ESSENTIAL

FREUDENBERG SEALING TECHNOLOGIES

H_2 – HYPE OR HOPE?

A CHALLENGING GAS
Interview: Why hydrogen is spurring engineers' ambitions.

READY FOR EXPANSION
The demand for electrolysis is rising – and for seals as well.

ON THE WAY
How does hydrogen get to where it's needed?

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IN 50 WORDS

Again and again, hydrogen has spurred high expectations only to dampen them. Yet it continues to be promising. It is no longer just a fuel. It is transforming the energy sector and industry. But more progress will take material and engineering expertise, in everything from production to transport and use.

H_2 – Hype or Hope?

By Claus Möhlenkamp, Chief Executive Officer,
Freudenberg Sealing Technologies

Overblown expectations are a feature of everyday life. People are inclined to be optimistic. Our brains respond positively to new information, and we tend to develop a herd mentality. This all can lead to "hype." The derivation of the word has never been clarified. It likely comes from either the rhetorical device, hyperbole, or from the underworld slang of the early 20th Century, when drug addicts gave themselves injections with hypodermic needles. The possibility is not far-fetched: Hype frequently takes the form of an intoxication that seizes people and entire markets – until the hangover, that is. The dot.com bubble comes to mind.

The history of hydrogen is also a story of expectations, hopes and disappointments. In 1800, the gas was produced with electrolysis for the first time, and even back then, humanity dreamed of clean water replacing dirty coal. But hydrogen remained too expensive in the competition with oil and natural gas. It attracted serious attention again in the 1970s during the oil crisis. Automakers began developing the first fuel cell vehicles, but they remained experimental. It was perhaps due to this long prehistory that the world of the early 2000s was determined not to fall for another round of hype – and the disillusion turned out to be all the more severe. Then U.S. President George W. Bush made more than $1 billion available for his new hydrogen fuel initiative and outlined the mass production of hydrogen-fueled vehicles in the future.

> We were convinced early on that hydrogen is more than just a bubble: Hydrogen is here to stay.

That future was delayed. Once again, disappointments followed the hype. Reality can rarely keep up when hopes and expectations are overblown. It quickly turned out that the production of hydrogen was still much too expensive, and the infrastructure for economical transport was lacking. A hangover followed the high, and the hype gave way to a vale of tears.

But what actually happened? Was the vision of hydrogen a flop? Or did progress simply not keep up with expectations? We now know the latter was the case. There is potential in hydrogen – far more than imagined at the start of the 2000s, when too much attention was paid to fuel cells (forgetting the findings of 19th century researchers who worked with hydrogen as an energy storage medium). Hydrogen is helping to replace fossil fuels, store energy and generate heat in multifaceted ways. Incidentally, when expectations are over-the-top and rushing in just one direction, potential is more likely to be overlooked.

When we decided to pursue hydrogen at Freudenberg Sealing Technologies 20 years ago, we knew there was a risk. There is no natural law guaranteeing a new golden age after a time of disappointment. Some technologies and ideas never fly, and the hype may remain an illusion to some extent. But we were convinced early on that hydrogen is more than just a bubble: Hydrogen is here to stay. And we are sticking with it even if history is repeating itself. We are reading and hearing doubts and warnings that the technology is not moving very quickly and that much more research is needed.

Does that sound familiar? It does. And that's why we are looking at the future calmly: Around the world, governments are providing financial resources for their hydrogen initiatives. We expected that it would take time for the developments to find traction. But the money will help an industry that so far lacks the economies of scale it needs. It will help to achieve the clout that a certain size brings, even without subsidies. This underscores the fact that political support remains urgent. Governments must keep their eye on the ball, create the right conditions, and provide security. Otherwise, they will be hurting themselves and their economies.

It is part of a healthy development if doubts and setbacks recur in the coming months and years. That doesn't frighten us. It spurs us on, as we see research and innovation as a Freudenberg Sealing Technologies strength. We intend to actively participate in the development of the hydrogen economy.

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There are more than enough fields of application. In this issue of ESSENTIAL, we present a range of them. Hydrogen is a challenging element. It diffuses easily through many materials, has a very low density, takes up a lot of space, and corrodes materials. In short, it places extremely high demands on seals. And since the production, storage, transport and use of hydrogen are still in development stages, standardized processes, products and technologies have not become established in many cases. The situation is ideal for us to tap into our materials expertise and inventive spirit and participate in the industry's development, perhaps contributing to its standardization and scaling. The lesson is clear: It pays to keep a clear head amid the hype. ◎

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Sustainable Steel

There are few industrial sectors that generate the quantity of emissions that steel mills do. Coke and iron ore are melted in blast furnaces at up to 2,000°C (3,632°F). This releases oxygen from the iron ore, producing raw iron and CO_2. At a pilot facility in Lingen, Germany, researchers are now replacing the coke with hydrogen. Their work shows that similar high temperatures can be achieved with hydrogen, with water as a byproduct instead of carbon dioxide. The result: 80% fewer emissions during steel production. Although the process works well on a small scale, it poses a problem for the industry at large. Immense quantities of hydrogen would be needed to produce the steel. Its production from green energy sources would take an enormous effort and would not really be feasible today. ©

Ambitious Plans

“NEOM,” Saudi Arabia’s ambitious future project, is referred to as the “Land of the Future.” Along the Red Sea coast, a large, green, special economic zone is due to be built there. The plans include a large, carbon-neutral city with a huge industrial area, including one of the world’s largest electrolysis systems. It is expected to begin producing about 650 tons of green hydrogen per day in 2026. Its location guarantees enough water for electrolysis and good conditions for renewable energy. But NEOM still faces criticism despite the efforts to make it a sustainable metropolis. Several local tribes have been resettled, sometimes by force, to clear the way for construction projects. Environmental activists have also objected to interference with the ecosystem along the coast. ◎

Bountiful Air

What some Australian researchers have done sounds surreal. They have extracted extremely pure hydrogen from the air – using direct-air electrolysis (DAE) with an efficiency of 95%. This was shown in a test run in Melbourne, Australia, with five small DAE modules powered by solar cells. On sunny days, they produce a liter and a half of hydrogen at 20-to-40% air humidity. The system's core is a module made of glass wool placed between two platinum electrodes. The glass wool, which is permeated in sulfuric acid, is hydrophilic and absorbs water vapor. Prototypes are expected to get by with 4% relative humidity. Even in the Sahel, the humidity averages 20%. It would thus be possible to produce green hydrogen in the world's most arid regions without using precious fresh water. ◎

STRATEGY TALK

Hydrogen

The prospects for hydrogen have been swinging between hype and disenchantment for decades. But something is different this time. Marcel Schreiner, Global Segment Director, Energy, at Freudenberg Sealing Technologies, explains why he is impressed with the technology's long-term potential and why a radically new advance is needed in sealing technology.

Marcel Schreiner

As Global Segment Director, Energy, at Freudenberg Sealing Technologies, Marcel Schreiner is responsible for sales to customers worldwide. He keeps an eye on every application in the energy sphere that uses sealing solutions: manufacturing, transport, warehousing, and operations. Schreiner is a graduate engineer and has worked for Freudenberg Sealing Technologies since his dual study program in 2002.

> It takes a radical approach. That is the standard that Freudenberg has championed for 175 years."

MR. SCHREINER, WHY IS HYDROGEN THE TOPIC FOR THE FUTURE?
Let me turn that question around: why not? It is interesting that the fascination with the topic comes in waves. Early in the 2000s, it was thought that the fuel cell automobile was on the brink of a breakthrough. Then came the disenchantment. Today we have a different situation: We know that hydrogen is the key. About 170 countries now have a decarbonization strategy – anyone who really wants to be CO_2-neutral needs hydrogen. The current hype is no longer limited to individual applications such as fuel cells but rather involves the decarbonization of all industry. It is especially relevant for the steel and chemical industries.

WHAT BROUGHT THE HYPE TO A CLOSE IN THE 2000S?
What happens with any hype. At some point, it subsides. The market wasn't ready. The availability of green hydrogen was not taken into account. But the question is, what lesson do we draw from the experience? At the start of the hype back then, we formed an independent business unit dedicated to hydrogen. We developed know-how. When there was no global breakthrough, we could have put everything back in the drawer. But we deliberately decided not to. The current trend proved us right. The opportunities for us are no longer just in hydrogen's applications but in its production, the electrolysis, and all the steps in-between.

BUT THERE IS MORE THAN ONE TYPE OF ELECTROLYSIS …
That's right, there are currently various processes. Electrolysis with anion exchange membranes (AEM) interests us right now. It may well prove to be inexpensive and effective – but it is not yet tried and tested. Here we can contribute our development expertise. Alkaline electrolysis takes place in a strong, chemically corrosive environment, so identifying the right material is a challenge. With PEM electrolysis, the main issue is high pressure. These are two different challenges, but we know our way around both fields. We're also good at manufacturing at high volume since we have expertise in automation. Our customers find that helpful when they want to ramp up production later.

STANDARDIZATION IS NOT YET IN SIGHT?
That challenge will be with us for a while: Every customer has an individualized design, and transferability is limited.

WHY DO THE CUSTOMERS VARY SO MUCH?
For historical reasons. The outputs were relatively low for a long time. By 2050, we need at least 1200 gigawatts of electrolysis capacity to achieve the global CO_2 goals. The capacity today is closer to 3 gigawatts. That's quite a difference. So companies are pursuing their own strategies: Some are comfortable with the smaller dimensions because they are good at manufacturing at that level. The others want to grow quickly because they see the potential. These approaches necessarily develop into different technologies.

SO THESE KINDS OF INDIVIDUALIZED SOLUTIONS ARE AN OPPORTUNITY FOR A MANUFACTURER?
Definitely, but we are still interested in standardization. Our advantage is that we now have so many customers in the electrolysis field that we are being integrated at an early stage. That's where there is an opportunity for standardization. When we can turn to proven designs, the result is process reliability for customers.

YOU MENTIONED STRINGENT MATERIAL REQUIREMENTS – IN COMPRESSORS, FOR EXAMPLE?
For mobile applications, hydrogen is stored at 350 or 700 bar, so it has to be compressed first. Hydrogen is highly volatile, permeative and combustible. Not many compressors are actually capable of achieving 300 bar. Overall, the level of wear due to these extreme requirements is quite high, so the lifespan for seals is a few hundred operating hours today.

THAT'S NOT VERY MUCH.
That's true. And it spurs our engineering ambitions and speaks to our souls as developers. We would be happy to develop a solution that lasts much longer. 1,000 hours would be a good start. Not many companies can meet the requirements for

> It spurs our ambition as engineers and our souls as developers. The requirements for pressure and speed – and both with dry-running. Not many people can do that. It motivates us.”

pressure and speed in combination with dry-running. That motivates us. In addition, if I have a seal that works well in a piston compressor, it is easy to use in many other situations, from refueling to electrolysis.

IS THE TYPE OF MATERIAL THE CHALLENGE HERE?

It will probably be a combination of material and design. The obvious options are specially developed, wear-resistant, high-performance thermoplastics that show little extrusion under high stresses. Perhaps a fiber blend. But that’s all speculation at this point. We will certainly have to show a certain openness to materials and technologies. The solution will surely be a radical approach, but that is what is needed. That is our standard, and Freudenberg has championed it for 175 years.

SEALS ARE ALSO NEEDED IN TRANSPORTATION …

In transportation, we are in a situation where the industry has not yet agreed on the approach that will prevail. All the opportunities are variations of already existing technologies. It does not make much difference whether I transport natural gas or hydrogen in my pipelines. The conversion to ammonia to improve transport has been around 100 years, namely for fertilizer. So the technological hurdles are steadily shrinking. We are monitoring all this, but we believe we will be in a good position as soon as it becomes clear which solution will prevail. Other areas present greater technological challenges.

THERE ARE NOW MORE VOICES EXPRESSING FEARS THAT HYDROGEN DEVELOPMENTS WILL TAKE MUCH MORE TIME …

At the start, I spoke about the hype during the 2000s. We now have low-level hype coming from the announcements for various investment programs, from U.S. President Biden’s Inflation Reduction Act to Europe’s Green Deal. We are now at the realism stage. The developments are not moving as fast as many imagined they would. That is completely logical and hasn’t surprised me in the least.

YOU EXPECTED THIS?

Yes. After all, before we can deal with hydrogen’s applications, we have to have the gas in the first place. It is completely logical to have a time lag the further I go along the value creation chain. Fuel cells can’t take off if the hydrogen isn’t there. That’s why many people are hesitating to invest in the appropriate projects, and the overall impression intensifies pessimism. But we must not overlook the fact that investments are moving along nicely. There are funding programs worldwide, although disbursing many billions of euros is no easy task. Political ambitions run into a sobering bureaucratic reality. Still, nothing has changed in the prospects for hydrogen.

THAT AGAIN SOUNDS QUITE OPTIMISTIC.

We see a much more positive mood in companies than we do in the general public. Many companies, especially the electrolysis manufacturers, haven’t had much trouble filling their order books. When the hype cycle starts again, the issue will be the capacity to quickly meet the demands of the market.

WHAT DOES THAT COME DOWN TO?

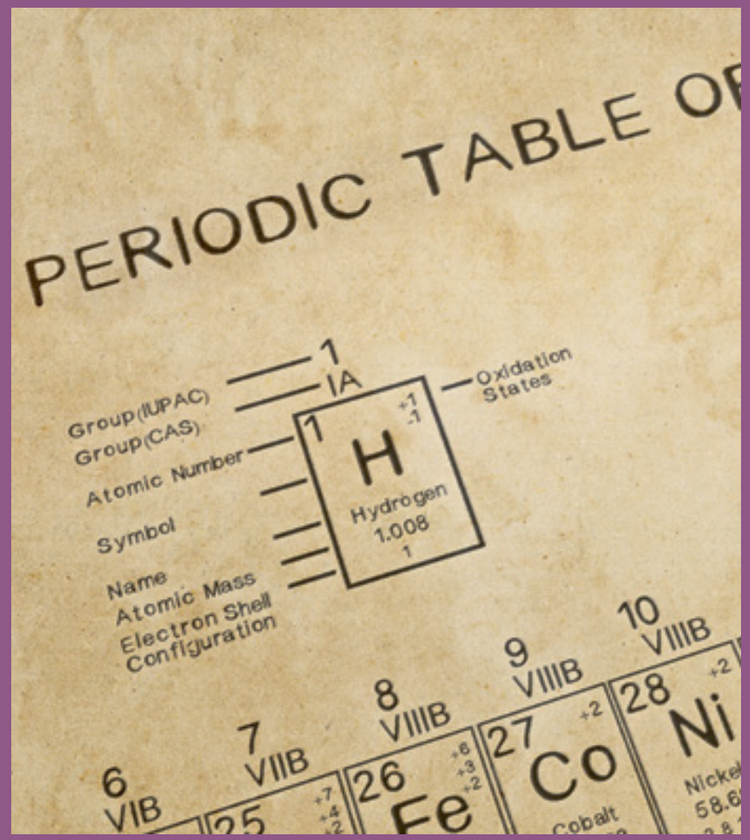
The standard we have set for ourselves is that our product should be an out-and-out winner when the customer tests it. We’re still not there yet in every case – but that’s not a problem at this point. But when the train gets rolling, it will make the difference. We want to be ready when the customer is.

THE TREND TOWARD HYDROGEN IS NOT REVERSIBLE?

No. The potential is building. If we accelerate our production of green hydrogen right now, an even greater expansion of solar and wind projects will follow. In the meantime, we have megatrends such as electric mobility and artificial intelligence at play – both will need energy. The connections run in all directions. And hydrogen is right in the thick of them. ◎

BY THE NUMBERS

Number 1



Since the end of 2015, the periodic table has included 118 chemical elements. Hydrogen with the atomic number 1 will never lose its lead position. It is the element with the lowest atomic mass (1.008 u) and has the simplest conceivable atomic structure. It has one proton in its nucleus and one electron in its atomic shell. First identified by scientists at the end of the 18th century, the gas is also the most common element in the solar system. It represents about 93% of all atoms and 75% of all mass. Even the sun consists of more than 70% hydrogen. The gaseous planets Jupiter and Saturn are mainly made of hydrogen and helium, which also form the outer layers of Uranus and Neptune. On earth, however, hydrogen only occurs as a compound. First and foremost, as water. That makes hydrogen crucial for life on earth. The sun provides light and heat. Water enables people, plants and animals to sustain their life functions. Hydrogen is now expected to make life on the blue planet more livable – as a source of the greenest possible energy and a medium for storing it. Hydrogen: so simple, yet so valuable. ◎

Ready for the Expansion

The demand for hydrogen is rising. That means that the world's electrolysis capacity has to be expanded. Artur Mähne, Global Segment Manager, Hydrogen Technologies, describes how Freudenberg Sealing Technologies is supporting electrolysis manufacturers in the process.

In 2022, the global production of hydrogen stood at 95 million tons – but only 0.1% was generated with water electrolysis. That figure is from a new report from the Fraunhofer Institute for Systems and Innovation Research. And it reflects something widely accepted in the debate on the global hydrogen supply: More electrolyzers are needed, as quickly as possible. "We are well-positioned for an expansion of production capacity, especially for green hydrogen," said Artur Mähne, Global Segment Manager, Hydrogen Technologies. Freudenberg Sealing Technologies is making a key contribution to the effort. "Over the years, we have developed a very deep understanding of hydrogen applications and can provide our customers with in-depth advice on the proper sealing of electrolyzer stacks, thanks to our material and process expertise."

Focus on Green Hydrogen

Freudenberg Sealing Technologies is especially zeroing in on electrolysis processes that can be used to produce green hydrogen: the anion exchange membrane (AEM) and proton exchange membrane (PEM) electrolysis. Either can be ramped up or down quickly, making them a practical option to use with inconsistent sources of renewable energy such as wind and solar power. In PEM electrolysis, an FKM material, fluororubber, seals the stack components. "It is resistant to the high oxygen

Left: This test specimen is checked to see whether the elastomers are properly bonded with the metallic carrier plate.

Below: The metal frame for the electrolyzer is over-molded with an elastomer seal.

Right: This test specimen is used to monitor the connection between the plastics and elastomers that are used on thermoplastic frames in electrolyzers.

pressures inside the electrolyzer," Mähne said. By contrast, an EPDM material, an ethylene propylene diene rubber, is used in AEM electrolysis, which takes place in an alkaline environment.

Both materials are key players at Freudenberg Sealing Technologies. Their development for use in electrolysis is ongoing. Advancements in the right materials for the third option, alkaline electrolysis, are proceeding in much the same way. "The combination of potash lye and oxygen poses major challenges for the materials. That is why PTFE is still frequently used in these situations," he said. Under certain conditions, EPDM can be used, however. "We are in the process of further developing this material as well."

Process Reliability during Assembly

Whichever material gets the nod, seals will be mounted directly onto the carrier plate. Depending on the process, the plate can either be a thermoplastic frame or a bipolar plate. "This can be handled with overmolding, that is, spraying the material right onto the carrier plate, or with mechanical integration," he explained. "What is important is creating a connection that remains stable over the entire lifespan and does not detach." One especially critical moment for the connection: assembling the stacks. The seal must not twist, slip or fall out during assembly. Especially with large systems, mounting individual components is very labor-intensive. "It takes considerable process reliability at our end to make sure everything stays in place. And we do that," Mähne said.

Carrier Plate and Seal from a Single Source

The sealing material is applied at Freudenberg Sealing Technologies. "In the future, other concepts such as a kind of shop-in-shop production is conceivable, but the quantities of ordered units are not there yet," Mähne said. The company has come up with another solution to keep customers' logistical expenses as low as possible. "We have a great deal of experience with plastics at Freudenberg, which is why we would be in a position to make thermoplastic frames ourselves. For the bipolar plates with a flow field, we have partners supplying the plates directly to us." Customers can order the carrier plate and the seal from Freudenberg Sealing Technologies and receive everything from a single source.

The manufacture of electrolyzers will be essential to meet the demand for hydrogen – and especially for green hydrogen – over the next few years. Mähne and his team are helping their customers as they expand their production capacity. It is still not clear whether one process will prevail. "At least until 2050, I think we will be using all three processes," Mähne said. All three have advantages and disadvantages, and each will be the preferred option for different application areas. Whatever happens, Mähne is convinced there is no way around water electrolysis. "We firmly believe in green hydrogen as an industrial sector. We see it as our obligation to support our customers in their efforts to actually industrialize the technology." ◎

Artur Mähne

Artur Mähne is Global Segment Manager, Hydrogen Technologies, at Freudenberg Sealing Technologies. He holds worldwide responsibility for the hydrogen technologies sales field in the energy segment, with a focus on electrolyzers and fuel cells. He considers it vital to develop customer-specific sealing solutions that make the industrial production of electrolyzers possible. "We are setting the course for the future and developing a new emerging industry and new markets."

A comparison of three electrolysis processes

Alkaline Electrolysis (AEL)

Process: AEL uses an aqueous potassium hydroxide (KOH) or sodium hydroxide (NaOH) as the electrolyte to increase the conductivity of the water. Electrodes are dipped into the solution, kept physically apart from one another and then connected exclusively by electric current, which breaks down the water into oxygen and hydrogen. The hydrogen is formed at the cathode and the oxygen at the anode.

Advantages: AEL is a process that has been tried-and-tested over the years. Since no precious metals are involved, the investment is less than with other processes.

Disadvantages: Alkaline electrolyzers need plenty of space, along with a constant supply of electric current, so they are not particularly suited for operation with wind or solar power. Since the solution in their interiors is corrosive, they are subject to strict safety standards.

Proton Exchange Membrane (PEM) Electrolysis

Process: PEM electrolysis uses a solid polymer membrane as the electrolyte. The membrane separates the two electrodes, which contain catalysts in the form of precious metals. When the current flows through the electrolyzer, water is broken down into protons, electrons and oxygen at the anode. The protons migrate through the membrane along the electric field to the cathode, becoming hydrogen.

Advantages: PEM electrolyzers can be ramped up from standby operation quickly. This makes them ideal for use with renewable energy sources such as wind or solar power. The resulting hydrogen is also extremely pure. They have a compact design and can be used in relatively small systems.

Disadvantages: PEM electrolyzers are costly to make since they use precious metals such as platinum and iridium, along with titanium and fluorinated membrane polymers. The systems are also more sensitive to contaminants than alkaline electrolyzers.

Anion Exchange Membrane (AEM) Electrolysis

Process: In AEM electrolysis, hydrogen is formed at the cathode. Negatively charged hydroxide ions migrate through the anion exchange membrane (AEM) to the anode, where the oxygen is formed. The process uses a highly-dilute, alkaline solution as a liquid electrolyte, which protects the electrodes from corrosion on one hand and improves the conductivity of the water on the other.

Advantages: In its flexibility, AEM electrolysis is similar to the PEM process. It can also be used in combination with wind and hydropower systems. But it does not use precious metals, which is why AEM electrolyzers are less expensive to produce. They are theoretically an ideal compromise between AEL and PEM electrolysis.

Disadvantages: AEM electrolysis is a relatively new technology and has not been fully tried-and-tested, especially regarding the stability of its membrane materials. As a result, little empirical data is available on lifespans and long-term stability.

The Trailblazers

Fuel cells make sense as a powertrain technology for heavy-duty transport. Seals perform important tasks in these applications. The right seal material has to be selected. In addition, integrated solutions are in demand for manufacturing processes.

Jürgen Emig and Dr. Alexander Hähnel believe in fuel cells and their future prospects. After all, the technology has what it takes to decarbonize industrial sectors. It also has advantages over other types of powertrains. “Fuel cells allow greater ranges than those for battery-electric vehicles, and they are more efficient than synthetic fuels,” said Hähnel, a materials specialist at Freudenberg Sealing Technologies. “In addition, the energy costs for fuel cells per kilometer driven are about 50% less than for e-fuels.” Even with those advantages, the two experts see the breakthrough coming first in heavy-duty transport and stationary facilities. “Unlike passenger cars, there is already a very attractive market in trucks, buses, construction equipment, logistical vehicles, ships and aircraft,” said Emig, who is Director, Pre-Product Development Hydrogen Applications, at Freudenberg Sealing Technologies.

Economies of Scale Thanks to Integrated Sealing Solutions

Efficient production is an important success factor for fuel cells. One way to achieve it is the rapid integration of hundreds of seals in fuel cell stacks. “In the auto industry, we are known for manufacturing our products in high volumes with reliable processes,” Emig said. “That is exactly what fuel cell producers are looking for in the seals they need.” The industry wants to be ready when the demand for fuel cells picks up. To achieve the right economies of scale, intricate seals must also be applied to the fuel cell’s bipolar plates, plastic film or gas diffusion layers using an automated process. Until now, the work has taken place in separate process steps. By contrast, Freudenberg Sealing Technologies can apply the seals directly onto the substrates that the customer desires during the injection molding process. “Since we can also manufacture bipolar plates and gas diffusion layers, customers would get everything from us as a single source,” Hähnel said. In any case, it will take Integrated solutions such as sprayed-on seals to achieve high cycle rates cost-effectively and to avoid scrap.

Freudenberg could become a key problem-solver since it has been deeply involved with fuel cell technology for more than 20 years – even as the general hype surrounding it has subsided. “We know the technology inside and out. We know what is important for seals,” Emig said. The company is serving the entire fuel cell periphery with components – from valve seals to the pressure equalization element DIAvent®. In the stacks, gaskets are being used to seal individual cells or bipolar plates firmly against one another. They keep the hydrogen in and unwanted media out.

> We know the technology inside and out. We know what is important for seals.”
>
> Jürgen Emig, Director, Pre-Product Development Hydrogen Applications, at Freudenberg Sealing Technologies

High-performance Elastomer

The right seal material is also crucial. “In fuel cell polyolefin (FCPO), we have a material that is being installed in series-production, low-temperature PEM (PEM: proton exchange membrane) fuel cells,” Hähnel said. The strengths of FCPO are self-evident since it is impermeable. Even small hydrogen molecules can only cross it slowly. Fuel cells are often very sensitive to harmful substances like those often found in rubber compounds. These substances gradually reach the fuel cells from the seals, which reduces their performance. But FCPO contains no harmful substances. The elastomer has a longer lifespan than standard silicone solutions and withstands temperatures up to 120°C (248°F), even in contact with water and typical coolants. Another advantage: When FCPO is applied to a bipolar plate, overhead installation is possible without a bonding agent, as the material securely adheres in any position. The material alone offers sufficient adhesion, but it does not stick to other components. That means it meets the requirement for mono-material recycling.

With FCPO and creative ideas for integration, Freudenberg Sealing Technologies is breaking new ground in the manufacture of fuel cells at competitive prices. ◎

CUSTOMER STORY

Electrolysis Made Easy

A German-Italian company has developed a patented process to produce green hydrogen. Enapter AG has turned to flexible, easily scalable devices for its production. One key to success: seals from Freudenberg Sealing Technologies.

The first megawatt electrolyzer from Enapter combines 2.4 kilowatt modules into one container solution.

How does a company become a global market leader? For example, by refining a little-noticed electrolysis process and making it so attractive that companies and households feel it is perfect for them. That is what Enapter AG has achieved. The German-Italian company manufactures systems using anion exchange membrane electrolysis (AEM). Until now, the process has been a minor player in the global electrolysis mix. Enapter is changing that, and co-founder Jan-Justus Schmidt is confident about its prospects. “Thanks to the flexibility of our AEM electrolysis, we can compete with the processes that have been in the lead until now.” They are the proton exchange membrane electrolysis (PEM) and traditional alkaline electrolysis (AEL) systems.

The advantages are clear: PEM electrolyzers use expensive, rare precious metals like iridium. Enapter’s AEM stacks get by with less costly nickel and steel and still produce extremely pure hydrogen. Additional purification steps are unnecessary. Another plus is the comparatively simple construction of the Enapter systems. It permits modular planning and execution, which reduces development times for new stacks. AEM electrolyzers have advantages over the AEL variety since AEL is suited for large facilities. By contrast, Enapter can fabricate small AEM modules at competitive costs, enabling it to develop new, attractive markets.

Modular solutions

The bottom line is that Enapter designs and builds high-performance systems at appealing prices. The systems are based on small 2.4 kilowatt modules that can be quickly assembled into larger configurations. This allows Enapter to adapt electrolyzers to special needs. The company also offers standard sizes. One example is the 2.4 kilowatt electrolyzer’s single-core solution. The other possibilities are two-multicore systems: Enapter’s AEM Flex 120, in which 50 of the 2.4 kilowatt stacks are installed, and the AEM Nexus megawatt solution, that has bundled 420 stacks into a container system. “This modularity makes our technology attractive and accessible to the hydrogen market,” Schmidt said. “It brings the energy transition to small and medium-size companies, and even for households.”

For example, the single-core electrolyzer, which is the size of a microwave oven, is suited for households looking for energy self-sufficiency. “The energy of the summer sun is collected as

Right: Enapter builds its patented AEM stacks in Pisa, Italy.

Below: A megawatt electrolyzer is the heart of a hydrogen terminal at the Technical University of Braunschweig.

> Without seals, there is no electrolysis."
>
> Jan-Justus Schmidt,
> cofounder of Enapter AG

green hydrogen in a storage system and is used to generate heat in the winter," Schmidt said. A medium-sized brick factory recently began using the AEM Flex 120. It allows the company to be more independent of natural gas when clinker bricks are burned – an energy intensive process. The Enapter electrolyzer transforms solar energy from the factory roof into green hydrogen and feeds it directly to the manufacturing operations. Since the cost of electricity in commercial electrolysis represents the largest share of the overall costs, renewable energy from a company's own production system is the most economical option. Enapter's megawatt electrolyzer is particularly well suited for hydrogen filling stations, among other uses.

Energy Transition for Industry and Commerce

Enapter products give companies easy access to the hydrogen economy. "They don't even need to make a major investment to get started. They can get involved with our solutions and expand over time," Schmidt said. "Customers who initially acquired smaller systems are turning to our megawatt solution today. And due to industry's demand for green hydrogen, our megawatt solution is in greater demand than it was just a few years ago." In the meantime, Enapter's AEM electrolyzers have reached more than 1.5 million operating hours worldwide. That makes the company the world leader in AEM electrolysis. Software monitors the systems to guarantee safety and reliability. Additionally, the data collected allows for further development of the systems. Established electrolyzer manufacturers are also embracing AEM electrolysis in the pre-commercial sector. Schmidt considers it a positive sign that the competition recognizes the potential of the AEM technology.

Enapter is turning to a tried-and-tested partner strategy to expand in two dynamic, fast-growing markets: North America and the Far East. Enapter trains and certifies partners who sell AEM electrolyzers as components of an overall system. In China, Enapter has even entered into a joint venture with Wolong. The company is one of the world's three largest manufacturers of electric motors. Schmidt hopes the collaboration will quickly facilitate market access for its AEM electrolyzers.

Demand for High-Level Sealing Expertise

But even a well-designed electrolyzer would be nothing without the many high-performing seals inside it. If just one fails, the result would be a loss in pressure that would damage the stack and interrupt hydrogen production. "Without seals, there is no electrolysis," Schmidt said, zeroing in on a key issue.

420

stacks are bundled by Enapter AG to achieve a megawatt of hydrogen production.

Enapter electrolyzers have incorporated seals from Freudenberg Sealing Technologies for several years, especially where quality and safety requirements are high. "We are reassured about our partnership by the outstanding mix of very high technical expertise and very good interpersonal interactions," Schmidt said. "From the beginning, we worked extremely well together and developed solutions." A mutual understanding of the hydrolysis technology has been the foundation for the collaboration over the years. Enapter sees the sealing technology company as a problem solver as it ramps up production with the help of integrated sealing solutions. "We don't need to discuss the quality of the materials and process reliability at Freudenberg Sealing Technologies. They are both top-notch."

In any case, Enapter sees itself as extremely well-equipped to promote growth in the hydrogen industry with its AEM systems. After all, Schmidt is sure that "the hydrogen economy is on the move worldwide. It won't be stopped. And we are on board." ©

INSIDE

ELECTROLYSIS SEALS

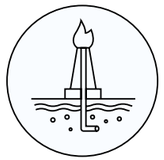
Various sealing solutions from Freudenberg Sealing Technologies are incorporated at a number of sealing points in Enapter AG's electrolysis stacks. The opportunities emerged because the company offers a wide array of sealing solutions, from O-rings and gaskets to integrated 2K-component sealing products. The company's sealing experts can customize the design and materials of the seals especially for environmental conditions prevailing in electrolysis applications. The goal is to keep the electrolytic liquid, oxygen and hydrogen in their prescribed locations.

Expertise in materials, design and processes:

Integrated sealing solutions
Seal fastened to a plastic frame or bipolar plate

O-rings and gaskets
From rapid prototyping to large-scale production

Learn more about the sealing solutions for hydrogen applications



White

This is the natural hydrogen that exists in the environment. It is mostly found in layers of rock deep in the earth. It can be extracted with **hydraulic fracturing or thermal fracking**.

CO_2-neutral: No
Thermal fracking is only CO_2-neutral if renewable energy is exclusively used in the process.

Yellow

Here the electric current for the electrolysis comes from the **mix of power sources** available today.

CO_2-neutral: No
Since the global electric power mix was only about 30% renewable in 2023, it is not (yet) carbon-neutral.

Orange

Biomass is used for the production of this type of hydrogen. The process can take place in two ways. Either by heating the biomass and then filtering the hydrogen out of the resulting gases. Or with electrolysis, with the electricity coming solely from waste incineration facilities.

CO_2-neutral: No
CO_2 is one of the gases released as biomass is incinerated.

Purple

The hydrogen is extracted with electrolysis. Electricity from **nuclear power** is exclusively used in this case.

CO_2-neutral: No
While the production with nuclear power is CO_2-neutral, carbon dioxide is emitted over the lifecycle of nuclear electric power, in the mining of uranium or the processing of nuclear fuel, for example.

Green

The electricity for the electrolysis comes exclusively from **renewable energy sources** such as photovoltaics and wind energy.

CO_2-neutral: Yes
The hydrogen is only produced using a CO_2-neutral and environmentally friendly process.

Turquoise

Methane is used instead of water in the production of this type of hydrogen. Methane is broken down into solid carbon and hydrogen with methane pyrolysis.

CO_2-neutral: Yes
Solid carbon is produced instead of CO_2. The material can then be reused.

Blue

This hydrogen is produced with the steam reformation of **natural gas**. The methane reacts with water vapor.

CO_2-neutral: No.
The resulting CO_2 is not released into the atmosphere but rather compressed underground.

Brown

To produce this kind of hydrogen, **brown coal** is transformed into a synthetic gas under high temperatures and controlled oxygen input.

CO_2-neutral: No
The synthetic gas mainly consists of H_2 and CO_2.

Gray

This type of hydrogen is extracted from **natural gas**. Using steam reformation, methane is transformed into hydrogen and carbon dioxide. This is how most hydrogen is produced worldwide.

CO_2-neutral: No
The ratio of hydrogen to carbon dioxide is 1:10 in natural gas, mirroring the proportion of the hydrogen that is generated and the CO_2 that is released.

Black

Much like brown hydrogen, coal is the base material for the production of hydrogen. Instead of brown coal, **hard coal** is used here. The coal is gasified and broken down into hydrogen and carbon monoxide.

CO_2-neutral: No
As is the case with brown hydrogen, this process releases substantial quantities of CO_2.

The Hydrogen Rainbow

All hydrogen is not the same. Although it is colorless in its natural form, we differentiate it into separate color classes based on its mode of production. Whether it is green, yellow or gray, we explain what it stands for.

Moving Forward with Clean Power

Hydrogen engines have come a long way technically and are ready for series production. In many cases, they can directly replace a conventional internal combustion engine.

On land, in the water or in the air: Combustion engines propel vehicles and generate electricity in stationary equipment. Ideally that's what we will see in the future – an environmentally-friendly and carbon-neutral technology, without CO_2 emissions or other pollutants. This scenario focuses on hydrogen as a fuel. Instead of fossil fuels such as gasoline or diesel, it is hydrogen that ignites in the engine's combustion chamber, providing the drive energy. The combustion is clean – only water vapor and nitrogen oxides result as waste. If the hydrogen is produced carbon-neutrally, no CO_2 emissions are involved. This makes the hydrogen engine a good alternative to battery-electric drives or fuel cells.

The technology is quite advanced. Major engine manufacturers have introduced the first hydrogen engines or are preparing for series production. They are zeroing in on applications where diesel engines have largely been successful.

Deutz is one example. Its TCG 7.8 H_2 hydrogen engine generates 220 kilowatts (299 horsepower) and develops 1,000 newton meters of torque. It is based on the TCD 7.8 diesel six-cylinder engine. The hydrogen version can be used wherever the diesel is used – and with the same displacement, 7.8 liters, the company says. Series production is set for late this year. The first customer, a Chinese company, envisions using it as a stationary unit to power an electric generator.

Engine Conversion Is Necessary

Hydrogen engines benefit from the fact that combustion technologies are very advanced, engine manufacturing is well-established, and the service networks are dense. Still, it's not just a matter of giving a diesel engine the other fuel.

"A conversion is required. For example, the seals must be geared to hydrogen. The injection system, in particular, has to be totally reworked to achieve efficiencies similar to those for diesel fuel," said Robin Möller, Global Segment Director, Power Generation, Freudenberg Sealing Technologies.

“The hydrogen engine is a further development of well-known combustion technologies and is viewed as a way to reduce emissions in demanding applications in the medium and long term future. That makes products for hydrogen combustion an integral part of our hydrogen strategy.”

The company has an excellent starting point: It has decades of experience with developing and manufacturing the many different seal components for combustion engines that consume natural gas.

But the demands on seals in hydrogen engines are much greater than those for conventional models. There are two main goals here: The first is to minimize hydrogen permeation – that is, the escape of this extremely volatile gas from the system, and its penetration into the sealing material. The second is to maintain the seals’ lifespans during the engine’s operating life and maintenance cycles, despite the chemical and mechanical factors in play.

High-tech Sealing Materials Are Available

“The selection of the sealing material is crucial,” Möller said. “We not only have very broad knowledge of materials but also have the high-tech materials for hydrogen applications available.” As in the case of traditional internal combustion engines, the company is using its wide-ranging expertise to help perfect the new hydrogen engines, he added. “The first step is reliable operation. In parallel, engine developers are improving efficiency to make their fuel consumption as low as possible.”

The U.S. company, Cummins, is one of the world’s largest engine manufacturers and has already exhibited the B6.7H hydrogen engine. It generates 216 kilowatts (290 horsepower) and 1,200 newton-meters from a displacement of 6.7 liters. Cummins says the assembly is based on a completely new engine platform to optimize power density, frictional losses, and thermal efficiency. As a result, the engine offers the same performance as a comparable diesel engine and is completely compatible with its existing drivetrain, transmission and cooling system. Another B6.7H advantage is that it is much quieter.

As a test, the hydrogen engine has been installed in a standard truck in the 10- to 26-ton gross-vehicle-weight-class commonly used in distribution. There is no difference in road performance, payload, or cargo space. Maintenance and the costs associated with it are comparable to diesel engines. Cummins says the solution is a cost-effective technology to drive the decarbonization of the transport sector. Its concept truck stores the hydrogen in two 700-bar, high-pressure tanks, giving it a range of up to 500 kilometers (311 miles) – enough for typical every day operations and more than the range for a comparable truck with a battery-electric drive. The two tanks can be refilled in just 10 minutes. Cummins is also working on its X15H hydrogen engine with a displacement of 15 liters for heavy commercial vehicles.

Stationary Use of Hydrogen Engines

Hydrogen engines are also an important option for stationary equipment, Möller said. “Emergency generators are one example. The spectrum extends to very large versions with several megawatts of output for institutions such as hospitals, airports, and data centers.” The lifespan of these large engines is 20 to 30 years, and seals must maintain their function over that time.

“Our customers see Freudenberg Sealing Technologies as an innovation partner. As we advise them, we draw on our in-depth knowledge of seals, including materials, designs, and production processes. We continually invest in research and development as well, to further improve the performance and lifespan of our seals,” he said. This includes research into new materials and production processes to meet rising requirements. “That’s how to get the best possible results and advance hydrogen technology,” Möller concluded. ©

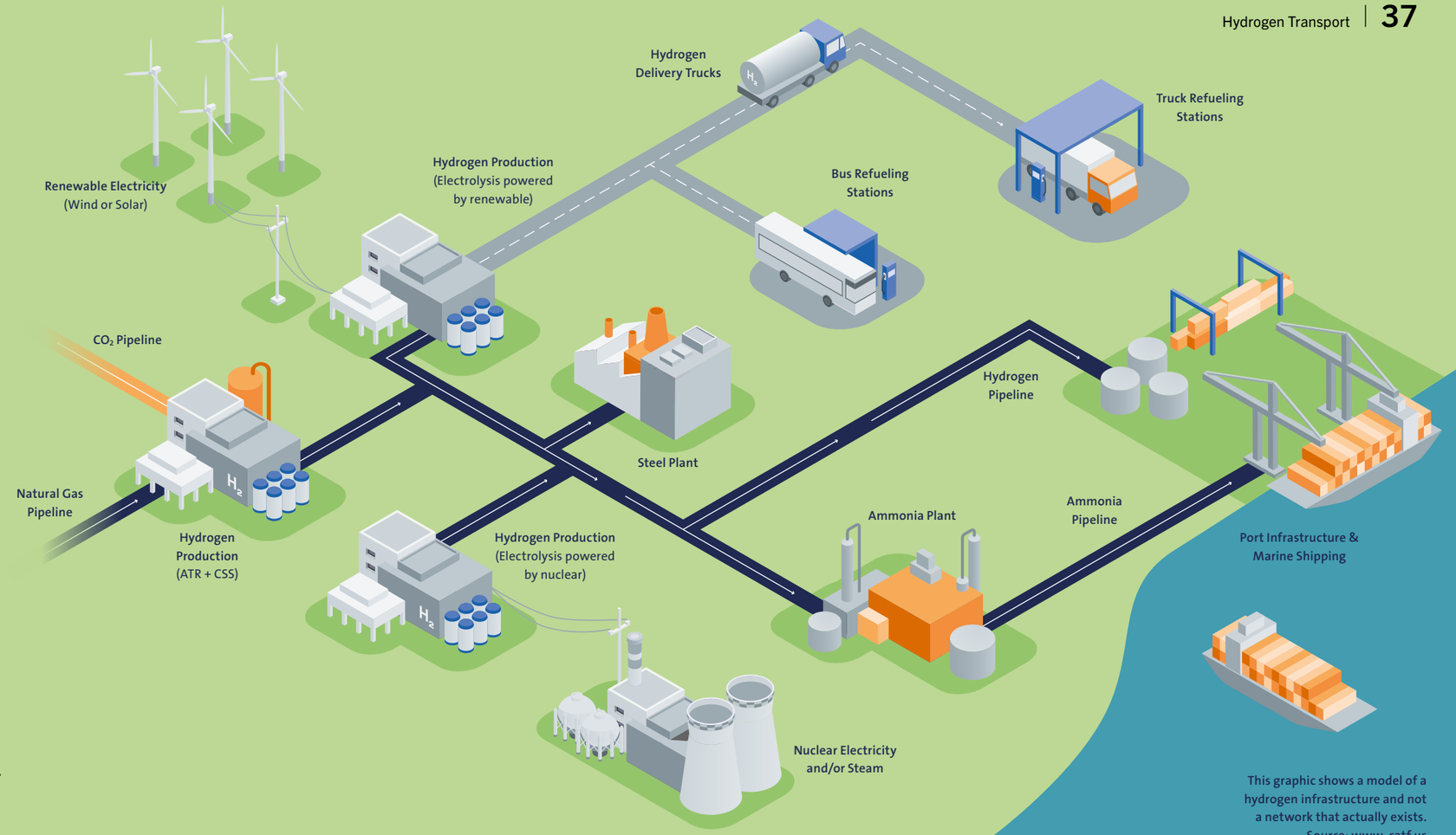
10

minutes is all it takes for a hydrogen fill-up.

Filling up as usual: It only takes a few minutes at the fueling station to give a hydrogen vehicle its full range.

> Our customers see Freudenberg Sealing Technologies as an innovation partner. As we advise them, we draw on our in-depth knowledge of seals, including materials, designs, and production processes.”
>
> Robin Möller, Global Segment Director, Power Generation, at Freudenberg Sealing Technologies

On the Path to Infrastructure



This graphic shows a model of a hydrogen infrastructure and not a network that actually exists. Source: www. catf.us

The demand for green hydrogen is rising steadily. But how does it arrive where it is needed? Dr. Britta Mayerhöfer, Application Specialist, Hydrogen, Freudenberg Sealing Technologies, highlights the challenges and opportunities that a comprehensive hydrogen infrastructure poses.

Hydrogen is no longer considered merely an energy carrier of the future – and it hasn't been for some time. It is seen as an important and established raw material in the chemical industry. Glassworks, steel mills and chemical plants – they all need hydrogen, whether for the production of ammonia and methanol or for the decarbonization of individual process steps. Green hydrogen is needed for the latter. "But it can often be produced more affordably, elsewhere," said Dr. Britta Mayerhöfer, Application Specialist Hydrogen, Freudenberg Sealing Technologies. "This is why it is so important to create a good hydrogen infrastructure. The focus will first be on industry. This is where a large share of emissions can be avoided by using green hydrogen," she said. Aviation and heavy-duty transport are next. "As soon as we have ample amounts of green hydrogen available, we can gradually use it for cars and even for heating."

Imports via Shipping

The first task is to connect industrial sites to the ports. Especially in Europe, many countries will be dependent on the import of green hydrogen, long-term. It often comes from North Africa, South America and Australia – by ship. In gaseous form, hydrogen is too voluminous for this method of transport, which is why it is either liquefied or chemically transformed into ammonia, methanol or methane. The liquefaction of hydrogen is extremely energy-intensive. The gas

Dr. Britta Mayerhöfer

Dr. Britta Mayerhöfer is an Application Specialist on Hydrogen at Freudenberg Sealing Technologies. During her doctoral studies, she focused on electrolysis and electrochemistry and then worked on the development of proton exchange membrane electrolyzers and electrolysis components. At Freudenberg Sealing Technologies, she is responsible for business development in the hydrogen sector worldwide. “We are looking at the entire hydrogen value chain and are investigating applications for their potential and their relevance for different global regions.”

has to be cooled to -253°C (-423.4°F) and maintained at that temperature. This approach is not commonly used for large volumes.

Before transport, nitrogen or carbon is added to the hydrogen to turn it into ammonia or methanol. Ammonia can be transported at a temperature of just -33°C (-27.4°F). Methanol does not need to be cooled at all. “The chemical industry needs both substances as precursor materials,” Mayerhöfer said. “If I can produce them with a green process, that is obviously an advantage.” The chemical industry has a great deal of experience with the transport of ammonia and methanol. But new challenges are proposed by the transport of the huge quantities that will be needed to cover Europe’s needs in the future. “For that, we would need sufficient intermediate storage or similar options. And not every port has suitable import terminals for loading and unloading ammonia or methanol,” Mayerhöfer admitted. These chemicals are a threat to bodies of water and subject to specific transport rules. If they escape, they are toxic to aquatic life.

Uniform European Infrastructure

Once the green hydrogen arrives on the mainland, it can be further transported by train, truck or pipeline. “As part of the Green Deal, people are striving for a uniform domestic market so that the hydrogen can be easily transported across national boundaries within the European Union,” Mayerhöfer said. But that’s easier said than done. “In Europe, a great deal of coordination is needed before a joint hydrogen network can be launched. That takes time,” she said. The situation is different in the United States, for example. “Here hydrogen hubs – that is, model regions – with a strong local focus are being set up. They cover almost every aspect of the value chain, from production to transport, all the way to the end-user.”

New Materials for Compressors

Hydrogen can be transported via pipeline wherever the networks of the future extend over the mainland. The advantage: neither liquefaction nor transformation is required. In some cases, even existing natural gas pipelines can be used, Mayerhöfer said. “As long as we are transporting natural gas as an admixture with 5-to-10% hydrogen content, the existing infrastructure can continue to be used for the most part.” But for pure hydrogen to go through the lines, a change in the equipment would be necessary. The seals along the pipelines would have to be checked for compatibility with the much more volatile hydrogen. Mayerhöfer sees compressors as the main problem. “The turbo compressors used in natural gas networks are not well-suited to create the required pressure for hydrogen. Yet compressors are critical to guarantee that hydrogen flows through the pipeline at the right pressure. “That’s why Freudenberg Sealing Technologies is focusing on the seals for piston compressors,” she said. “We are optimizing our materials precisely for the operating requirements of the compressors.”

In the future, LNG terminals could be used for the interim storage of imported hydrogen and then its further distribution.

–253° C

(-423.4°F) is the temperature required to maintain hydrogen in liquid form.

A Lack of Certainty

So Freudenberg will be ready when the pipeline network is expanded. But the core hydrogen network is currently under construction and is not expected to be finished until 2032. And a crucial ingredient – the hydrogen – is still lacking. “That’s a basic problem. There is not yet enough green hydrogen for large investments in a comprehensive infrastructure to be worthwhile. On the other hand, it is hard to make a strong business case for hydrogen when the required infrastructure for transport and distribution is lacking,” she said. Unlike renewable energy, such as solar facilities, operating costs come into play, and not just investment costs. “Green hydrogen is still significantly more expensive than the gray variety, and companies have few incentives to invest in green hydrogen.”

Political leaders would have to create them. “Expanding the supply of green hydrogen will take planning certainty for both producers and consumers,” Mayerhöfer said. Since it is still under development, the regulatory regime is another reason for delays in the expansion of the hydrogen infrastructure. “At the moment, there are many ideas on the form of hydrogen and what route it will take from the production site to the end user. We are taking many directions in our research and development at once,” she said. But a clear framework is needed to ramp up hydrogen production and expand the infrastructure for it as quickly as possible. “Together with our customers, we have found solutions on a small scale for many of the challenges. As soon as we know where we are headed, we can start scaling them up.” ◎

Pressing Ahead on Hydrogen

Hydrogen must be highly compressed so it can be transported and used. But the process pushes existing compressor seals to their limits. They wear out more quickly than they should. Wanted: a new idea.

700 bar

are needed for hydrogen applications – a demanding level of pressure.

About two years ago, customers began telling Dominik Schneider, Segment Manager, Fluid Handling Europe, about a problem. Their compressors, which subjected hydrogen to pressures ranging from 700 to more than 1000 bar, often needed maintenance. It turned out that the seals are exposed to enormous stresses and wear out very quickly. "The users would prefer to service their equipment once a year," Schneider estimated. The current interval for small, unlubricated compressors is closer to every four months. And every breakdown costs money.

Hydrogen needs space. In most cases, it emerges from electrolysis at a pressure of about 20 bar. That means it takes roughly the volume of an Olympic pool to store 100 kilograms of hydrogen at this point. That's too large a volume for transport. The obvious solution is to compress the hydrogen. It is pumped through lines at about 70 bar. At the point of fueling an automobile, if not sooner, the pressures of 700 to more than 1000 bar, cited above, are required. Then a kilo of hydrogen would fit in a typical commercial refrigerator.

A variety of different methods and tools can be used to compress hydrogen. One is the piston compressor, a technology that dates back to the 18th century. It can produce very high pressures. But hydrogen is a challenge: The gas has to be compressed in a dry-running process and diffused through metal in the bargain. The high pressure leads to very high temperatures and puts a strain on the seal. There was a reason why Freudenberg Sealing Technologies did not occur to Schneider's customers at first. "Many people were not aware that we had piston seals in our portfolio," he said. The quantities also tended to be small, leading customers to source them directly from distributors.

> Here we are talking about the famous green field."
>
> Dominik Schneider, Segment Manager, Fluid Handling Europe

Piston Compressors Are Versatile and Vary Widely

Much like other processes involving hydrogen, it is not clear which technology will prevail. They are versatile, vary widely, and can regulate flow rates. "This makes it possible to repeatedly compress hydrogen to gradually increase the pressure – and do it very elegantly," Schneider said. But the way seals have been designed so far, they wear out too quickly. What is needed is a new idea, an innovation that charts a new course.

In all probability, the seal for high hydrogen compression would have to be completely reimagined. "Here we are talking about the famous green field," Schneider said. The functionality would have to be impressive, and none of the options are today. Engineers won't be getting a finished drawing – they have to set out on their own. "You don't see much of that." That means Freudenberg Sealing Technologies can play to its own strengths as a company: a knowledge of materials as well as expertise in design and scaling. And most of all, an inventive spirit.

Wanted: The Right Combination of Material and Design

The design and the choice of material, will likely be the crucial challenges. A combination is needed that produces little wear at high pressures and temperatures, and at sliding speeds up to 5 meters per second. Freudenberg Sealing Technologies has extensive materials expertise, in part due to projects involving high-performance plastics in recent years. Testing is a watchword since the solutions are only possible when there is cooperation with customers. That's another reason why Schneider is thankful that companies have been approaching him. One thing is clear: "The solution will take time." It will require tests and trial runs. "With their own tests, it is impossible for customers to know why something doesn't work – that is our job." In turn, engineers cannot do their development work without an error analysis onsite when the compressor is in operation. "With our know-how and our technology, we can assess and analyze a great deal ahead of time," Schneider said.

Freudenberg Sealing Technologies is imposing a restriction of its own on the product, stipulating that it be PFAS-free. That means it will do without per- and polyfluorinated chemicals. "When we are doing the development work, we want to seize the opportunity to keep the production process clean, including the production of materials," Schneider said. That is just being consistent with the energy source's promise of a clean future. Schneider is convinced that this promise will soon be a reality. "Hydrogen is here to stay."

COUNTRY FOCUS

The Space for New Ideas

Raw materials colossus Australia is embracing green hydrogen. Its sunny weather and windy coastlines are ideal for the technology, and industry is interested. A great many opportunities for innovation are opening up.

Coal and natural gas have made Australia one of the world's largest energy exporters. It has recently been selling about 370 million tons of coal annually, second only to Indonesia. The country even tops the list of liquid natural gas exporters. And more than half of the world's iron ore exports come from the continent. Without a doubt, Australia is the powerhouse of heavy industry worldwide, the raw materials colossus of the 21st century.

3,000

is the number of hours of sunshine in the sunniest regions of Australia, on average.

Australia's Potential for Green Energy

But Australia also has superb conditions for renewable energy. The country is on par with southern Europe and California with up to 3,000 hours of sunlight per year. It also has large, thinly populated areas available for solar installations. Strong, stable westerly winds provide the ideal conditions for wind turbines on its long coastline. As a result, the economic winds have been shifting toward hydrogen for several years. Since 2019, the country has had a national hydrogen strategy, currently with numerous funding initiatives and the "Hydrogen Headstart" program, which is providing more than 1 billion euros in subsidies.

"We are seeing massive interest in investment from the private sector, including a few big names," said Benjamin Crouch, National Business Development Manager for Freudenberg Sealing Technologies in Australia. Crouch has been heavily involved in shifting the business's focus to hydrogen. It had tended to concentrate on classic products until now. "I believe the segment will soon be larger than anything that we did previously in Australia."

Australia has embarked on a journey toward green hydrogen. According to some experts, the shift is urgently needed even if fossil resources are available at attractive prices at present.

"If Australian industry doesn't start using hydrogen while it's expensive, it won't have the option to use hydrogen cheaply in the future," warned the Melbourne-based think tank Grattan Institute, among other observers. Crouch sees many companies agreeing with it. "The market is extremely dynamic." Startups coming from university projects are competing with large companies from the fossil energy sector. Each side has its strengths and challenges. That is presenting Crouch with some exciting possibilities. "We are working with very different customers," he said. It takes material expertise to identify the best solutions and future standards, and the willingness to work together and experiment. "That's what people appreciate about us since these are the strengths of Freudenberg Sealing Technologies."

Dynamic Market: Engineering Innovation in Demand

Crouch sees the greatest potential from electrolyzer manufacturers. The segment is in flux: Many different ideas are being tested and positioned for success in the market. Engineering

innovation is especially in demand in seal design – as is the ability to quickly scale up production. These issues are pluses for him and his team. But special challenges lurk in this very dynamic market. “We are seeing customers leave details out of the description of their requirements. They want to protect their ideas despite the nondisclosure agreements.” That can prolong processes, yet Crouch is not overly concerned. “Trust comes with time and with good cooperation.”

There is another issue that applies to Australia: Hydrogen keeps the entire value chain busy, from production to transport and storage, all the way to its use. Exporting hydrogen poses a significant hurdle. Since it is surrounded by water, the country relies on shipping. But Crouch sees the search for solutions picking up speed. Considerable funds are being spent on port infrastructure and hydrogen hubs where production, processing and logistics are concentrated as much as possible. Given the immense distances in the country’s interior, the hubs present Crouch’s team – which is still relatively small – with the opportunity to support customers at these key centers.

Green Steel: An Australian Advantage?

The prospect of “green steel” is especially well-suited to Australia. The country’s immense iron ore exports hide the fact that companies can make more money when they convert iron ore directly into steel. But traditional steel production produces a great deal of CO_2. With hydrogen, on the other hand, the steel would be produced sustainably, making it attractive internationally. The idea is appealing given the good conditions for hydrogen production in the country. But it continues to be associated with high costs and the appropriate infrastructure for the plants is still needed. The challenge applies to nearly every aspect of hydrogen, so it is more of a reason to tackle the transformation – and less of an obstacle to it. “We are still a couple years away from the breakthrough,” Crouch said. “But many decisions will be made over the next 12 months.” ◎

Benjamin Crouch

Born in Britain, Crouch has about 15 years’ experience in the oil and gas sector in his home country and in Southeast Asia, among other locations. He moved to Australia four years ago looking for a new challenge and new fields to explore. His experience and contacts in the energy sector were helpful because many people from the oil and gas industry are now working in the hydrogen field. Crouch is now National Business Development Manager and Western Australia State Manager for Freudenberg Sealing Technologies.

NOW IT’S MY TURN

Hydrogen

I am a very useful gas. But it’s been an uphill battle for me. One reason is the “Hindenburg” disaster at Lakehurst, New Jersey, in 1937. Also known as Zeppelin LC 129, the airship burst into flames as it attempted to land. Thirty-six people lost their lives. The tragedy marred my image for generations. Today, we know that the explosion was triggered by the material coating on the textile used to make the airship’s hull.

The level of protection today is very high, thanks to state-of-the-art technology, so accidents fortunately are rare. Refineries, the chemical industry and semiconductor manufacturing, for example, have been using me in large quantities for decades.

Material research has led to decisive progress. Tanks, lines and seals today are made of specially developed materials. There are also guidelines for weld seams. They all make hydrogen systems highly resistant to damage and minimize the risk that I might escape in an uncontrolled release. Advanced sensors and monitoring equipment identify even the tiniest leaks and introduce the appropriate safety measures. Automated shut-off systems help to neutralize potential hazards. Tanks and lines are generally designed so that a release would be controlled if there is an accident. All of this greatly reduces risk.

That’s why experts have long considered me just as safe as other combustible substances. Responsible handling is always in order. I started out as a gas classified as dangerous and have become a safe, promising alternative for energy production and storage. I am looking forward to the future. ◎

FASCINATION TECHNOLOGY

At Its Best Under Pressure

Durable, high-performance seals are a key to producing hydrogen with electrolyzers, and the right designs are crucial. Freudenberg Sealing Technologies is scoring points with a novel high-pressure gasket.

Initial Situation

Different forms of electrolysis are suited to various purposes. Electrolyzers with a polymer electrolyte membrane (PEM) stand out for their fast cold starts and quick response times. For example, they are especially suited to applications where electric current has to be drawn off in the shortest possible time. That's the case with electricity from wind turbines, whose output naturally fluctuates. PEM electrolyzers have a market share of about 30% worldwide, and that percentage is rising – not least of all because the underlying technology is becoming more mature.

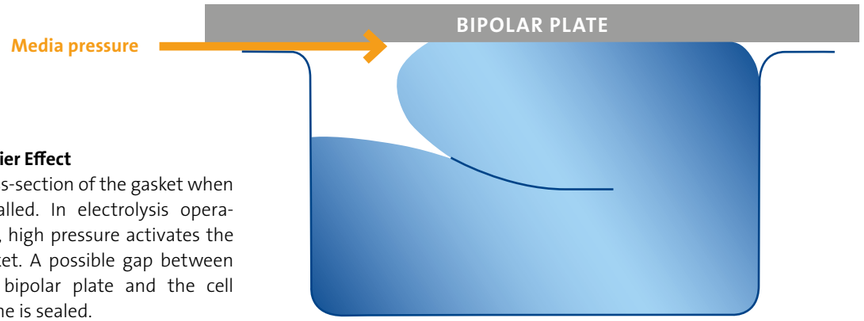
The Problem

Gaskets in PEM electrolyzers are important safety components. After all, they seal off electrolytic cells from one another, ensuring that the gaps in bipolar plates are sealed. They also prevent gases and liquid media from escaping into the environment. Standard gaskets like those used in the automotive industry are totally unsuited for electrolyzers due to the increased pressures that are involved. To seal the cells against each other, the gaskets must be inserted into grooves in the cell frame. The gasket's instability in the groove turned out to be a drawback at high pressures.

The Solution

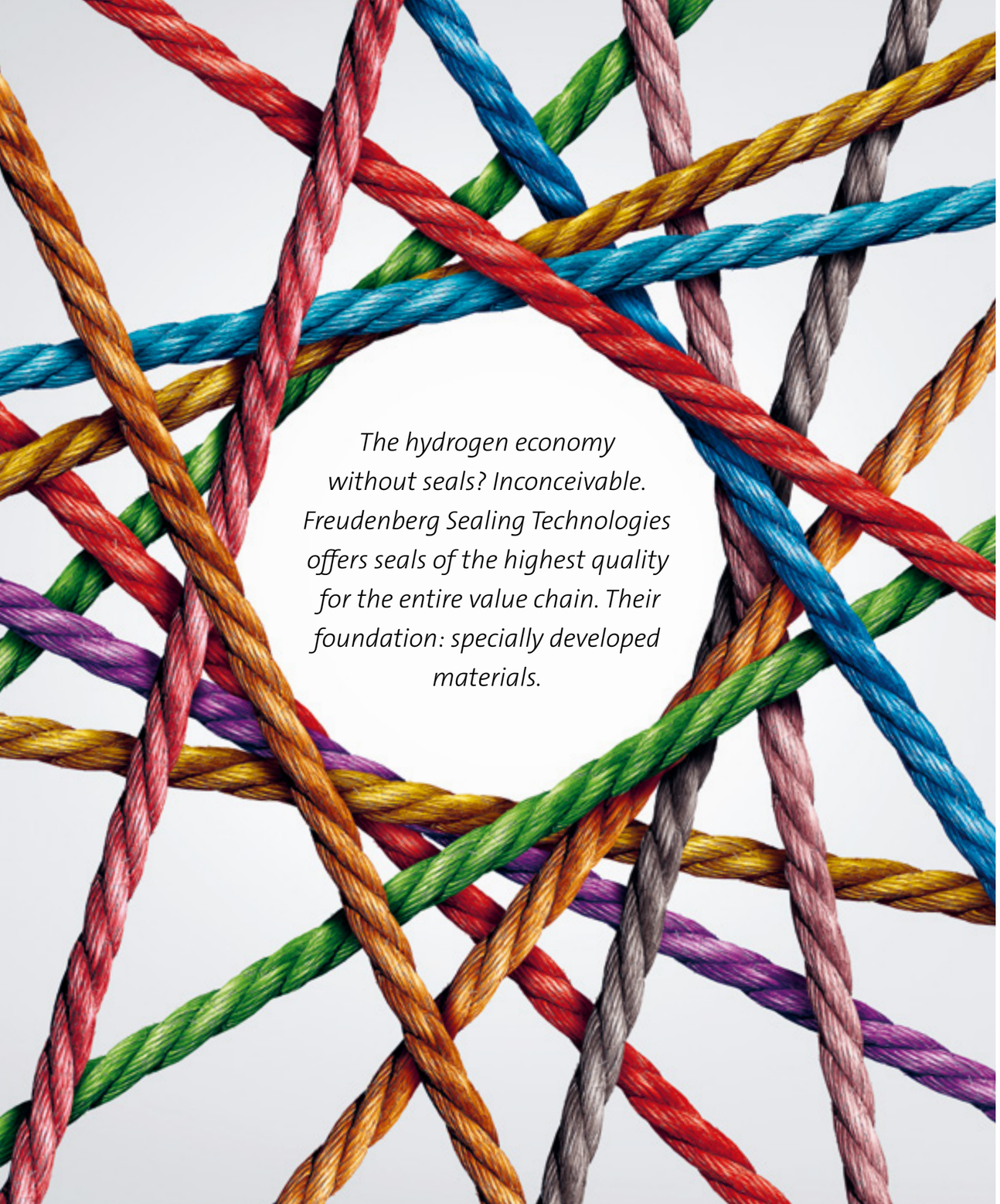
Freudenberg Sealing Technologies focused on the gasket design. The new gasket has been given small retaining features on both sides to lock it into the groove. This holds the part in place after assembly. Engineers selected a novel L-shape for its cross-section. As soon as the electrolyzer is in operation, the pressure rises in its interior and activates the gasket, which then assumes a C-shape. The gasket's contact pressure increases to make it a reliable barrier. The high-pressure gasket impressed customers when they tested it themselves, and they are already using it in series production.

Lock
Cross-section of the gasket during the assembly process into the groove of the cell frame. The retaining features on both sides hold the gasket in place.



Barrier Effect
Cross-section of the gasket when installed. In electrolysis operation, high pressure activates the gasket. A possible gap between the bipolar plate and the cell frame is sealed.

Learn more about seals for electrolyzers at FST.com



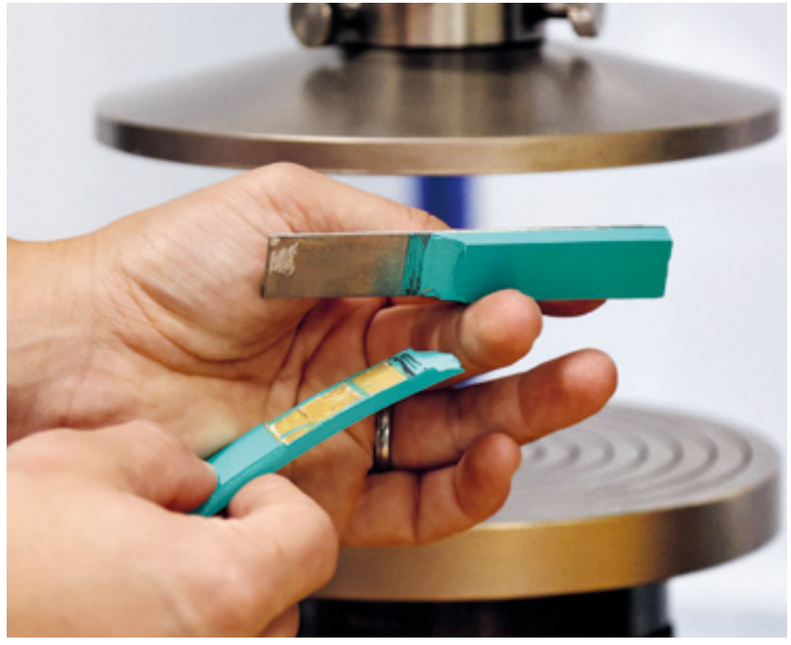
Made-to-order and Multifaceted

Materials for the hydrogen economy must meet extremely stringent requirements. To start with, hydrogen is the smallest chemical element on the periodic table. The diameter of a hydrogen molecule is just 0.07 nanometers, or less than a billionth of a meter. That means hydrogen gas can penetrate the tiniest openings. “The permeation definitely has to be minimized, more to make systems safe and less due to losses in efficiency. If the hydrogen reaches the ambient air, the mixture with oxygen could quickly explode,” said Dr. Alexander Hähnel, a chemist. He is a member of the Technology & Innovation team working on hydrogen applications at Freudenberg Sealing Technologies.

Facility operators are also insisting on tremendously long operating lives for seals. For example, an electrolysis system is expected to run nonstop for at least 10 years. That’s why their seals are designed for a lifespan of 100,000 hours.

If a sealing material has to maintain its full function over the entire lifespan, it cannot be allowed to age prematurely. It is not the hydrogen that attacks the rubber material. It is rather the side effects of the particular application. They result from high temperature and pressure differences interacting with large temperature fluctuations.

For example, when hydrogen tanks are filled up, explosive decompression can result in the event of very fast changes in pressure. Gas bubbles explode in the sealing material as they do in the blood of a diver ascending too quickly from deep water. Fine cracks are the result, along with an irreversibly damaged material structure. Other chemical effects cause the seal’s rubber compound to age. One example is oxidation from the oxygen in an electrolysis system. At a system pressure of 35 bar, the oxygen content is 175 times greater than the level in ambient air. The impact: Extremely



High standards: Lab investigations and component tests are essential elements of seal development.

100,000

hours is the target operating life for seals in electrolysis systems.

> The material is the key to the seals' optimal performance and the perfect operation of any system."
>
> Jürgen Emig, Director, Pre-Product Development Hydrogen Applications, at Freudenberg Sealing Technologies

aggressive oxidation acts on the sealing material and greatly accelerates the aging process. High temperatures intensify the effect.

A Material's Selection Is Based on Pressure, Temperature and Duration of Operation

"The material is the key to the seals' optimal performance and the perfect operation of any system," said Jürgen Emig, plastics technology engineer on the Technology & Innovation team. "We develop components specifically for a particular application. Our strength: The company recommends the optimal design to the customer based on the best-possible materials in close coordination with the requirements profile. The seals deliver the desired performance over the entire required lifespan." Experts from various disciplines pull together – true to the company's guiding concept of "Innovating Together." The seals can also be combined with various other components to form a single part. Some examples are bipolar plates, thermoplastic films and gas diffusion layers.

The product portfolio for the hydrogen economy is wide-ranging. Two examples: Especially for low-temperature, proton exchange membrane (PEM) fuel cells, Freudenberg Sealing Technologies has developed the 35 FCPO 100 as a material for seal cells. "It is a very clean elastomer based on polyolefin," said Dr. Hähnel. "It contains no harmful substances that could damage the catalysts of a fuel cell or otherwise reduce its efficiency." The portfolio also contains LSR (liquid silicone rubber) materials.

The company also has a made-to-order sealing material for high-temperature fuel cells running as high as 200°C (392°F). The material 60 FC-FKM 200 – FKMs are fluorocarbon rubbers – established itself in the market early on. Due to a change in the raw material, 70 FKM 256261 recently advanced to the industrial stage, becoming its successor. Like 60 FC-FKM 200, it releases no substances that would impair a fuel cell's operation. Another advantage: The material is just as suited to PEM electrolysis. "The first series production for cell seals using 70 FKM 256261 was launched recently," Emig said. At present, EPDM (ethylene properly diene rubber) is the standard for alkaline electrolysis, "We are currently working on a material class with an even longer lifespan."

Investment in Sophisticated Test Facilities

Freudenberg Sealing Technologies' expertise relies on more than just materials, design and production processes. Wide-ranging lab research and component testing are essential components of its development process. Does a newly developed material meet the objectives set for it? Older testing technologies are reaching their limits in light of the more demanding requirements. "We want to know in greater detail what happens under operating conditions so we can do our development work even closer to real-life applications," Dr. Hähnel said. "Depending on the result, we are adjusting recipes and processes, pushing the limits of what is feasible." All the tests make material qualities comprehensible to customers and allow operating life estimates for entire systems.

Freudenberg Sealing Technologies is now investing in other test equipment that will play to its strengths, especially in hydrogen applications. Some examples are new test stands to measure impermeability with higher precision and a greater range of pressures. Experts can gauge the impact of higher oxygen concentrations on aging with targeted tests. Electrochemical test stands are also expanding horizons: "Properties are affected by the electrical current running in the technical processes of fuel cells and electrolyzers. Now we can apply electric current to materials on a targeted basis and examine the effects," Emig said. A number of research projects are also underway to explore material effects even more fully.

"This is the highest level of material development. The work is paying off. Our customers are purchasing considerable know-how with every seal," Dr. Hähnel said. "In exchange, they are mainly getting higher process reliability for their facility." ◎

June 2024

Aftermarket: Heavy-Duty-Segment Expanded

With its Corteco subsidiary, Freudenberg Sealing Technologies now stands for high quality and innovation in sealing systems for the heavy-duty aftermarket. It is putting a special focus on radial shaft seal rings specifically developed for the demanding conditions faced by construction and farm machinery, along with heavy-duty applications. In past years, Corteco has steadily expanded its market share in the heavy-duty segment. The trend is expected to continue in 2024 with more product groups such as accumulators. Freudenberg Sealing Technologies is moving well beyond the requirements of particular OEMs. One example is the world's largest testing facility of its kind in Weinheim. Seals and other products are tested under simulated conditions on more than 300 test stands to guarantee performance over more than 300,000 kilometers (186,000 miles). The wide-ranging tests make sure that the products are prepared for all real-life applications. The demand for high-quality products in the heavy-duty segment has been growing steadily, especially in the aftermarket. A seal costing just a few euros can help protectan investment valued at several hundred thousand euros. Reliable, high-quality products in this segment are of paramount importance. ◎

February 2024

Major Orders for DIAvent®

With its DIAvent® HighFlow component, Freudenberg Sealing Technologies is offering a pressure compensation element that is unique in the industry and makes the lithium ion batteries for electric cars safer. The auto industry, including one Asian and one U.S. car company, has demonstrated its interest in the technology by placing several major orders. To meet the huge demand, Freudenberg Sealing Technologies has tripled its production capacity on short notice. At the start of 2023, the first completely automated high-tech production cell for the DIAvent® HighFlow went into operation. A second followed in December 2023. A third DIAvent® production line is starting up in Berlin this year. And there is more: To fill a major order in the U.S., Freudenberg will begin operating another assembly line at one of its North American sites, Shelbyville in the U.S. State of Indiana, further expanding its capacity. ◎

May 2024

A Boost for the Service Business

Freudenberg Sealing Technologies acquired the corporate group Trygonal on April 30, 2024, strengthening one of its global business units, Freudenberg Xpress®, and the company's in-house service business in the process. Trygonal manufactures sealing solutions in thermoplastics, elastomers and rubber-metal composites at eight sites in Germany, Spain, Austria and Switzerland. Trygonal can call on a wide array of production processes. With the acquisition, Freudenberg Xpress® expands its current core business in CNC-machining. ◎

More news online at: https://on.fst.com/2PCI9mR

August 2024

Optimal Higher Pressures for Heavy Vehicles

Freudenberg Sealing Technologies has improved its seals for Central Tire Inflation Systems (CTIS) used in construction and farm equipment. The new systems adapt tire pressure automatically to changing ground conditions and vehicle loads. This saves time, reduces CO_2 emissions and extends tire operating life. The rationale is that tire pressure has a major impact on the performance of heavy vehicles, and can even cause ground damage. The CTIS technology from Freudenberg uses a double-lipped seal in the wheel hub. It separates oil from compressed air and allows adjustments in tire pressure without an external hose. That means the seals positioned in the wheel hub are protected from external influences. This is a unique selling feature and represents an advantage over competitors. The CTIS systems combine advanced material and design know-how with state-of-the-art electronics and sensor technologies. They are installed directly into axle applications on the manufacturer's production line. Freudenberg has been providing CTIS systems for more than 15 years. ◎

Feedback and Contact

More Information
Would you like to learn more about Freudenberg Sealing Technologies, our products, solutions and services? Then take a look at **www.fst.com** and discover our wide-ranging portfolio. On our Internet site, you can also download all the issues of our company magazine as PDFs or subscribe to the magazine at no charge.

If you no longer want to receive ESSENTIAL, simply send an email including your address to: **essential@fst.com**

We look forward to a dialogue with you!

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Outstanding Communication

We cover current, entertaining and astonishing topics for you with the same passion that drives our development of high-performance products. With some success, as these awards for our company magazine ESSENTIAL clearly show.

MarCom Awards 2023 – Platinum
Publications | Magazine | Corporate

MarCom Awards 2023 – Gold
Creativity | Design | Magazine Cover

Galaxy 2022 – Silver
Category Brochures – Corporate Magazine

Galaxy 2022 – Gold
Trailer, Videos – Promotion

Internationaler Deutscher PR-Preis 2021 – Finalist
Category Corporate Media (Print and Online)

Videographer 2019 – Gold
Trailer Thirst, Category Video Production | Video | 43. Other

Videographer 2019 – Gold
Trailer Digitalization, Category Video Production | Video | 43. Other

BCM Award 2023 – Silver
Category B2B – Pharma / Chemistry

BCM Award 2022 – Silver
Category Magazine Industry, Chemistry, Pharma, Health

BCM Award 2022 – Silver
Trailer, Category Moving Image Fiction

BCM Award 2022 – Gold
Trailer, Category Audience Award

ICMA 2021 – Best of Decade
Category Customer Media B2C

Communicator Awards 2019 – Silver
Category Marketing / Promotion – Magazine-Corporate

PR Daily Award 2019 – Winner
Category Print Publication

FOX AWARDS 2022 – Gold
Category Industry, Technology, Production

FOX AWARDS 2022 – Silver
Trailer, Category Industry, Technology, Production

FOX AWARDS 2021 – Gold
Category Industry, Technology, Production

FOX AWARDS 2020 – Gold
Category Transport, Logistics

FOX AWARDS 2019 – Gold
Category Industry, Technology, Production

FOX VISUALS 2022 – Gold
Category Industry, Technology, Production

FOX VISUALS 2022 – Silver
Trailer, Category Industry, Technology, Production

FOX VISUALS 2021 – Silver
Category Industry, Technology, Production

FOX VISUALS 2020 – Silver
Category Transport, Logistics

FOX VISUALS 2019 – Gold
Category Industry, Technology, Production

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