nils Aldag, CEO of Sunfire. "We stand ready to meet the demand for green hydrogen in Europe and to contribute to a strong, resilient and competitive Europe." ▷

At the same time, Europe faces the challenge of maintaining its technological leadership. Long-term and reliable demand through implementation of the RED III targets in the transport and industrial sectors, along with strengthening European resilience in electrolyser technologies, will be decisive factors.

Yet there are already positive signals for green hydrogen from Europe: the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) and Holst Centre in the Dutch province of Noord-Brabant are working together on innovative approaches to advance the design and production of more cost-effective and scalable AEM electrolysers. The "genAEMStack" project is testing new components and manufacturing processes. The goal is an electrolyser stack with a high share of European value creation. Both partners aim to strengthen their regions as development platforms for proprietary product development and the establishment of regional value chains.

This is also why the Ministry of Economic Affairs of the Federal State of Baden-Württemberg is funding ZSW with around 1.6 million EUR from the European Regional Development Fund (ERDF). The project has a duration of 2.5 years. "Water electrolysis is the key technology for climate-neutral, green hydrogen – and central to fulfilling the EU regulation on Strategic Technologies for Europe (STEP). Hydrogen produced in Europe through electrolysis does not need to be imported and avoids dependencies on supplier countries outside Europe. This is particularly valuable when electrolysers are deployed that make a significant contribution to industrial value creation in the EU," explains Marc Simon Löffler, Head of the Electrolysis Development Department at ZSW.

Bringing innovations to market faster At the end of 2025, Bosch commissioned an electrolyser with two Hybrion PEM electrolysis stacks at its Bamberg site. The plant has a total capacity of 2.5 MW and meets EU requirements for renewable hydrogen. Both Hybrion stacks were manufactured at the Bosch plant in Bamberg and produce around 23 kilograms of hydrogen per

The test station in Bamberg for the Hybrion PEM electrolysis stacks manufactured at the plant

© Bosch

hour. The electrolyser was built by the company Fest, based in Goslar. At full load, it can generate more than one tonne of hydrogen per day.

The commissioning marks the start of an entire hydrogen landscape in Bamberg. The site demonstrates how hydrogen can be produced, stored and utilised. A 21-metre-high tank stores the hydrogen from the electrolyser at up to 50 bar. The Hybrion stack features high modularity, enabling applications ranging from decentralised electrolysers for commercial operations to central industrial solutions with capacities of several hundred MW. "Our design is based on decades of experience from the automotive sector, particularly from fuel cell technology," says Carola Ruse, Head of the Electrolysis Product Division at Bosch. A stack consists of more than 100 electrochemical cells and achieves an efficiency of up to 50 kWh per kilogram of hydrogen.

Economic viability depends not solely on plant size, but on additional key factors. "Operating costs are of central importance and are largely determined by electricity costs and annual full-load hours," emphasises Ruse. Capital expenditure (CAPEX) for the overall system is another factor. Bosch aims to reduce this through scaling and automated manufacturing. "In addition, we are continuously working to improve products and manufacturing processes – for example through reduced material usage, higher quality and optimised production processes."

Materials research and ageing analysis A further focus is optimising the service life and maintenance intensity of PEM electrolysis stacks. This ranges from intensive materials research and ageing analyses to testing under real operating conditions. An international team at several Bosch locations is working on stack development: in Linz (Austria) and in Feuerbach, north of Stuttgart, there is dedicated test infrastructure capable of testing full-size electrolysis stacks. "A decisive advantage, since typically only much smaller test samples are used," explains Ruse. The results of these extensive tests feed directly into further development. In Tilburg, the Netherlands, a team focuses on materials research and detailed analysis of ageing processes in the materials used.

In Bamberg, Bavaria, the Hybrion PEM electrolysis stacks are manufactured and tested under real operating conditions. Bosch is thus gaining valuable experience. "This enables us to comprehensively analyse and optimise aspects such as service life and maintenance intensity under real load profiles," says Ruse. At the same time, she calls for clear political signals and reliable framework conditions. These are essential for resilience, jobs and competitiveness in the global technology race for hydrogen. Ruse advocates greater pragmatism and flexibility in the ramp-up phase to avoid blocking investments. A key aspect is the design of the EU criteria for electricity sourcing for the production of green hydrogen via electrolysis. The options for sourcing renewable electricity must be designed to both promote decarbonisation and enable the scaling of the hydrogen economy. Ruse: "The technology is ready. The regulatory framework must now enable the ramp-up – not hold it back." ○

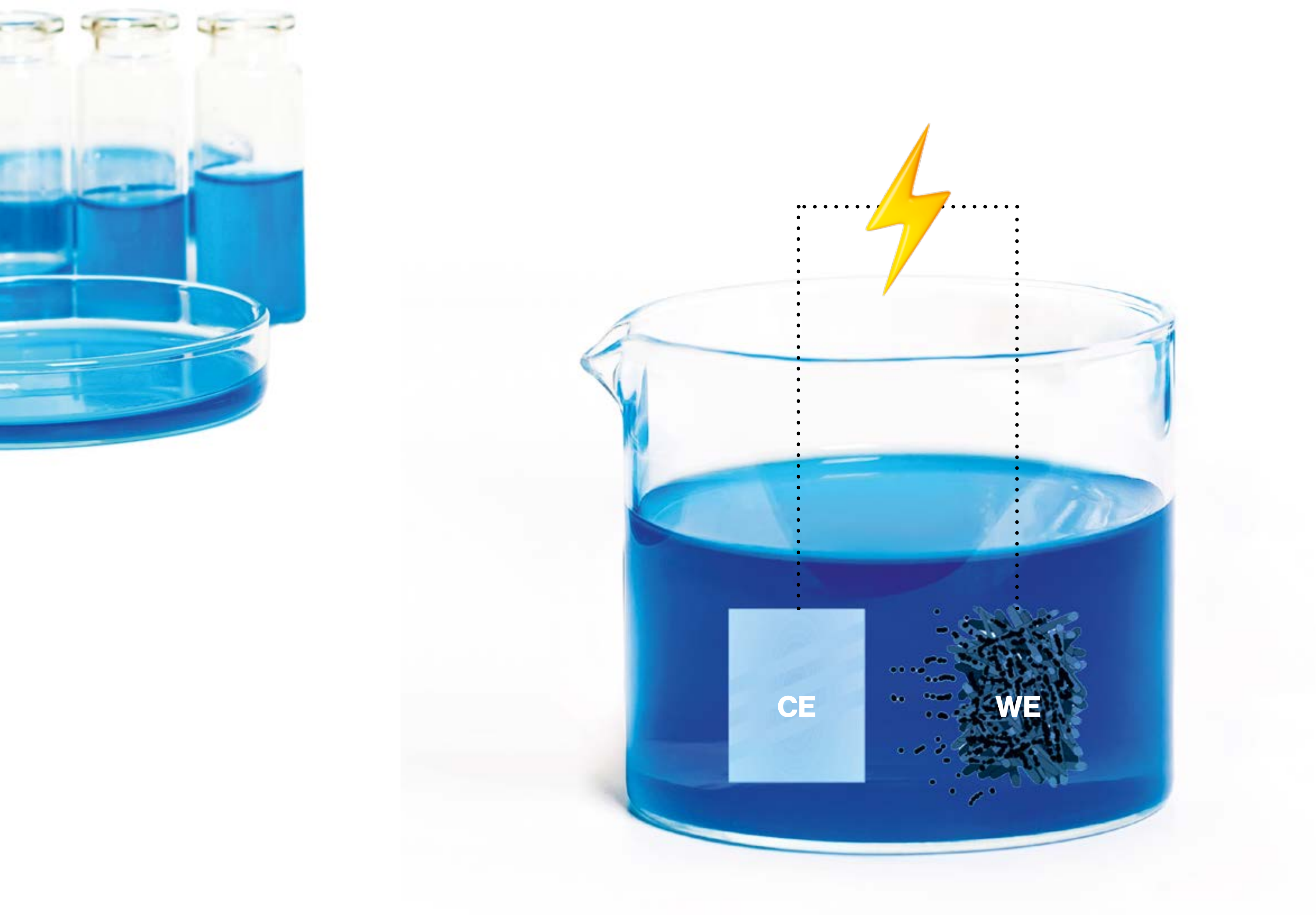
Simulation of various load profiles ensures the robustness and reliability of each individual Hybrion PEM electrolysis stack

© Bosch

Innovative electrodes for more efficient electrolysis

By Miriam Hesse, Henning Winter

A catalyst based on nickel and sulphur with a nanostructured surface can significantly improve the efficiency of electrodes for AEM electrolysers. This is the finding of a recently published study by ZBT, fem Forschungsinstitut and Ruhr-Universität Bochum in Germany.



Schematic representation of the electrodeposition of the novel catalyst material onto the stainless steel nonwoven. CE = counter electrode; WE = working electrode

Catalysts for AEM electrolysers (anion exchange membrane electrolysers) do not require expensive precious metals. Yet there is still scope to reduce costs further. Work is ongoing to improve the performance and durability of catalyst-coated electrodes. In addition to material suitability, researchers are conducting extensive investigations into alternative catalyst compositions and manufacturing processes.

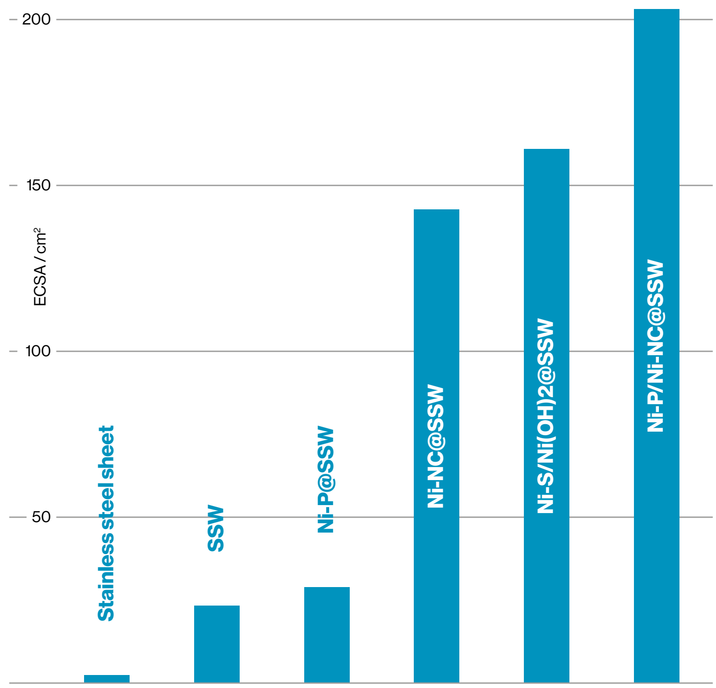
Researchers from ZBT – Zentrum für Brennstoffzellentechnik in Duisburg, fem Forschungsinstitut in Schwäbisch Gmünd and Ruhr-Universität Bochum have made significant progress in developing cost-effective and durable anodes for hydrogen production as part of a joint project funded by the IGF (Industrielle Gemeinschaftsforschung), a German programme for pre-competitive industrial collective research. To enhance the performance and corrosion resistance of the nickel-based catalyst layer, the team incorporated non-metallic elements such as sulphur and phosphorus into the catalyst layer and formed nanocone structures in the anode layer.

The anodes developed in the project, produced by electrodeposition onto porous stainless steel non-woven material, achieve approximately 20 percent higher current density at the same cell voltage compared to untreated stainless steel non-woven. Stainless steel already demonstrates good catalytic activity in AEM electrolysis and therefore serves as the reference.

Optimised surface and durability The modified anodes optimise the active surface area, thereby improving the kinetics of the oxygen evolution reaction (OER). Using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX), the researchers confirmed the desired nanostructured morphology and homogeneous element distribution.

In single-cell tests, they also observed superior activity of Ni-S electrodes compared to bare stainless steel. During constant current measurement at 2.5 A over ten hours, the electrolysis cell with the optimised anode started at 1.69 V, while the stainless steel non-woven required 1.92 V. This corresponds to a reduction in cell voltage of approximately 12 percent. Furthermore, pronounced corrosion was observed on the bare stainless steel non-woven after the constant current measurement, whereas the Ni-S layer remained structurally intact.

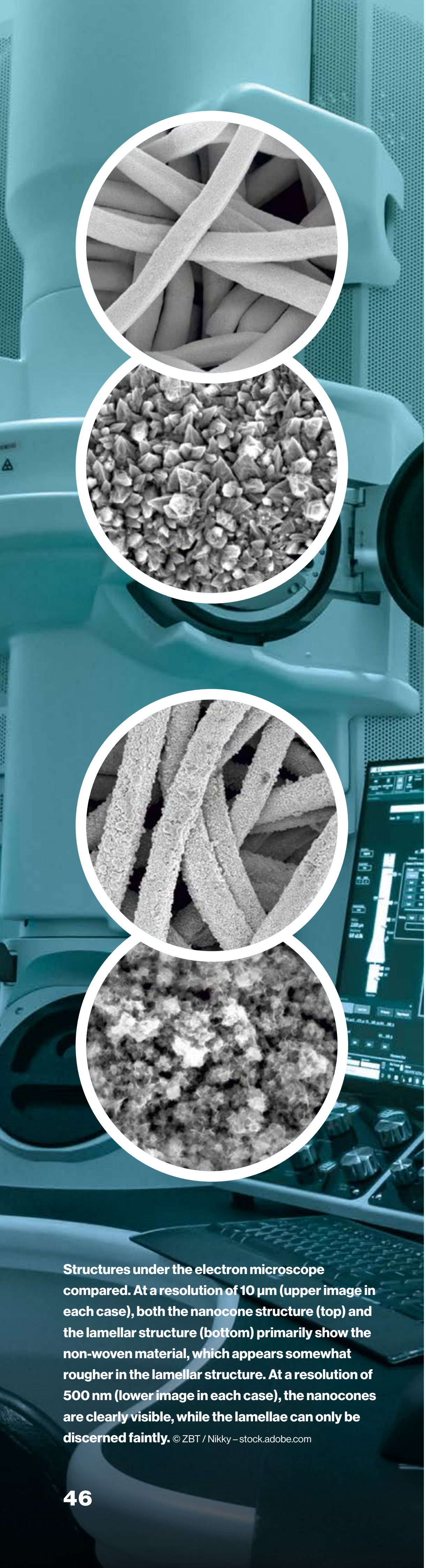
The targeted formation of lamellar hydroxide structures on the electrode surface, which are retained after electrolysis, stabilises and further enhances catalytic activity in the alkaline environment. The nanocone structures increase the effective surface area of the electrode and can serve as robust supports for active catalyst coatings, as they remain stable even after electrolysis under alkaline conditions.



Comparison of the active surface area (ECSA = electrochemical surface area) of various catalyst materials. The bar represents the area on which the chemical reaction can take place. SSW (stainless steel non-woven) serves as the base substrate for deposition in each case. According to the measurements, Ni-S/Ni(OH)$_2$ and the nanocone structures (Ni-P/Ni-NC) offer the largest available area for the reaction. © ZBT/NEONBOLD

Through electrochemical measurements as well as structural and chemical analyses, the researchers demonstrated that the combination of nickel and sulphur forms a particularly active and stable surface for oxygen evolution:

- Nickel hydroxide and nickel oxyhydroxide phases are known to actively participate in the OER in alkaline media – including in AEM electrolysis.
- The incorporation of sulphur modifies the electronic structure of nickel – the electron properties that influence its conductivity, binding strengths to reactants and thus its catalytic activity.
- This optimises the adsorption strength of oxygen intermediates on the catalyst surface. The binding energy is shifted towards an optimal value (neither too strong nor too weak).
- The result: lower anodic overpotential at a given current density, which translates into lower cell voltages. ▻



Structures under the electron microscope compared. At a resolution of 10 µm (upper image in each case), both the nanocone structure (top) and the lamellar structure (bottom) primarily show the non-woven material, which appears somewhat rougher in the lamellar structure. At a resolution of 500 nm (lower image in each case), the nanocones are clearly visible, while the lamellae can only be discerned faintly.

Scalable manufacturing process The key innovation for future application lies in electrochemical deposition (electrodeposition). This process allows precise control over the composition and structure of the catalyst layer. The method is also scalable and therefore industrially viable – a decisive advantage over more complex manufacturing processes.

Miriam Hesse, a doctoral researcher at ZBT and co-author of the publication, focuses her research on the production, characterisation and testing of precious-metal-free electrodes in real AEM electrolysis systems. She investigates how the composition, structure and surface morphology of catalysts influence their activity and stability. Her work includes electrochemical measurements and analyses using X-ray fluorescence (XRF), X-ray diffractometry (XRD) and scanning electron microscopy (SEM), which she performs before and after electrolysis operation to assess changes in the composition and microstructure of the materials.

The project not only demonstrates that numerous promising materials have been developed in laboratory research in recent years, but also addresses precisely this point by advancing their transfer into practical electrolysis applications. Hesse's work thus bridges the gap between fundamental materials science research and the application-oriented evaluation of electrodes for future electrolysis systems.

The recently published study highlights the potential of electrodeposited nickel-based materials for the scalable production of efficient anodes for AEM electrolysis. It provides an important impetus for the development of cost-effective hydrogen production technologies. ○

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ABOUT ZBT

ZBT – Zentrum für BrennstoffzellenTechnik was founded in Duisburg, Germany, in 2001 and is one of Europe's leading application-oriented research institutions for fuel cells, hydrogen technologies and electrolysis processes. ZBT is a sought-after research and development partner in European and national cutting-edge research as well as in industry projects. From materials to components and complete systems, from green hydrogen production through refuelling to reconversion to electricity, from prototypes through small-series to mass production – ZBT bridges the gap between university-based fundamental research and industrial development departments.

www.zbt.de

The study has been published under the title "Enhancing anion exchange membrane water electrolysis: A study of electrodeposited nickel-based anode materials" in the International Journal of Hydrogen Energy and can be accessed online free of charge.

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Components

Fully controlled

By Eva Augsten

Precisely controlling the flow of gases and liquids is an essential yet intricate task in hydrogen technology. Fluidics specialist Bürkert offers complete solutions from a single source.

It is not easy to concentrate on the PowerPoint presentation in Bürkert's conference room. Anyone interested in the manufacture of measurement, control and regulation components can see far more through the large glass wall. The view sweeps across a modern factory floor. From above, the most striking features are the glazed work areas where people sit at computer workstations. Using Bürkert valves, sensors and controllers, they design complete assemblies and solutions tailored specifically to individual customer requirements. "We call this place the Systemhaus," says Dominik Fröhlich, responsible for Bürkert's business development for energy sector customers in Germany, Austria and Switzerland.

For the company, whose history began 80 years ago with solenoid valves and which today also manufactures sen-

View of the factory floor with the Systemhaus facilities

© Bürkert

sors and controllers, the hydrogen sector is one of four target industries. “We see the energy market – hydrogen in particular – as a clear future market with significant growth potential,” Fröhlich adds.

A solution from the Systemhaus might, for example, combine a Siemens PLC control unit with a Bürkert valve terminal. The latter translates electrical control signals into compressed air to actuate the pneumatic valves. The entire assembly is not only designed for the ATEX zone often specified by customers, but can also be deployed in functionally safe installations.

According to Fröhlich, this high level of integration is particularly attractive for electrolysis plants in the hydrogen sector. Understanding customer requirements and working together in a spirit of trust is a distinctive strength, he says. This close technical relationship with customers is how the company sets itself apart from global competitors. Another decisive factor is the continuous investment in developing the portfolio for these applications, reinforcing the company’s leading position in the industry.

One source for everything For electrolysers, Bürkert aims to score as a one-stop shop. “A 100 megawatt electrolyser contains several hundred control valves, ball valves and butterfly valves, plus roughly the same number of sensors again,” says Fröhlich. Each component has interfaces in the system – not just in the physical sense – and must be specified, ordered, inspected and, in some cases, maintained. “The sheer number of components and interfaces is a challenge for any company. Especially for start-ups whose focus and specialist expertise lie in particular electrolysis technologies, our concept can be a major support,” Fröhlich explains. After delivery, the portfolio optionally includes maintenance services such as seal replacement or calibration – even if the plant contains products from other manufacturers.

Keeping it sealed Hydrogen as a medium is nothing new for the company. Bürkert components have been in use in some applications involving the fugitive gas for 25 years. The fundamental requirements are therefore well understood. Yet a few adaptations were still needed for modern applications. Electrolysers and hydrogen refuelling stations in particular operate at very high pressures – several hundred bar in many places. Bürkert had to optimise its portfolio for this, adapting sealing materials in particular and re-testing them under these special conditions. “Our components are designed for the entire service life of an electrolyser,” says Fröhlich. Even in demanding applications such as alkaline electrolysers, where aggressive media like potassium hydroxide (KOH) are used, Bürkert offers an optimised portfolio that reliably handles these conditions. This ensures that the company’s solutions remain durable and high-performing even under extreme demands. “Because we understand the requirements, we can not only supply the right components but also provide the service to go with them,” Fröhlich says.

Components for niche applications and beyond Bürkert can justifiably claim to have the right fluidic solution for virtually any application – a result of the company’s strategy. The fluidics experts, headquartered in Ingelfingen, place a strong emphasis on system solutions. By skilfully selecting from the standard range of individual valves, sensors and controllers, they create new system solutions matched to specific requirements.

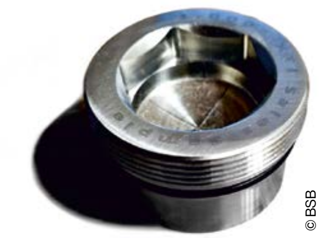
The components and system solutions are often assembled by hand at dedicated workstations. The experienced assembly team, many of whom draw on decades of expertise, carries out the defined assembly steps with precision. Staff are supported by state-of-the-art technology. Parts for individual components travel from the high-bay warehouse in transport boxes along roller conveyors beneath the hall ceiling and via lifts to arrive almost directly at the respective assembly station. A monitor at each workstation displays which product is to be assembled and what needs to be observed. Some assembly stations also have robots to assist the operators.

Bürkert is also prepared for potential future large-scale series production, as the Gerabronn production site demonstrates. There, the company already manufactures coils and valve components on production lines designed for high volumes. Should the hydrogen industry continue to grow and scaling of valve production become necessary, nothing stands in the way. Fröhlich says: “We expect the industry to take off in the 2030s.” ○

Dominik Fröhlich is responsible for business development for energy sector customers in Germany, Austria and Switzerland at Bürkert.

Rupture disc without welding

The new XTI rupture disc from Bormann & Neupert by BS&B is milled from solid material and manufactured entirely without weld seams. This is designed to ensure particularly good leak-tightness in high-pressure applications.



© BSB

Weld seams found on some rupture discs also represent a potential weak point during operation. According to BS&B, the integrated design of the XTI therefore eliminates joints entirely. This is intended to offer plant operators absolute leak-tightness and high process reliability. It also eliminates the need for weld inspections and documentation, simplifying the technical approval of systems.

In addition, the XTI rupture disc is very compact and lightweight, making it suitable for mobile applications or installation in confined spaces. Continuous operating pressure of up to 80 percent of the minimum burst pressure is possible without increased risk, as is use in vacuum conditions or with frequently changing pressure cycles. The disc responds with high precision when the critical pressure is reached, BS&B states. The cross-scored design also prevents fragments from being released – an important safety feature. The XTI rupture discs are also maintenance-free and meet the relevant safety standards, such as the Pressure Equipment Directive.

BS&B manufactures the discs to customer specifications "in all common materials" and in diameters from 0.25 to 1 inch, with customised process connections. Small quantities or one-off production runs are also possible. Delivery is ready-to-use, fully assembled and operational. ○

More information: bormann-neupertbsb.de

High-performance compressors for hydrogen pipelines

Greene Tweed has introduced a new compressor technology for hydrogen pipelines. The closed impeller made from composite materials achieved a tip speed of 688 m/s in tests – twice that of conventional metallic impellers, according to the company.

Transporting hydrogen by pipeline requires high-performance centrifugal compressors to maintain system pressure. However, tip speed is limited by the material, which in extreme cases could burst under excessive load. According to Greene Tweed, metallic impellers reach 360 m/s in closed designs and up to 500 m/s in open designs. With light gases such as hydrogen, this is insufficient to achieve the desired compression ratio, meaning additional compression stages are required. This takes up space and adds costs for procurement and maintenance.

© Greene Tweed

With the EU's current plans envisaging tens of thousands of kilometres of pipelines by 2040, cost-effective, durable high-speed compressor technologies are needed. Composite materials offer significant potential in this regard.

Greene Tweed says it has been working on the new impeller since 2020. The company uses carbon fibre-reinforced polyetheretherketone (C/PEEK) due to its high specific strength and temperature resistance. The target was a tip speed of over 600 m/s, which has now been exceeded after three development and testing cycles.

According to Greene Tweed, the new impeller weighs only around one fifth as much as metallic impellers and is said to have three times the strength-to-weight ratio.

The technology is also highly scalable. Greene Tweed is currently working with centrifugal compressor manufacturers (OEMs) to bring the new technology to industrial applications.

Greene Tweed manufactures high-performance thermoplastics, composite materials, sealing systems and engineered components for specialised applications. Customers of the 160-year-old company come from the semiconductor industry, oil and gas, aerospace, defence, and the chemical and pharmaceutical process industries. ○

More information: www.gtweed.com

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Ultrasonic sensor designed specifically for electrolysers

Allengra has optimised its ultrasonic flow sensor for process monitoring in electrolysers. The sensor enables inline measurement of electrolyser production rates through precise detection of the wet hydrogen gas flow directly after hydrogen generation. At the same time, it detects oxygen (O2) levels in the hydrogen stream, providing valuable data for process safety.

The integrated speed-of-sound measurement can detect changes in the gas mixture, enabling stack monitoring and predictive maintenance. This allows operators to maximise system efficiency and service life.

The hydrogen sensor is now also available with Tri-Clamp process connections, allowing easy and secure integration into existing pipelines. ○

More information: allengra.eu

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H2int. 2/2026 will be published on April 15th 2026.


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IMPRINT

H2int.
THE HYDROGEN MAGAZINE

PUBLISHER AND COMPANY
Gentner Energy Media GmbH
Forststraße 131, 70193 Stuttgart
Postfach 10 17 42,
70015 Stuttgart, Germany

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DESIGN AND LAYOUT
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WEBSITE
www.h2-international.com

PUBLICATION DETAILS
Publication Frequency: 4 issues per year
26th Year, 2026
ISSN: 1862-393X

SUBSCRIPTION PRICES
€129.90 per year (including VAT),

New orders are subject to the subscription prices valid at the time of order. The applicable advertising rate list No. 27 from 01.01.2026 applies.

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