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Hydrogen Tech World

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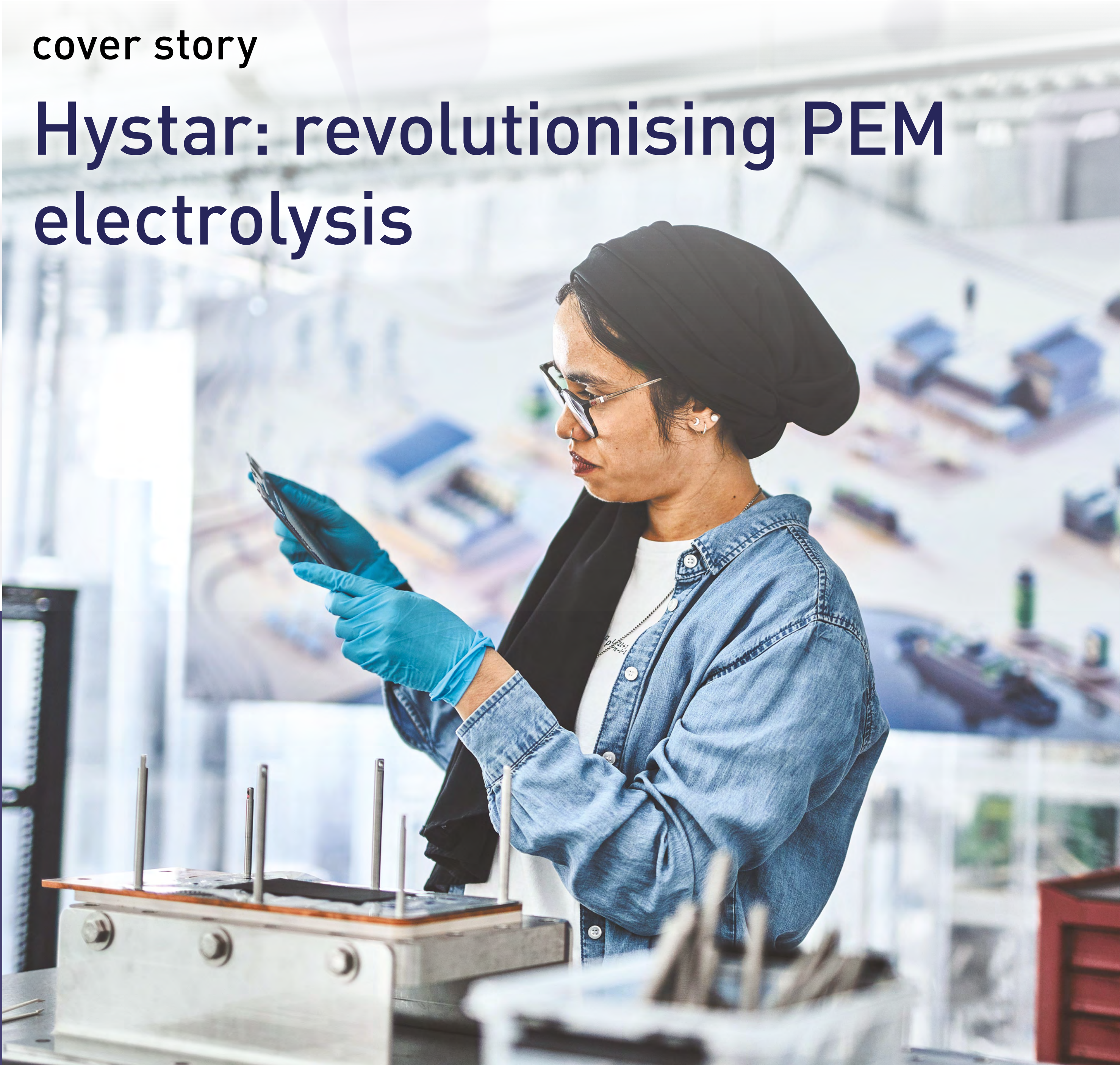

cover story

Hystar: revolutionising PEM electrolysis

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Dear readers,

Even as 2022 draws to a close, the pace of technological advancements and exciting new developments in the green hydrogen sector shows no signs of slowing down. Among the key areas of research are the materials used as catalysts in the production of hydrogen through water electrolysis. For the current generation of PEM electrolysers, iridium remains the most active and stable catalysts used at the anode. However, with iridium being one of the rarest materials on Earth, scientists are exploring ways to reduce the industry's dependence on it.

As reported in the 'Industry Update' section of this issue, two major milestones in this quest have recently been reached. In a potentially game-changing development, H2U Technologies has demonstrated PEM electrolyser stacks that replace iridium catalysts with inexpensive and abundant catalyst materials, while in another breakthrough, TNO researchers have developed an advanced electrocatalyst that reduces the required amount of iridium by a factor of 200.

Against the backdrop of these ongoing research activities, it is reassuring to learn from Johnson Matthey, a global authority on platinum group metals (PGMs), that iridium and other PGMs pose no barrier to large-scale deployment of PEM electrolysers and fuel cells. In her insightful article, Margery Ryan, Principal Strategy Analyst for PGM at Johnson Matthey, argues compellingly that, "if used efficiently, these metals will actually facilitate the development of a resilient supply chain." As she illustrates, the combined impact of thrifting and closed-loop recycling on PEM capacity would be such "that even within an applied constraint of just 1.5 tonnes per year of primary iridium and using an ambitious scenario for hydrogen uptake, PEM can take market share of 40%, and achieve an installed capacity of over 1,000 GW by 2050."

In another interesting article, Shuang Ma Andersen delves deeper into the subject of PGM recycling, providing a useful overview of current recycling methods as well as introducing a promising new process developed at the University of Southern Denmark.

Sustainability is also at the heart of Hystar, a Norwegian electrolyser manufacturer featured in the cover story of this issue. Committed to a circular economy and aware of the scarcity of catalytic materials used in PEM electrolysers, Hystar is exploring various options to reacquire end-of-life products from its customers as well as engaging with industry partners about the best recycling routes. Having developed 'the world's most efficient PEM electrolyser,' the company is now gearing up to fully automate its production process and ramp up production capacity to gigawatt scale.

As this issue of Hydrogen Tech World magazine demonstrates, the green hydrogen sector is brimming with innovation and activity, with the year ahead promising to be at least as exciting as 2022. An early highlight of the new year will be the inaugural Hydrogen Tech World Expo & Conference, to be held in conjunction with the Green Steel World Expo & Conference on 4 and 5 April in Essen, Germany. For information on how to participate as an exhibitor or conference speaker, please see pages 42–43.

On behalf of the entire Hydrogen Tech World team, I wish you a gentle end to 2022, and a happy, healthy, and prosperous 2023.

All the best,

Matjaž Matošec
Editor-in-Chief

Industry Update

H2U Technologies demonstrates iridium-free PEM electrolyzer

In what represents a potentially game-changing development, H2U Technologies has demonstrated first-of-its-kind proton exchange membrane (PEM) electrolyzer stacks that replace expensive and scarce iridium catalysts with inexpensive and abundant catalyst materials. The company's electrolyzer stacks leverage readily available catalyst materials to enable cost-effective green hydrogen generation.

The development of alternative catalysts is significant as highly constrained sources of costly platinum group metal (PGM) materials, such as iridium, will lead to supply chain shortages and price increases. With this successful demonstration, H2U is on track to ship its first proof-of-concept electrolyzer systems in 2023.

The catalysts used in the new electrolyzer stack are optimized with H2U's Catalyst Discovery Engine™ (CDE™) originally developed by Caltech. The data-driven CDE rapid-screening process allows scientists to make, characterize and quantify the catalytic activity of thousands of material compositions per week – faster than any other screening process available. The H2U scientists then explore multiple options to get the ideal materials into the electrolyzer using their expertise in catalyst coatings, binders, and deposition methods. The materials used in the demo stack have separately been evaluated and verified through independent third-party testing.

GrInHy2.0 project completed with record production rates

Salzgitter AG and Sunfire have successfully completed the EU-funded GrInHy2.0 (Green Industrial Hydrogen) project. Since 2019, the project partners have been operating a high-temperature electrolyzer from Sunfire with an electrical connected load of 720 kW on the premises of Salzgitter Flachstahl. The plant is considered the world's largest and most efficient of its kind. The electrolyzer is based on the innovative solid oxide electrolysis cell (SOEC) technology and runs at operating temperatures of 850°C. The system utilizes industrial waste heat and renewable electricity to split steam into its components hydrogen and oxygen.

"Green hydrogen is essential for producing low-CO2 steel, as it reduces carbon emissions very efficiently," said Dr. Alexander Redenius from Salzgitter Mannesmann Forschung. "With GrInHy2.0, we have gained valuable insights into the integration of electrolysis into our production processes."

The green hydrogen produced is fed directly into the hydrogen grid of Salzgitter Flachstahl. To date, almost 100 tons of the gas have been used in annealing processes and galvanizing plants for steel finishing. The partnership between Sunfire and Salzgitter AG is to continue beyond GrInHy2.0.

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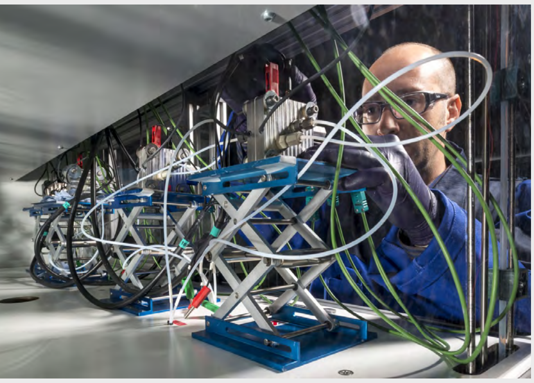
Breakthrough development heralds new generation of PEM electrolysers

In what is seen as a major technological breakthrough, researchers of the Dutch applied technology institute TNO have developed an advanced electrocatalyst that reduces the required amount of iridium by a factor of 200, while achieving an average of one third of the performance of current PEM electrolysers.

To make PEM technology a viable option for the electrolyser capacity upscaling towards 40 GW in Europe by 2030, a drastic decrease in iridium dependency is needed. In the last two years, the TNO scientists successfully executed a number of experiments, resulting in a breakthrough patented technology developed within the Voltachem program. To realise an ultra-thin, porous iridium catalyst layer in PEM stacks, experts from the TNO Holst Centre employed the spatial Atomic Layer Deposition (ALD) technology. In the TNO Faraday Lab, the stability of the resulting new electrolyser cell was demonstrated with a so called 'accelerated stress test protocol' to test the cell under extremely harsh conditions. After this validation test, there was hardly any degradation.



The TNO will now work together with industrial partners to accelerate this development and bring the technology to the market before 2030. The next steps are to prove that the technology will work on a larger electrolyser cell area, that the degradation is limited over a longer lifespan, and that the efficiency of the cell can be increase towards the state-of-the-art level of PEM electrolysis.

McPhy Energy takes FID for electrolyzer Gigafactory in Belfort

McPhy Energy has announced the final investment decision (FID) for its Gigafactory of alkaline electrolyzers on the Belfort site in France. Commissioning is scheduled for the first half of 2024, with a gradual ramp-up to reach an annual production capacity of 1 GW.

The future plant in Belfort will host new developments and production of the large electrolyzers in the 'Augmented McLyzer' range, a real technological breakthrough, enabling architectures of 20 MW, 100 MW and beyond (GW) to be equipped with an output pressure of 30 bar.

Belfort's location at the crossroads of many European countries, with a genuine research and development ecosystem dedicated to innovation and hydrogen, will foster the multiplication of potential industrial and commercial partnerships.

New joint venture formed to propel India's hydrogen economy

H2B2 Electrolysis Technologies and GR Promoter Group have formed a new joint venture to develop hydrogen solutions. Named GreenH Electrolysis, the joint venture will engage in the manufacture of electrolyzers and development of green hydrogen production plants based on off-take agreements.

The first project of the newly established company will be the deployment of an electrolyzer production plant with an initial production capacity of 100 MW, later to be ramped up to the GW scale. Construction is expected to start in early 2023.

Operating in the Indian market, with the possibility to extend its activities to other countries in Asia, GreenH Electrolysis will cover the entire hydrogen value chain, including innovation, design, engineering, manufacturing, integration, financing and O&M for modular hydrogen production systems and ad hoc/industrial solutions.

Bloom Energy inaugurates high-volume electrolyzer production line

On 1 November 2022, Bloom Energy inaugurated its high-volume commercial electrolyzer line at the company's Newark, Delaware facility, increasing the company's generating capacity of electrolyzers to 2 GW.

In the last decade, the facility has produced over 1 GW of resilient, sustainable, and cost-effective fuel-cell-based energy servers. The Bloom Electrolyzer relies on the same, commercially proven solid oxide technology platform used to produce electricity, so streamlining existing manufacturing for higher volume electrolyzer output allows Bloom to best meet the needs of the market.

The technology's significant capabilities for hydrogen production are being demonstrated in partnerships with Xcel Energy and Idaho National Labs to harness nuclear and steam power, and will be demonstrated with LSB Industries, Inc. to decarbonize industrial and agricultural sectors. Internationally, the technology is in use in South Korea.

The Bloom Electrolyzer supports a trajectory for hydrogen to become economically accessible by producing hydrogen up to 45% more efficiently than PEM and alkaline electrolyzers when combined with external heat. By operating at high temperatures, Bloom's electrolyzer consumes 15% less electricity than other electrolyzer technologies when electricity is the sole input source. This allows for the Bloom Electrolyzer to be deployed across a broad variety of commercial hydrogen applications, using multiple energy sources, including intermittent renewable energy and excess heat at manufacturing facilities and businesses.

Cummins to expand electrolyzer manufacturing footprint to U.S.

Cummins will begin producing electrolyzers in the United States, starting at 500 MW of manufacturing capacity annually, scalable to 1 GW in the future.

The company plans to dedicate 89,000 sq. ft. of its existing Fridley facility to electrolyzer production. Initially, the facility will manufacture its HyLYZER®-500 and HyLYZER®-5000 PEM electrolyzers there, with the potential to manufacture other electrolyzer products in the future. This range of products can accommodate power needs from 1.25 MW to more than 200 MW for both small- and large-scale hydrogen generation projects.

This new production space in Fridley, Minnesota, adds to the company's growing global electrolyzer development and manufacturing footprint. Cummins recently announced expansion of PEM electrolyzer manufacturing capacity at its Belgium factory to 1 GW and has added space to its Mississauga, Canada, site. Cummins is also building two new electrolyzer factories in Spain and China, each starting at 500 MW of manufacturing capacity and scalable to 1 GW.

Nel and GM join forces on cost-competitive green H2 production

Nel Hydrogen US has entered into a joint development agreement with General Motors (GM) to help accelerate the industrialisation of its PEM electrolyser platform.

Nel was the first company in the world with a fully automated alkaline electrolyser production line. The next step will be to industrialise the production of its PEM electrolyser equipment in a similar way, which will enable considerable technology advancement.

"An automated production concept is key when scaling up and driving down cost on electrolyser technology. By utilizing the combined expertise of both companies, it will help to more quickly develop a green hydrogen technology that is competitive with fossil fuels," said Håkon Volldal, CEO of Nel.

"Adding Nel as a strategic collaborator is an important step to help us commercialize fuel cell technology," said Charles Freese, GM executive director, Global HYDROTEC. "Electrolysis is key to creating consistent, clean sources of hydrogen to power fuel cells. Nel has some of the most promising electrolyser technology to help develop clean hydrogen infrastructure, and we believe our HYDROTEC fuel cell IP can help them get closer to scale."

Stargate Hydrogen launches next generation of its electrolysers

Stargate Hydrogen has launched its Gateway product family comprising containerised green hydrogen production systems up to 10 MW. By utilising proprietary technology, the Estonian company strives to continuously improve the efficiency and cost-effectiveness of its alkaline electrolysers.

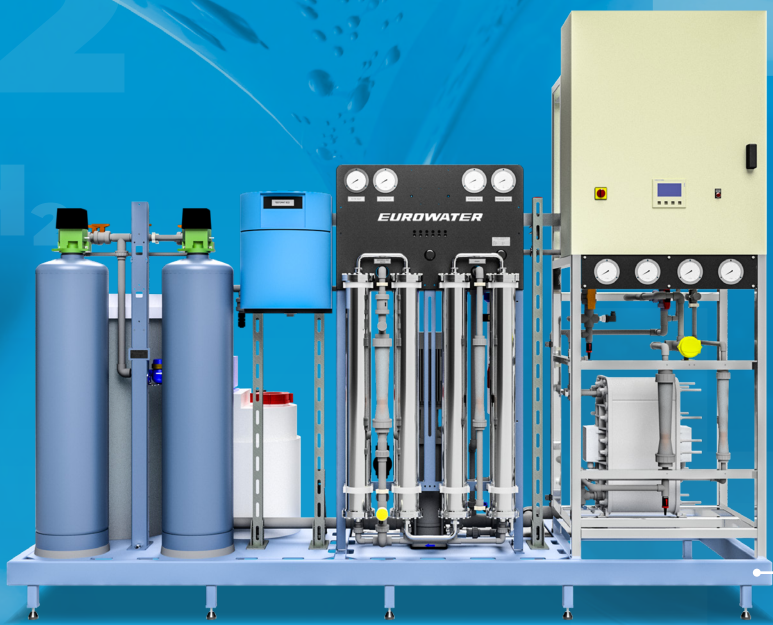
The Gateway series comprises five models with a 30-bar output pressure and system efficiencies of 74.5% (HVV) and 62.9% (LHV). These characteristics reduce both capital and levelized hydrogen costs. The top-end 'Gateway 2000' model has a maximum hydrogen hourly production rate of 2,000 Nm^3/h and a daily production rate of 4,320 kg.

Rainer Küngas, CTO of Stargate, said: "Stargate employs alkaline electrolyser technology: a technology that is commercially proven and reliable, but that has been underdeveloped in the past decades. We believe that there is considerable untapped potential in the alkaline technology, and that alkaline electrolysers are the most viable and affordable solution for decarbonization of the so-called hard-to-abate industries such as ammonia synthesis, refining, glass and paper production."

Water treatment is key

Electrolysers rely heavily on water quality.

A proper water treatment solution is crucial to ensure long-term and problem-free operation.



Frame mounted water treatment plant for a 5 MW PEM electrolyser system.

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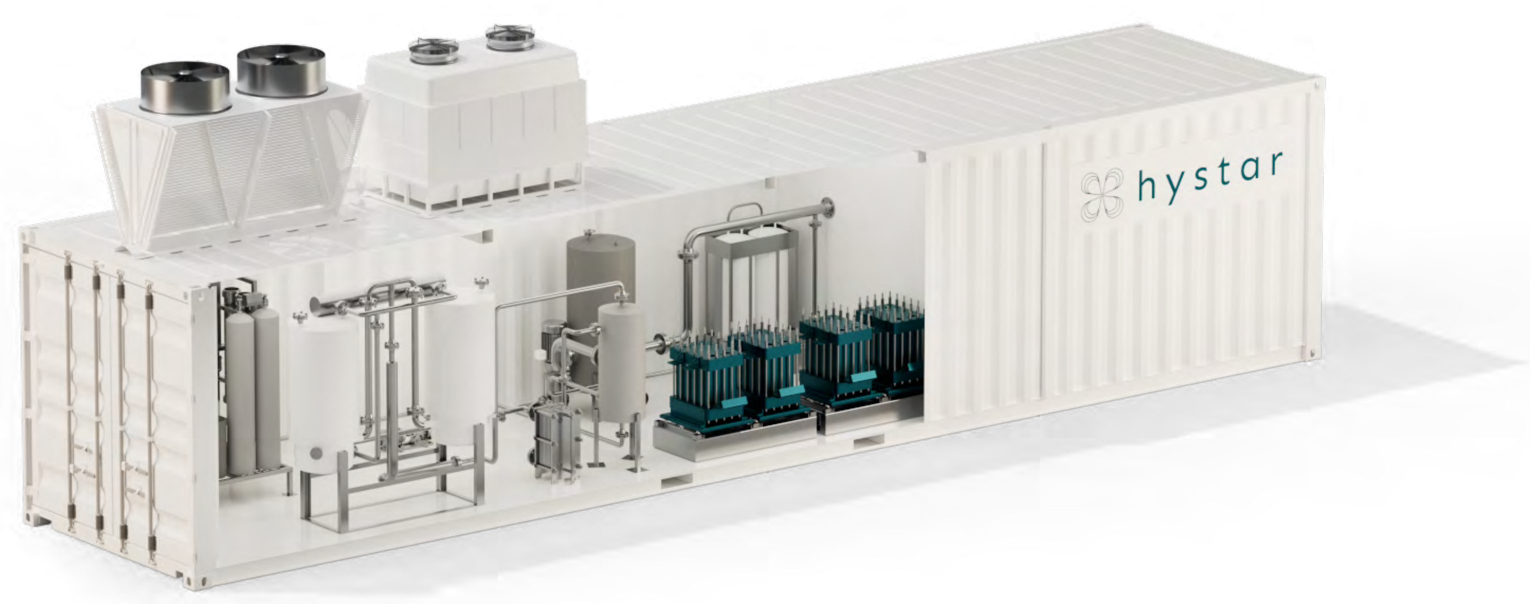


Hystar's containerised electrolyser

Hystar: revolutionising PEM electrolysis

Among the recent entrants to the rapidly expanding universe of electrolyser manufacturers, Hystar is shining particularly brightly. Combining knowledge from the fuel cell industry with electrolyser technology, the Norwegian company claims to have developed the world's most efficient PEM electrolyser. With market-ready solutions, Hystar is now gearing up to fully automate its production process and ramp up production capacity to gigawatt scale.

By Matjaž Matošec

Founded in 2020, Hystar is a young – yet quickly growing – enterprise. As a spin-off from SINTEF, Scandinavia's largest independent research organisation, the company has a background of over 15 years of research into PEM technology, making its patented electrolysis process the fruit of thorough development work and testing. Born out of a desire to facilitate and accelerate the transition to a green future, Hystar has the vision and ambition to become one of the top electrolyser suppliers worldwide, setting new standards in terms of efficiency, scalability, and sustainability. To learn more about their technology and growth plans, we spoke to Jan Schmidt, Hystar's project engineer.

Originally from Austria, Jan forms part of a 30-strong international team based in Høvik, just outside of Oslo. Having previously worked as a fuel cell development engineer for a global technology provider, his main responsibility at Hystar is the development of a modular approach for the company's game-changing electrolyser.

Rethinking the electrolysis process

At the heart of Hystar's patented technology is the operating principle of a PEM electrolyser. Traditionally in PEM electrolysis, water is fed into the anode chamber. By moving the water feed to the cathode side, Hystar has devised a process solution that offers an array of benefits. "If you find this solution simple, this is because it is simple, beautifully so," says Jan.

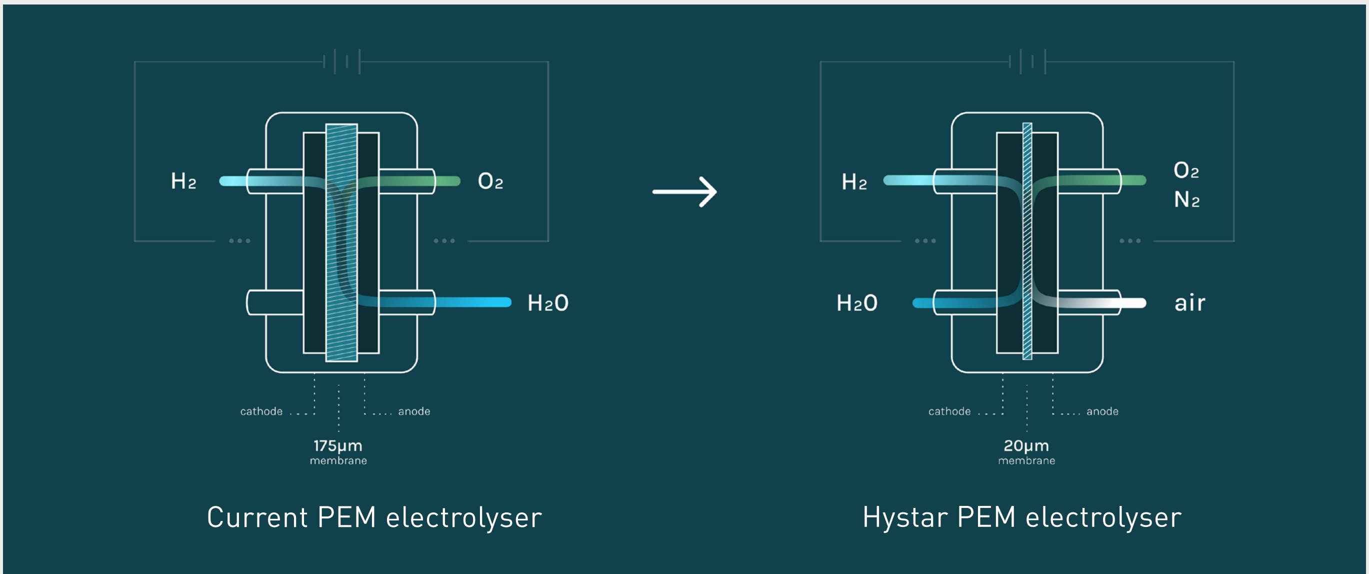
"By changing the point of water supply to the cell, we have created conditions allowing us to reduce the membrane thickness by as much as 90% compared to conventional PEM electrolysers, which is remarkable. Hydrogen crossover to the oxygen-containing anode side is a major concern for all electrolysers, because the combination of the two gasses creates a potentially explosive environment. To prevent this crossover, all other PEM electrolyser manufacturers use a relatively thick membrane. While ensuring safety, however, this has a negative impact on the electrolyser efficiency since a thick membrane creates high electrical resistance. And the higher the resistance across the membrane, the lower the efficiency. Our solution, with a significantly thinner membrane, allows the water to travel from the cathode to the anode side, which creates the necessary conditions for the electrochemical splitting of water into hydrogen and oxygen. And by introducing another unique feature – the blowing of air into the freed-up anode chamber, our patented solution dilutes any crossover hydrogen, thereby eliminating the risk of forming a dangerous gas mixture."

What is more, the ventilation rate can be adjusted, providing additional safety and operational advantages.

"For example, a membrane rupture or stack malfunction would normally trigger an emergency shutdown," explains Jan. "In a Hystar system, however, we can immediately increase the air feed to stabilise the electrolyser and allow it to continue running safely until the malfunctioning component can be replaced."

Scalability

Besides efficiency and safety gains, Hystar's technology provides another crucial advantage: compactness. By using a thinner membrane, Hystar has managed to reduce the size of other system components, making them resemble those originally designed for fuel cells. In doing so, the company can piggyback on the



The operating principle of a conventional (left) and Hystar's (right) PEM electrolyser development work done by the fuel cell industry as well as rely on its existing manufacturing capabilities.

"Our stack is designed and optimised for mass production," explains Jan. "All our components are designed and developed in-house, in close collaboration with our high-quality suppliers around the globe."

In an ambitious plan to have a fully automated, gigawatt-scale assembly line in place by 2025, the company has launched a project aimed at developing the best approach to scalable, flexible, and quality-focused stack production. Dubbed 'Autostack,' the project gathers Hystar engineers and experts from three external partners. Semcon brings valuable experience from fuel cell design and manufacturing, Tronrud Engineering brings know-how in advanced engineering, while SINTEF Digital brings a holistic approach to the project, looking at the entirety of the supply chain and bringing expertise on modern manufacturing in high-cost countries.

"Our stack is designed and optimised for mass production."


Jan Schmidt, project engineer at Hystar

Containerised electrolyser

Despite being founded just over two years ago, Hystar is already taking orders from customers for its containerised, turnkey electrolyser solution, which is available in two main variants – Vega and Mira. Optimised for high efficiency, Vega has been designed for systems associated with high electricity consumption and costs, such as those found in heavy industry. By contrast, Mira is ideally suited for systems powered by intermittent energy sources and for customers looking to reduce capital investment costs compared to conventional PEM electrolysers. Both variants are available in the 1–6 MW range, with a lead time of 12–18 months.

In March 2022, the company, in partnership with Equinor and Gassco, launched a three-year project focused on gaining operational experience. In September, the HyPilot project was joined by another partner, Yara Clean Ammonia, the world's largest ammonia distributor. As part of the project, Hystar will design and construct a containerised 1 MW electrolyser with a hydrogen production capacity of up to 500 kg/day. The electrolyser will be installed at Equinor's K-lab facilities, close to the Gassco-operated Kårstø gas processing plant near Stavanger, Norway, and will run for a total of 10,000 hours, starting at the end of 2023. Being the first in-field installation of Hystar's containerised electrolyser, the HyPilot project will see the system designed to suit variable production loads typically found in wind applications. Less variable production regimes will also be tested to provide data on the performance of Hystar's electrolysers for industrial-scale hydrogen production.

Orion: large-scale, modular solution

Seeing the efforts to decarbonise hard-to-abate sectors as the main drivers of future demand for green hydrogen, Hystar is fully aware that quenching the thirst for hydrogen of industrial customers will require an electrolyser solution that can be easily scalable from 20 MW to 1 GW and beyond. Named Orion and described as a constellation of either Vega or Mira stacks (or a combination of the two), Hystar's modular electrolyser concept provides exactly that.

"Unlike containerised electrolysers, which are standardised, 'plug-and-play' products, so to speak, large-scale plants typically require customised solutions," explains Jan. "To avoid having to design every plant from scratch, we are busy developing a scalable electrolyser concept based on modules that can be multiplied to create a large green hydrogen plant of virtually any capacity. In an ideal world, we would be able to build large-scale electrolysers just like any Lego structure, so adding a given number of standardised building blocks, or modules, to reach the desired plant capacity and specifications. This is the idea behind the Orion concept: building large facilities using multiple stack modules and just one balance of plant. By achieving this, we will

be able to reduce production costs, improve the quality of the product and shorten lead times because there will be no need to re-engineer again and again."

Sustainability

Along with efficiency and scalability, sustainability is at the heart of Hystar's endeavours, playing a key role not only in supplier management, but also process development. Committed to a circular economy and aware of the scarcity of catalytic materials used in PEM electrolysers, the company is determined to facilitate their reuse in every

> *"Everything we do is done with sustainability in mind."*

possible way they can. Jan elaborates: "Everything we do is done with sustainability in mind. As part of the Autostack project, for example, we are looking at how to design and build our stack in such a way that after the end of the product's lifetime, all its recyclable parts can be recycled as easily as possible. In addition, we are exploring different options to reacquire end-of-life products from our customers as well as engaging with industry partners about the best recycling routes."

"Reaching for the stars, we believe in a bright future – for Hystar and our planet," concludes Jan.

What's in the name and logo?

The company name – Hystar – is inspired by the abundance of hydrogen in the universe. With the lightest of all elements being the main constituent of stars, the future of green hydrogen is seen by Hystar as being written in the stars.

The shape of the logo is inspired by a hydrogen density plot that represents how the electron of a hydrogen atom moves in orbit, capturing the dynamic and vibrant character of Hystar. Additionally, the logo has strong references to water, as the thin lines add a dynamic feeling, giving associations to water ripples, and each 'petal' (orbital) resembles the shape of a water droplet. The logo can also be seen as an 'H' for Hystar, or even as a clover leaf, representing sustainability.

Platinum group metals: an enabler for hydrogen, not a barrier

Proton exchange membrane (PEM) electrolysers and PEM fuel cells rely on platinum group metal (PGM) catalysts, notably platinum and iridium. Many see this as a challenge, given the rarity and value of the PGMs. In fact, if used efficiently, these metals will actually facilitate the development of a resilient supply chain. To understand why this is, let's look at the PGM landscape and the implications for PEM technologies in more detail.

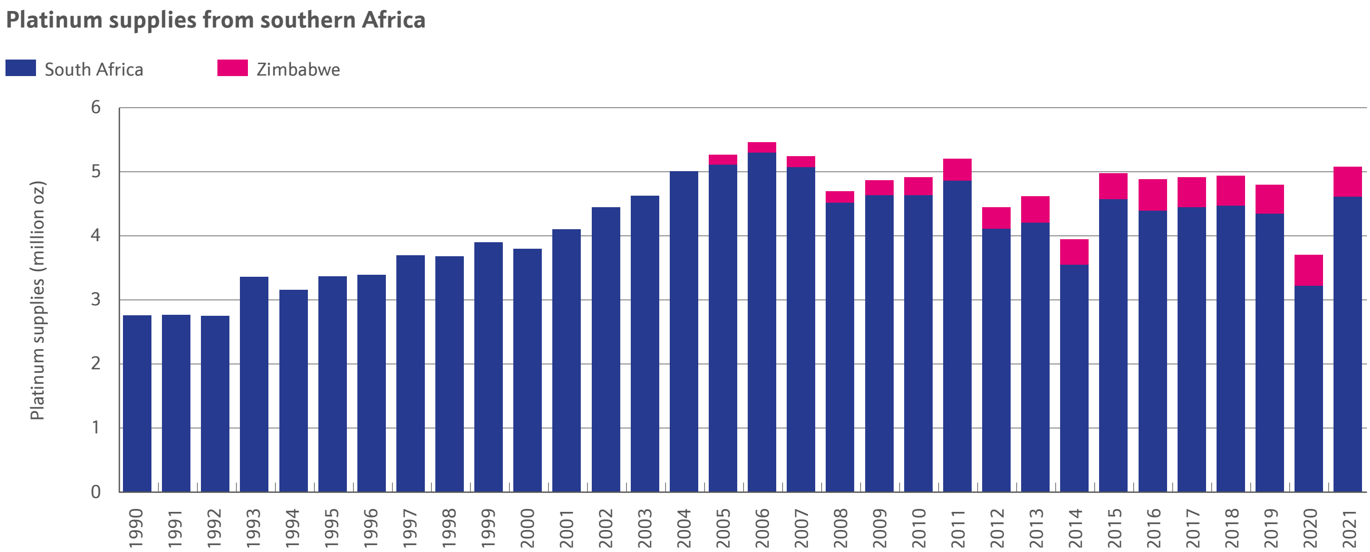
By Margery Ryan, Principal Strategy Analyst for PGM, Johnson Matthey

Established mining operations – extensive reserves

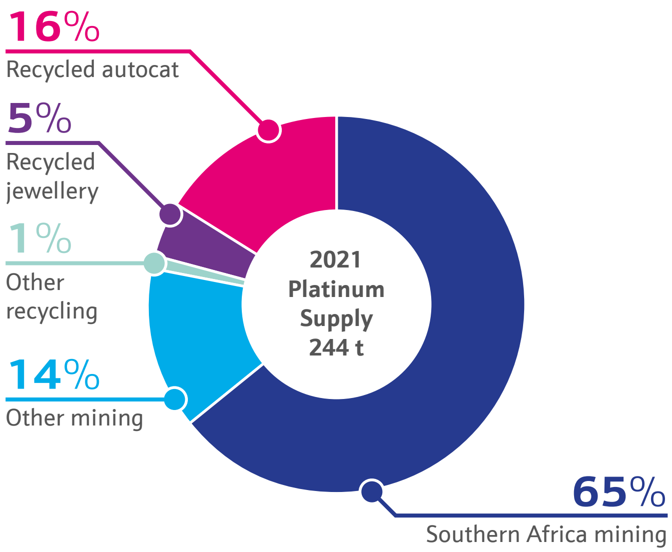
What is the platinum group? It is a set of six precious metals – platinum, palladium, rhodium, ruthenium, iridium and osmium – that are close together on the periodic table and have a unique combination of useful properties that make them indispensable in their applications. They also occur in association with each other in mineral deposits. Most PGM mining occurs in its own right, although some PGM is also extracted as a by-product of mining for other metals (notably nickel and copper in Canada and Russia).

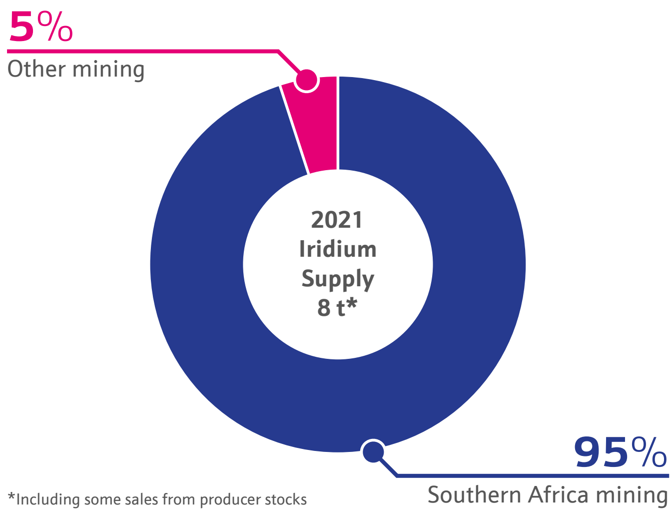
PGM mining is heavily concentrated in southern Africa, targeting igneous deposits in South Africa and Zimbabwe that were formed two billion years ago by huge intrusions of magma from the Earth's mantle that solidified below the Earth's surface. These deposits are unique in their size, extending over 66,000 km^2 (an area equivalent to Sri Lanka), and in the quantity of PGMs they contain.

Around 80% of the 190 tonnes (approximately) of primary platinum extracted every year comes from southern Africa. At the other end of the scale, 7 to 8 tonnes of iridium are mined every year, mainly as a minor by-product of platinum mining, and up to 95% of annual iridium extraction occurs in southern Africa. On the face of it, this could look like a geopolitical risk. But let's dig a little deeper.



Resilient mine supplies from southern Africa since 1990 (matthey.com/pgm-demand-history)





Platinum and iridium total supply (primary and secondary) in 2021 (matthey.com/pgm-market-report-2022)

PGM mining and refining is complex and technically challenging, so the sector is populated by several large, publicly quoted mining companies who are subject to stringent mining and labour regulation, rather than 'artisanal' mining. These well-established companies report annually on their production plus environmental, social and governance (ESG) performance. While the wider operating environment in South Africa and Zimbabwe has frequently been challenging, and risks remain as they do for mining operations anywhere, output from these operations has been remarkably resilient. At a political level, South Africa and Zimbabwe both recognise the enormous economic benefit of their PGM mining operations.

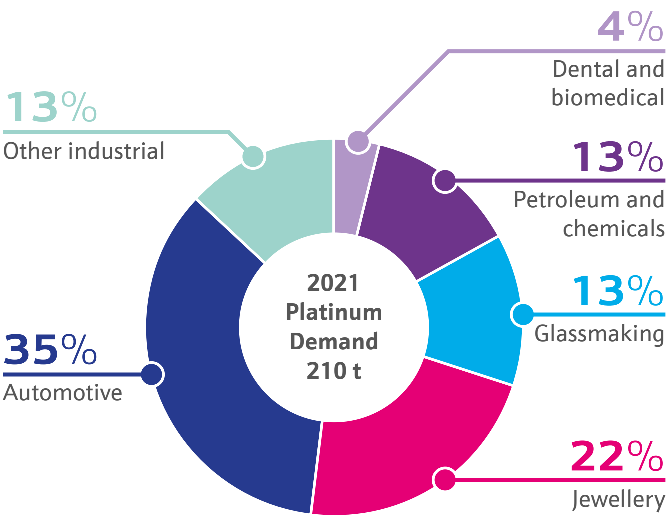
Thanks to the size of these deposits, and the vast quantities of PGMs they are estimated to host, we can be confident that enough PGM can be extracted to meet global needs for decades to come – although further investment will be needed to maintain and expand output. As the primary product of this mining, platinum's central role in hydrogen technologies will be an important incentive for investment. And a strong business case for continued investment in platinum helps deliver a healthy supply of iridium.

Recycling is a given for PGMs

PGM recycling happens routinely. Johnson Matthey was a pioneer in PGM recycling and is the largest global secondary refiner by volume of these metals today. Other companies also operate large secondary PGM refineries across the world that process substantial volumes of scrap material. The largest source of recycled metal returned to the market every year (known as secondary supply) is catalytic converters, recovered from scrapped diesel and gasoline vehicles. Collection and processing of these parts can be encouraged by recycling mandates but is primarily incentivised by the value of the PGMs they contain.

Already nearly a quarter of platinum supplied to the market every year is recycled metal. But even that is not the whole story: significant PGM recycling also happens in what we call 'closed loop'. This is metal that is recovered from end-of-life products, processed, but then returned to the original owner for reuse in the same application, for example in PGM-based process catalysts. This closed-loop recycling considerably reduces the ongoing requirement for primary (mined) metal in a wide range of industrial applications.

This is particularly important for iridium, because the recyclability of iridium is often raised as a challenge. In fact, substantial quantities of iridium



Platinum demand by application in 2021

are circulating constantly in closed loop, generally unseen by the market (Johnson Matthey does not report closed-loop recycling in its supply and demand figures). Johnson Matthey and others have established efficient processes for recycling iridium. Although investment continues to optimise these processes, iridium in PEM components can be recycled today.

This points to two important advantages in using PGM: the first is that PGM recycling is value driven. The second is that PGM used in hydrogen technologies remains an asset that will be recovered and reused as much as possible. As with other industrial applications to date, we expect to see an inventory of recycled PGM building up within the hydrogen industry over the longer term.

Platinum is ready for a new market

When looking at any commodity, it is important to understand the balance between supply and demand. Platinum is currently in industrial oversupply: more of the metal is put on to the market every year than industrial users require. The 'grouped' nature of PGM mining explains this: in today's market, palladium and rhodium, which are by-products of platinum mining, are undersupplied and in high demand by the automotive industry for catalytic converters.

Therefore, it would not make sense to mine less platinum, because this would then also produce less palladium and rhodium.

The single biggest use of platinum today is in automotive emissions control catalysts, although platinum is much less dominated by automotive consumption than palladium and rhodium. But in the long term, this market will decline as the internal combustion engine is eventually phased out.

Platinum's second largest market – jewellery – has been in decline for some years. The largest regional market for platinum jewellery is China and consumer spending patterns have shifted in that market. Globally, we expect almost 30 tonnes less platinum will be used in jewellery this year than in 2017.

Hydrogen technologies will therefore be replacing some of platinum's older markets. Contrast this to the situation in the battery sector where users of metals such as lithium and nickel face stiff competition for supply, which has to expand dramatically amid sharply rising demand.

Minimising mineral intensity

That said, platinum is still a valuable and limited resource, and must be used efficiently. Considerable reductions to the intensity of platinum use in fuel cells have already been achieved through innovation, to around 30 g per vehicle (without compromising performance), and this 'thrifting' continues. It's a familiar progression in the PGM industry: for example, the reliance of automotive emissions control on PGM has only been sustainable because of increasingly efficient metal use.

Only a few grams of PGM are needed to treat the pollutants in a gasoline vehicle's exhaust to meet the stringent standards required today, and only a few grams will be needed to catalyse the fuel cell vehicles of the future.

Iridium: small but mighty

For PEM electrolysers the key metal is iridium. PEM electrolysers use iridium at the anode and platinum at the cathode, which are typically printed as catalyst-containing 'inks' in a thin layer applied to the proton-exchange membrane. This forms a catalyst coated membrane (CCM), which splits water into oxygen and hydrogen under an electric current, with a semi-permeable membrane that allows proton exchange. Seals are applied and the CCM is then sandwiched between gas diffusion layers to allow the gases to move to and from the active layers, forming a cell. A number of these cells connected in series then forms the heart of the electrolyser stack.

Platinum and iridium are ideal catalysts for PEM electrolysis due to their high activity levels and inherent stability in the electrolyser system – there are no known suitable substitutes that work as effectively in the high-voltage, acidic conditions of a PEM cell. Platinum is used at a low loading already in CCMs, but current iridium usage for every kilo of hydrogen produced presents a significant opportunity for optimisation.

While platinum is targeted as one of the major products of mining operations, iridium occurs in such small quantities that nobody goes after it in its own right: it gets a free ride to the surface on the back of platinum.

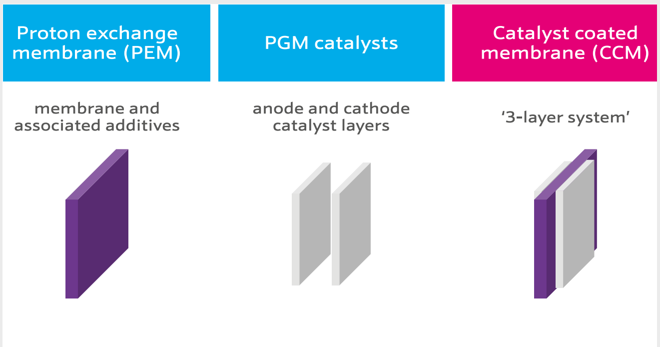


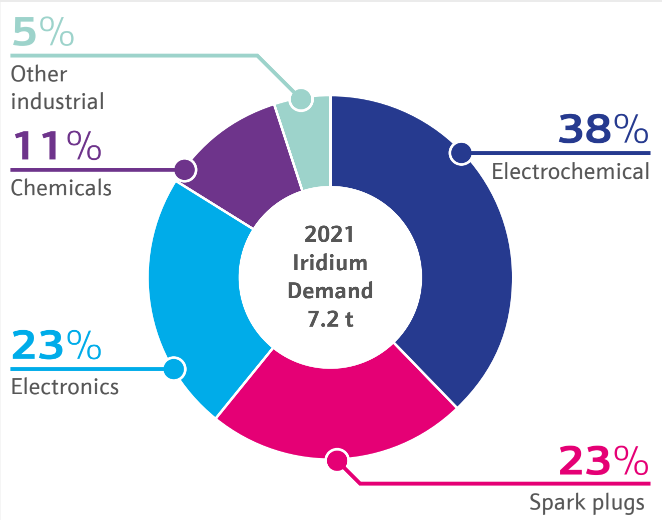
Diagram of the catalyst coated membrane (CCM) and PGM use within it

Minor in quantity it may be, but iridium is a very useful industrial metal. Its electrochemical power is harnessed not just in PEM electrolysis, but also in the chlor-alkali industry, in the production of copper foil by electrodeposition, and in other applications. As a chemical catalyst, it is often used to produce acetic acid. In electronics, it is used in OLEDs and as solid iridium crucibles to 'grow' crystals that are used as filters in our mobile phones. But it is probably most familiar as the ignition tips in long-life spark plugs for our cars.

Currently the iridium market is balanced, in that all metal produced by the mines each year is used by these various applications (2021 was unusual: demand was still recovering from Covid, and some of the miners sold additional metal from stocks). With new applications such as PEM electrolysis expected to see growing demand, demand reduction in other areas will occur in response, through a mixture of technological innovations that allow switching to substitutes, increased efficiency and therefore thrifting, or increased recycling.

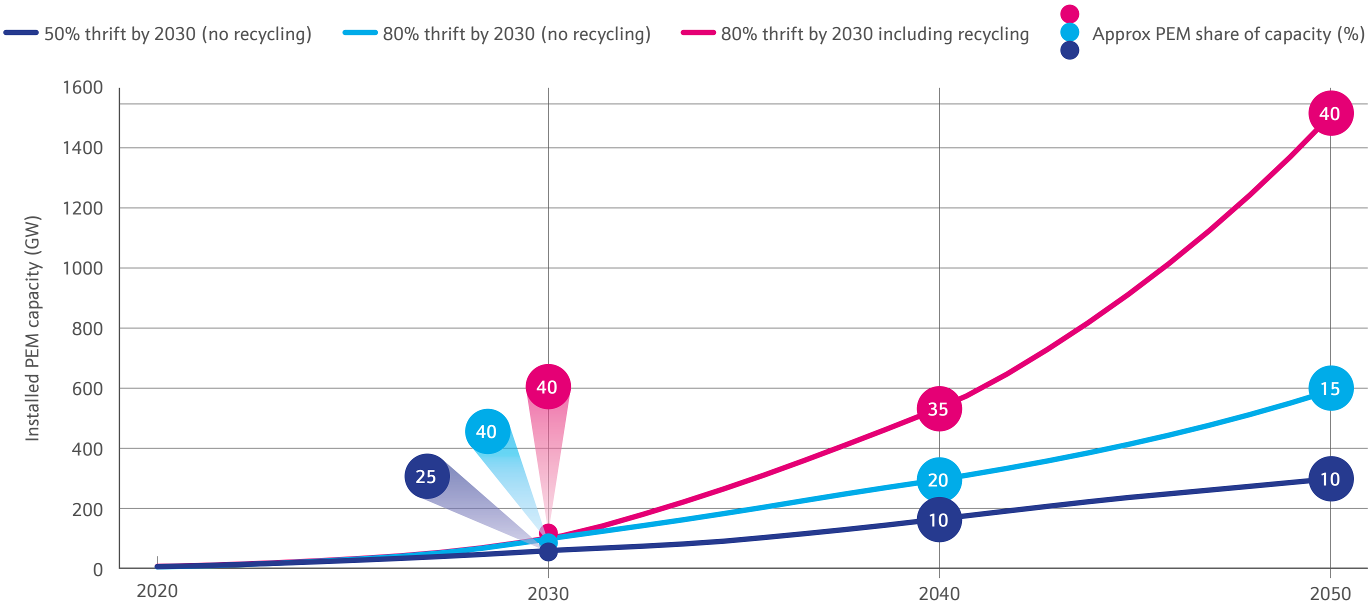
Solving the iridium challenge

So, the key question: will there be enough iridium available for PEM electrolysis capacity to grow as



Iridium demand by application in 2021

The impact of thrifting and recycling on PEM capacity, based on 1.5 tonnes p.a. iridium supply



Source: Hydrogen Council, JM analysis

Projected cumulative PEM capacity with consumption limited to 1.5 tonnes of primary iridium per year, using the Hydrogen Council 1.5°C scenario

hoped? The answer is yes – if we maximise the efficiency with which we use the metal, and if we recycle.

To illustrate the power of these two drivers, let's look at a theoretical case where just 1.5 tonnes per year of iridium is available to be used in PEM electrolysis (this is only around 20% of annual mined production, so a realistic assumption). How much PEM capacity could we build up within that constraint?

Today's technology uses around 400 kg per gigawatt of PEM capacity, so 1.5 tonnes doesn't buy you a lot of gigawatts. The blue lines on the chart show the impact of progressive thrifting: reduce the metal per gigawatt by 80% by 2030 and you can build 60% more capacity than if you only halve your metal requirement by 2030 (and our projection assumes continued thrifting to 2050). Add recycling to that, with an assumption that it happens in 'closed loop', so the iridium is retained within this industry, and we see a growth curve that gives over 2.5 times more capacity by 2050 than with thrifting alone.

In this exercise, even within an applied constraint of just 1.5 tonnes per year of primary iridium and using an ambitious scenario for hydrogen uptake, PEM can take market share of 40%, and achieve an installed capacity of over 1,000 GW by 2050 (based on the Hydrogen Council scenario and JM analysis).

There is one more thing to say about efficiency. Formulating more effective catalysts, more efficient membranes, and tuning the way they are assembled into catalyst coated membranes (CCMs) will increase overall system performance, so that not only will less iridium be used per gigawatt, but each gigawatt will be able to produce more hydrogen, boosting the efficiency of our raw materials use even more.

PGM for resilient supply chains

This is the power of the PGMs: they need only be used in small quantities to deliver a powerful technological impact. They are precious metals, and their price reflects that, but it is exactly this value that ensures they are used efficiently and are recycled. Circularity and minimised mineral intensity – or 'reduce, reuse, recycle' – are well known concepts in the PGM industry.

Added to that, supply chains that are based on PGMs rather than on base metals face different dynamics, e.g., from those experienced in the battery industry, and those dynamics support the use of PGMs in hydrogen technologies.

We know these aims can be achieved. Johnson Matthey has a long track record in PGM thrifting and in catalyst technology, and this know-how is being brought to bear on the components we produce for fuel cells and electrolysers. We can support our customers throughout the electrolyser product lifecycle, beyond system design and manufacture, offering deep understanding of the PGM markets, PGM supply and management, and a full recycling solution.

The hydrogen industry faces many challenges as it scales up and becomes an essential part of the energy transition, but concerns that platinum group metals are a barrier are misplaced. If we use them well, they can help to enable hydrogen energy.

About Johnson Matthey

Johnson Matthey (JM) is a 205-year-old British company that has become a global leader in sustainable technologies, with a vision to make the world cleaner and healthier, today and for future generations. Today, JM is applying its unique expertise in platinum group metals, complex chemistry, catalysis, and process engineering to catalyse the net-zero transition, and through the development of new solutions is supporting the emerging hydrogen economy. Underpinning this is its expert team of PGM market researchers and analysts, giving unique and informed insights on key issues in PGMs and how the markets are likely to develop.

Artist's impression of the VoltH2 electrolyser project in Vlissingen, the Netherlands, planned to become operational in 2025

Hydrogen development is crucial for storage and transportation of renewables

Two major challenges are hiding behind the investments in green energy production. They arise from the fact that (variable) renewables are often produced at the wrong time and place. Therefore, the development of both storage and transportation capacity is crucial. Sweco shares lessons learned from the first large-scale project developments with VoltH2.

By Bert van Renselaar, Business Director Energy Transition, Sweco

On the shores of the Western Scheldt, one of four major port areas in the Netherlands, the first large-scale electrolyser projects in the Benelux are being developed. On behalf of green hydrogen developer VoltH2, Sweco has designed and permitted two 25 MW electrolyser projects in Vlissingen and Terneuzen. At the two planned hydrogen production plants, green hydrogen will be generated with electricity from offshore wind energy and supplied to local filling stations via the integration of hydrogen storage. Due to its design, the green hydrogen factories will be expandable to 100 MW, with a potential production of approximately 15 million kg of green hydrogen per year.

In this article the lessons learned from the first projects are shared on design, permitting and project development. The projects designed by Sweco are characterized by their complex situations, in which the electrolysers are connected to other assets like solar farms or small heat plants.

Design – improving the business case

The design of hydrogen production installations starts with the idea for a total concept. Because the business case for hydrogen is still difficult to calculate, it is important to find as many sources of income as possible. The options discussed below sometimes turned out to be possible and sometimes not.

Grid congestion

Storing energy in hydrogen is particularly interesting from a development perspective if the electricity production cannot be connected to the grid. The electricity grid is overloaded in many places. There is insufficient grid capacity available in various places in the Netherlands, which means that new solar energy projects are not always connected immediately. Existing solar energy projects can also suffer from this. The transmission system operator (TSO) as well as the local distribution system operators (DSOs) are working hard to improve and upgrade the electricity grid. Yet many initiators of solar energy projects will not receive a (full) grid connection in the coming years. They have to wait even longer for that. In such cases, the production of hydrogen can be interesting to facilitate the construction of the solar park. In this way, the business case of solar and hydrogen is combined.

In addition, an electrolyser can also be used to stabilize the grid. A so-called balancing service provider (BSP) offers the grid operator balancing energy and/or balancing power. The grid operator purchases balancing power and activates balancing energy from BSPs to eliminate unforeseen imbalances in the electricity grid. This allows additional income to be generated by turning the electrolyser on or off at desired times. The electrolyser as such becomes a flexible load within the grid.

Heat demand

The efficiency of hydrogen production is a disadvantage, as is the production of electricity with coal or gas-fired power stations. However, the residual heat that is released can be put to good use in local heat networks. This is applied in some projects, provided that there are sufficient heat consumers in the area. With this, the business case can be significantly improved, as well as the sustainability of the project because the excess heat is used efficiently. The disadvantage of many hydrogen production projects is that electrolysers are usually not built next to densely populated areas. As a result, some port areas lack the necessary customers, which means that the heat cannot be used effectively.

Oxygen

In every project designed so far, the business case for using oxygen was hard to make. The market value of oxygen currently barely outweighs the costs that must be incurred to store oxygen that is released.

Permitting – the legal framework

With the ambition of the Dutch government for large amounts of green hydrogen production, a lot of permit applications would be expected. However, since the end of 2021 only the VoltH2 projects have received an environmental and building permit. For the competent authority that needs to assess the permit application this is therefore also relatively new. A 'hydrogen plant' or an 'electrolyser' is not yet imbedded in the current environmental legislation. There is also a small chance that you will encounter these activities in a zoning plan.

Legal framework

In the Netherlands, an establishment for the production of hydrogen is subject to a license. There is a (form-free) environmental impact assessment (EIA) obligation (provided the installation remains below the threshold value). A notification memorandum must be drawn up, on the basis of which the competent authority can determine whether there are (potential) significant adverse environmental consequences. Electrolysers do not fall under the BEVI or BRZO decree. The Provincial Executive is the competent authority. On the basis of Annex I, article 4.2 of the European Industrial Emissions Directive, a hydrogen plant is an IPPC (Integrated Pollution Prevention and Control) installation.

VoltH2 is currently developing three green hydrogen production projects in the Netherlands, to be located in Vlissingen, Terneuzen and Delfzijl, with a combined initial capacity of 100 MW. Sweco is responsible for design and permitting. For project details, visit www.volth2.com/en/.

Permit VoltH2

Looking into the design permit for VoltH2, published on 22 September 2021, the hydrogen plant has hardly any significant environmental impact (other than noise from fans). The license mainly contains the usual provisions. It is striking, however, that PGS 35 (for hydrogen delivery installations) is applied 'analogously' to ensure that the hydrogen storage installation complies with BAT (Best Available Techniques).

No Wnb (Dutch Nature Conservation Act) permit is required. A quantitative risk analysis (QRA) has been made as if it were a BEVI facility. The QRA shows that the 10-6 site-specific risk contour lies outside the establishment. Since hydrogen gas is a combustible gas and production takes place under high pressure, this is not illogical. Safety is of course paramount.

There are no emissions of substances of very high concern. The emission of (in short) particulate matter does not make a significant contribution. The oxygen released during the production of 1,800 tons of hydrogen is 'released' into the atmosphere. It is a pity that no useful application has been found for this. Also, for the released heat no end users seem to be in the picture.

The environmental permit (construction) is tested against the building and usage rules of the zoning plan. If there is a business destination with a 'State of Business List', then the hydrogen plant in principle falls under the category of chemical plants, inorganic substances category 4.2 (standard distance: 300 meters due to noise) or under the category 'other gases factory, explosive', category 5.1 (standard distance: 500 meters due to noise).

Project development – the main risks

Project development is a risky business. For the substantial investments required for hydrogen production, we currently see three main investment risks: increased costs, uncertainty of the business case, and development risks.

Increased costs

Over the last 10 years, costs in the renewable energy sector have been constantly decreasing. However, recent macro-economic shifts and political tensions are causing costs to rise. For the time being, there is no prospect of this changing. Higher prices for products like steel and iridium also make the development of hydrogen production more expensive. For many projects, rising wage costs are also a significant component, driven further by the growing shortage of personnel to carry out the work.

Rising energy costs are a driver for many to quickly switch to alternative energy sources. But not everyone has the capacity to invest, especially now that interest rates are rising and the cost of capital is increasing. Besides being an opportunity, the high costs of fossil energy are therefore also a risk. For some time now, the active policy of many governments has focused on discouraging fossil energy use by setting prices. As a result, fossil energy users have less budget to invest in, for example, PV panels or to convert their installation to use hydrogen as an energy source.

Business case

A second risk concerns the uncertain business case for energy storage. The market needs the right price incentives. At the moment, it can still be the case that charging your car at night is cheaper than during the day, while charging when the sun is shining is the best time for the system. The government needs to play a guiding role here to support the best system solution. There are sufficient policy instruments for the production of sustainable energy, of which the SDE++ is the best known. This provides a guaranteed business case at a time when market prices for renewable energy are too low. No such instrument exists for energy storage, which means that the business case has a greater risk if revenues are disappointing.

The complexity of the energy storage market is also a risk, especially for incoming cash flows, which are difficult to predict. In addition to buying at a low price and selling at a higher price, there are other revenue models. These include reducing grid connections, providing grid balancing or congestion management services, and providing back-up/emergency power services. It is important to stack these models cleverly in order to be able to draw up a balanced business case.

Development risks

Finally, energy storage projects are subject to the 'normal' development risks. These include the risks of whether or not to obtain a permit, but also agreements with energy companies regarding the connection to local energy networks. With regard to the technological risk, investors naturally look at the core technology of the storage method. In the case of hydrogen, this concerns the electrolyser. The preference is usually for proven technology. This does not always benefit the transition because promising new technologies are then applied less quickly and less frequently.

Although not directly related to the technology in question, the risks associated with the construction and/or operation of the storage facility are also important. These are mainly risks related to construction planning and budget control. Ultimately, this risk revolves around the question of whether the frequency of maintenance – and the associated budget – is appropriate to the technological specifications of the storage system. If more maintenance is required due to quality issues, this will have a direct impact on cash flows. The same applies to cost overruns due to insufficient budgets. It is therefore important to have a clear picture of the entire lifecycle of the project and to apply a healthy risk margin in terms of time and money. And it is precisely this aspect that is not always clear with new, unproven technologies. Here too, combining generation and storage forms can offer a solution so that the risk of innovative forms can be covered by proven technologies.

About Sweco

Sweco is a leading European architecture and engineering consultancy. Together with our clients and the collective knowledge of our 18,000 architects, engineers and other specialists, we co-create solutions that address urbanisation, capture the power of digitalisation, and make our societies more sustainable. We offer our clients the combination of global expertise and local understanding of their business and context. Our ambition is to be our clients' most relevant partner and we aim to solve any challenge, no matter the scale or location. Our work with sustainable buildings, efficient infrastructure and access to electricity and clean water promotes sustainable development. In close collaboration with our clients, we conduct more than 100,000 projects every year, and sustainability is at the heart of every single one of them.

Image by Corona Borealis – stock.adobe.com

Electrolyser safety through certification

Electrolysers range from small, appliance-size products to large, multi-megawatt-scale production facilities. In all cases quality and safety must be ensured. One of the major concerns when designing, building, operating or even talking about a hydrogen system is safety. Known for its high flammability range and small molecular size, hydrogen can easily leak, forming an explosive mixture if adequate measures are not taken. Taking adequate measures, however, can be a straightforward process if attention is paid to safety from the design on.

By Rashi Mor and Álvaro Fernandes, Kiwa

To be able to determine whether a design is safe or not, the associated hazards expected during the lifetime of the system should be identified. This is where risk assessment comes into the picture.

Risk assessment

Risk assessment is a process that helps identify hazards and quantify the risks associated with hazards by taking into consideration factors like likelihood and severity. Several methods exist (HAZOP, FMEA, HAZID, QRA, etc.) that can be used to conduct a risk assessment for a given system. The same is applicable to electrolysers. Electrolysers are peculiar systems due to the presence of flammable gases, oxygen and electricity in the vicinity of each other, high-pressure – and possibly high-temperature – operating conditions, and potential release of toxic gases. All these characteristics can result in fatal events if not properly considered. Therefore, in addition to a risk assessment, explosion and fire safety assessment as well as appropriate certification should also be conducted for electrolyser systems.

HAZOP

A Hazards and operability study (HAZOP) is one of the methods widely used by industry for risk assessment. HAZOP provides a structured manner to review the design of the electrolyser system and identify possible hazards that may have been ignored during the general design phase. HAZOP is performed after the first design freeze, i.e., when the first version of the P&ID (piping and instrumentation diagram) is defined, detailing the complete system layout with all existing components. HAZOP is conducted in several sessions where a core team of people with relevant skills brainstorm together. The sessions should be facilitated by a HAZOP moderator experienced with the HAZOP method as well as by a scribe who documents progress. The HAZOP moderator and the scribe need not be aware of the nitty-gritty of the system. Furthermore, the team should consist of engineers involved with the system design and the operator/user if possible.

During HAZOP, a system is divided into several nodes, depending on the complexity of the system, and hazards are identified for individual nodes with the help of standard guide terms and process parameters. For electrolysers, the most commonly used nodes are:

- Anode loop
- Cathode loop
- Coolant loop, if any
- Nitrogen loop, if any
- Gas separators
- External factors such as air intake and exhaust obstructions, rain, etc.

These nodes are just an example, and the actual nodes selection depends highly on the system design and complexity. The first HAZOP study will result in system design changes to eliminate or mitigate the risks identified. A risk assessment should be performed on this revised system again to assess the emergence of new risks resulting from the design change.

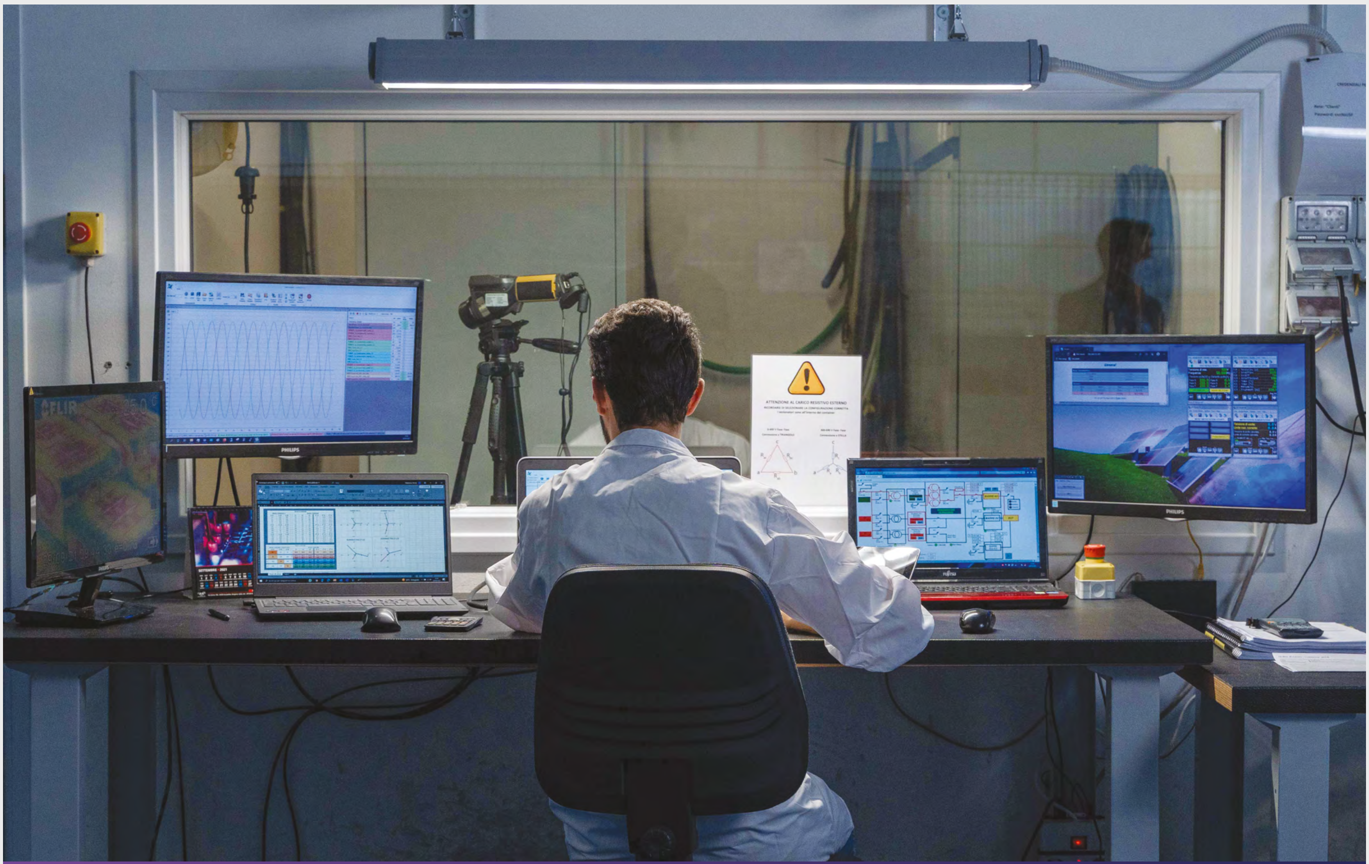
Explosion and fire safety

Combustion requires three elements, commonly shown as the fire triangle: combustible, oxidant and ignition. In an electrolyser, all these three elements exist in close proximity to each other. The first common approach is to avoid ignition sources. This, however, is difficult for hydrogen due to its low ignition energy. A simple static spark is sufficient for ignition of a hydrogen-air mixture. As part of the explosion and fire safety assessment, the system design should be reviewed, also in a team of experienced engineers, to identify potential leak sources (during normal operation as well as failure modes).

Depending on the potential leaks, sufficient ventilation (natural or mechanical) should be sized and installed to dilute the formation of explosive mixture. *EN-IEC 60079-10-1: Classification of areas – explosive gas atmosphere* provides a guideline on identifying and characterising potential leak sources, assessing the ventilation availability and accordingly defining the hazardous areas in the installation area. It is not always possible to eliminate the risk of explosion, especially in electrolysers.

A few common practices are suggested to be adopted for electrolysers to reduce the risk of explosion:

1. Divide the system into two sections separated by a gas-tight wall – one section contains all the hydrogen-related equipment whereas the other container contains the electrical parts and control system.
2. Install hydrogen-detecting equipment at the highest possible point in the system – at a location where the chances of hydrogen leakage and accumulation are highest. Programme this detection equipment to provide an alarm at 10% LEL and automatically shut down the system at 25% LEL detection.



Testing for certification and quality assurance at one of Kiwa's testing facilities

3. All electrical equipment should be grounded.
4. All metallic parts should be at ground potential.
5. Explosion relief panels can be installed for safe venting of explosion pressure.
6. The outlet from relief valves or purge lines should be at the top-most location and about 4–5 m above ground level. The outlets of hydrogen and oxygen should be as far from each other as possible.

Certification

Any product to be commercialised needs to comply with regulations or directives of the target market. These requirements are, however, limited to generally described fundamental objectives (termed 'essential requirements').

It is the manufacturer's responsibility to demonstrate that its product complies with these requirements according to the current state of technology ('state of the art'). The manufacturer retains the freedom to choose how it determines the technical criteria required to demonstrate compliance. It is assumed that the current state of technology is reflected in the relevant European and/or international standards.

By affixing the market symbol (CE for the EU market) to the product and issuing the product certificate, the manufacturer indicates the 'presumption of conformity' of its product with relevant regulations and directives.

Electrolysers are not an exception and need to comply with certain regulations and directives, commonly PED (Pressure Equipment Directive), MD (Machinery Directive), EMCD (Electromagnetic Compatibility Directive) and others for the EU market. Although the declaration of compliance with most of the directives can be a self-declaration act by the manufacturer, for some particular directives, such as PED and ATEX, the assessment of the safety and issue of a certificate shall be performed by a legally appointed notified body (so-called NoBo) to the manufacturer. The certificate is then linked to the manufacturer's certificate.

The process of certification usually follows four steps: the pre-assessment, constructional review, field-test testing and field-test certification (optional), and full compliance testing and certification. Field-test testing and certification is used if the electrolyser is not fully compliant with relevant standards at the end of the second step.

The objective of the first step is to assess the safety of the electrolyser design by identifying the possible hazards present in all stages of the lifetime of the electrolyser, such as operation, transportation, handling, maintenance, and misuse, among others. The main outcome is to propose design changes to eliminate or mitigate the risks presented by the hazards either by implementing good practice design solutions and/or safeguards. This is an interactive step where a number of sessions are conducted between the certification assessors and the manufacturer designers. It ends when the design has adequate safety implementation. At the end of this step, the design of the electrolyser and the HAZOP document are frozen.

Then the second step is followed and the list of components and their documentation/certificates shall be available. The design of the electrolyser is verified if it meets the requirements of the relevant standards and a test program is identified. The test program includes the testing of the product according to the type tests listed in the product, electrical, functional and EMC standards. Additional tests might be required for components that are not compliant with the relevant standards.

The optional step of field-test testing and certification allows the manufacturer to deploy a limited number of electrolyser systems in the field for a defined period. In this period, the manufacturer can then develop and implement the required changes. It requires a limited/partial test program that shall be performed in ISO 17025 accredited labs or, alternatively, at the manufacturer's premises with ISO 17025 calibrated measuring instrumentation and witnessed by experienced test engineers. Test reports and a certificate are issued and valid for a defined period.

The final step of full-compliance testing and certification aims to conclude the test program defined in the second step. The tests shall be performed as mentioned in the previous paragraph. The passing of the tests will indicate that the electrolyser complies with the relevant directives and regulations. This needs to be documented and can be used to prove that the manufacturer satisfied the essential requirements to show that the product is safe. Only at this stage the product can be commercialised without limitations.

Ensuring confidence through quality and safety

At Kiwa, we have experience with a broad range of electrolyser technologies, and we help our clients with risk assessment – and management – of components, products and systems, their certification, as well as operational and functional evaluations. We also assist our clients in the purchasing, manufacturing, installation and commissioning of electrolysis plants, helping to ensure both their safety and quality.

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Is recycling a shortcut for hydrogen technologies?

The first recorded instance of recycling can be dated to nearly 1,000 years ago, with ancient cultures using recycling even much earlier – mainly due to lack of resources and lengthy manufacturing processes. Nowadays, the same arguments apply, plus additional urgent considerations on the environment. Recycling is crucial for polymer fuel cells and electrolyzers, which are key elements in the hydrogen economy.

By Shuang Ma Andersen, Principal Investigator, University of Southern Denmark

Platinum group metals (PGMs)

The platinum group metals or PGMs are a cluster of six transition metals on the periodic table (Figure 1). They are noble and precious metals with chemical and physical properties similar to those of platinum and occurring in the same ore deposits. The PGMs are among the rarest elements in the Earth's crust,[1] with over 88% of world reserves located in Southern Africa and Russia. They are durable, highly valuable and classified as Critical Raw Material (CRM) by the EU.[2] They play a vital role in modern industry, with a dominating market demand (71.2%) from autocatalysts.[3]

PGMs in renewable energy

As the central component of proton exchange membrane (PEM) fuel cells (FCs) and electrolyzer cells (ECs), PGM nanoparticles

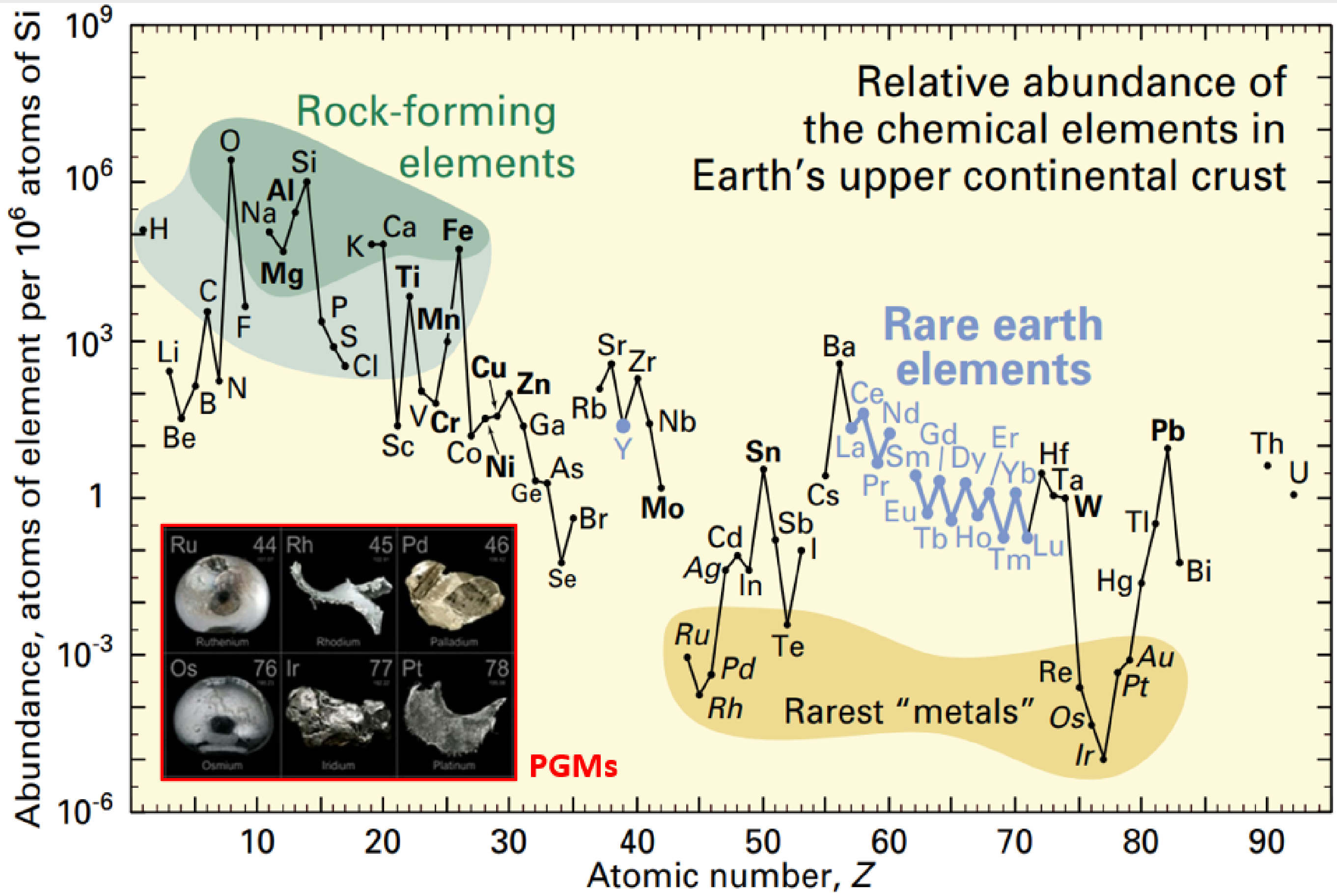

Fig. 1. Abundance of elements including platinum group metals (PGMs) in Earth's upper continental crust

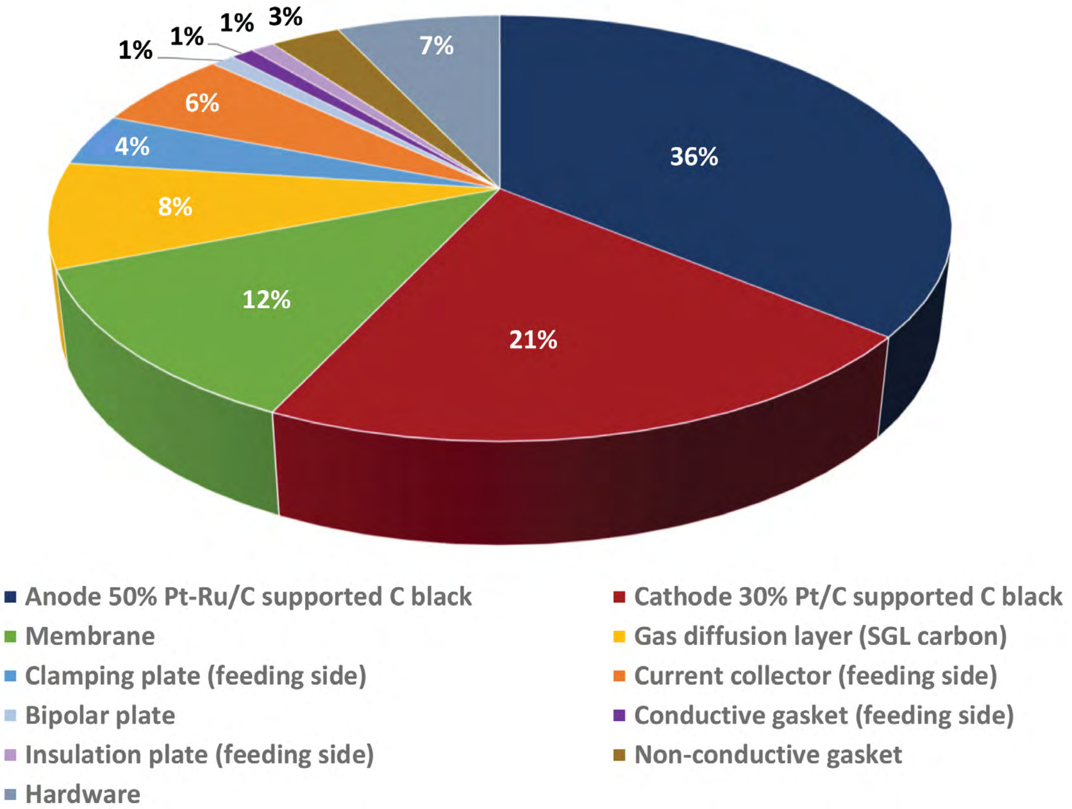

Fig. 2. Cost breakdown in percentage for a PEM fuel cell (single-stack components) in mass production (10,000 units per year)

are the state-of-the-art electrocatalysts. Depending on the exact type of PEM system, customer demands, and scalability of the production process, the PGM component typically contributes 30–60% of the total membrane electrode assembly (MEA) cost (Figure 2).[4]

Based on the power generation from one gram of PGMs (U.S. DOE 2017 record) of 8.75 kW/g, around 289 tons of PGMs are required to meet the total annual electricity demand.[5] This accounts for nearly half of the total global annual PGM consumption. Such demand is unrealistic to keep up with the expansion of the renewable energy market, increasing electricity demand, depletion of mineral reserves and rising market price of the elements, UNLESS contribution from a secondary resource – recycling – is considered.

Rich PGM content (mainly platinum, ruthenium and iridium) in MEA of PEMFCs & ECs presents a high-quality, high-concentration PGM resource, which is around 10 times that of autocatalyst and 1,000 times that of primary ore.[6] Moreover, large-scale deployment of PEMFCs & ECs will accelerate in the coming years.

Current PGM recycling technology

State-of-the-art technology for autocatalyst recycling involves a pyrometallurgical process (Figure 3) operating at temperatures over 1,500°C, followed by a series of refinery steps.[7] After nearly 50 years of operation, the route is well established and efficient. However, the technology is used by very few specialized industrial cooperations. Moreover, huge energy consumption, large initial investment, high requirement for operation and maintenance, long processing/queuing period, and health and environmental risks due to off-gas are major concerns and strong motivations for improvements or alternative technologies.

Fig 3. Pyrometallurgical processing of PGM-containing materials

The greatest drawback is the fact that the current recycling process with high-temperature thermal treatment CANNOT be applied to PEM components, due to emission of notorious fluoro compounds. Moreover, the value of the polymer component can never be regained.

Fluoropolymers in MEA

A typical MEA has 25–50% by weight composition of fluoropolymer (Figure 4).[8] Fluoropolymers are (1) an excellent proton exchange polymer, perfluorinated sulfonic acid (PFSA), used as electrolyte (function of proton conduction, electron insulation, preventing gas permeation, high chemical and mechanical stability, etc.) and ionomer in the catalyst layer (to expand the reaction zone); and (2) hydrophobic agents, polytetrafluoroethylene (PTFE, or Teflon™) in the catalyst layer, microporous layer and gas diffusion layer for water management. This also means that even if the membrane itself is separated or replaced by a hydrocarbon-type polymer, the remaining electrodes would still represent a large carrier of fluorine.

Severe emission from incineration of fluoropolymer has been well documented[9] by several groups. Gaseous fluoro compounds, generated from the burning of MEAs, have a global warming potential (GWP) of 10,000 to 22,000 times that of CO_2, which aggressively promotes the greenhouse effect.

MEA recycling using pyrometallurgy

Since PGMs from spent MEAs are still a very small stream of the secondary PGM resource, the current recycling process relies on the existing PGM recycling infrastructure based on pyrometallurgical processes. This involves incineration of the entire MEA as a way to separate the PGMs from fluoropolymers and other MEA constituents. PFSA polymer itself is expensive to produce, and incineration not only causes the loss of the inherent value of the PFSA polymer component, but also generates severe environmental burdens as toxic hydrofluoric fumes are released in the process. A major concern is the formation of hydrogen fluoride (HF), a toxic compound that is both harmful to human health and highly corrosive. The application of the pyrometallurgical procedures therefore requires special protective linings for the furnaces as well as elaborate scrubbing systems to eliminate HF from the emission.[10] Despite such investments, any fluorine constituents remaining in the PGM-containing slag could hamper the subsequent separation. In addition, through incineration the valuable PFSA material is essentially destroyed and cannot be recycled. Therefore, with the rapidly increasing feed of spent MEAs, the traditional pyrometallurgical recycling method will not be feasible.

MEA recycling using classic hydrometallurgy

Internationally, many groups have expressed interest in MEA recycling, and a number of procedures for recovering PGMs from end-of-life fuel cells with high efficiencies and under the premise of avoiding HF emissions have been reported. It must be stressed, however, that none of these procedures has been implemented on an industrial scale so far. The most common technique is leaching of the individual PGMs by hydrometallurgy. However, as PGMs have very noble characteristics, their resistance to dissolution is also quite high. Consequently, strong acids in combination with strong oxidants[11] are required in the leaching process, leading to the formation of soluble PGM complexes. In addition, platinum dissolution and mineral extraction were also studied using ionic liquids and deep eutectic solvents[12,13], which showed high extraction efficiency. However, their large-scale implementation is undesirable due to the corrosive or high-cost chemicals involved in the process and due to related emission issues.

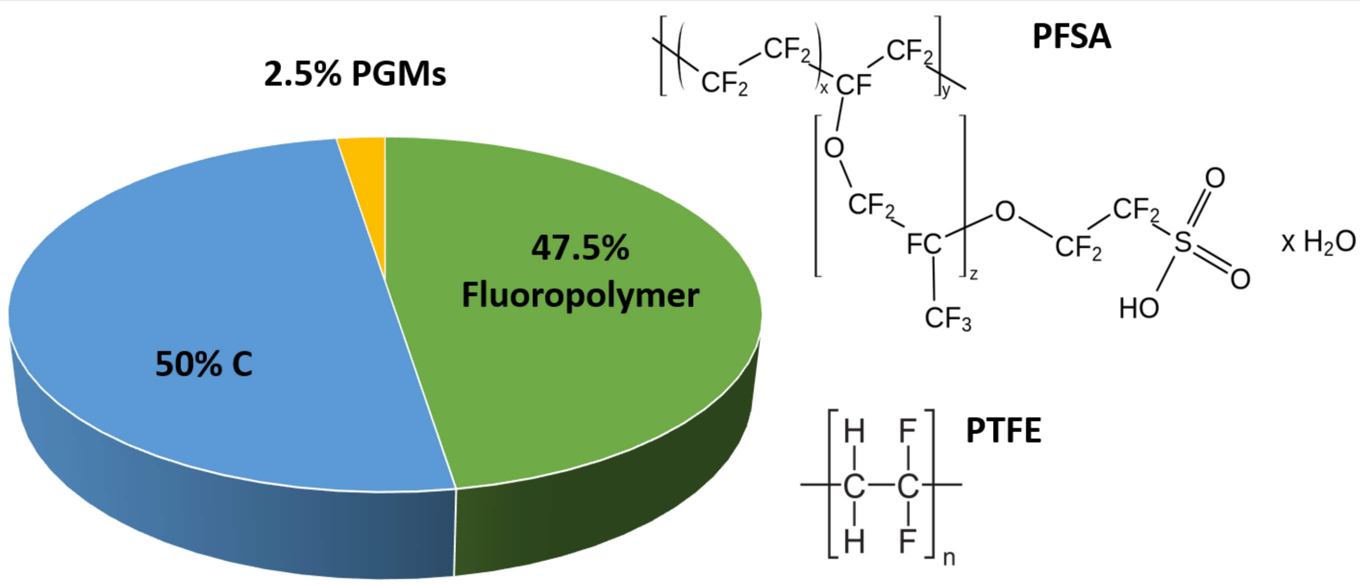

Fig 4. A representative material composition in a polymer fuel cell MEA, where the fluoropolymer includes both PFSA and PTFE

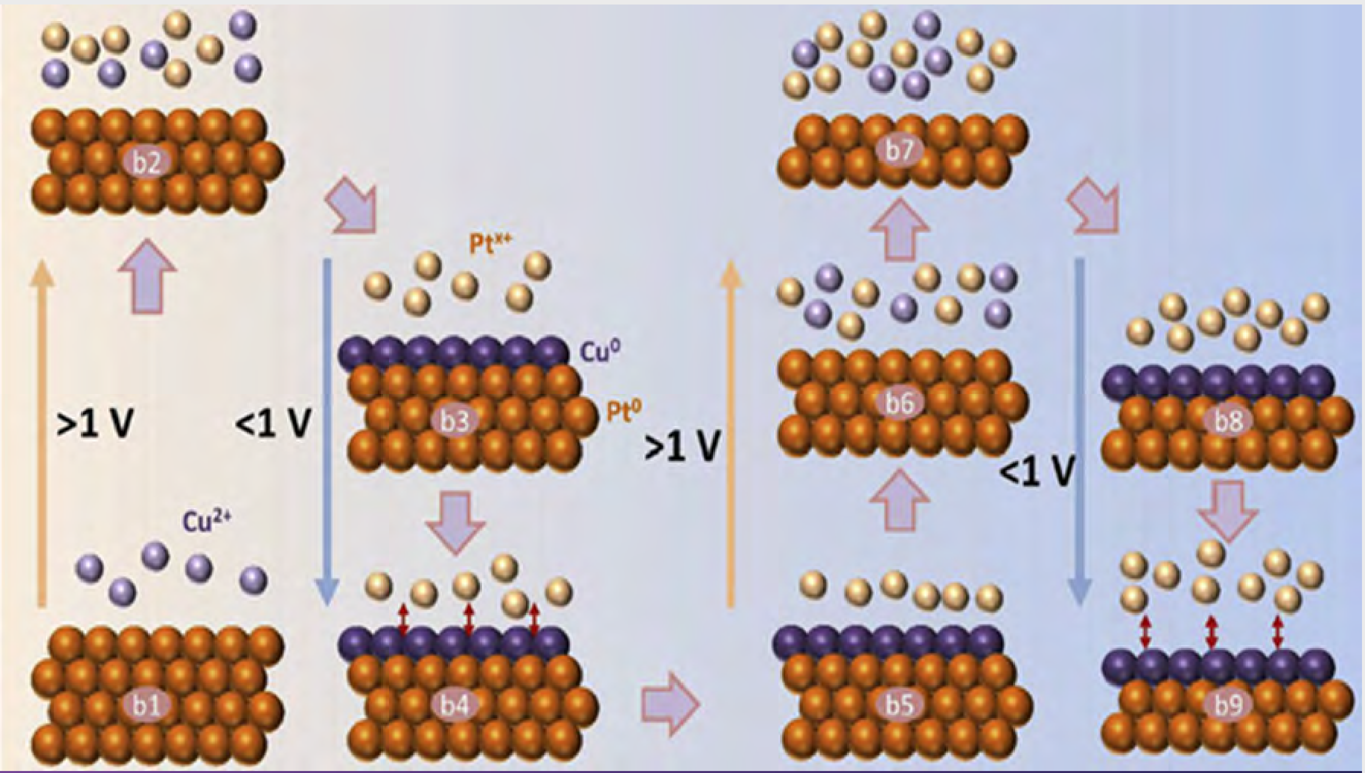

Fig. 5. Process mechanism for platinum dissolution through electrochemical route

MEA recycling using innovative electrochemical method

As a special branch of hydrochemistry, the electrochemical process for precious-metal dissolution has drawn particular attention, due to its ability to simplify the dissolution matrix and its well-controlled redox conditions to be customized towards the materials of interest. The electrochemical approach allows for the use of cheaper and less corrosive chemicals compared to classic hydrometallurgy.

Several approaches for electrochemical dissolution of platinum have been investigated. It was concordantly observed that electrostatic conditions lead to surface passivation, whereas electrodynamic treatments improve dissolution by several orders of magnitude. The metal dissolution mechanism is clarified as atomic-lattice incompatibility from a place-exchange mechanism (transition of oxygen atoms from surface to sub-surface positions).[14] This knowledge can be further expanded to cover strategically important PGMs (platinum, palladium, ruthenium, iridium, etc.) as well as non-PGMs.

Since more than a decade, a vast body of valuable knowledge and first-hand experience on recycling of PGM catalysts from spent

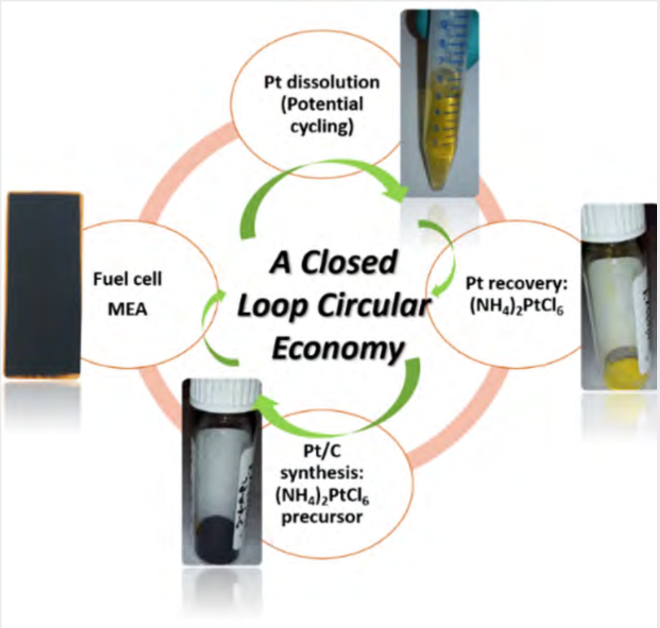

Fig. 6. Demonstration of a closed-loop circular economy from spent MEA to competitive fuel cell catalyst

Fig 7. Sustainable recycling of PGMs and fluoropolymer

PEMFCs and ECs has been obtained at the University of Southern Denmark. The unique electrochemical process is carried out at mild condition, requires minimal energy input, delivers high recovery efficiency (99%), involves a flexible process, and has possibilities for further customization. An example of efficient catalyst-dissolution route[15] utilizing redox property of metallic elements is illustrated in Figure 5. A number of intellectual properties have been established in this area. After several generations of optimization, the process is industrially friendly and scalable.

In collaboration with industrial partners, a closed-loop circular economy was validated,[16] where PGMs from end-of-life fuel cell and electrolyzer MEAs were successfully recycled and showed competitive catalyst performance compared to commercial equivalents, but only at a fraction of the cost of the primary production.

One of the major advantages of this recycling technology is its material selective treatment, which leaves the highly valuable membrane component unharmed during the recycling process (Figure 7). This opens wide possibilities to recover additional value from used MEAs, which will further reduce overall MEA cost, secure material supply, improve system Key Performance Indicator (KPI) and strengthen the competitiveness of the PEM industry.

Sustainable recycling – an inevitable shortcut to boost hydrogen technologies!

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About the author

Shuang Ma Andersen holds a PhD in chemistry and the positions of Principal Investigator, Project Manager, Board Member and Associate Professor at the University of Southern Denmark. Shuang is passionate about developing groundbreaking solutions to tackle bottlenecks of renewable energy technologies, especially in the areas of material development, degradation mechanism, mitigation strategy, recycling technology and circular economy. Shuang has been active in the field for the past 18 years, with a unique vision of research trends, private-public collaboration, communication and technology transfer.

Safety for hydrogen vent systems

Hydrogen vent systems play an essential role in ensuring hydrogen safety. For many applications, it is common practice to connect all normal hydrogen piping vent points, including relief valves, to a vent system. Evaluating this system during the facility hazard review is essential. This evaluation is often missed, and there have been numerous incidents in which improper vent stack design or operation caused injuries and property damage. This article addresses critical safety issues in vent system design and operation for liquefied (LH2) and gaseous (GH2) hydrogen.

By Thomas G Witte, CEO of Witte Engineered Gases, and Nick Barilo, Executive Director of Center for Hydrogen Safety

Vent systems are used to safely release hydrogen during normal and abnormal events such as high-flow relief device operation. When properly designed and installed, these systems reduce the effects of fire, asphyxiation, and fog (cold gas released from a liquefied hydrogen tank) on people, equipment, and the environment. Vent system designs are based on the properties of hydrogen. For example, because hydrogen is extremely buoyant, has low ignition energy, and can condense water vapor in the air from LH2, vent systems are designed to move hydrogen away from ground level for safety purposes. Typical equipment connected to a vent system can include pressure relief devices, purge and vent valves, bleed valves, and any opening that can vent hydrogen under operation or maintenance.

Unfortunately, the configuration of hydrogen vent systems may not be considered during the initial design or not included in the process hazard assessment (PHA). This can lead to vent stack damage or failure and hydrogen being discharged to undesired locations. It is essential that vent systems be designed by qualified engineers or designers. Designers need to consider the following:

- Process flow parameters (including maximum pressure, peak flow, maximum or minimum temperature, and composition)
- Materials of construction
- Supports
- Location
- Hydrogen operations
- Vent outlet piping design
- Expansion/contraction
- Flares or flame arrestors
- Grounding
- Purge gases

These design considerations are critical to the safe operation of the vent system and preventing vent system failure. Additionally, the design parameters (e.g., vent diameter, vent supports, interaction with other streams) must be evaluated for each process stream entering the vent system.

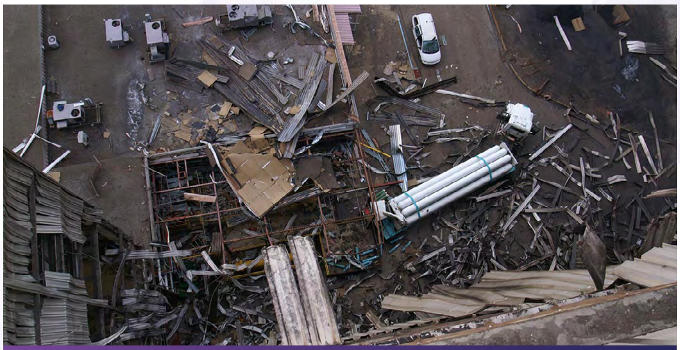
Improper designs that can cause vent system failure include:

- Incorrect supports
- Incorrect piping expansion/contraction
- Joints or vent system components with melting points below the hydrogen flame temperatures
- Undersizing the vent system
- Incorrect vent stack termination

Failures include:

- Overpressurization
- Plugging the vent system

Vent system incidents


Muskingum River Power Plant explosion

Improper design of vent systems has caused injury and death and damaged property.

On 8 January 2007, a hydrogen release killed one person and injured eight others at the Muskingum River Power Plant in Beverly, Ohio, and caused substantial damage to the facility. The incident was caused by the hydrogen vent stack failing within the building in response to a change in the direction of the hydrogen flow when the safety device was activated.

In 1974 in Lubbock, TX, an LH2 tank exploded when the local fire department sprayed water directly on the end of the only vent stack, plugging the stack. This destroyed the LH2 tank, injured several people, and damaged property.

On 11 February 2018, an incorrectly rated rupture disc prematurely opened, damaging the vent systems and causing a fire on the back of a hydrogen trailer at Diamond Bar, CA. During the event, the vent system piping was also pulled out of the compression fittings due to incorrect installation.

- Air ingress during a release
- Interaction between flow streams
- Liquid air or ice issues as a result of incorrect installation
- A hydrogen release adversely affecting people or property

Clearly, many potential failures for a system can be (and often are) overlooked in the design and PHA for a hydrogen system.

The Center for Hydrogen Safety (CHS), a global membership organization dedicated to promoting hydrogen safety and best practices worldwide, has had extensive discussions among its members and the Hydrogen Safety Panel about vent design and other hydrogen safety practices. As a result of these discussions, CHS has developed a list of the top 10 considerations for designers to avoid the most common mistakes that can result in vent system failure.

1. Overpressurization

The system should be designed for a minimum pressure of 40 bar, as recommended by the European Industrial Gas Association (EIGA) 211/17, Hydrogen Vent Systems for Customer Applications. Additionally, it is a best safety practice to design the pressure rating of the piping at the highest rated pressure entering the vent system.

2. Plugging/blocking the vent system

The vent system should be designed to avoid freezing from the introduction of moisture or other obstructions (such as insects or bird nests). For either an LH2 or a GH2 vent stack, ensure water cannot collect in the vent stack by using a water barrier cap that will open only during required hydrogen releases. If water can collect in the vent system, such as in a cold LH2 stack interaction with humid air, provide a monitored water collection chamber at least 0.6 m (2 ft) below the cold hydrogen inlet at the bottom of the vent stack and ensure that it provides enough volume to collect water from the vent, typically several gallons for small vent stacks. All piping from any relief valve or valve outlet should slope downward with no liquid collection points between the components and the vertical vent stack. Signs should be placed near the vent system directing the fire department not to spray water on the vent stack outlet. Only helium should be used for LH2 systems if a purge gas is required, since it is the only gas that will not solidify at LH2 temperatures.

3. Incorrect supports

The design of supports for vent stacks should consider reaction forces (especially from pressure safety relief valve activating), local wind, and seismic forces, and ensure that the supports are designed for vent system expansion/contraction due to temperature changes. The end of the vent stack must be supported such that the reaction forces sum to zero. This is accomplished by vertical flow upward or a tee stack that equalizes the flow through both opposing legs of the tee. 'L' type or single-exit horizontal flow direction vent stacks are discouraged due to the large directional reaction forces. Even with tee stacks, harmonic motion can occur if the top vent stack outlet supports are more than 0.5–0.6 m (1.5–2 ft) below the top of the vent stack.

4. Incorrect piping expansion/contraction

Consider pipe and fitting expansion/contraction due to temperature changes. Make sure piping connected to the vent piping (such as conduit or propane for flaring) expands or contracts at the same rate as the hydrogen piping or the attached conduit/piping is designed to move independently of the hydrogen vent stack. Installation errors have caused vent stack failures from changes in flow direction (forces on elbows) and the use of compression fittings on thick walls and/or large-diameter tubing being incorrectly installed. Changes in flow direction create reaction forces within the piping that can result in failures. Typically, vent systems are not pressure tested after installation; thus, incorrectly connected joints may fail during the operation of the vent system. An example of this is swaged tubing on thick-walled or large-diameter piping. This type of connection requires hydraulic machinery to ensure a correct connection with good mechanical integrity.

5. Incorrect temperature rating for joints or vent system

Ensure the melting point for the joints and vent system components is above the hydrogen flame temperature during a release. This is especially a risk for plastic piping and copper-brazed joints. Welded 304 or 316-type stainless steel is the recommended material for the vent system. Plastic, cast iron, ductile or malleable iron, and high silicone should be avoided. Materials with low melting points (i.e., aluminum, copper, brass, and bronze) are not recommended because of their reduced strength at high temperatures. Carbon steel and many polymers are not suitable materials for LH2 hydrogen systems with operating temperatures below -29°C (-20°F).

6. Air ingress during a release

Ensure there are no openings in the vent system that can pull air into the vent stack during a flow event (i.e., from a venturi effect), which may result in a fire or deflagration in the vent stack.

7. Undersizing the vent system

Vent systems should be designed for the maximum peak flow at the operating pressure of every stream that can flow simultaneously. The design should address the distance and pressure drop of each flow stream.

8. Interaction between flow streams

Ensure any interaction between the flow streams is considered for all the design parameters. For example, combining multiple hydrogen streams into one stack is common. Designers should ask whether a single vent stack is acceptable or if multiple vent stacks are needed. Operating conditions should be evaluated in this instance. In the case of two streams – e.g., one with a pressure of 700 barg and the other at 12 barg – two stacks are recommended. Another scenario may be combining GH2 at cold temperature (from an LH2 source) with a stream of GH2 at ambient


Improper vent stack discharge

temperature that has nitrogen gas for purging. This scenario will likely require separate vent stacks to ensure nitrogen doesn't freeze solid and plug the vent stack.

9. Incorrect vent stack termination and release flow
The vent stacks should direct the flow of hydrogen upward and be designed to minimize reaction forces at the top of the vent stack. Refer to the vent stack design criteria within EIGA and Compressed Gas Association (CGA-North America) documents for details. These stacks should be located to ensure that a hydrogen release does not harm people or damage property. Vent stack outlets should be located outdoors, typically at a minimum elevation of 3 m (10 ft) for GH2 and 7.6 m (25 ft) for LH2. These elevations should be increased if roofing and adjacent buildings or structures are nearby. Refer to local codes for specific required heights and allowed locations.

10. Not considering liquid air or ice
Oxygen-rich liquid air and ice can form on piping and supports when flowing LH2 or cold hydrogen gas from an LH2 source. The oxygen-rich liquid air can cause flammable materials (e.g., asphalt) to burn or explode. Extreme cold temperatures can also damage concrete and cause embrittlement and failure of surrounding supports that are not rated for the temperature, such as carbon steel. Flowing LH2 or cold hydrogen gas from an LH2 source can result in oxygen-rich liquid air and ice forming on the piping.

Other design criteria

- **Grounding**. To minimize ignition sources, the system (including the vent stack) and the delivery vehicle should be grounded.


LH2 pipe with liquid air


LH2 pipe with ice

- **Flaring**. Unless a steady flow of hydrogen is continually vented, flaring is not recommended. Flaring requires a constant velocity and controls to ensure that the flare is not extinguished and air is not allowed to backflow into the vent stack.
- **Inert gases**. Inert gases are not typically used for extinguishing fires in a hydrogen vent system. If a fire occurs at the top of a vent stack, the best action is to isolate the source or let the hydrogen fire burn out. Putting the hydrogen fire out without isolating the source allows a build-up of hydrogen that can lead to reignition and increases the risk of an explosion.
- **Mufflers or silencers**. Silencers are usually not used due to high-pressure drop at the required flow rates. Codes such as EIGA 211/17, Hydrogen Vent Systems for Customer Applications expressly prohibit the use of silencers.

In conclusion, many conditions must be considered during design and verified during installation. Observing best safety practices and sound engineering principles and performing a thorough hazard review will minimize the potential for injury or property damage and bolster stakeholder confidence in hydrogen systems.

About the CHS and HSP

Founded in 2018, the Center for Hydrogen Safety (CHS) is a non-profit, unbiased corporate membership organization that promotes the safe operation, handling, and use of hydrogen and hydrogen systems across all installations and applications. A global technical community within the American Institute of Chemical Engineers (AIChE), the CHS builds upon the technical expertise embodied by AIChE, its Center for Chemical Process Safety (CCPS), and partnering organizations to identify and address concerns regarding the safe use of hydrogen as a sustainable energy carrier, in commercial and industrial applications, and in hydrogen and fuel cell technologies.

A trusted and highly respected resource, the Hydrogen Safety Panel (HSP) is a pioneer in reducing knowledge barriers to hydrogen fuel cell deployment and enabling timely technology adoption by cities and communities. Building on its diverse knowledge, rich experience, and technical objectivity, this not-for-profit expert panel utilizes safety reviews, research, information dissemination, and training to help government agencies, industry and other stakeholders ensure that hydrogen is safely stored and handled.

China hydrogen fuel cell technology update

As a huge and rapidly expanding market for proton exchange membrane (PEM) fuel cells, China is well positioned to help attain the global goal of fuel cell cost reduction by means of mass production. Hydrogen Tech World attended a local fuel cell summit to learn about the latest technological developments and trends in hydrogen fuel cells.

By Jude Jiang, Hydrogen Tech World

China's interest in hydrogen development has been deeply connected with hydrogen applications in the transport sector. By the end of 2020, the country achieved a global first in commercial deployment of fuel cell trucks and buses. Based on Hydrogen Tech World (HTW) research, the majority of Chinese hydrogen-themed industry events have focused on fuel cell applications in transport and on developments in fuel cell technologies. To drive progress and innovation in these areas, the country is fostering research through government funding. So, what are the most notable recent developments in this field?

Gas diffusion layer

The bipolar plate and the membrane electrode assembly (MEA) are two of the most critical components in PEM fuel cells, determining to a large degree the performance of the fuel cell stack. Although only a few domestic companies are currently capable of carrying out comprehensive localised production of core components of the integrated MEA, including the catalyst, PEM and gas diffusion layer, the government-supported fuel cell industry is poised to accelerate the commercialization of domestically manufactured products.

As a crucial component of the MEA, the gas diffusion layer (GDL) is responsible for the gas and water transport in PEM fuel cells. Superior GDL materials exhibit high mechanical strength, high conductivity, and high gas permeability. Carbon fibre paper is the main material of construction for GDLs and as such has been a technological barrier hampering China's localised production.

In the absence of a domestic production base for carbon fibre paper, Chinese GDL manufacturers had been reliant on imports from industry leading suppliers such as Japan's Toray and Germany's SGL. Two years ago, however, the domestic sector made a major step towards self-reliance, with G-Hydrogen™ becoming the first Chinese company to start mass producing GDLs and carbon fibre paper.

A representative of G-Hydrogen™ told HTW that, following the launch of a roll-to-roll GDL production line with an annual output of 100,000 square meters in southern China, the company recently started up a fully automated plant in northern China, where carbon fibre paper up to 1,000 meters in length can be manufactured. Both plants produce a complete array of product categories from carbon fibre paper to carbon paper and GDLs.

The company's breakthrough progress stems from the innovation in surface treatment of carbon-cloth GDL with advanced hydrophobic agents made from polytetrafluoroethylene (PTFE) and fluorinated ethylene-propylene, in which increased sensitivity improves the fuel cell performance, the company representative said. To date, G-hydrogen has supplied GDL-S-16,


G-Hydrogen's fully automated production line for carbon fibre paper in northern China

GDL-S-18, GDL-S-20 and GDL-S-22 products fitted with liquid-cooled and air-cooled fuel cell stacks to key industry players like Ballard Power Systems, Shanghai Hydrogen Propulsion Technology and Weichai Power.

Metallic bipolar plate and coatings

In fuel cell technology, the bipolar plate is the backbone of the PEM stack and plays a central role in the conversion process of oxidized hydrogen into electricity and water. As the carrier plate forming the two poles of a single fuel cell – the anode plate and the cathode plate, the bipolar plate is responsible for conducting electricity, the distribution of H_2 and O_2 used in the reaction, and for dissipating the heat from the reaction.

The transport sector, particularly trucks and buses, may remain China's focus for fuel cell application, but there is also an emerging interest in the application of fuel cells in passenger vehicles. According to data from Chinese market research company Huaon, in 2021, the national production capacity for bipolar plates was around 20 million units. 53% of fuel cell stacks manufactured domestically were composed of graphite bipolar plates, with the remaining 47% incorporating metallic bipolar plates. Compared to 2020, the number of metallic bipolar plates grew by 203%.

Driven by the passenger vehicle market, a growing number of Chinese bipolar plate makers have been increasing their production capacities. Compared to graphite bipolar plates, their metallic counterparts are believed to be the better choice for long-term cost targets as well as a more efficient solution for fuel cell stacks used in passenger vehicles. In the full production process of a metallic bipolar plate, which includes moulding, stamping, coating and encapsulation, coating usually accounts for 50% of the entire plate cost and is key to the longevity of metallic bipolar plates.

In this regard, one of the domestic industry leaders, Shanghai Zhizhen New Energy, has introduced a practical technological solution that not only reduces the cost of coating by half but also extends the product life from thousands of hours to more than 20,000 hours.

Different from the mainstream approach of using precious metal coatings on titanium or stainless steel substrates, Shanghai Zhizhen has introduced nanocrystalline structures with specific crystalline orientation in an amorphous carbon coating. Since it is technically challenging to make a chemical bond between carbon coatings and metals, the company has also implemented interlayer gradient matching technologies and enhanced plasma deposition.

In a market with wide application of optical thin-film coatings on lenses, mirrors and filters for digital cameras, LCD projectors and other applications, rapid development of vacuum coating technologies adapted specifically for metallic bipolar plates comes naturally.

"Production line development for physical vapor deposition of thin-film coatings in China has a strong advantage over other countries," said a representative of HCVAC. This vacuum coating company, which utilises high-power impulse magnetron sputtering (HIPIMS), a relatively recent advancement in thin-film deposition technology, claims to have an output capability of up to nine metallic bipolar plates measuring 420x151x0.1 mm per minute.

Advanced technology penetrating domestic production

Contamination greatly affects fuel cell performance. It was found that even trace amounts of impurities present in either fuel or air streams or within fuel cell system components could severely poison the anode, membrane, and cathode, according to an article published in the *Journal of Power Sources.*

Identifying fuel cell contamination sources is critical. Recent research by Dr. Tamim P. Sidiki, Yu Bin and Dr. Robert Janssen from DSM Engineering Materials has revealed that, although technical thermoplastics are ideal for fuel cell systems, constant direct contact with gases and liquids in fuel cell systems leads to hydrolysis of thermoplastic components and the accompanying ion leaching may result in membrane contamination. Among all the engineering materials, the polyphenylene sulfide (PPS) stands out due to its excellent hydrolytic resistance and low ion leaching. DSM Engineering Materials, however, is able to create a complete material portfolio and simulation platform based on Xytron PPS to achieve even lower ion leaching and better hydrolytic resistance.

"DSM products for fuel cells are used globally, but compared to western markets, China is faster in trying out new research and development achievements," said Yu Bin, Global Advanced Engineering Manager for Electric Vehicles at DSM Engineering Materials. "Although the Chinese government began rolling out incentives to develop the fuel cell sector as recently as 2019, DSM PPS materials entered mass production only a year later, in 2020. Currently, the majority of domestically produced fuel cell stacks and systems use the DSM PPS materials."

Traditionally, China's energy sector has been dominated by state-owned enterprises and domestic companies receiving subsidies, thus undercutting foreign competition. However, with regard to hydrogen application in general and fuel cells in particular, opportunities for foreign investors with strong technological advantages remain attractive.

Among the foreign firms participating in the growing Chinese fuel cell market is Swiss precision processing company Feintool. At its existing production plant in Taicang, Jiangsu province, Feintool, in collaboration with German laser specialist SITEC, is set to introduce its FEINforming technology for the production of bipolar plates as well as its latest generation of hydraulic presses, FB one. From 2023, the plant will have an annual production capacity of 10 million metallic bipolar plates.

Incentivised by government funding and supported by foreign know-how, China's rapid adoption of hydrogen fuel cells is accelerating domestic technological advancements as well manufacturing capabilities in this field, paving the way for cost reductions and, in turn, accelerated deployment of fuel cell technologies and their applications.

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The Hydrogen Tech World Expo & Conference 2023 will bring together hydrogen experts from around the globe, providing an excellent opportunity to meet with leading equipment and component manufacturers, system developers and service providers from across the hydrogen value chain as well as to learn from and talk to engineers, system integrators, technology innovators and end users at the two-day conference, which will be openly accessible to all event visitors.

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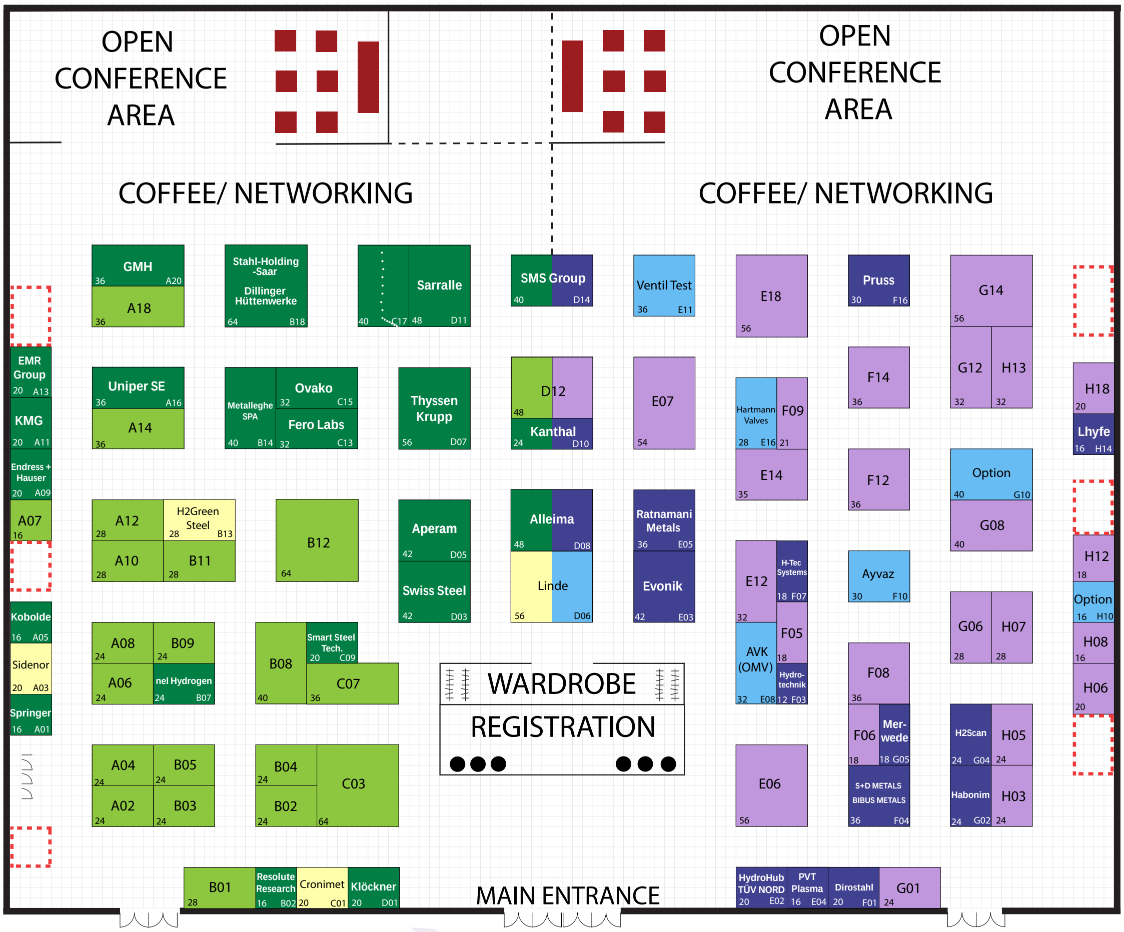

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