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H2 international

THE E-JOURNAL ON HYDROGEN AND FUEL CELLS

20

→ CELEBRATING 20 YEARS OF HZWEI

→ CURRENT HOME FUEL CELL OFFERINGS

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H2 international – E-JOURNAL ON HYDROGEN AND FUEL CELLS

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Cover image Celebrating 20 years of HZwei

A NEW ALLIANCE

Dear readers,

Like other industries, the energy sector has seen events being postponed or cancelled, making it difficult if not impossible to unveil new products, attend discussion panels and meet new people. But the partial lockdown has also opened up some new opportunities. Thanks to greater digitalization, online product presentations can still reach a global audience, face-to-face meetings are being replaced with webinars and video conferences, and phone calls have become an even more important means to stay in touch. Additionally, fewer commutes and business trips leave more time for other things and help reduce environmentally harmful emissions.

Nevertheless, the question remains what to do when an event like Hannover Messe is postponed even though you were planning to attend it to unveil your latest product in front of a throng of journalists?

It may still take a few weeks or months until we know whether shows and conferences will merely be pushed back to a later date. As it looks now, it seems extremely doubtful that those planned for summer or fall can be held. More likely, they will not take place this year at all. It will be interesting to see if and how successfully online solutions, including state-of-the-art communication channels, can replace them for the time being.

Whatever happens, Covid-19 will not be able to severely impede or stop the advance of hydrogen and fuel cells. Growth in the market will slow down somewhat, true, also considering the German cabinet has again postponed the debate on a national hydrogen strategy. We will simply have to be patient. As of this writing, it was not clear when the strategy would be put back on the agenda.

And yet, it is safe to say that the current trend is irreversible. The public discussion on how to transform the energy sector in Germany and the changes we see happening in the market have demonstrated to politicians and the population that there will be no way around hydrogen. A national hydrogen strategy will come. The only question is what it will look like.

However, Germany is not the only EU member that is waking up to the potential of hydrogen and fuel cells. Countries across the continent have realized what key contribution the technology could make to decarburizing the economy. As a result, the European Commission is currently preparing a white paper on how to create a cleaner industrial strategy specifically by using hydrogen.

In early March, the Brussels-based agency announced it wanted to launch a Clean Hydrogen Alliance in collaboration with governments and businesses from across the Union. In order to provide a foundation for this kind of partnership, it has already approved funding based on the IPCEI (Important Projects of Common European Interest) platform. This means we could see an alliance being forged as early as this summer.

Overall, we are moving forward at a decent pace. Considering recent announcements, it seems people are expecting hydrogen to take on a bigger role in the future, albeit some could be setting the bar a bit too high. There is already talk of hydrogen replacing an energy source such as brown coal, a suggestion that is being floated by a top-level executive who works for a large coal power company, no less. Others are saying Germany could eventually become the number one market for hydrogen around the globe, like the United States was for oil and gas for over 50 years. That is quite the comparison.

All of these ideas may seem a bit far-fetched today. Nevertheless, they show what we can achieve by continuing to go down this road. And even though the Summer Olympics that were supposed to take place in Tokyo have been postponed and Japan will not be able to broadcast to the whole world this year what fuel cell vehicles can do, the trend in the market will continue.

In short, we could use this unexpected break from normal life to prepare ourselves for a clean future.

Let me end this editorial by saying that I hope you have enjoyed reading the H2-international journal over the past five years (see pp. 6 and 32) and that we can continue to be your trusted source for news and in-depth reports on the hydrogen and fuel cell sector for a long time to come.

Best wishes,

Sven Geitmann
Editor of H2-international

TOTAL RESTRUCTURING

Since January, Jan Petersen has been in charge of developing forward-looking transportation solutions at Total in Germany. He is heading a new division that aims to install not only ultrafast chargers but also hydrogen and natural gas stations. Bruno Daude-Lagrave, the chief executive of Total Deutschland, said the company created the department to respond quickly to market changes and make an active contribution to emissions reduction. He added that the main goal of Total is to be able to provide the energy needed for future generations of vehicles, a goal that can only be achieved by using a combination of different technologies.

Petersen, who has degrees in physics and engineering management, used to work for Elf and Tyczka Totalgaz, both of which are now owned by the Total Group. He was also the director of retail and consumer business at Total Deutschland and the managing director of Total Mineralöl. ||

SILKE FRANK LAUNCHES MISSION HYDROGEN

Early this year, Silke Frank, the longtime face of the f-cell trade show, left event organizer Peter Sauber Agentur Messen und Kongresse and went on to found Mission Hydrogen in nearby Winnenden on March 1. She had been with Peter Sauber Agentur since 2003 and worked her way up the ladder to become owner and founder Peter Sauber's right-hand woman who oversaw day-to-day operations at the company. In that time, she had, for many years, a decisive influence on how the f-cell show held in Stuttgart was run.

Because of this, Frank was believed to be the one who would eventually succeed him. In February, however, she and Sauber parted ways over differences in their vision for the company's future. Sauber told H2-international that her leaving was "naturally a big loss" but that the f-cell show would continue. However, in late March, Sandra Bilz, who had worked for the business for seven years, left as well. This means Evelyn Hettich is now in charge of the symposium in Stuttgart.

Silke Frank told H2-international she intended to keep doing what a show, conference and event manager was best at and that was connecting people, in her case in the hydrogen and fuel cell sector. The chief executive of Ulm-based Wenger Engineering, David Wenger, wrote about the startup in March: "Mission Hydrogen's aim is to support, promote and enable the hydrogen society long term." The company markets itself as an independent partner to those who want to grow and strengthen the hydrogen and fuel cell community. It is offering consulting services to industry stakeholders and has also been planning to launch new events together with other hydrogen and fuel cell organizations.

Peter Sauber Agentur and Mission Hydrogen had both partnered with scientific institutions located in different German states to bid on hosting the 23rd World Hydrogen Energy Conference 2022 in Germany before it was announced that the WHEC would be postponed by two years because of the Covid-19 virus outbreak. As the next conference will reportedly be held from June 26 to 30, 2022, in Istanbul, it is now entirely unclear when the event will take place in Germany again. ||

HYDROGEN COUNCIL EXPANDS ITS INFLUENCE

Following an influx of new members, the Hydrogen Council has seen its influence grow around the world. In mid-January, the association said several global players, including Chevron, ElringKlinger, Mann+Hummel, McDermott and Nikola Motor, had joined the council in supporting roles. Its steering committee had also grown by five new members, namely CNH Industrial, Michelin, Saudi Aramco, Schaeffler and Siemens. And another five, all of which operate in the finance sector, have formed an investor group. The organization's membership total now stands at 81.

Benoît Potier, co-chair of the Hydrogen Council, which was founded by 13 organizations in 2017, said that the association was "very pleased to see continued interest from world-renowned companies," businesses that "recognize the massive potential of hydrogen and share our mission of scaling up hydrogen solutions." Co-chair Eui-sun Chung added: "We believe in the power of hydrogen and the role it can play in our existing energy system as well as a new, cleaner one." ||

IN A POSITIVE MOOD

The Automotive Business Barometer has found that a clear majority of executives working in the auto industry wish automakers and politicians in Germany would support more of the technologies deployed in electric vehicles. Over 80 percent of those who took part in the survey criticized the current focus of politics and industry on all-electric transportation.

Early this year, online market research firm Dynata conducted a survey on behalf of PwC Strategy& among more than 200 executives working in the German auto sector at manufacturers, suppliers and dealerships that generate annual revenues in excess of EUR 500,000. They said electric transportation, fuel cells and batteries were the most important future-proof markets in need of innovation and believe their own companies to be relatively well-prepared for the challenges ahead, in particular when it comes to electric motor technology. However, almost two-thirds doubt alternative motors will ever be able to fully replace combustion engines. >>

Peter Gassmann, Managing Director of PwC Strategy& Europe, said that Germany, as well as Europe, will need to rethink its reliance on manufacturing facilities in Asia and build up local expertise and capacities. This could help ensure that “the auto industry, as one of the country’s most important industries, can stave off competition from the US and China.“

Another survey, conducted by Kantar Emnid for gas network operator Open Grid Europe, found the German public to have quite a positive attitude toward hydrogen. Most respondents saw it as an important technology to complete the country’s transition to a renewable economy. In all, 69 percent viewed hydrogen as future proof and expect it to make an important contribution to transforming the energy market, while 76 percent agreed that politicians and business leaders needed to increase investments in the technology and offer more support for the sector. ||

HZWEI TURNS 20

Fig. 1: First cover of HZwei, from January 2006

It has been over 20 years since the “Magazin für Wasserstoff und Brennstoffzellen” started covering the hydrogen and fuel cell sector. H_2Tec, as it was called at the time, was launched by Hanover-based SunMedia Verlags GmbH at the turn of this century. In 2005, the company decided to cease publication and transfer the rights to the trade magazine to Hydrogeit Verlag, a small publisher that had been founded in Kremmen in 2004 and had since become Germany’s premier source for books about hydrogen and fuel cells.

The H_2Tec magazine was issued twice a year and was printed mainly in two colors, blue and black. With 20 or 24 pages, it was relatively thin. But as a quick look in the archive will show, some of the experts who used to write for the publication are still working in the hydrogen and fuel cell sector today.

When Hydrogeit Verlag took over, it changed more than the name on the magazine cover. Issues were now 32 pages and came in an entirely new design (see fig. 1, plus cover collage on p. 32). Since then, the magazine has grown with the rising interest in hydrogen and fuel cells. Today, it is an average of 64 pages. Hydrogeit Verlag also did away with the English paragraphs that summarized a few of the articles in H_2Tec. Instead, it launched an English edition of HZwei, as the magazine was now called, in 2015 and named it “H2-international – the e-Journal on Hydrogen and Fuel Cells.”

Sven Geitmann, the editor-in-chief and founder of Hydrogeit Verlag, was pleased to note that “now in its 15th year, HZwei has grown more popular than ever. I would like to thank all our contributors, who have helped turn this magazine into an industry staple and continue to fill its pages with novel and exciting stories each quarter.“ He said that “Hydrogeit Verlag will keep working hard to ensure we produce a publication that both champions and challenges the hydrogen and fuel cell industry.“ ||

VIESSMANN SHUTS DOWN HEXIS

On March 19, German heating manufacturer Viessmann, based in Allendorf, announced it would shut down Hexis, its subsidiary in charge of developing SOFCs. The headline of the press release sounded rather innocuous: “Viessmann takes new path to implementing future-proof technology.“ However, in the third paragraph, the company then said it “will discontinue operations at Hexis.“

It went on to write that while it had taken note of ”the growing importance of hydrogen and fuel cells in supplying energy to homes in Germany as well as Europe“ and intends to stay committed to the technology, it will no longer manufacture its own devices, offered across Europe since 2014. They will be replaced by a Panasonic PEM system, which is run at relatively low temperatures and is suited especially for new or recently renovated buildings. In Japan, Panasonic has already installed more than 290,000 of the devices.

Compared to the Panasonic system, the SOFC unit made by Hexis has always been at a disadvantage. Run at higher temperatures, the module was designed to provide power mainly in existing building stock at higher output. Named Galileo, it worked as expected but was expensive and less tried and tested. Hexis said several hundred of the devices had been installed as part of multiple demonstration projects.

Consequently, the parent company’s management decided to keep offering both PEMFCs and SOFCs but limit itself to the role of system integrator. Viessmann is now looking for industrial partners from which it could purchase the fuel

Galileo device showcased at the IBZ booth at Hannover Messe in 2015 cell technology, with the aim of reaching economies of scale in much less time.

The shutdown marks the end of an era for the subsidiary's 40 employees, 34 of whom were based in Winterthur in Switzerland and six in Constance in Germany. Founded by Swiss-based Sulzer in 1998, Hexis almost had to file for bankruptcy in 2006 but was saved by Viessmann, which acquired 50 percent of the company in 2012 (see the photo of Hannover Messe 2012 on p. 3 of this issue) and the second half in 2015. As recently as 2019, Hexis announced it was working on the next generation of fuel cell systems, called Galileo 1000 N. Volker Nerlich, longtime sales director at Hexis, left the business last summer. It is still unclear what will happen to its other employees. A spokesperson for Viessmann said the parent company was in regular talks with Hexis staff to find solutions that will benefit everyone.

Alexander Schuler, the chief executive of Hexis, told H2-international that "this is a sad time for us, but we have not given up as a team. Making the decision public could open an opportunity for finding new investors or partners that can help us scale up the technology. We have been assured the equipment in Winterthur and Constance will be kept for another two months so we can start looking. Likewise, Viessmann would be the first customer, or client, of any such venture. We are now concentrating all our efforts on finding a solution so we can keep making fuel cells." ||

HYVOLUTION TO BE HELD ANNUALLY

Twenty years later and a country apart, the French HyVolution show brings back memories of how Hydrogen + Fuel Cells Europe started out at Hannover Messe in Germany. Launched by Bertrand Chauvet, the president of Seiya Consulting, the first HyVolution attracted a relatively small number of exhibitors and attendees when it was held in September 2013 in Albi. After a short stint in Grenoble in 2014, it found a permanent home in Paris two years later as GL Events took over management of the event.

In the meantime, the French government has also started to promote the hydrogen market, so that HyVolution has turned into a global show buzzing with activity. In all, 120 exhibitors presented their products to over 2,000 industry professionals who attended HyVolution between Feb. 4 and 5, twice as many as in 2018. Hype, a French operator of hydrogen taxi cabs, came to the event with 15 Toyota Mirai cars to shuttle visitors between the metro station and the expo area. The number of people asking for its hydrogen taxi services in Paris is so high that Hype decided not to promote its smartphone app, as it can no longer meet all requests.

Although French exhibitors and attendees were again in the majority this year, interest in the Paris-based show has been growing around the world. For example, many German businesses have been pushing into the French market, and HyVolution is offering them an ideal opportunity for establishing a network in France. Some of the other exhibitors at the event were from Belgium, Canada, Denmark or the UK. Both they and the attendees had many positive things to say about the conversations they had and they people they got to know, even if it is not always easy for foreign companies to get a foot in the door.

Additionally, FCH JU took advantage of the opportunity to run an information day on upcoming EU requests for bids in the sector, while members of the Hydrogen Valley Partnerships based in France, Germany, Greece, Italy, Scandinavia, Scotland, Spain and Portugal decided to hold their third plenary session at HyVolution. The Espace Ateliers served a purpose similar to that of the Public Forum at Hydrogen + Fuel Cells Europe, namely offering a central platform where exhibitors could showcase their expertise. The roundtable discussions, held mostly in French and sometimes in English, were recorded for broadcast on TV. The show even had a space allocated for business meetings. Although a few things could become a bit more intuitive, it is clear that the Paris HyVolution show, which GL Events is planning to hold annually from now on, has become a big asset to Europe's hydrogen and fuel cell community.

In 2021, HyVolution will take place on Feb. 10 and 11 at Parc Floral on the outskirts of Paris. ||

Author: Uta Mummert

POSTPONED OR CANCELLED EVENTS

Many events that were to be held this spring have been either cancelled or postponed because of public health concerns over Covid-19. Hannover Messe and Düsseldorf-based Energy Storage Europe will only return in 2021, the latter between March 16 and 18 next year. Essen-based SHK, the largest show for heating and sanitation in Germany, has been rescheduled to take place in late summer, from Sept. 1 through 4, 2020. The global impact of the coronavirus pandemic has also affected the Vancouver-based f-cell+HFC 2020, which has been pushed back to September 9 and 10, 2020.

The World Hydrogen Energy Conference 2020, originally scheduled to take place in Copenhagen, Denmark, was first moved to Istanbul, Turkey, following seemingly irreconcilable differences of opinion between IAHE and the local event organizer. But after Covid-19 began sweeping the globe, it was decided that the conference will not be held at all over the next two years. The next WHEC has been set for June 26 through 30, 2022.

The calendar on page 63 of this issue will tell you what events are still to come this year. We will notify you on our website or as part of our free monthly newsletter should more of them be postponed or cancelled. You can click on one of the following links to get to an up-to-date list of events or to the H2-international newsletter section:

→ www.h2-international.com/events/
→ www.h2-international.com/h2i-newsletter/

Category: Building sector | **Author:** Sven Geitmann

FUEL CELL STACKS FROM KÖPENICK

Fuel cell CHP system made in China

Mostly out of the public eye, Berlin-based inhouse engineering has been working for years behind the scenes on a fuel cell system that does not quite fit in with other suppliers' product offerings. With 5 kW capacity, it is much more powerful than devices offered by, for example, IBZ partners (see list on p. 10). Likewise, it is used mainly to supply energy for commercial multi-family and business properties, not single- or two-family homes. It has been said that the system might now be brought to market during the second half of this year.

Fig. 1: Testing a distributed energy system that runs off a hydrogen fuel cell in the energy zone at industrial park Bitterfeld-Wolfen [Source: inhouse engineering]

The inhouse5000+ has already been field-tested for several years in projects using either natural gas or hydrogen. The fuel may be the single biggest difference to other smaller devices, as it has been the only low-temperature PEM system capable of running on hydrogen only. Most competing products have so far used fossil fuels, that is, natural gas or LPG, to power homes.

When the chief executive of inhouse engineering, Christoph Hildebrandt, was asked why the device had not yet been brought to market, he said there were several reasons development had taken longer than expected. One of them had been a shortage in catalysts used in the reformer, another the terms and conditions of KfW bank's funding opportunity, which had initially been limited to single- and two-family homes. It also had been difficult to find partner companies that could distribute the product.

Today, inhouse engineering is in a successful collaboration with DiLiCo engineering, a Magdeburg-based supplier of instrumentation and control equipment. The supplier is not only helping to improve the CHP device but is also distributing it across the German state of Saxony-Anhalt.

So far, inhouse engineering has put up nearly 20 demonstration systems. One of them meets baseload demand at a swimming pool in Döbeln, another supplies energy for a multi-family building in Reichenbach. One more has been installed at Riesa State Academy, both to meet baseload demand and educate students about the inner workings of the device. This spring, yet another will be put up at a retirement home near Nuremberg. The CHP system can be fueled by natural gas, LPG or biogas and two of the devices currently installed use hydrogen alone. All of them have been designed to generate over 100,000 kilowatt-hours of heat and up to 25,000 kilowatt-hours of electricity.

ONE OF FEW GERMAN STACK MANUFACTURERS In contrast to other suppliers' small fuel cell heaters, the inhouse5000+ is not equipped with a peak load boiler or a hot water storage tank. This means it needs to be connected to an existing heating system, such as a natural gas boiler, or such a system would have to be bought. Hildebrandt said the modular design makes it possible to "install the device even in hard-to-access spaces without the use of heavy machinery."

Located in Berlin's Köpenick district, inhouse engineering manufactures all fuel cell stacks on-site. Components are bought from several suppliers, some based in Denmark, while the unit reforming natural gas comes from WS Reformer. Stacks are still made by hand in the workshop in Köpenick. However, the new building into which the small

Fig. 2: PEM stacks with end plates and a compression spring assembly

The 24-staff business has been working on the fuel cell CHP system for nearly five years and is currently testing it in the Hydrogen Village in Bitterfeld-Wolfen, as part of publicly funded Hypos project H2-Home. The site is also home to a second Hypos project named H2-Netz, the aim of which is to, for example, determine what kind of pipeline is suitable for delivering hydrogen (see H2-international, December 2017). Work on the system, which recovers some of the latent heat of vaporization when it generates heat and power, started in 2016. "We have achieved all that we wanted to achieve," said Hildebrandt. The hydrogen-fueled device generates electricity at around 50 percent efficiency and has a total efficiency of either up to 92 percent (HHV) or 104 percent (LHV).

Now that H2-Home is in its second stage, the CHP system was put up for demonstration purposes at the Mitnetz Gas 12,000 m^2 testing site in the Bitterfeld-Wolfen industrial park. Besides improving the unit, the focus of this stage will be on identifying and solving possible supply and storage issues in partnership with H2-Netz members.

In October 2019, multiple German and French organizations also launched LivingH2, a collaborative venture that aims to integrate the device into the building systems at the new Engie Lab Crigen in Paris. Other aims are to test a new a membrane electrode assembly that has been non-uniformly coated with a catalyst and see how feasible of an idea it is to use odorants to detect hydrogen leaks. In addition to inhouse engineering and Engie Lab Crigen, the partners in this project are DBI – Gastechnologisches Institut and OTH Regensburg University, both based in Germany, and CEA-Liten, based in France. ||

business is planning to move this year could provide sufficient room to revamp production.

The first thing on the agenda right now would be to get the device CE-certified, Hildebrandt said. If everything goes as planned, a partner company in China could start manufacturing and shipping products in the second half of 2020. Initial batches would run primarily on natural gas, although up to 30 percent hydrogen blends would "not be an issue," he said. He added that the systems would be priced at around EUR 60,000 (excluding VAT but including full maintenance services and stack replacement after around five years). Funds from the KfW bank and the Clean CHP Act program could cut the price roughly in half, though it would take eight to nine years to recoup the full cost. "We will be getting the price down soon," he said.

S&R BECOMES INHOUSE

Following a statutory merger in 2008, S&R Schalt- und Regeltechnik, founded in 1991, ceased to exist, with only inhouse engineering staying in business. Jürgen Arnold, who founded S&R and was its chief executive, is still a member of inhouse despite his retirement. He was the one who turned the company's focus to fuel cells, even though S&R was making most of its money with building automation and management equipment.

In 2017, inhouse engineering established a partnership with a business in China. In April 2018, they went on to form a joint venture with the aim of making fuel cell CHP systems in the People's Republic and exporting them to Europe.

Category: Building sector

OVERVIEW FUEL CELL HEATING SYSTEMS




MANUFACTURER	BUDERUS	SENERTEC	SOLIDPOWER	VIESSMANN
MODEL	BLUEGEN BG-0	DACHS 0.8	BLUEGEN BG-15	VITOVALOR PT2
FC TYPE	SOFC	PEMFC	SOFC	PEMFC
FUEL	Natural gas, bio natural gas	Natural gas	Natural gas, bio natural gas	Natural gas
POWER ($_{EL}$/$_{TH}$)	1.5/0.6 kW	0.75/1.1 kW	1.5/0.85 kW	0.75/1.1 kW
STORAGE	external	Buffer storage 300 L	external	Buffer storage 220 L
ELECTRICAL EFFICIENCY	60 %	38 %	55 %	37 %
OVERALL EFFICIENCY	85 %	92 %	88 %	92 %
ENERGY EFFICIENCY CLASS	A+++	A+++	A+++	A++
DIMENSIONS PARTLY WITH STORAGE UNIT (D × W × H)	660 × 600 × 1,100 mm	1,080 × 1,410 × 1,870 mm	800 × 550 × 1.200 mm	595 × 1,200 × 1,800 mm
WEIGHT	195 kg	332 kg (total)	250 kg	326 kg (total)
FIELD TESTS, OLLABORATIONS, DEMONSTRATION PROJECTS	ene.field PACE	Callux ene.field PACE	ene.field (EU) PACE	PACE
MARKET LAUNCH	3rd quarter 2016	June 2016	2012	April 2014
FIELD OF APPLICATION	Residential and small office buildings	One- and two-family homes	Residential build-ings and commer-cial enterprises	One- and two-family homes
PRICE	31.071 € (VAT included)	20.000 € (plus VAT)	25.000 € (plus VAT)	20.000 to 25.000 € (VAT included)
INCENTIVE OF UP TO	16,050 €	11,100 €	16,050 €	11,100 €

Sources: Initiative Brennstoffzelle, own research – accuracy cannot be guaranteed



REMEHA	SUNFIRE	INHOUSE
ELECTA 300	SUNFIRE-HOME	INHOUSE5000+
PEMFC	SOFC	PEMFC
Natural gas	Natural gas, LPG	Natural gas, bio natural gas, LPG, hydrogen
0.75/1.1 kW	0.75/1.25 kW	4.2/7.5 kW
Buffer storage 300 L	external, individu-ally selectable	external,individu-ally selectable
38 %	37.7 % (at full load)	34 % (CH_4) / 50 % (H_2)
95 %	90 %	92 %
A++	A++	
1.070 × 1,500 × 1,810 mm	600 × 680 × 1,150 mm	1,160 × 740 × 1,550 mm
350 kg (total)	150 kg	380 kg (total)
ene.field PACE	Callux ene.field PACE	ene.field
3rd quarter 2016	January 2020	2nd half 2020
One- and two-family homes	One- and two-family homes	Multi-family proper-ties and commercial buildings
23.000 € (plus VAT)	23.315 € (VAT included, LPG)	around 60.000 € (plus VAT)
11,100 €	11,100 €	37,000 €

Category: Building sector | **Author:** Sven Geitmann

NEW GAS BOILERS RUN ON HYDROGEN

Manufacturers prepare for hydrogen network

German consumers in need of a new heating system have expressed growing interest in home fuel cells, an assessment shared by the public hydrogen and fuel cell agency. Although there are few systems on the market these days, and pretty expensive ones at that, their numbers are rising. As it looks now, the government will continue to fund the sector for a while. The following paragraphs offer a summary of what is currently available for sale.

IN COMPETITION WITH HEAT PUMPS

Holzminden-based Stiebel Eltron is not an IBZ member. Besides the fact that most of its products are heat pumps, there is this example from its internal magazine to illustrate why membership may not be an option: An employee reports that "in a recent conversation, a builder spoke to me about his construction project and told me he really wanted to use renewable energy to supply heat and power to the building. He was thinking about having a fuel cell installed. In the end, however, he became convinced that a heat pump solution brings more advantages to the table."

Fig. 1: Sunfire-Home

German home heating suppliers say they are ready to shift into high gear. At least, the members of the Fuel Cell Initiative, also known as IBZ, are reportedly working on bringing new systems to market.

In February, Neubrandenburg-based Sunfire Fuel Cells, a Sunfire subsidiary, unveiled a new heater in Berlin. This solid oxide fuel cell system can run on methane, the main component of natural gas, or a mixture of propane and butane. As Sunfire's sales strategy has centered around the use of LPG, it has partnered with gas companies to benefit from their distribution channels.

Liquefied petroleum gas has been in use in the residential sector for decades, primarily in the countryside, where some buildings are not connected to the natural gas network. Sunfire-Home offers suppliers an opportunity for gaining new customers who want to switch from oil to gas. Typically, these customers need a greater quantity of LPG as well, since (some) home fuel cells are configured for combined heat and power.

Designed in part by drawing on the expertise of Sunfire's former business partner Vaillant, the new SOFC system will now go into commercial production. Sunfire-Home is installed as an add-on to a conventional heating system and can be run in buildings with or without a connection to the gas grid, in the latter case by using LPG.

Bosch, too, has been intensifying its efforts to develop fuel cells, even for non-automotive applications. In August 2018, it formed a strategic partnership with Ceres Power, an SOFC manufacturer based in Horsham, UK. Bosch said the aim of this partnership was to offer customers SOFC modules with 10 kilowatts generating capacity in order to get a foothold in the market for fuel cell power plants. Phil Caldwell, the chief executive of Ceres Power, said the partnership had "the potential to drive the widespread adoption of SOFC for distributed power generation products using the Ceres Steel Cell technology."

By contrast, Freudenberg Sealing, based in Weinheim, Germany, has taken its NEX 2400 (previously known as elcore 2400) off the market. The company announced it would no longer manufacture or sell the device, although it would keep supporting its latest product generation based on the terms and conditions of existing maintenance contracts.

HIGH-PRICED MARKET Prices for home fuel cells are set by installers so guidelines on what you can expect to pay are hard to come by. As an example, the suggested retail price for a Vitovalor PT2 is EUR 18,773. This excludes the cost of putting up the device and the 19 percent VAT rate on equipment and installation. The government supports the latter with EUR 9,300 and, based on the German CHP act, may award a one-time grant to applicants who rather get paid for future energy deliveries upfront instead of having to bill deliveries monthly.

This means that consumers who want to use fuel cells to power their homes would have to invest between EUR 20,000 and EUR 25,000 depending on site conditions. The

EXAMPLE: FUEL CELL INSTALLED IN A NEWBUILD

A single-family detached home consumes an average of 4,200 kilowatt-hours per year. A residential fuel cell can generate up to 6,200 kilowatt-hours of electricity annually, around 60 percent of which can be used on-site. This results in 2,520 kilowatt-hours that will no longer need to be bought from a utility. At an average electricity price of EUR 0.25 a kilowatt-hour, the family in this example will therefore save EUR 630 per year. The remaining 1,680 kilowatt-hours can be fed into the grid and will bring in another EUR 84 thanks to Germany's feed-in tariff system. Overall, owners of single-family homes can save EUR 714, that is, EUR 10,710 over 15 years, assuming the fuel cell stack does not need to be replaced during that time.

Fig. 2: Hydrogen storage module installed in Zusmarshausen [Source: Hörmann Solartechnik]

price is about the same as for installing a brine water heat pump. This means home fuel cells are four or five times as expensive as the latest generation of gas boilers, despite national and EU-wide funding opportunities. Recouping that money through energy savings alone will be difficult to achieve.

MULTI-ENERGY RESIDENTIAL SYSTEMS Besides replacing old devices to put in newer, more efficient ones, there also seems to be a trend toward more complex solutions. For example, Sunfire expects that at some point, entire neighborhoods will be supplied with energy through a combination of solar PV, heat pump and large fuel cell devices. These multi-energy residential systems will no longer produce heat and power for individual buildings but several residential units at once.

Similarly, Home Power Solutions, also known as HPS, is redoubling its efforts to provide homeowners with off-grid CHP solutions for energy-independent buildings. In mid-February, the business announced it had partnered with Gasag, a Berlin-based gas supplier, to install its products.

HPS said it was now planning to ramp up sales. Since early 2019, the company has been offering homeowners a system to store self-generated renewable energy, with the aim of making them energy-independent throughout the year. Called Picea, it consists of a solar PV unit equipped with a load controller and an inverter, batteries, an electrolyzer, a fuel cell and ventilation (see H2-international, September 2018).

The 300-bar modules offered by HPS (see fig. 2) are made by Wystrach, based in Weeze, Germany. The supplier announced the collaboration with HPS a year ago, during the Energy Storage Europe show in Düsseldorf. At the show, Wystrach's sales director, Wolfgang Wolter, said that "Picea is a great example of how to use our stationary solutions for maximum benefit. Our modules can adapt to very different consumption profiles, from single-family homes to office buildings and power plants." The electrolyzer integrated into Picea is delivered by HPS' business partner Enapter.

One such Picea system was installed in Zusmarshausen, where it provides heat and power for the home of the Hörmanns, located not far from their installation business called Hörmann Solartechnik. The device, ordered in December 2018, supplies the household with solar energy throughout the year, as the building is not connected to the gas grid. Business owner Rita Hörmann said the Picea unit, as well as its auxiliary components, was the "first commercially available and financially sound CHP system that pays for itself over time." In all, her husband Markus added, they had paid around EUR 70,000 to get it up and running (see also "Solar, hydrogen and fuel cells combined" on p. 54).

STATIONARY HYDROGEN COMBUSTION ENGINE The WTZ engine and machinery research center in Roßlau chose a different path to developing a new stationary zero-emission system. It designed an air-independent propulsion engine called H_2 DI Zero. The name stems from the fact that some of the combustion gases are recovered so the engine emits nothing but steam. Instead of air, it uses argon, an inert gas that can be retrieved multiple times over, and pure oxygen, mixed with hydrogen. This eliminates nitrogen and carbon from the combustion cycle, thus also removing hydrocarbons, carbon dioxides and nitrogen oxides from the equation. >>

Fig. 3: H_2 DI Zero engine developed by WTZ [Source: WTZ]

MTU IS BACK

MTU Friedrichshafen, renamed Tognum in 2006, conducted extensive research into stationary fuel cell power systems as early as the turn of this century. It put up several molten carbonate fuel cells named Hot Modules as part of government-funded demonstration projects. In 2010, however, its management decided to discontinue developing stationary high-temperature fuel cells (see HZwei, October 2010). In 2011, Rolls-Royce and Mercedes-Benz then founded Engine Holding, which owned 98 percent of Tognum's assets at the time. In 2014, the former acquired the latter's stake in the business.

Fig. 4: Hyundai's hydrogen-powered generator

H – NOT L
Since 2015, an increasing number of L-gas pipelines in western Germany have been converted to deliver H-gas, that is, gas with a high calorific value. The less energy-dense L-gas has been extracted and for the most part used locally in the Netherlands and the German states of Bremen, Hesse, Lower Saxony, North Rhine-Westphalia and Rhineland-Palatinate, as well as Saxony-Anhalt. By 2030, all sources that have a low calorific value will be replaced with methane-rich H-gas coming from Norway, Russia and the UK.

By contrast, conventional hydrogen combustion engines use air as the reactant. However, air contains 78 percent nitrogen. At high temperatures, nitrogen reacts with oxygen to form nitrogen oxide, which is a danger to the climate. Manuel Cech, who heads the WTZ project, said "the use of argon has allowed us to improve combustion engine efficiency to unprecedented levels."

The Roßlau-based engineers noted the engine would be a good fit for stationary multi-megawatt systems, not for vehicles. The main goal was to develop a system that can compete with fuel cell and CHP power plants. At 50 percent engine efficiency, the device is certainly a viable candidate for the market. Prospective customers include public utilities that have so far relied on natural gas-fired CHP systems but would like to use renewable hydrogen from now on, for example, to balance supply and demand.

Cech told H2-international that the idea for the 50-kilowatt unit had been thought up during a research project. This project was launched three years ago and work on the engine has been made possible through funding the nonprofit organization has received from the government. WTZ is also a partner in LocalHy, set up to investigate opportunities for producing hydrogen and oxygen through distributed water electrolysis.

AUTOMAKERS WORK ON STATIONARY SYSTEMS Similar to reciprocating internal combustion engines used in CHP, fuel cell systems originally developed for the automotive industry are now being installed in stationary systems that supply heat and power to buildings.

For example, Mercedes-Benz has asked Lab1886, its innovation lab for new business models, to develop, in partnership with Rolls-Royce Power Systems and under its MTU brand, a backup power generator running off automotive fuel cells. A pilot project, scheduled for completion in early 2021, will reportedly use both batteries and fuel cells.

MCFC technology could, for example, power server farms, as their electricity needs have increased with greater digitalization. Providing them with a reliable, clean source of energy will probably become ever more important. "The principle of the fuel cell is as ingenious as it is simple," Martin Teigeler, executive vice president of research and development at Rolls-Royce Power Systems, said. He added that the technology was not just well-known but also suited for challenging tasks. Now that it had become advanced enough, it was ready to be brought to market.

Toyota and Hyundai are taking the same approach of transferring technology between markets. At IAA 2019, Hyundai showcased a system made up of two fuel cells, the same cells used in its Nexo car, for charging electric vehicles (see fig. 4). The two manufacturers hope that going the route through the market for stationary power systems will boost production volumes overall and quickly reduce the cost of vehicle fuel cells as well.

HYDROGEN PIPELINE NETWORK Today, most stationary power systems run on natural gas. The idea of blending hydrogen into the gas pipeline network, however, has been under discussion for a while, and there have already been some tests conducted on its feasibility. Heating manufacturers have assured clients that current-generation systems can run on low-level 10 percent hydrogen blends and announced that the next generation could manage up to 30 percent. They said in the long term, it would also be possible to use hydrogen only. For example, Viessmann has announced that all of its new gas boilers would be "hydrogen-ready" starting in 2023 or 2024.

In late January, during the DVGW association's Parliamentary Evening in Berlin, the chairman of Zukunft Erdgas, Timm Kehler, suggested converting one of four parallel transmission pipelines to deliver 100 percent hydrogen instead of a 25-percent blend in each. He pointed to the H21 project in Leeds, UK, where the city's council aims to convert the gas supply to hydrogen only. Thorsten Herdan, director of energy policy at the German economy and energy ministry, replied that he could very well imagine using the L-gas pipeline network for this purpose, as it would no longer be needed anyway. However, the government would not step in but let the market decide what to do.

Jörg Bergmann, who chairs Open Grid Europe's executive board, said his company had already been developing small hydrogen-only networks. Volkmar Pflug, vice president for energy economics at Siemens, explained that "gas turbines are not the issue. New ones accept up to 20 percent blends." He added that turbines to be put up by 2030 could be powered by hydrogen alone. "As soon as there is enough gas available, turbines will be ready to run on 100 percent hydrogen," he said and noted that old systems could be upgraded to do the same. ||

"When we devised the national hydrogen strategy, the building sector had not been foremost in our minds."
Thorsten Herdan, German economy and energy ministry

Category: Policy | **Author:** Sven Jösting |

HANDELSBLATT ENERGY SUMMIT IN BERLIN

Opinion: A green deal is on the table

The Handelsblatt Energy Summit, which took place in Berlin from Jan. 20 to 22, was the right kind of event to take the pulse of the energy industry. Attendees typically discuss issues that have far-reaching implications for the German market. This year, it seemed as if over 80 percent of all presentations, speeches, panel discussions and shared opinions included, at the very least, a passing reference to hydrogen, its uses and its contribution to fighting climate change and creating a renewable energy supply chain.

Fig. 1: Johannes Teyssen [Source: Dietmar Gust / Euroforum]

The way in which Germany has crafted national energy policy could soon become a model for other countries to emulate. The German renewable energy law, known as EEG, was a good start but is now yesterday's news. The time has come to devise an industrial strategy that responds to the latest changes in the market, provides energy security and ensures affordable prices. The government's decision to phase out coal and nuclear energy seems final, so what systems will supply the country with baseload power? "Do we have enough backup capacity?" was thus a fitting question and the title of one of the panel discussions held at the summit. LNG and CNG will be used for transitioning to a renewable energy system and batteries could store energy for certain applications, but that is about all. The lack of alternatives is the reason why hydrogen is moving more and more into focus.

Johannes Teyssen, the chief executive of E.ON, said it in a nutshell: Instead of gradually dismantling the EEG, as the German economy minister Peter Altmaier is offering to do, the clean energy law would need to be scrapped altogether. Teyssen suggested using carbon credits to cover the budget gap that would result. Some propose a price of EUR 150 to EUR 350 for one metric ton of carbon dioxide emissions, which would turn the credits into a perfect regulatory measure. Overall, the price would need to be much higher, high enough to encourage massive investment in clean energy and energy efficiency improvements to combat climate change. Attendees at the summit called for raising the cost of fossil fuels and lowering the cost of green electricity, especially if produced from hydrogen. Cut away the red tape, get rid of regulations suffocating the industry, and invest in innovative solutions on a massive scale, I would say. Change is more likely to happen when people are fully committed to the cause and not when doomsday scenarios and a general sense of panic drive them to action. Clean energy should always be supplied by distributed generation systems, ideally at the point of use.

Gutting the renewable energy law would benefit taxpayers, who would have more money in their pockets at the end of each month. It would also cause a drop in energy prices for businesses, factories and communities across the country. This would spur investment, a blessing to many German state governments as they are trying to put their best foot forward. As for industrial companies, they are ready to take the next step. Many communities also sense great opportunities, not just for taking climate action but also for establishing new markets that create jobs and, ultimately, generate tax revenues. The government and parliament need to work together to increase funding for renewable energy considerably, promote research, and accelerate the transition from living labs to commercial production. They need to create programs for market adoption and partner with other members of the European Union instead of trying to have companies develop technology nationally.

As one attendee at the event put it: "We need everything and all of it." While Europe is extracting less and less natural gas at home, it imports an ever-greater quantity from abroad. LNG can meet demand for a short while, but hydrogen is more suited for bridging the gap left by coal and nuclear. Power-to-X will grow in importance as well, since it is not just used to generate electricity but also supplies low-carbon and zero-emission energy in the heating, cooling and transportation sectors.

Most attendees at the summit agreed that hydrogen and fuel cell technology would assume a crucial role, and a more important one than batteries, in the heavy-duty truck market, where 90 percent of trips are long distance. Someday, of course, 18-wheelers may run on electrofuels. However, it will take some time until these fuels are available in large quantities. It needs to be said that German politicians focus too much of their attention on all-electric transportation. Instead, they should fund distributed generation systems and help bring about a massive increase in electrolysis capacity, as well as be more open to all forms of clean energy.

Many speakers at the event zeroed in on large, ever-more powerful electrolysis systems that generate hydrogen ideally from clean electric power. It should be noted that electricity prices contribute over 90 percent to the cost of production. In 10 to 20 years, green hydrogen is expected to be less expensive than gray hydrogen and could cost as little as USD 1 to USD 2 per kilogram.

My conclusion is that the hydrogen and fuel cell market is showing a lot of promise these days, and Power-to-X is on the right track as well. German politicians will now have to learn to break old patterns and step on the gas. ||

Category: Policy | Author: Sven Geitmann

GOVERNMENT AGENCIES ARGUE ABOUT WHO IS IN CHARGE

Christian Democrats backed by industry, SPD by the public

Who can make the most of hydrogen and fuel cells? This question seems to have sparked a fierce competition between several German government ministries since late 2019 as they are vying with each other for control over the debate. Their tug-of-war began spreading through the political landscape when hydrogen became an issue to campaign on early this year, prior to the Hamburg state elections. Although the Christian Democrats were the ones who actively promoted the technology for a while, public opinion seems to have shifted in favor of what the Social Democrats are planning to do with it.

Fig. 1: Elisabeth Winkelmeier-Becker

Meanwhile, the draft document mapping out Germany's hydrogen strategy has grown from six to 21 pages and the government agencies involved are taking longer than expected to reach an agreement. These could be signs that policymakers have belatedly but finally acknowledged that hydrogen will have an important role to play in a next-generation energy system.

There is consensus on a few basic points. Most political party representatives want to make use of hydrogen and are willing to fund efforts to bring it to market. Exactly what form their support will take, however, is something the ministries, and party representatives, are still arguing about.

They do have some similar ideas. It has become obvious that a great deal of hydrogen will be needed to further decarburize every industry. Some debates about what impact, if any, an increase in demand could have on the fuel cell vehicle market are pretty much irrelevant at this time. German automakers will not manufacture many FCEVs before the start of the next decade or even later than that.

FROM QUOTA TO HYDROGEN COUNCIL The much-discussed draft strategy includes a plan that specifies five areas of action to improve conditions for generating and using hydrogen. It also suggests measures for each stage of market development. The overall aim is to continue to support R&D efforts and establish a national market by 2023. Starting in 2024, the focus is to be on strengthening that burgeoning market as well as identifying opportunities in Europe and all over the globe.

The government is also planning to create a national hydrogen council, preferably at a meeting of staff members from relevant departments during the first three months of 2020. Up to 13 influential researchers and business leaders from Germany and abroad will sit on the council to review progress and advise and support department staff so course corrections can be made if and when they are needed. A National Hydrogen Office will reportedly be set up as well, in order to oversee operations.

The funding opportunities offered by the National Innovation Program Hydrogen and Fuel Cell Technology, also known as NIP, are expected to continue. The German government will likewise set aside EUR 3.6 billion to keep supporting purchases of light-duty and heavy-duty trucks and vans, buses, trains, inland and coastal vessels, and fleet cars until 2023. The infrastructure buildup will be supported with EUR 4.5 billion. To create an incentive for switching to climate-friendly engines, especially in trucking, there is also talk of a Europe-wide toll system, with payments based on the carbon dioxide emissions from individual vehicles.

Regarding the transportation sector, the government has announced it will soon transpose the EU's Renewable Energy Directive, known as RED II, into national law. This will involve implementing a quota of at minimum 20 percent clean energy by 2030 to increase the proportion of renewables in final energy consumption.

Additionally, it has been stressed over and again that Germany intends to use its presidency of the EU Council in the second half of this year to take further steps "to develop sustainability standards and generate demand for zero-carbon hydrogen." It also wanted to set a framework for energy systems integration and create a European market for the gas. Likewise, as part of the European Green Deal, unveiled by European Commission President Ursula von der Leyen in 2019, it was planning to speed up implementation of the Union's hydrogen initiatives.

SURCHARGES REMAIN At the Lausitzer Energiefachtagung conference held in late January, Elisabeth Winkelmeier-Becker, who works at the German economy ministry, said one concrete aim was to see the government support businesses that are close to commercializing their products or where the EU may threaten to impose fines. This would concern the petrochemical and rail sectors especially but also some other energy-intensive industries. Likewise, it wanted to help wherever hydrogen is the only option for decarburizing applications, such as in the steel, cement, glass and chemical industries. She went on to say that not unlike today, where energy imports meet 70 percent of demand, Germany would continue to receive most of its energy from abroad.

The German economy minister, Peter Altmaier, had already rejected the idea of changing regulations on energy surcharges, for example, by eliminating the EEG surcharge for power-to-gas plants, early this year. He was quoted by Jörg Steinbach, Brandenburg state's economy minister, as saying that the system was so complex it would be impossible to "disentangle." Steinbach, however, said that "if the national hydrogen strategy does not mention these surcharges, it is simply not worth the paper it is printed on."

Thorsten Herdan, who leads the economy ministry's energy policy sub-department, said that "if energy-intensive businesses no longer need to pay a surcharge on electricity, hydrogen needs to be excluded too. To implement this, you do not have to reinvent the wheel." But he also cautioned that the national hydrogen strategy was not a step-by-step road map: "The national hydrogen strategy will not provide an answer to every question. We will have to work together to develop appropriate solutions."

The above is what the economy ministry, headed by a Christian Democrat, had to say about the national strategy that it drafted. The Social Democrat-led environment ministry has sometimes taken a different approach. A paper published by the agency quotes environment minister Svenja Schulze as saying that the heat market needs to be excluded from consideration for the time being. However, she will most likely face little pushback from the economy ministry on this score, as it had already stated that the building sector had not been a top priority when it had created the national hydrogen strategy.

Another point of debate has been the electrolyzer capacity that is to be added over the next decade. While the economy ministry seems to be content with a total of 5,000 megawatts by 2030, the environment and science ministries intend to have between 10,000 megawatts and 15,000 megawatts up and running by then.

GRAY, BLUE, TURQUOISE OR GREEN As for colors, Winkelmeier-Becker made clear that Germany "will use blue hydrogen on its way to a 100-percent renewable, green hydrogen industry." Herdan added that "in order to get to green, we need to go through blue first. […] We cannot skip this stage."

Herdan referenced a statement made by Greens member Ingrid Nestle, who had signaled that her party would agree to this kind of transition scenario. Even environmental organizations could live with the deal if Norway is able to store the gas safely. However, the path taken by Japan was not on the table. "We do not want to start at gray," Herdan said. Japan seemed little interested in hearing about which color was assigned to what gas. Rather, it wanted to import hydrogen produced in coal-fired plants in Australia. In Germany, the all-important question was how to design energy >>

"From an economic perspective, carbon-neutral, that is, 'blue,' hydrogen will have to play a role in the market in order to ensure the rapid adoption of new technology and lower carbon emissions for a variety of applications."
National Hydrogen Strategy (draft version)

"The long-term goal is to produce green hydrogen."
Economy minister Peter Altmaier

Fig. 2: Thorsten Herdan: "We will be forced to import large quantities of the renewable energy we need."

IS BLUE HYDROGEN THE SOLUTION OR THE PROBLEM?

The debate about hydrogen colors is in full swing. Early this year, Hamburg-based renewable energy supplier Greenpeace Energy published a 60-page document to bring greater transparency and some hard evidence to the discussion. Titled "Blue Hydrogen: Prospects and Limits," it provides facts and background information on the gas and explains the benefits and drawbacks of this new technology pathway. At the same time, the supplier also created a 16-page brochure to answer the question, "Blue hydrogen: Solution or detriment to transforming the energy system?"

Some of the main conclusions of the 60-page study are that blue hydrogen could only "be decarburized in part," as even "state-of-the-art industrial plants emit, on average, 143 grams of CO_2 per kilowatt-hour." And upgraded plants gave off "as much as 218 grams." Furthermore, "green hydrogen emits only 26 grams of CO_2 per kilowatt-hour," compared to 691 grams for producing blue hydrogen based on the current energy mix. However, one advantage seems to be the cost of production. According to the study, it accounts for only EUR 0.063 per kilowatt-hour while green hydrogen comes to EUR 0.165 on average.

The study's author, Steffen Bukold, also mentions a variety of risks, such as complicated natural gas pricing, CO_2 emissions and the objections to CCS, as well as its limited capacity. Bukold wrote that using blue hydrogen would "not help Germany meet its climate targets for 2050."

Additionally, the author said, Greenpeace Energy had criticized that blue hydrogen was often labelled as carbon-free or carbon-neutral. The study proved that such labels were misleading.

> "Of course, one option would be to sell the plant. We would rather keep it and adapt it to run on a different fuel, such as natural gas. However, this is something we cannot achieve without help from the government."
> *Vattenfall CEO Magnus Hall, in an interview with Die Welt on Nov. 15, 2019*

policy that would eventually lead from blue to green. "We must not see a lock-in taking hold, as this would drive us to rely on blue hydrogen," Herdan said. Electrolysis could play the role of the linchpin and act as a kind of conduit between electricity and gas grid operators.

Alexander Land, head of energy policy and communications at gas pipeline operator Open Grid Europe, said that "blue hydrogen will be the spark to decarburize the industrial sector." Matthias Deutsch, who works for Agora Energiewende, was even more direct in his call for using natural gas to produce hydrogen. He said that "we will definitely need carbon capture and storage" to, for example, decarburize the cement industry. However, since no one had been exploring this technology pathway so far, it was important that the German government learned early on how to deal with negative emissions.

By contrast, Werner Diwald, the chairman of the German DWV hydrogen and fuel cell association, criticized that "blue hydrogen will not create jobs in Germany." Today, green hydrogen was "of great import, especially if we want to increase market uptake." He warned that the negative image of CCS could tarnish that of hydrogen too.

INDUSTRY FIRST One fundamental difference between the approaches taken by the economy and environment ministries is that the economy ministry remains focused on the impact that the energy market transformation will have on business. Herdan said: "The hydrogen strategy is first and foremost an industrial strategy. Strategies to address energy and climate issues will be developed at a later time." His mantra was: "Industry first."

The environment ministry is seeing things from a different angle and expects the hydrogen strategy to deliver on climate action and protect business interests at the same time. This means that the plan is supposed to address environmental and sustainability issues now, not later. However, the economy ministry believes that creating a favorable business environment to ensure cost savings and access to new markets will prove beneficial to dealing with environmental and climate issues later on.

Meanwhile, the Greens are sticking to their guns: "The primary energy source should be electricity wherever you can make use of it. We want to think about hydrogen only where it is really needed." This would include especially the chemical industry and the commercial vehicle sector.

More concrete plans were announced in northern Germany in February. Shortly before the state-wide elections, Hamburg's mayor, Peter Tschentscher, rushed to declare he wanted to help turn one of the units at the Moorburg coal power plant into a hydrogen generation system by having a powerful multi-megawatt electrolyzer installed. The other could then be run on natural gas.

Time will tell if the announcement was just made to score points on the campaign trail. At least, Hamburg's state economy minister Michael Westhagemann said Vattenfall, which runs the black coal-fired power station, wanted to exit the coal power industry altogether and fast, even though the Moorburg plant came online as recently as 2015. In any case, the Social Democrats garnered a lot of media attention for Tschentscher's suggestion.

Regarding the present situation and the sometimes heated debate throughout the energy sector, Herdan heavily criticized the high expectations that people had. Abroad, he said, Germany was lauded for first deciding to phase out nuclear and now coal power. While traveling, he had been asked repeatedly how the country had been able to accomplish such a feat. But as soon as he came back home, he was inundated with criticism of the supposedly slow handling of it all. He lamented: "We are forgetting what we have achieved thus far."

Still, he openly conceded that the "wind power sector was in shambles." He added: "What is happening in the wind energy industry is a disaster. [...] We must get back to increasing clean capacity additions."

DEBATES AMONG CABINET MEMBERS What will happen now? The German cabinet was supposed to discuss the national hydrogen strategy and decide on final matters in mid-December 2019. Later, it was said a decision would be made in the first quarter of 2020, on March 18 or 23. As of this writing, however, the ministries have yet to reach an agreement, mostly due to the global Covid-19 virus outbreak.

Still, there is a general sense of direction, as (virtually) everyone says Yes to hydrogen. But a clear plan for how to create a hydrogen economy is still missing. Asked about this, Herdan pointed to the Gas 2030 report that was published by the economy ministry in October 2019. He said: "Our strategy for the gas sector makes it clear that we will not see the emergence of an all-electric world but a world populated with molecules as well." He also stressed that the gas sector, and its infrastructure, would become the third pillar of energy sector transformation in addition to renewable electricity generation and energy efficiency improvements. He said: "Hydrogen is part of our gas strategy and a key foundation for the third pillar." ||

CAUCUS ON ENERGY SYSTEMS INTEGRATION

As the Social Democrats' Bundestag spokesperson for transportation and an avid supporter of hydrogen, Andreas Rimkus (see photo) announced in late 2019 the founding of a caucus on energy systems integration. By his own account, he "set up the caucus together with four highly respected Bundestag colleagues from other democratic parties: Mark Helfrich from the Christian Democrats, Ralph Lenkert from The Left, Ingrid Nestle from the Greens, and Martin Neumann from the Free Democrats." The aim is to exchange information and expertise across party boundaries. This includes having debates to answer such questions as how to transmit wind energy from wind turbines to electric charging points, make manufacturing carbon-neutral along the entire process chain, produce climate-friendly steel and choose systems to store large amounts of energy.

Fig. 1: Hydrogen platform [Source: Tractebel]

Thema: Energy storage | Author: Sven Geitmann

ON TO THE SEA

Electrolyzers to produce hydrogen on platforms and islands

Building platforms or artificial islands to produce hydrogen near wind farms is not a new idea. In the meantime, however, a growing number of organizations have announced that they intend to turn this vision into action. For instance, at the UN Climate Change Conference held in Madrid in late 2019, the Danish climate and energy minister, Dan Jørgensen, outlined plans for building an artificial island for electrolyzers in the North Sea. And in January, engineering firm Tractebel presented a new offshore platform design for producing hydrogen on the ocean.

Hydrogen is a hot topic across the energy sector, though it is still unclear what method should be used to produce the gas, especially the clean, green version of it. There is likewise a lack of electrolyzer capacity and not enough electric power generated by renewable sources of energy.

Large multi-megawatt electrolyzers could be manufactured as soon as the German hydrogen strategy (see p. 16) is in place to provide a stable and reliable framework for business. But where should all the clean electricity come from if fewer and fewer solar and wind farms are being added each year?

Offshore wind seems to be the solution, since the ocean offers enough space for putting up multiple large wind energy systems. This raises the question of how the electric power they produce is going to get to the coast.

The AC power currently generated by offshore wind turbines is first transmitted to special platforms equipped with large power converters to change AC to DC power, as the latter is easier to transmit over a distance of 100 kilometers to 200 kilometers (60 miles to 120 miles). Long 320-kilovolt submarine cables then transfer the DC power to the coast, where it is converted back to AC and fed into the public grid. Both times, energy is lost, though it is said that transmitting AC power without conversion is even less efficient. The interconnection to the grid contributes up to 26 percent to the levelized cost of offshore wind energy.

Electrolyzers could be a more convenient alternative. They would produce industrial-scale quantities of hydrogen from electricity available onsite. The gas could then be stored and transported at relative ease by ship or pipeline to wherever it needs to go. This is true pretty much regardless of whether the electrolyzers are installed on repurposed oil rigs, new hydrogen platforms or artificial islands and depends a great deal on site conditions.

HYDROGEN PLATFORM OFF THE COAST Over the past months, Tractebel Overdick and Tractebel Engineering, two engineering and service firms owned by French energy >>

> Germany's federal energy regulator said that in 2018, it had curtailed output to the tune of 5,403 gigawatt-hours, more than 1,300 of which would have been generated by offshore wind systems. Rebates paid to plant operators to compensate them for economic losses amounted to an estimated EUR 635 million.

Fig. 2: Thomas Brandstätt, the chief executive of Tractebel Engineering, during his presentation of the 400 MW electrolyzer platform

provider Engie, have designed an offshore platform that they say would offer room for up to 400 megawatts of electrolyzer capacity. The electrolyzers could produce up to 80,000 m^3 of hydrogen an hour when supplied with 125 m^3 of water from an onsite desalination plant during that time. The amount of hydrogen generated this way could power 230,000 fuel cell cars and be transported to the coast either by tanker or through a 100-bar pipeline.

During the Hydrogen Forum held on Jan. 21 at Tractebel Engineering's headquarters in Bad Vilbel, Germany, Felix Knicker, of Tractebel Engineering, and Manuel Manzke, of Tractebel Overdick, presented the findings from case study research they undertook last year. Their research focused on the challenges posed by intermittent clean energy sources, which are not continuously available for meeting demand, making energy storage and transfer all the more important. So far, they said, offshore wind farms had been designed for maximum energy extraction. However, when the wind was not blowing at full strength, little use would be made of the

"Our hydrogen platform was not developed for a specific client or a group of clients. Rather, we saw an opportunity for creating a product that has the potential to do well in the marketplace. To this end, we have already spent a great deal of effort into establishing its technical and commercial feasibility.
The five-year period for implementing the project represents an optimistic estimate, although we believe it is a realistic scenario. The accuracy of our forecast, however, depends on many factors over which we have little or no control. In Germany, we will certainly have to build a platform of this size in an offshore area that is designated for green hydrogen production and has been classified by the German maritime agency BSH under the category of 'other energy lease areas.' [...]
What we are sure of, however, is that today's industry can meet the technical requirements, such as the delivery of the required number of electrolyzers. We see most electrolyzer manufacturers expanding production capacity or have heard that they would do so soon. [...]
Furthermore, other countries besides Germany may be interested in putting up hydrogen platforms."
Felix Knicker, Tractebel Engineering

expensive transmission system, which got even more expensive the greater the distance to the onshore connection site. Storing energy had not been possible either.

By contrast, a hydrogen platform in the North or Baltic Sea could not only store energy but cut costs as well. It would raise the efficiency of the interconnection, opening up opportunities for improving its economic viability. Today, there are two ways to construct this type of platform:

A two-pronged approach would include putting up a hydrogen platform in addition to an existing transmission system so wind energy could be either transmitted through submarine cables or used for producing hydrogen onsite. In this case, the interconnection to the grid does not have to be designed for maximum energy extraction, which would save a considerable amount of costs. Some installations, especially those located far off the coast, could also be turned into off-grid wind farms. The wind energy harvested by them could then be used exclusively for electrolysis.

Besides reducing the cost of interconnections, offshore platforms that produce hydrogen would lower the cost of expanding onshore transmission networks as well. They would also reduce overcapacity and thus curtailment. This way, Knicker and Manzke said, the entire grid connection could be made more efficient. By their account, the new platform could be implemented within five years.

DENMARK TO BUILD ARTIFICIAL HYDROGEN ISLAND Instead of a grounded platform, similar to a traditional oil rig, electrolyzers could also be installed on other types of platforms, for example, sand islands, caisson islands or those using a gravity-based structure as foundation.

The Danish climate and energy minister, Dan Jørgensen, told the German Spiegel magazine that he favored the idea of building artificial islands. According to him, one of these islands and the required equipment to generate hydrogen could be up prior to 2030, with siting and approval completed by 2021. The project would make use of up to 10 gigawatts of offshore wind energy and is estimated to cost between EUR 27 billion and EUR 40 billion.

The idea of hydrogen islands was put forward by transmission grid operator TenneT as early as 2016 (see H2-international, April 2019). At the time, the focus was on a single, centralized hydrogen hub. However, based on new research, the plan was changed to a network of several, smaller hubs that would be added over time and tailored to local conditions to lower their environmental footprint. In July 2019, TenneT presented a feasibility study on behalf of North Sea Wind Power Hub, a global consortium of organizations, to discuss this new hub-and-spoke concept. The study compares different methods for wind power hubs in the North Sea.

As shown by the study, sand islands are the most suitable for large offshore wind farms with a generating capacity between 12 gigawatts and 36 gigawatts. Their construction would take around eight years. Less time, between three and five years, would be needed to build caisson islands, which could be used for smaller 6-gigawatt hubs. Their maximum water depth is less than 25 meters (82 feet). Jacket or gravity-based platforms would take around five years until they are up and running and can be installed farther out into the ocean.

Currently, however, there are no plans for building a platform solely for the purpose of producing hydrogen. The feasibility study says the first hub project is expected to have only an interconnection to the grid and an additional onshore power-to-gas system for providing electric system flexibility. It is scheduled to come online in the 2030s.

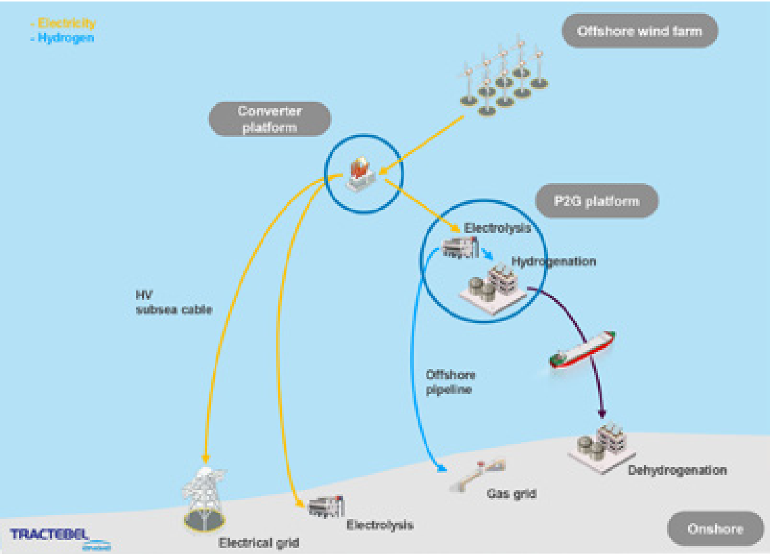

Fig. 3: Schematic diagram illustrating the interconnection to the grid

> "In 2028, we will have an electric grid based on 100 percent renewable energy."
> *Denmark's energy minister Dan Jørgensen, in an interview with Der Spiegel*

FEASIBILITY STUDY FOR A 100-MEGAWATT GIGASTACK

Besides the North Sea Wind Power Hub consortium, which, in addition to TenneT, includes Danish transmission grid operator Energinet and Dutch pipeline operator Gasunie, several, mainly British-based organizations, including the UK's economy ministry, electrolyzer manufacturer ITM, consulting firm Element Energy and Danish energy corporation Ørsted, have set up a similar venture called Gigastack. Their aim is to identify regulatory, commercial and technical challenges of deploying industrial-scale renewable hydrogen systems.

After the first project stage, which revolved around developing an inexpensive modular 5-megawatt electrolysis stack, was completed in 2019, the focus is now on designing a 100-megawatt electrolyzer. This system could later be supplied with electricity from 1.4-gigawatt wind farm Hornsea 2, which Ørsted is planning to bring online in 2022 and which would then be the biggest offshore wind farm in the world. The UK's treasury department is supporting the project with EUR 9 million in funding.

In late 2019, Ørsted also announced plans for building a 5-gigawatt hub at Rønne Banke, a shallow area off the coast of a Danish island named Bornholm, in the Baltic Sea. Initially, the hub would include 1 gigawatt installed to the southwest of Bornholm before capacity would eventually grow to somewhere between 3 gigawatts and 5 gigawatts in order to deliver clean energy to Sweden, Poland and Germany. ||

> "Creating renewable hydrogen with offshore wind really has the potential to decarbonize industrial processes, and what is needed now is to scale up the electrolyzer technology and bring the cost down. We have seen this happen in offshore wind. With industry and government working together, there has been a rapid deployment and a huge cost reduction. This project aims to do the same with hydrogen."
> *Anders Christian Nordstrøm, Ørsted*

Category: Energy storage | **Interview Partner:** Andreas Kuhlmann |

CAPACITY NEEDS TO GROW

Interview with Andreas Kuhlmann, chief executive of dena

Known in English as the German Energy Agency, dena calls itself a "center of expertise for energy efficiency, renewable energy sources and smart energy systems". Its aim is to support the government in meeting energy and climate targets. And yet, there is little evidence a transformation is underway. We spoke with Andreas Kuhlmann about dena's chief executive, about curtailed wind power, energy imports and Germany's hydrogen strategy.

Mr. Kuhlmann, you have been the chief executive since July 2015. The energy market is changing, but little of it has to do with the planned transformation of the sector. Are we making progress?

It is pretty amazing how rapidly things have advanced in recent years. Today, we are taking a much more forceful approach to debating and implementing the market transformation. Of course, the reason for this is that society is demanding better results overall. However, there is another, namely that a growing number of businesses are discovering what this transformation can do for them. New business models are popping up and entire industries are in a state of flux. It is a difficult time for policymakers, but there is only one way forward and the transition period is brimming with opportunity.

We at dena have been focusing since 2015 on identifying the rapidly changing dynamics of this transformation and the global climate change debate. Our main aim was to spur innovation and bring together a wide range of energy carriers with other infrastructures. Our efforts have borne fruit, and this is something I believe we can be proud of.

However, there are many new challenges to take on. For example, now that we are in the second phase of the transformation, we are seeing a slowdown in renewable capacity additions. We cannot let this continue. Last year, when we published an energy systems integration [ESI] study, we estimated the amount of green electricity needed if direct use and retail sales continue to rise unabated. There are also around 52 gigawatts of clean energy capacity for which federal government support will end by 2030, and we are running the risk of losing urgently needed capacity if these plants are not kept operational through power purchase agreements or similar legal instruments. This is particularly true for onshore wind power and, to a lesser extent, for solar PV and bioenergy.

Currently, there is a lot of debate about the practice of wind energy curtailment. What do you think? Should we continue to limit production?

There are no longer good reasons for limiting offshore wind energy generation. The capacity targets for offshore systems should be raised. The idea of energy curtailment stems from a time when estimates showed little cost-saving potential for offshore wind energy. Since then, a great deal has happened to lower the cost of producing electricity on the ocean and improve the technology. The energy generated by offshore wind farms will also be crucial to meeting the ambitious objectives stated in the government's coalition agreement. According to the agreement, renewable energy systems are to provide 65 percent of gross electricity production in 2030. Plus, there are signs that expanding onshore capacity will take longer than people would like and longer than politicians had hoped. Lastly, we are seeing growing demand for clean power from the transportation, industrial and building sectors.

Because of this, wind energy should again, and quickly, reach the capacity targets set by the government. We could really use the onshore wind power we are now losing to curtailment. The federal and state governments in Germany need to start removing impediments to growth. It seems they have reached an agreement, especially on setback requirements [i.e., the minimum distance wind turbines are to be built from a neighboring property line]. However, approving new wind turbines still takes a lot of time and slows down capacity additions.

What is the current strategy? Will we see an end to curtailment?

We believe so. When the German government presented its climate action plan, it announced that it would raise the 2030 target for offshore wind power from 15 gigawatts to 20 gigawatts in light of its overall aim to have renewables produce 65 percent of the electricity consumed in Germany in that year. This is a crucial step forward and needs to be followed by putting in place relevant regulations. We will also need to have a debate in politics about how much offshore capacity is to be added beyond 2030, that is, by 2050. Let us not forget that it takes a long time to plan offshore projects. Companies need to know what to expect of the market and whether they will receive political support.

The German government must send out a clear signal that it wants a further expansion of offshore wind capacity. This has been the conclusion of, for example, a study by the World Wind Energy Association. The study shows that due to national limits on expansion, Germany will have farms with as little as 26 gigawatts installed by 2050, compared to a total of 60 gigawatts in the Netherlands, 80 in the UK and 450 in all of Europe. This makes clear that Germany is increasingly lagging behind in the development of a key technology for our future energy system. The government needs to create opportunities for capacity additions through promoting a collaborative effort between neighboring countries across the continent.

What should happen with renewable electricity that is generated locally but cannot be used onsite?

As said, demand from prospective consumers has been quite high. There has also been an intensive discussion on using offshore wind energy for hydrogen production in manufacturing, among other sectors. The low price for offshore wind power and the high number of full-load hours are arguments in favor of this kind of approach. It would certainly make sense to use offshore wind especially for those processes and industries that cannot be decarburized or where doing so is possible only at great cost. This is not to say we should ignore some of the sectors because they do not fit a certain profile. An example of how much demand there is for clean and inexpensive electricity is the recent offshore wind PPA signed by Oersted and German chemicals manufacturer Covestro, the biggest deal of its kind worldwide.

PPAs could likewise play a vital role in promoting green hydrogen, particularly considering the EU Commission's suggestion to make "additionality" [evidence that buying clean electricity helped add renewable capacity to the grid] a requirement for emission allowances under its GHG reductions program. Our recently published analysis demonstrates that compared to conventionally generated electricity, companies could benefit from renewable hydrogen not just from an environmental but also a financial perspective, especially if the government changed the current system of surcharges and rebates.

Do you also believe that we should continue importing most of the energy we need, for example, in the form of hydrogen delivered from North Africa? Is expanding renewable energy capacity in Germany a waste of time?

Germany imports around 70 percent of its primary energy, including gasoline, black coal and natural gas. We will have to replace these fossil fuels with renewables if we want the market transformation to be a success. But longer transportation routes raise energy consumption and increase the need for infrastructure. Adding capacity at home is thus preferable to receiving clean energy from abroad. Our ESI study has shown that a large-scale expansion of renewable resources in Germany could reduce the share of imports from 70 percent to 50 percent. The conclusion is the same in all our scenarios. However, these numbers also illustrate that we cannot go it alone. Utilizing the full potential of Germany's clean energy resources could net us more than half the energy we need.

We can fill the gap in supply by using electricity stored in H_2. In contrast to clean electricity from the public grid, H_2 can be transported long distance and allows for the global trading of clean energy. This means Germany will be supplied by a mix of imported and locally generated energy, just as it is the case today. Our aim is to diversify, not become energy-independent.

But, all things considered, we will have to make sure the expansion of renewable generation capacity does not turn into the Achilles heel of the market transformation. When taking a closer look at some of today's industries, you can see that we will require large amounts of renewable electricity in the long run. The most recent study by the VCI chemicals industry association estimates that demand will total 628 terawatt-hours by 2050, a gigantic amount that far exceeds what we currently use across all of Germany.

So far, dena has not stood out as a proponent of hydrogen technology. Is the current debate about to change the agency's view?

As early as 2011, we started supporting the Power to Gas strategy platform in building a market for green H_2. We partnered with business leaders, researchers and association representatives to promote a dialog with politicians and the public to help bring about the advances you see today. In 2017, we published our Power to Gas road map. It shows for which applications a market could develop in the short, medium and long term and it identifies the potential of green hydrogen production, as well as the many hurdles for power-to-gas.

In addition, our e-fuels and ESI studies have highlighted the key role green hydrogen can play in energy systems integration. In the current debate, we think of ourselves as consultants and moderators, especially during those times when politics meets business. However, our aim is not to force certain energy carriers into the market. As advocates for ESI, we rather intend to find the most cost-effective option for meeting climate targets and make use of existing solutions if we can. At the same time, we aim to provide suggestions on how to create a suitable market environment for new, innovative technologies.

In late 2017, dena published a study that it conducted in collaboration with German automotive association VDA. Its conclusion was that "e-fuels are necessary to meet EU climate targets for transportation." Does this still hold true today?

We considered our analysis to be correct based on what we knew at the time. It remains true today, even if we rapidly electrify transportation. In order to meet climate targets, especially in a European or a global setting, we will need high-density energy carriers generated from electricity. The only difference to 2017 is that an even greater number of stakeholders now support the statement you quoted.

The main criticism leveled against synthetic fuels is that they extend the era of combustion engines and delay the shift to electrification. How do you respond to such criticism?

We define e-fuels, or powerfuels, as energy carriers or basic compounds produced from renewable electricity. This means hydrogen is a powerfuel and the basis for all other energy carriers. It is important to us not to be dogmatic in our approach but determine exactly how to drive demand for powerfuels as part of the global energy market transformation. We think there should be a level playing field for a variety of technological options, the requirement being comparable levels of emissions reductions. This requirement puts powerfuels in direct competition with ICE technology, though the goal cannot be to compare only the costs of fossil fuels and those of clean sources of energy. We also need to explore the differences between renewable alternatives. If all-electric transportation is the more cost-effective option in the end, it will grow in the market.

In your opinion, what will need to happen to ensure a successful market transformation?

The coming weeks and months will be important to answer that question. My colleagues and I hope the government and parliament will soon take steps to remove barriers to growth and map out a clear strategy for how to achieve energy systems integration, or the transformation of all sectors. This involves implementing the measures mentioned in the German climate action plan and adapt them to meet the more stringent targets of the European Union's Green Deal. In the end, the higher EU targets will have a considerable impact on policy implementation in Germany.

But although the debate we are having is important, we must not forget to focus our efforts on actually solving these challenges. I am essentially talking about practicality. We need to take real action in the real world. If we achieve what we set out to do, we will have made an important contribution to preparing Germany and Europe for what is to come.

What do you hope will be the impact of the national hydrogen strategy on climate targets?

Adding hydrogen capacity, as suggested in the draft strategy paper, is a start. From an industrial policy perspective, the expansion will help ramp up the market. It will further innovation and secure as well as strengthen Germany's technological leadership. But considering the actions we intend to take to fight climate change, the targets mentioned in the paper will be insufficient. When implementing the hydrogen strategy, the government should be focusing on these targets and on developing policy instruments and other measures to support the sector. This is what politicians and industry stakeholders will still need to work on together.

Mr. Kuhlmann, thank you for our interview.

Category: Energy storage | **Authors:** Felix Heubner, Thomas Weißgärber, Lars Röntzsch

SOLID HYDROGEN CARRIERS

Advanced metal hydrides

The Metal Hydride Center of Excellence at Fraunhofer Institute for Manufacturing Technology and Advanced Materials – IFAM is developing composites that offer considerable advantages over conventional powder- or granule-based metal hydride storage. Heat management and sensors to determine the state of charge allow these new systems to respond quickly during rapid uptake-discharge cycles that take only a few minutes.

Implementing an energy cycle that uses hydrogen requires a variety of storage and distribution technologies. As solid hydrogen carriers, also known as SHCs, metal hydrides are a commercially viable alternative to compressed or liquid hydrogen if the aim is to safely store gas of the highest purity (7.0), at low pressures (2 bars to 40 bars), in a small space (up to 0.15 kg_{H2}/dm^3; compared to 0.04 kg_{H2}/dm^3 for hydrogen below 700 bars) and without boil-off losses (see fig. 1) [GUP16].

SHCs take up hydrogen by forming a chemical bond with a solid-state carrier material. In the event of a leak, the gas will not be released into the atmosphere all at once but in small amounts over time. This ensures a high level of system safety.

In the past few years, multiple industries have begun using hydrogen stored in metal hydrides to run submarines, stationary power devices and portable electronics, among other things. Hydrides are also part of vibration-free thermochemical hydrogen compressors, thermochemical heat pumps, and systems for separating H_2 and D_2, that is, deuterium, isotopes. In addition, they can serve as reversible getters, selectively removing hydrogen from a gas mixture.

In multiple applied research projects, Fraunhofer IFAM is exploring ways to improve metal hydride and storage tank properties such as density, durability and reliability and, most importantly, lower the cost of materials and production. The overall aim is to develop systems toward commercialization. Compared to conventional storage, which often uses highly porous materials in block, granule or powder form, the advanced composites created by Fraunhofer IFAM consist of, more compact metal hydride-forming alloy powders and support phases, such as graphite and polymers. The second phase ensures hydrides retain their shape and allows them to conduct a greater amount of heat. The long-term stability of these composites prevents degradation, opening up a myriad of opportunities in the industrial sector. They can also be monitored at relative ease to determine the state of charge and detect possible signs of degradation.

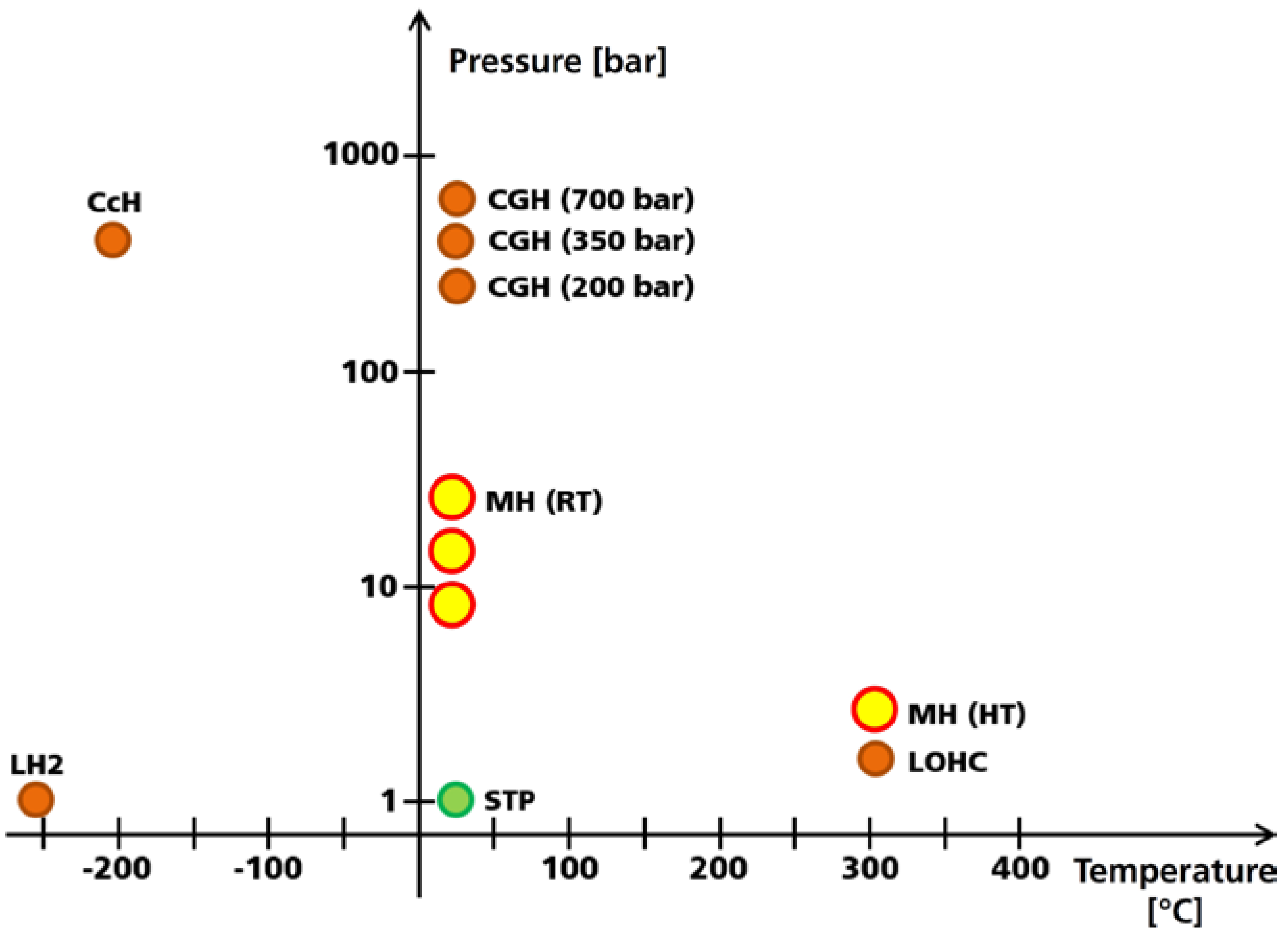

Fig. 1: Hydrogen energy carriers compared (CcH: cryo-compressed; CGH: compressed; LH_2: liquid; SHC: solid; LOHC: liquid organic; STP: standard temperature and pressure; RT: room temperature; HT: high temperature)

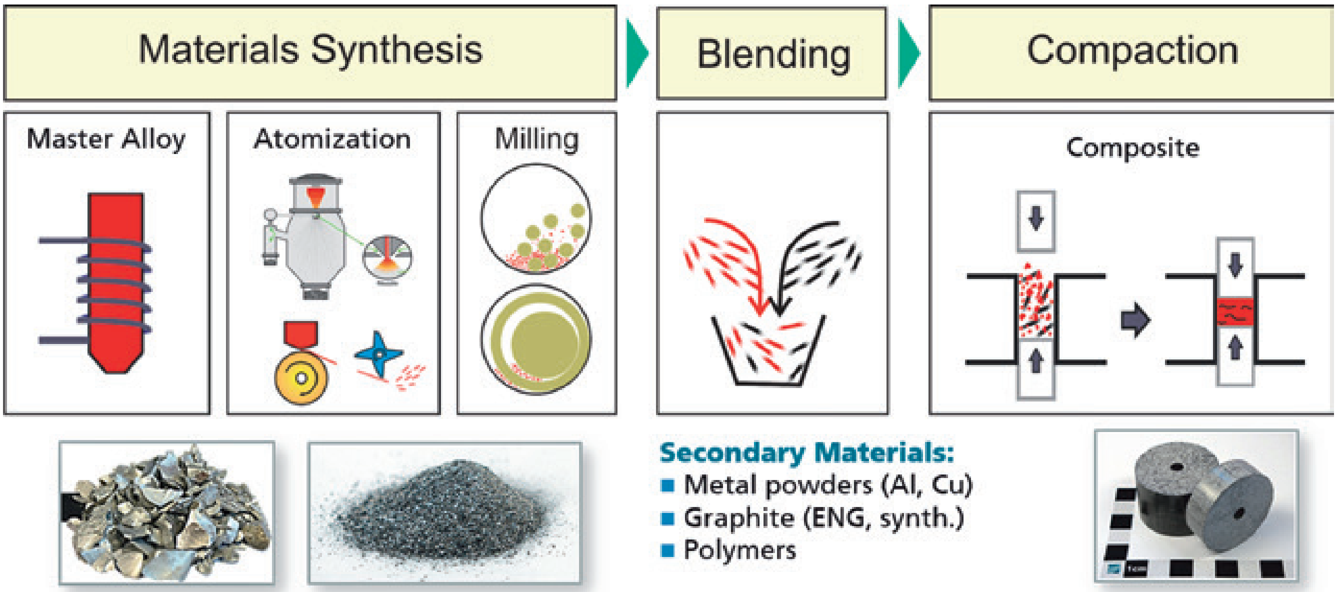

Fig. 2: Schematic diagram of composite production combining a hydride-forming phase and a stabilizing support phase with high thermal conductivity

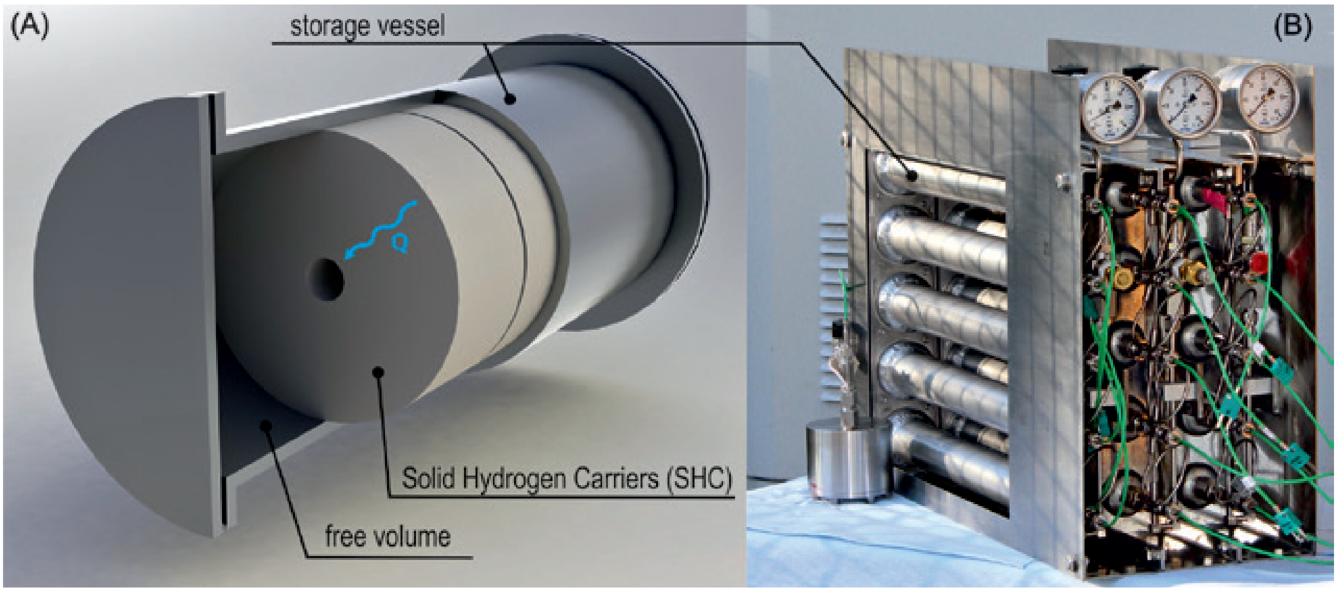

Fig. 3: Schematic diagram of an SHC storage module (left), including heat transfer (Q) during desorption. Right: A 15-module storage system equipped with temperature, pressure and fuel sensors.

METAL HYDRIDES AS SOLID HYDROGEN CARRIERS (SHCS)

Metal hydrides are formed by a multistep chemical reaction that releases tens of kilojoules of heat per mole of hydrogen, based on the kind of alloy that reacts with the gas. Conversely, dehydrogenating the material, that is, releasing hydrogen from the hydride, is an endothermic process that consumes heat. This is important in the context of fuel cells, as waste heat from fuel cell systems could be used to release hydrogen and reduce the size of cooling loops. What needs to be borne in mind, however, is that the hydrogen filling the lattice will result in a slight increase in alloy weight.

Currently, metal hydride storage is available in capacities from few normal liters (portable cartridges) to several hundred normal cubic meters (stationary storage). Conventional tanks have modular designs, that is, they consist of one or more pressure containers that hold the energy storage material, whereas hydride-forming alloys come in block, granule or powder form. Each module possesses some space in the hydride bed to counteract a change in volume to ensure that the alloys are not generating stress in the tank walls. Nevertheless, this method has its drawbacks, since it affects usable space, heat and mass flow, system safety and, above all, the uptake-discharge rate (speed).

Hydrogen adsorption can last several hours, even if heat exchangers are installed in or outside the bed to manage heat transfer. Without the use of composites made up of a hydride-forming compound and a stabilizing material with high thermal conductivity, it will not be reasonably possible to deliver fast response times, such as during rapid uptake-discharge cycles that take only a few minutes. A storage design using the composites discussed in this article was developed by McPhy [JEH13].

One challenge that remains is to preserve structural integrity following multiple hydrogenation-dehydrogenation cycles, since they could result in particle migration, lower thermal conductivity and a loss of thermal contact with heat transfer media. These drawbacks of current-generation systems are being addressed through ongoing work. >>

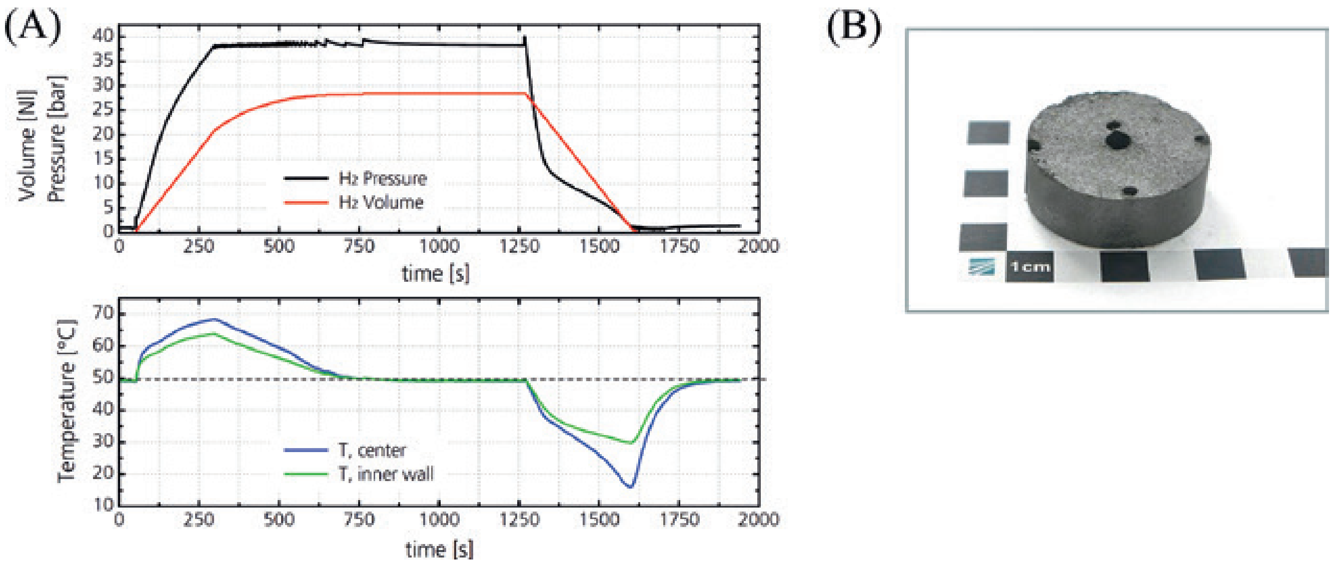

Fig. 4: Uptake-discharge capacity of a metal hydride composite following 20 adsorption-desorption cycles. The material in this example consists of a TiMn alloy and expanded graphite. The predrilled holes are used to insert thermocouples.

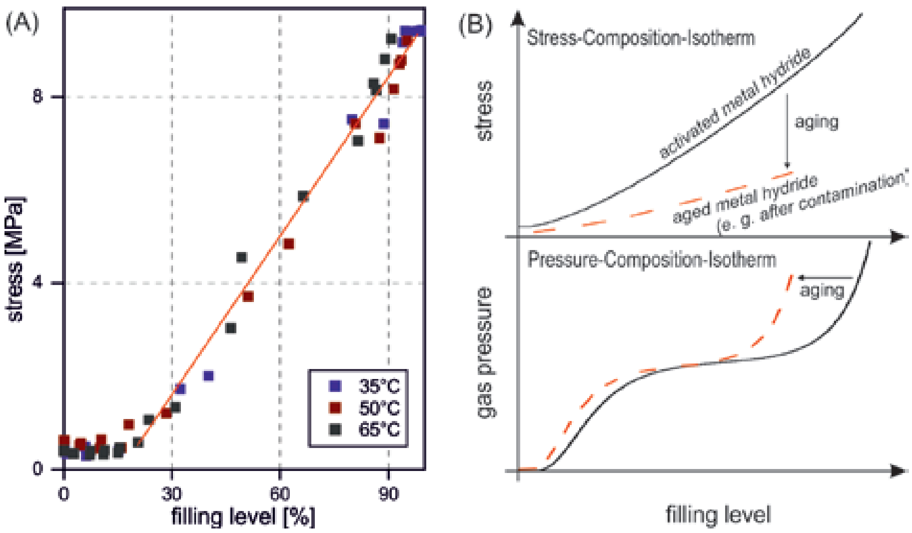

Fig. 5: (A) Stress concentration isotherms to determine the amount of hydrogen fuel remaining in metal hydride composites (B) Schematic diagram showing a method for monitoring degradation by measuring the increase in mechanical stress during hydrogenation-dehydrogenation cycles (stress concentration isotherms) and how this graph differs from that of pressure concentration isotherms.

Fraunhofer IFAM is currently developing new materials, storage modules and concepts to provide more durable, stable, and thus safer and less expensive metal hydride storage solutions than are available today.

COMPOSITE MATERIALS AND STORAGE SYSTEMS Special focus is given to the relation between the hydride-forming material, that is, the magnesium or titanium alloy (FeTi or TiMn), the support phase and the combination of both to improve properties relevant to storing hydrogen. These properties indicate how much fuel the storage system can take up, how efficiently it transfers heat, how permeable, porous and stable it is, to what extent chemical bonds are reversible, and at which rate it can charge and discharge the gas.

The first step in creating a composite is to employ metallurgical processes to make the hydride-forming storage powder (fig. 2). These include atomizing, melt spinning, electrolytic extraction, grinding and decrepitation. After the particles have formed, they are blended with a support phase, mainly graphite, before being compacted (by uniaxial hot pressing) into composites that can be hydrogenated.

The support phase serves three main purposes. First, it raises effective thermal conductivity (> 10 W/(m·K)) by transferring around 20 kilojoules to 80 kilojoules of heat per 1 mole of hydrogen in a relatively small amount of time (few minutes). Second, it provides composites with greater mechanical stability to offset a change in volume when hydrogenating and dehydrogenating storage material. Composites must be capable of accommodating the change and the resultant forces without altering shape. Third, it enhances structural integrity and raises process efficiency when the storage material is being compacted.

Research has shown graphite to be especially suitable as a support phase, as it provides the highest return with the least effort. Modifying graphite can affect thermal conductivity in several ways. Residual porosity can be 20 percent to 30 percent by volume and anisotropic thermal conductivity up to 45 W/(m·K) if the composites are pressed along the vertical axis. The shape of the graphite particles and the direction they face when the mixture is pressed are what produces these internal anisotropic and thermally conductive structures.

Anisotropic, pelletized composites are an excellent choice for storage systems. Typically, the pellets are stacked on top of each other inside a cylindrical pressure vessel. They possess radial gaps as a result of their manufacture, and these gaps are filled as soon as the storage material begins to expand. Heat is transferred mainly toward the heat exchange area inside the container (fig. 3). The two factors that have the most influence over storage tank design are the type of application for which the storage system is required and the amount of waste heat to be recovered. A system that uses gas to transfer heat will likely have small pipe diameters and large heat exchange areas.

Typical methods for identifying and monitoring composite characteristics either focus on values related to heat and mass flow (volumetric, gravimetric or calorimetric analysis) or on single-point measurements, for example, by inserting a thermocouple into the hydride bed to measure the temperature (fig. 4). Figure (A) illustrates how rapidly hydrogen is being absorbed and released by exothermic and endothermic reactions, respectively. From this, it follows that proper thermal management makes it possible to charge and discharge storage tanks within a few minutes.

SORPTION MATERIAL EXPANDS IN VOLUME Hydrogen storage in particular demands highly compacted hydride-forming metal alloys. This requires optimized bed designs and controlled rates of thermal expansion. The expanding hydrogen-absorbing phase increases the volume of the entire composite, although the degree of expansion depends on the kind of material used as well as its internal structure.

Nanopores in the composite can partly or even fully accommodate the volume change. However, metal hydride phases expanding into intraparticle voids can generate mechanical stress. In the case of technical equipment, it is therefore recommended that the increase and the resultant stress be monitored. The monitoring data can be used to calculate the degree to which stress affects storage tanks and makes changes to the bed quantifiable. It can also provide an indication of how much fuel remains in the system and how well the storage tank has aged (fig. 5 A) [HEU15, HEU17, HEU18].

As the thermochemical equivalent to pressure concentration isotherms, stress concentration isotherms can be calculated based on the data referenced above. The key characteristic of these isotherms, first mentioned by Heubner et al. [HEU15], is that they show a linear relationship across a wide range of hydrogenation levels. They are also independent from gas pressure and temperature variables. However, a notable influence is exerted by the expanding lattice as hydrogen is being absorbed. This sets these isotherms apart from pressure concentration isotherms, for which pressure is constant over a wide range of concentrations (fig. 5 B). As a result, the state of charge can be more easily determined by measuring stress rather than measuring hydrogen pressure [HEU15].

In addition, the diagram shown in fig. 5 B illustrates how measuring mechanical stress allows detecting changes in the storage material, that is, degradation, for example, due to gas impurities. The diagram depicts the stress curve for two storage materials, one of them being fully intact and the other degraded. It makes clear that there is no difference in pressure concentration isotherms, that is, the pressure level remains the same, whereas there are notable differences in stress concentration isotherms as regards maximum stress and the upward slope.

The novel measuring technique has been instrumental in developing a new fuel gauge and new state-of-charge monitoring capabilities for hydride storage [HEU15]. To demonstrate the technology, a fuel sensor was added to the bypass line of the storage system shown in fig. 3. Current research work at Fraunhofer IFAM focuses on, for example, designing a miniaturized gauge and on integrating sensing equipment into the hydride bed. Prototypes with diameters of less than 1.6 centimeters (0.63 inch) have already been produced and successfully tested in the laboratory.

CONCLUSION Advanced metal hydride composites that are manufactured using a powder metallurgy process have distinctive advantages over conventional powder- or granule-based metal hydride storage materials. The safe operation of hydride composite systems can be improved with the help of thermomechanical sensors to determine the state of charge as well as degradation. State-of-the-art hydride storage systems provide fast response times by offering heat management capabilities to control hydrogen absorption-desorption cycles so that they take no more than a few minutes. ||

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HYDROGEN VEHICLES: TRENDS AND OUTLOOK

DVGW study illustrates market opportunities

Fig. 1: Buses especially... [Source: Van Hool]

This March, the German gas and water industries association DVGW published the findings of a study called "Hydrogen electric vehicles – trends and outlook," which the organization had commissioned to evaluate the prospects for hydrogen in the transportation sector. Conducted by the Center of Automotive Management between June 2019 and this January, it explored the opportunities to be had from producing and transporting hydrogen in the gas industry when taking several technical, economic and environmental factors into account. The conclusion was that hydrogen producers and suppliers will see attractive markets emerging in the not-so-distant future.

Analyzing current advances in hydrogen-fueled transportation across the European Union and five EU countries in particular, including Germany, the study found that there was substantial political support for the technology across the continent and increasing dynamism in the market. For example, funding opportunities for developing new technology have helped businesses and public agencies add fuel cell cars to their fleets and expand the hydrogen infrastructure. In April 2019, around 1,500 fuel cell passenger vehicles were registered in the EU, while another 1,400 will be soon. The number of operational gas stations stood at 173 and 50 more are being built. Despite the comparatively low number of vehicles currently in use, the market for hydrogen-fueled cars has been growing at an impressive rate, showing what opportunities it provides.

REGULATORY FRAMEWORK Binding regulations, especially those set by the Union, have a decisive impact on the success of engine designs. The rules on carbon dioxide emissions from passenger cars and commercial vehicles and the requirements found in the Clean Vehicles Directive regarding the purchase of low- and zero-carbon alternatives starting in 2021 have been strong drivers of growth in the market for hydrogen-fueled transportation. The key objectives put forth can only be met by using either fuel cell or battery electric vehicles. In addition, there have been more and more calls to have cars run on clean, low-carbon fuel, including hydrogen. Compared to other countries around the world, Germany is also fast-tracking a regulatory framework for hydrogen-fueled transportation, spurring growth in the market.

IN-DEPTH ANALYSIS So far, Hyundai has sold about 3,800 Nexo cars around the world. By 2022, it will reportedly increase production capacity to 40,000 a year before reaching 700,000 by 2030. Until the end of 2019, it sold 10,000 Mirai cars and showcased a successor model, of which it is planning to make 30,000 a year. Honda, which offers its Clarity Fuel Cell outside Germany, has likewise announced that it was working on its next generation of FCEVs. Overall, there are around 18,000 fuel cell vehicles in use around the world and it is expected that the growing manufacturing capacity will lead to considerable price cuts.

The bus sector is believed to be a particularly attractive market for fuel cell engines, not just because buses would become emission-free. Their fueling infrastructure would also require only few adjustments. Fuel cell buses are currently built by manufacturers such as Van Hool, Solaris and Daimler and are mostly running in EU projects that aim to increase their number to 1,000 by 2023. The average price for one bus has gone down steadily and should drop to about EUR 400,000 in a few years. There are also bright prospects for the technology in the market for light- and heavy-duty trucks, as fuel cells offer a large range and great flexibility. Over 2,000 heavy-duty fuel cell trucks will reportedly be built by Hyundai and Nikola in Switzerland and the USA over the next years.

FUELING INFRASTRUCTURE The company in charge of building the fueling infrastructure for FCEVs in Germany is H2 Mobility. In mid-March, the country had 84 operational stations and 24 were under construction. The plan is to increase the total to 140 by 2021, although the exact number of fueling stations will depend on the growth in FCEV sales. The stations use 700-bar refueling, which allows drivers to fill up their cars within three minutes. Studies have shown that in the final expansion phase, a Germany-wide fueling infrastructure for hydrogen-powered passenger vehicles will cost much less than a charging network for a comparable number of battery vehicles.

Fueling stations for buses and other heavy-duty vehicles are always put up based on demand. They not only allow for sufficient fuel supply, but little effort is required to expand this kind of hydrogen infrastructure. These stations are being implemented as part of several German and international projects. Although they are typically designed to store hydrogen at 350 bars, 700-bar hydrogen could be an interesting option, at least for fueling trucks, as this could deliver effective synergies if new stations are installed together with those for fueling passenger cars.

In all, the global increase in refueling stations marks a great opportunity for hydrogen producers and distributors, just like the growth in the FCEV market thanks to automak-

Fig. 2: ...but also trucks could benefit a great deal from fuel cell engines. [Source: H2 Energy]

ers based in Asia and the ambitious targets that have been set for commercial vehicle deployment.

ESTIMATING FUTURE DEMAND FOR HYDROGEN Several studies and road maps estimating future needs for hydrogen from different sectors in Germany as well as Europe have confirmed that the market has significant potential. All of them expect strongly growing demand, of up to several hundred terawatt-hours by 2050 in the case of Germany. In Europe, estimates speak of petawatts upon petawatts, with much of it being used for hydrogen-fueled transportation.

COMPARISON WITH OTHER GASES Comparing cars running on hydrogen and gas, such as CNG or biogas, shows that, in many respects, the outlook for the two pathways is similarly bright. For instance, both show ultra-low emissions in well-to-wheel analysis if renewable sources of energy are used to produce fuel. However, the previously mentioned regulations on carbon dioxide emissions and low- and zero-emission fuel cell commercial vehicles essentially exclude gas-powered cars, as those rules focus on emissions from vehicle use.

FUNDING RECOMMENDATIONS Hydrogen-powered transportation could offer significant environmental and economic benefits. Exploiting those benefits, however, has so far rarely been possible, as the technology currently lacks the cost-competitiveness required for the marketplace. As an especially suitable candidate for powering heavy-duty vehicles, which need a long range and high power output, hydrogen will nevertheless be crucial to meeting climate aims. The DVGW study thus analyzed the regulatory framework for the market. It concluded that the framework has progressed quite far but recommends several improvements, which will be described in the following paragraphs.

European Union directives on carbon dioxide emissions put strict limits on emissions from vehicles. Moreover, the requirements of the Clean Vehicles Directive mean that government agencies will soon be able to purchase only low- or zero-emission cars. The key objectives of this directive can only be achieved by electric cars; the use of renewable and low-carbon fuel, including hydrogen, is a must. While this has been hailed as a strong driver of growth in the FCEV market, the tank-to-wheel analysis used in legislation fails to factor in important variables that have a detrimental impact on the environment. Thus, the study recommends replacing TTW analyses with well-to-wheel or lifecycle assessments to gain a more complete and technologically unbiased understanding of environmental factors.

Furthermore, the Union will need to continue its support for fuel cell research and development and help create a market for the technology if it wants to achieve its ambitious climate targets. This means that additional funding will be needed to drive down costs and meet remaining R&D objectives. It is therefore recommended that the German and European funding opportunities for FCEVs be kept in place. To achieve economies of scale, the study also suggests boosting market growth through public procurement programs.

The fueling infrastructure will require similar levels of support, which means that relevant funding programs need to be kept in operation here as well. In order to lower the cost of water electrolysis using clean sources of energy, the study recommends temporarily eliminating the difference in operating costs between hydrogen generated from natural gas and hydrogen produced from renewables. High surcharges and taxes on electrolytic hydrogen production have been a major impediment to operating power-to-X systems in Germany and producers will need help with the financial burden this is placing on them.

CONCLUSION Hydrogen vehicles are only starting to become available in Germany and Europe, but their numbers are growing rapidly. Current climate policy and strong competition from Asia drive their commercialization and help them, and the fueling infrastructure, become more technologically and economically viable. It is very likely that those producing and distributing clean hydrogen will see new, attractive sales opportunities emerging. The gas industry could benefit from these bright prospects, particularly because it could take advantage of its expertise in power-to-gas technology and because it could keep the existing pipeline network in place. ||

The 112-page study is based on 194 up-to-date sources.
A summary is available at dvgw.de for free.

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| **Category:** Electric transportation | **Author:** Edgar Lange |

FUEL CELLS GO THE EXTRA MILE

Transportation study by Fraunhofer ISE and H2 Mobility

Are batteries or fuel cells the more environmentally friendly, technically superior and economically prudent solution for electric transportation? Short answer: It depends. A great many studies have been published on the subject in recent months, one of which was conducted by Fraunhofer Institute for Solar Energy Systems – ISE on behalf of H2 Mobility. Titled "GHG emissions from battery and fuel cell electric vehicles," it looked at the entire lifecycle of a car, including the manufacture, use and disposal of batteries, fuel cells and hydrogen tanks.

The study compares a Hyundai Nexo-type fuel cell vehicle with a power output of 95 kilowatts, a 5.6-kilogram hydrogen tank and a range of over 500 kilometers (310 miles) with an all-electric car equipped with a 60- or a 90-kilowatt-hour battery for driving around 300 to 400 kilometers (190 to 250 miles; curb weight excl. battery pack: 1,600 kilograms).

The key takeaway for the years between 2020 and 2030 is that the manufacture of the fuel cell model creates fewer GHG emissions than either the 60- or 90-kilowatt-hour battery electric vehicle. Today, manufacturers of all-electric cars still have to contend with a great deal of what could be called climate baggage, though further advances in technology will make this less of a problem eventually. "Even if you count GHG emissions over the entire lifecycle of the car, fuel cell vehicles retain their advantage. The higher efficiency of battery electric cars is insufficient to compensate for the GHG emissions from their manufacture," at least, if assuming a lifespan of 150,000 kilometers (93,000 miles), André Sternberg, a researcher working for Fraunhofer ISE, said.

In this scenario, a 90-kilowatt-hour battery electric vehicle that receives its energy from the grid comes to 0.18 kilogram of CO_2 per kilometer (0.29 kilogram per mile), while a fuel cell electric vehicle using hydrogen produced by burning natural gas emits 0.15 kilogram of CO_2 (0.24 kilogram per mile). The same ratio can be observed if electricity is generated by wind turbines or solar PV. Only if a BEV is equipped with the smaller 60-kilowatt-hour battery do both vehicles have the same carbon footprint.

According to ISE, fuel cell cars will also benefit from lower GHG emissions between 2030 and 2040, at least, if both FCEVs and BEVs use green electricity. Long-distance routes especially would become the domain of fuel cells, as FCEVs would be more environmentally friendly even though they cost a great deal more than battery electric vehicles, which are expensive enough already. The material mainly driving up the cost of FCEVs is the platinum needed in making the fuel cells.

From an environmental perspective, BEVs can score points against FCEVs at low battery capacity, that is, under 50 kilowatt-hours. A vehicle equipped with a battery of that capacity would also offer a lower range, under 160 miles (250 kilometers), making it an ideal choice for urban areas. However, the difference in GHG emissions between them is not as pronounced as one might expect. Not surprisingly, both FCEVs and BEVs produce fewer GHG emissions than conventional diesel-powered cars of a similar size, although fuel cell versions provide more of a benefit in this case.

SERIES PRODUCTION CREATES OPPORTUNITIES FOR FCEVS Overall, the above findings confirm those of the joint VDI and VDE study "Fuel cell and battery electric vehicles and their importance in electric transportation" (see H2-international, October 2019). The authors of the prior study concluded that FCEVs provide more cost benefits than BEVs if they are used to meet greater power, load or distance requirements. These benefits will be even more apparent as soon as FCEVs enter series production. By contrast, BEVs have the upper hand regarding short-distance trips in urban areas. Today, the production of batteries has, of course, advanced further than that of fuel cells. As a result, the market for batteries has seen a much greater reduction in prices. However, a sizeable portion of the value chain is located outside Europe, with most battery manufacturing facilities being located in Asia.

The authors of the VDI-VDE study believe that the manufacture of fuel cells and fuel cell systems could provide value to Germany and Europe. Additionally, a diverse portfolio of electric transportation options would reduce the impact of raw materials shortages. Nevertheless, the authors also mention the biggest drawback of fuel cell technology, namely that BEVs are twice as efficient as FCEVs in converting primary energy.

What it seen as an advantage is that FCEVs separate energy conversion and storage, thereby uncoupling output from capacity. The range, i.e., the capacity, can be increased simply by installing a bigger-sized tank; the weight this adds to the vehicle is negligible. FCEVs can thus provide a range

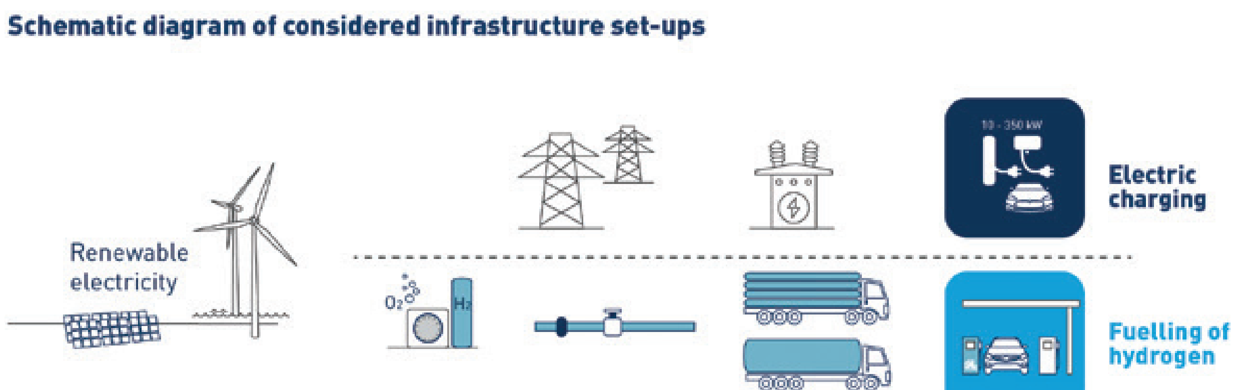

Fig. 1: Comparing two energy production pathways [Source: FZ-Jülich]

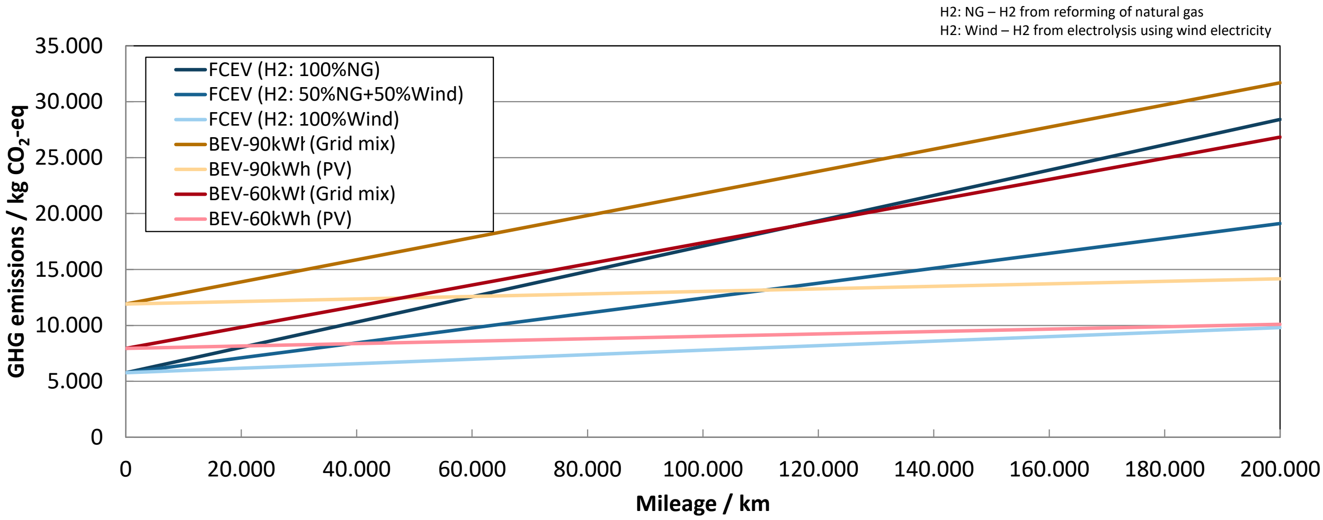

Fig. 2: GHG emissions from vehicles between 2020 and 2030, also considering the manufacture and disposal of batteries, fuel cells and hydrogen tanks [Source: Fraunhofer ISE]

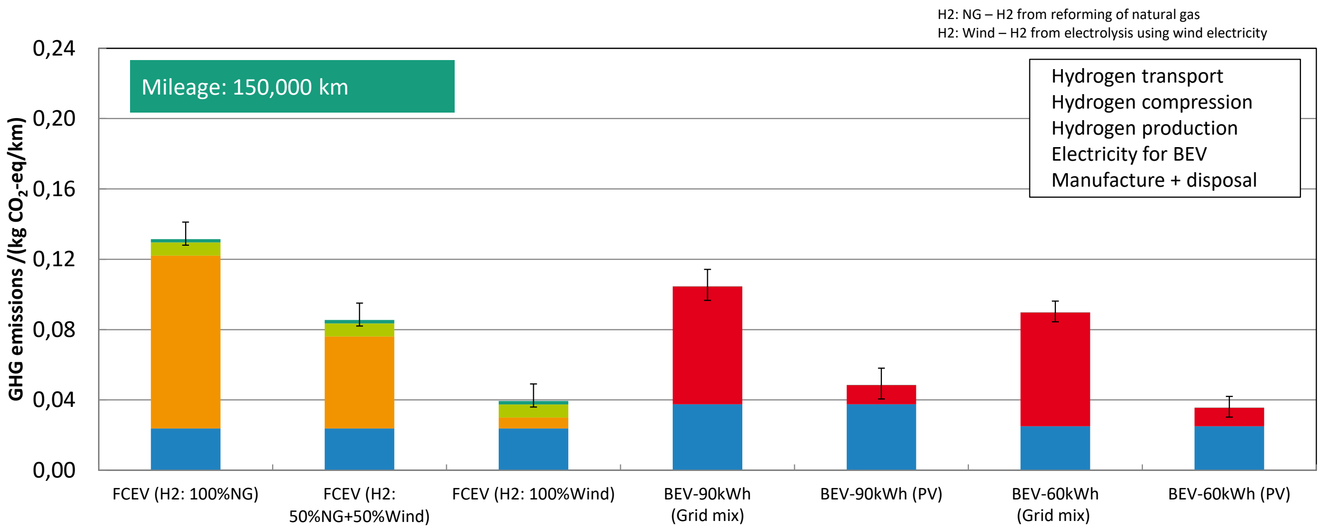

Fig. 3: GHG emissions from vehicles between 2020 and 2030, also considering the manufacture and disposal of batteries, fuel cells and hydrogen tanks [Source: Fraunhofer ISE]

comparable to that of conventional cars. A fuel cell vehicle equipped with a standard 700-bar hydrogen tank can easily go for 800 kilometers (500 miles) or more. By contrast, the battery capacity of a BEV is tied to its power output. Increasing the range will add to the weight of the car, limiting how far it can go on a single charge. Oftentimes, a fuel cell also produces enough waste heat to warm the interior of an FCEV without affecting its range.

As for availability and costs compared to diesel fuel, the VDI-VDE study says that purchasing hydrogen will pose little difficulty throughout the three stages of market introduction, growth and maturity. Another advantage of the gas is that it can be used to store energy long term at little cost, although this would increase energy losses. What is still a challenge today is how to deliver hydrogen in sufficient quantities and at reasonable prices to gas stations in Germany. This would require an expansion of the supply network. However, when acceptance of the technology has reached a certain level, that is, when around 20 million electric vehicles have been registered in Germany, the authors of the VDI-VDE study expect investment in a hydrogen network to drop to EUR 40 billion, compared to EUR 51 billion that will be spent on building up a comprehensive BEV charging infrastructure. Only if market acceptance remains negligible will a system of charging points be less expensive than a hydrogen grid. According to the study, one reason for this is that gas pumps all around the world possess the same mechanical injection system, whereas several solutions exist for charging all-electric cars. There are nine different types of plugs being used in Europe, the USA and Asia alone.

FUEL CELL VEHICLES NOT A MASS MARKET YET As production has become more advanced, prices for batteries have gone down. Fuel cells, introduced into the market at a later time, are still comparatively expensive. A U.S. Department of Energy report projected costs to drop to USD 47 per kilowatt by 2020, assuming 100,000 80-kilowatt fuel cell units were manufactured per year. A Type IV tank (a hydrogen storage tank with a polymer liner and a composite overwrap) with a capacity of 185 kilowatt-hours at 700 bars was expected to cost less than USD 16 per kilowatt-hour (around USD 3,000 in total). ||

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Category: Archive | **Author:** Hydrogeit Verlag |

ALL H_2TEC AND HZWEI MAGAZINE COVERS

20 years of hydrogen and fuel cell news

Category: Electric transportation | **Authors:** U. Bünger, M. Zerta, P. Schmidt, W. Weindorf, L. Langfeldt, B. Scholz, L.-V. Giebel, P. Klemm, G. Sattler

NO MORE DIESEL FUEL ON BOARD

ShipFuel study compares zero-emission options

A study called ShipFuel has analyzed how technically and economically feasible it is to use fuel cell systems running on electricity-derived fuels aboard inland waterway vessels by comparing them with conventional diesel engines used for ship propulsion.

The study, commissioned by the German transportation ministry, was coordinated by NOW under the auspices of the German NIP program. It covers the entire supply chain from fuel production, distribution and storage to refueling and onboard energy consumption. It takes a closer look at the current regulatory framework, identifies potential markets and provides suggestions for commercializing alternative fuel technology [1].

INTRODUCTION The GHG emissions reduction targets set by the German government and agreed on globally can only be achieved by a long-term and sustainable decrease in energy consumption and an extensive use of clean energy sources in all relevant industries. Inland waterways are a crucial means of transporting cargo over long distances across Germany. In the past years, the volume of goods shipped has remained at a nearly constant level of around 60 billion ton-kilometers (41 billion ton-miles) [2], which is around 9 percent of the total transported nationally [3]. Ferries and other passenger ships are similarly important to the German transportation sector. So far, many of these vessels use diesel to operate near or in urban areas. However, the market for inland waterway vessels will, not unlike other industries, have to contribute to emissions reductions to improve air quality across the country. Using electricity-derived fuels in fuel cells, especially if these fuels are produced from clean energy sources, has the potential to solve the aforementioned issues and help advance energy systems integration.

> **ELECTRICITY-DERIVED FUELS**
> These fuels are known by several names, such as e-fuels and power-to-fuels. Examples are hydrogen, substitute natural gas (primarily CH_4) and synthetic diesel fuel. What they have in common is that they are all produced from renewable electricity.

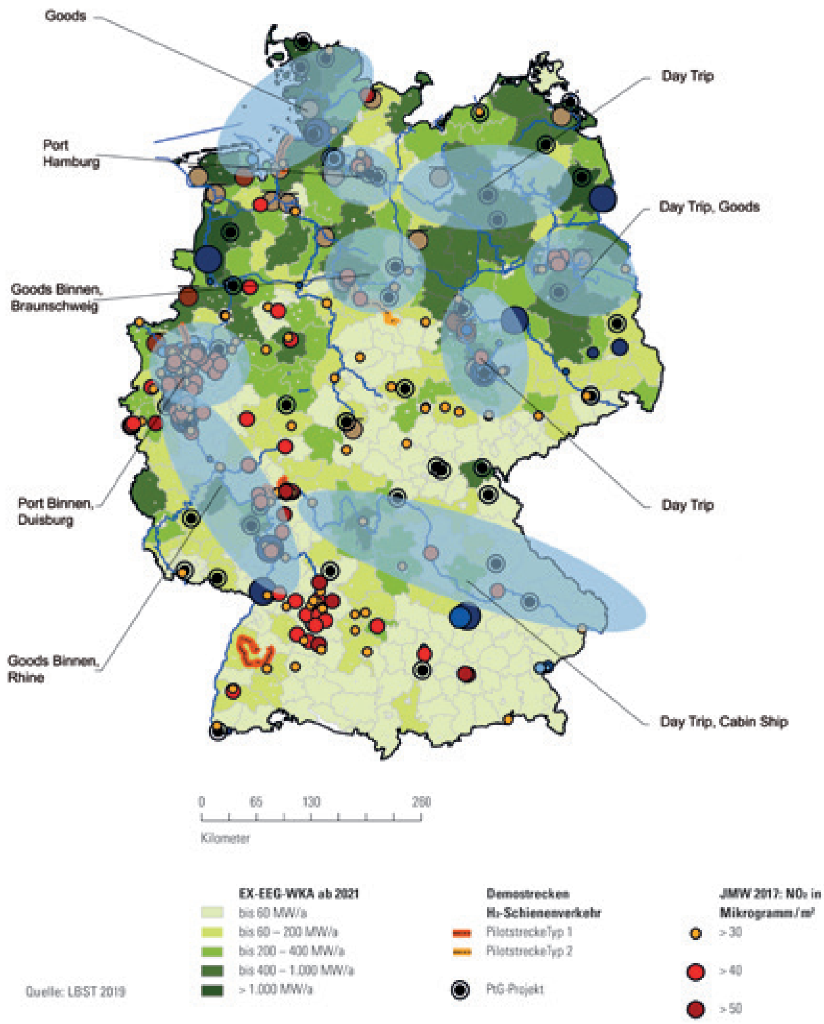

Fig. 1: Examples of possible key applications

MARKET ANALYSIS The ShipFuel study focused on the inland waterway transportation market in Germany. Four vessels were chosen to represent the most common ships and applications that consume great amounts of energy, as upgrading them would offer the largest emissions reduction potential. Two of the vessels transport cargo, one carries passengers during day trips and the fourth is available for longer river cruises. All of them could help lower GHG emissions in one of several German regions, such as in and around Berlin, on the Main and Danube rivers, and throughout Saxony and Mecklenburg-West Pomerania (see fig. 1).

FUEL CELL ENGINES TO POWER INLAND WATERWAY VESSELS Following years of development, testing and deployment, three kinds of fuel cells have come to be regarded as highly efficient and viable candidates for replacing the fossil fuel engines currently powering vehicles and vessels, including those aboard watercraft that travel on rivers and lakes. These are low- and high-temperature polymer electrolyte membrane fuel cells (PEMFCs) and solid oxide fuel cells (SOFCs). Using them for marine propulsion will change few operating parameters besides the need for taking additional safety precautions due to different fuel and battery properties. One benefit of fuel cell systems is that they are more efficient than onboard diesel generators, especially with partial load. This means that they would also improve the average efficiency in inland waterway transportation if current demand profiles are taken into account.

ALTERNATIVE FUELS USED IN FUEL CELL ENGINES The following kinds of alternative fuels were subjected to a more thorough analysis and were assigned to four types of ships and three types of fuel cell systems according to the values shown in table 1:

1. Liquid at ambient pressure and temperature (diesel, methanol and LOHC);
2. Liquid at cryogenic temperatures (LNG and liquid hydrogen);
3. Gaseous when kept under pressure (hydrogen at 350, 500 and 700 bars).

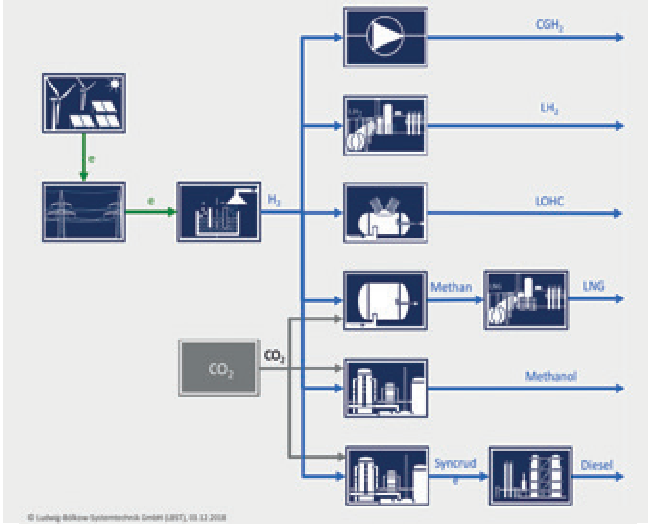

Fig. 2: Alternative production pathways discussed in the ShipFuel study [Source: LBST]

The choice of fuel system depends on the conditions listed above. Storing liquid fuel at ambient temperature and pressure requires tanks similar to those used aboard diesel vessels. These space-saving components can be either integrated with other systems immediately or adapted to the hull contour. Conversely, cryogenic fuel is stored under pressure in cylindrical tanks that need much more space than diesel containers. Tanks that hold cryogenic fuel also have another insulation layer, which increases their size yet again. In the future, some fuels may likewise require that additional safety precautions be taken, such as wrapping the tank in yet another layer of material or installing a cofferdam, so that they need even more space on board.

Comparing energy densities and tank sizes shows that using alternative fuels aboard compactly designed vessels such as passenger ships requires changes to timetables, fueling frequency or ship design. Wherever these kinds of adaptations are not possible, the fuel selected for the application must have a high volumetric energy density. Vessels that offer enough room for fuel storage or can be refueled more frequently could make do with less.

WELL-TO-TANK ANALYSIS (WTT) Comparing the fuel production pathways analyzed in this study (see fig. 2) indicates that the price for renewable electricity makes up most of the supply costs for electricity-derived fuels. Additionally, production pathways that use only hydrogen show considerably lower energy requirements than those based on hydrogen derivatives, i.e., clean synthetic fuels (LNG, methanol or Fischer-Tropsch diesel), and LOHC. Much potential could be tapped by further lowering the levelized cost of clean electricity and the cost of power-to-X equipment, in the latter case mostly by reducing the price for electrolyzer components and improving heat integration. A full fuel cycle analysis is crucial to allowing a fair comparison between different alternative fuel and engine options regardless of how advanced a particular technology is today. Current energy resource surcharges and pricing mechanisms in the electricity sector could change at any time. In fact, because the variable costs of wind and solar systems are quite low, one may expect these surcharges to change as renewable power plants meet an ever-growing proportion of total demand.

In the short term, that is, when analyzing business cases or launching lab-to-market initiatives, the focus could be on suggestions for lowering business costs. Regarding the renewable electricity-derived fuels discussed in the ShipFuel study, this could (under certain conditions) include eliminating the German EEG surcharge, as well as other charges and taxes, on power-to-X. However, a suggestion such as this is not universally applicable, which means that each individual scenario would need to be subjected to a separate, more thorough analysis first.

If clean energy pathways, especially those meant for generating clean electricity from wind energy plants and PV systems, received additional funding, the cost of renewable fuels could drop further and faster as well. Moreover, importing alternative fuels from abroad could lead to lower levelized cost of energy compared to producing them in Germany. For example, transporting compressed hydrogen through pipelines from North Africa could cut costs by a third (EUR 1.20 instead of around EUR 1.85 per diesel liter equivalent), according to estimates by LBST.

Using power-to-liquid systems to produce liquid synfuels in North Africa and import them by tanker to Germany could cut costs by around 50 percent compared to domestic production (EUR 1.30 instead of EUR 2.64).

WELL-TO-PROPELLER ANALYSIS (WTP) Calculating fuel and engine costs as part of a well-to-propeller analysis (WTP; see fig. 3) indicates that fuel costs make up the largest portion of the total and depend especially on the price for electricity (see above). Another main cost component is the price for pressure tanks if an engine runs on hydrogen and the price for the fuel cell system (which includes the cost of equipment used to process the fuel, e.g., the reformer) if it runs on a hydrogen derivative.

Supporting the adoption of fuel cell systems in multiple sectors could also reduce prices to levels below what the global industry expects to see today. This concerns especially the automotive market, where the broader uptake of this kind of technology would improve mass-manufacturing capabilities for fuel cell stacks, especially PEM fuel cells used in, for example, passenger cars, trucks and buses, and the market for stationary systems running off high-temperature PEMFCs or SOFCs. The same holds true for compressed hydrogen (CGH_2) storage tanks, which could be deployed in large numbers in land vehicles. Expectations are that CGH_2 engines will soon be used in trucks, buses and trains as well.

How cheap or expensive it is to produce clean power-to-X fuels mainly depends on the price for clean electricity. >>

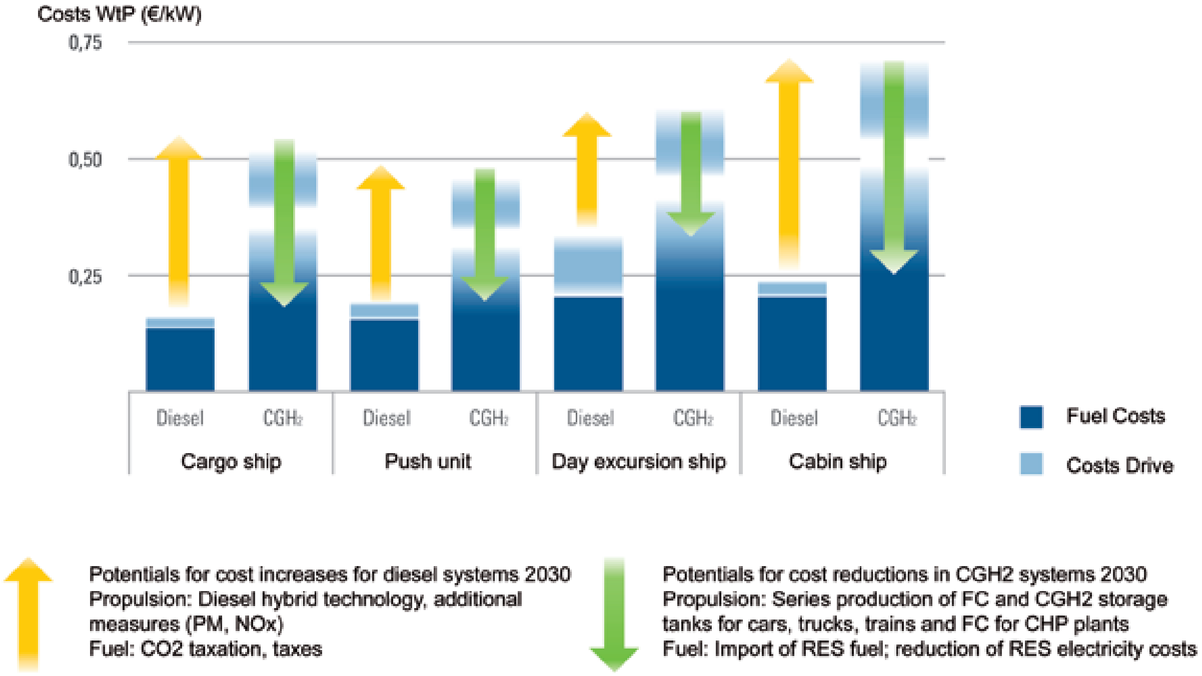

Fig. 3: Comparing an engine system made up of a hydrogen PEMFC and CGH_2 storage with a conventional diesel engine that powers vessels transporting goods or passengers in order to illustrate the key factors influencing WTP costs and determine the economic viability of fuel cell systems running on electricity-derived fuels

	Cargo ship	Push unit	Day excursion ship	Cabin ship
CGH_2 (35/50/70 MPa)	PEMFC	PEMFC	PEMFC	PEMFC
LH_2	PEMFC	PEMFC	PEMFC	PEMFC
LOHC	PEMFC	PEMFC	PEMFC	PEMFC
E-MeOH	HT-PEMFC	HT-PEMFC	HT-PEMFC	HT-PEMFC
E-LNG	SOFC	SOFC	SOFC	SOFC
E-Diesel	SOFC	SOFC	SOFC	SOFC

Table 1: Fuel cells chosen for life-cycle assessments of electricity-derived fuels

Lowering that price further would have a direct impact on the cost of hydrogen production. Possible measures from a business perspective are, for example, a temporary reduction in surcharges and taxes on green electricity used for power-to-X systems in Germany or the import of cheaper renewable energy or fuels from regions with higher solar resources, greater access to high wind speeds and large hydrogen production facilities. Cutting costs this way will also reduce those of producing clean synfuels.

To help bring electricity-derived fuels to market, consideration could also be given to an increase in the price for conventional diesel fuel. Nowadays, diesel fuel used in inland waterway transportation is mostly untaxed. A tax comparable to that on gasoline would increase the price considerably. Additional climate charges, such as a price on GHG emissions from ships (see fig. 3), could likewise raise the well-to-power costs of diesel-fueled propulsion.

These and other suggestions for displacing fossil fuel systems powering watercraft could make diesel engines much more expensive while making fuel cell systems that run on clean fuel much cheaper. But in order to seize the opportunities presented in the ShipFuel study, politicians and manufacturers need to act. ||

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Category: Research and development | **Authors:** Matthias Altmann, Patrick Schmidt

HOW TO GUARANTEE A RENEWABLE PRODUCT

CertifHy brings color into the market

The CertifHy system for tracking the origin of green (renewable) and blue (low-carbon) hydrogen has moved past the pilot stage and can now be used throughout the EU to certify the gas and issue guarantees of origin.

The recent dynamism in the hydrogen market has led to discussions about the methods by which it is produced and the sustainability of different production pathways. At issue are the expansion and use of renewable energy in every sector, but most of all in transportation, and the environmental footprint of markets that are difficult to decarburize. Examples of the latter include the chemical, petrochemical, petroleum refining and steel industries.

Current German and EU color schemes, if you will, range from gray to blue and turquoise to green. Two factors determine the color of hydrogen, which typically is almost impossible to see with the naked eye. One of them is primary energy demand, the other is the GHG footprint of production along the entire supply chain.

SUSTAINABILITY CRITERIA PROVIDE A SENSE OF DIRECTION In 2019, the stakeholders in CertifHy agreed on standardized requirements throughout Europe [1]. This has made the continent the leading force in tracking hydrogen production, a development followed closely by governments in Asia, the Americas and the Pacific. There are calls from many quarters for a single set of definitions and criteria to be used around the globe. CertifHy would be the ideal basis for this kind of standardization effort, since it was created based on broad consensus among EU countries and under the longtime watch of international observers.

One of the main criteria for issuing or refusing a CertifHy guarantee of origin is the GHG footprint of the selected production method. The footprint must be at least 60 percent below that of hydrogen produced from burning natural gas, or not exceed the yearly average of natural gas-based systems if a plant uses more than one type of energy source. For example, hydrogen generation plants that run on both fossil and clean sources of energy cannot rely mainly on coal-sourced electricity and only a small proportion of green electricity to power their electrolyzers. The purpose of this requirement is to prevent issuing certificates for systems that cause a net increase in GHG emissions compared to conventional hydrogen production.

The factor deciding if hydrogen is classified as a clean or low-carbon energy carrier is the primary energy source used in its manufacture (see fig. 1). German renewable energy regulations [2] list the following zero-emission sources for hydrogen production: onshore and offshore wind, solar thermal and PV, geothermal, ambient energy, tidal, wave and other ocean energy, hydropower, biomass, and landfill, sewage and biogas.

CertifHy even exceeds two of the current regulatory requirements. First, it must be proved that a certain method of hydrogen production leads to a net decrease in GHG emissions, which is especially relevant to pathways using bioenergy. Second, within 12 months, plants cannot give off more pollutants than a steam reformer running on natural gas (see fig. 2). German regulations also specifically mention the option of issuing guarantees for systems powered by non-renewable sources. The hydrogen they produce is classified as low carbon by CertifHy.

STANDARDIZED ACROSS THE EU Guarantees of origin show customers how eco-friendly a hydrogen production process is. This kind of certification system must meet the requirements stipulated in Article 19 of the European Union's renewable energy directive. The recast, i.e., substantively altered, directive that took effect in 2018 introduced two changes relevant to the hydrogen industry. Guarantees can now be issued for other sources besides electric power and a direct reference is made to CEN EN 16325, which was previ-

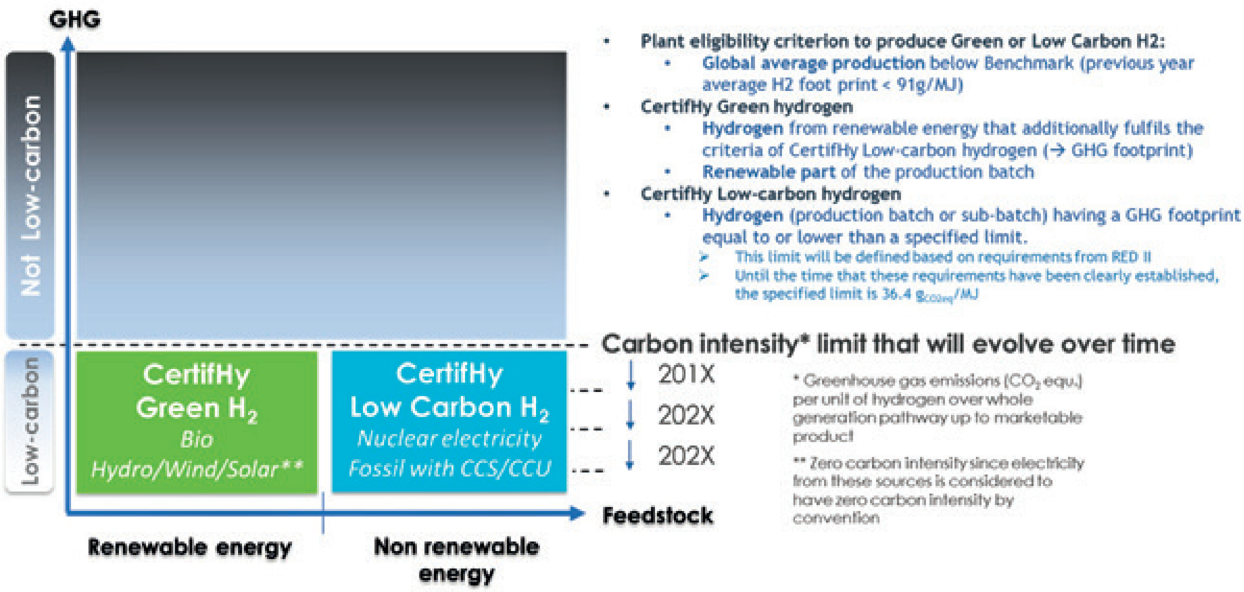

Fig. 1: GHG emissions and the primary energy source determine the color assigned to hydrogen by CertifHy. [Source: Hinicio]

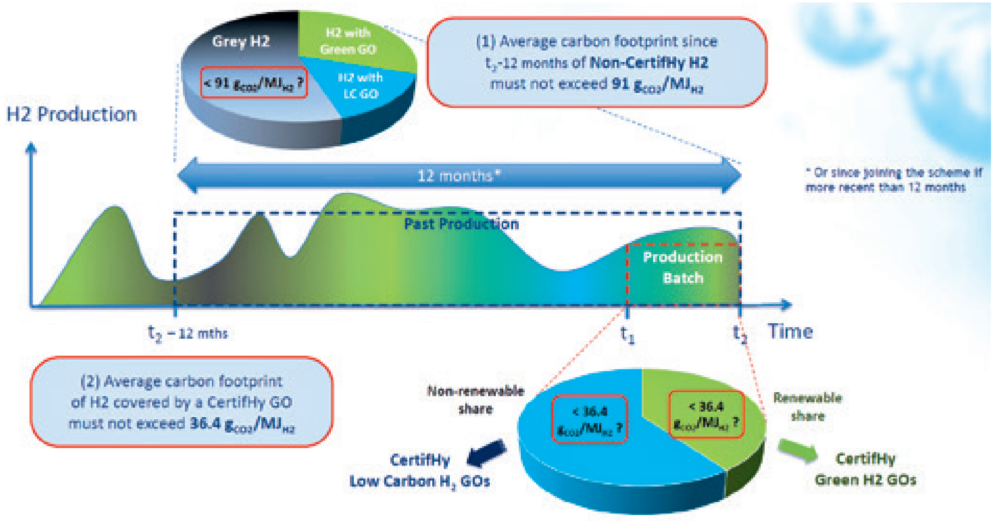

Fig. 2: CertifHy requirements for production facilities as well as clean and low-carbon hydrogen [Source: Hinicio]

ously only used for certifying the origin of electricity.

The debates among members of CertifHy about the revisions and the inclusion of hydrogen have prompted the European Committee for Standardization (CEN) to set up Working Group 5, "Guarantee of Origin," as part of Joint Technical Committee 14. Its first meeting was convened on Feb. 7 by Daniël Pol, the co-chair of CertifHy Working Group 1, "Guarantee of Origin Scheme and Procedures."

The aim is to have a full-fledged standard ready by July 1, 2021, at which point the EU directive must have been transposed into national law by the Union's 27 member countries. An important step forward would be to see hydrogen treated as an energy carrier in its own right, not have it lumped in with other renewable gases. Hopes are that the current task delegation, with a CEN working group focusing on the special requirements of hydrogen production and delivery, will ultimately lead to the creation of a separate category.

The renewable energy directive, which had been discussed for a good two years until the end of 2018, has so far failed to consider the growing importance of the market and continues to list the energy carrier as one of several under "Gas, including hydrogen." The same can be said about the regulatory environment in Germany, where it would be just as crucial to see hydrogen listed separately and not classified as biogas.

Given the ambitious timetable, the European Commission also invited bids on a supporting project, for which the contract was awarded to a consortium that is headed by AIB – Association of Issuing Bodies and includes CertifHy partners Hinicio and Grexel. Named FaStGO. it is meant to assist in the creation of a CEN standard.

The efforts undertaken by CEN further the goals of CertifHy to offer a uniform certification system in all of Europe and provide EU countries with a rich source of verified data. The aim of this database is to encourage businesses to exchange guarantees of origin for proving sustainability and deliver high-quality hydrogen across borders. The members of CertifHy have already been in frequent communication with government officials in those countries that announced highly ambitious targets for their hydrogen industries.

PRACTICAL APPLICATIONS Within the past year, H2 Mobility Deutschland has acquired CertifHy guarantees of origin for renewable hydrogen from Air Products based in the Netherlands. Nikolas Iwan, the managing director of H2 Mobility, explained that "CertifHy certificates from Air Products have greatly increased the proportion of renewable hydrogen delivered to our stations. We firmly believe the system will help spur innovation and provide transparency in the market."

CertifHy is currently being introduced to a growing number of EU projects to confirm that the hydrogen they use has been sourced from renewables. And the Work Plan 2020 [3] published by the Fuel Cells and Hydrogen 2 Joint Undertaking, also known as FCH 2 JU, mentions the project more than 30 times. Guarantees of origin will also be part of a new project on the production and delivery of green hydrogen for buses, ships and trains, and storage or insular systems running off fuel cells.

THE COST OF CERTIFICATION Like any other certification system, CertifHy requires the payment of several fees. Producers, traders and users of hydrogen must keep an account of all application and administration expenses in what is known as the CertifHy Registry. Production facilities must also be registered and audited and, as a last step, the production itself must be verified before guarantees of origin can be issued. However, there are no charges for invalidating certificates or transferring them to other account holders. You can contact one of the authors of this article to request an up-to-date list of all fees for using CertifHy. ||

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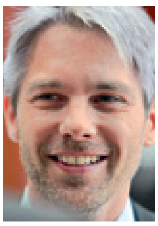

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HYDROGEN VEHICLE METROLOGY

The challenges of measuring and certifying hydrogen refueling stations

Fig. 1: The Hydrogen Field-Testing Standard (HFTS) is placed on a trailer for transport and during the measurements. The collected hydrogen is released through the lance in the front. [Source: Metas]

To promote hydrogen as a low-carbon transportation fuel, a large supply network is currently in development across Europe. However, companies operating in the hydrogen industry are faced with the dilemma of having to meet certain measurement requirements stipulated by law but not being able to do so because of a lack of available methods and standards. One important challenge is the accurate measurement of the amount of hydrogen used for refueling. Inaccurate or biased results carry a considerable financial risk, as they reduce the accuracy of billing and could slow down or stall the development of a hydrogen infrastructure.

In this article, we will present readers with an overview of the requirements that are included in current regulations and standards and that create challenges in metering hydrogen flow. We will also discuss how they are being addressed by the Metrology for Hydrogen Vehicles (MetroHyVe) project, which is part of the European Metrology Program for Innovation and Research (EMPIR). This collaborative effort comprises several technical work packages, one of which is dedicated to flow measurements. Among the around 20 partners that have joined the project are organizations specializing in metrology, scientific institutions and hydrogen energy businesses.

METROLOGICAL CERTIFICATION The amount of gasoline, diesel or liquefied petroleum gas dispensed to conventional vehicles must be measured so that vehicle drivers are billed correctly after refueling. To achieve this, the International Organization of Legal Metrology (OIML), an intergovernmental body, aims to harmonize the regulations and metrological controls put in place by individual countries. It has created global measurement standards for use in legislation and wrote International Recommendation OIML R 117 [1], which provides requirements for approving components that allow the dynamic metering of liquids other than water and are subject to measurement control. The recommendations put forth by OIML can subsequently be used as a basis for drafting national rules and certification.

Hydrogen refueling stations (HRS) look and work very similar to stations dispensing gasoline or compressed natural gas (CNG). Road users drive into allocated spaces, fill up the tanks of their vehicles and drive off after paying. In order for customers to be billed correctly, the quantity of fuel put into their vehicles must be known. In an HRS, it is a flow meter that measures the delivered mass.

International Recommendation OIML R 139 [2] covers measuring equipment integrated into systems for refueling road vehicles, railroad engines, small boats, and aircraft through the use of compressed natural gas, compressed gaseous hydrogen, biogas or other compressed gaseous fuels. It consists of three parts, with the first specifying certain measuring and technical requirements, the second setting guidelines for the type evaluation of systems and their components, as well as initial and subsequent verification, and the third describing the format for type evaluation reports. In 2018, OIML R 139 was extended to include hydrogen fuel dispensers. It now recommends accuracy classes of 2 percent and 4 percent for hydrogen, compared to 0.5 percent for gasoline and diesel and 1 percent for CNG.

Until the beginning of 2018, no certified facility could test, calibrate or verify, across an appropriate range of pressures, temperatures and flow rates, flow meters used in hydrogen refueling stations or a complete hydrogen refueling station based on OIML R 139 requirements. This implies that non-certified dispensers are still part of the HRS network, and national authorities are putting pressure on their owners to see these dispensers certified.

In the meantime, several national metrology institutes and stakeholders in the hydrogen industry have been working on a metrological infrastructure. One example of this kind of collaboration is EMPIR project MetroHyVe, which commenced in June 2017 and will run until June 2020. Through the FCH JU (Fuel Cells and Hydrogen Joint Undertaking), the European Union has also requested bids on developing a metering protocol for hydrogen refueling stations to accelerate research and provide a short-term solution for the approval of hydrogen dispensers before conclusions from MetroHyVe become available. This second program was launched in November 2017 and ended in April 2019.

Fig. 2: The HFTS is equipped with a nipple like a normal hydrogen-powered car. Filling procedure and filling time are similar to filling a car. [Source: Metas]

CHALLENGES OF METERING HYDROGEN FLOW Refueling procedures for compressed hydrogen are based on SAE J2601 [4], an international standard developed by the Society of Automotive Engineers (SAE). It establishes protocol and process limits for the refueling of light-duty hydrogen vehicles to prevent the overheating or overfilling of vehicle tanks. In pressure vessels filled with hydrogen, the heat created by compressing the gas leads to an increase in temperature, which should not exceed 85 °C. Fuel tanks are usually filled within three to five minutes by using pre-cooled gaseous hydrogen retrieved from banks of pressurized cylinders.

During refill, temperature and pressure show fluctuations over a wide spectrum. The pressure may range from 10 bars to a nominal working pressure of 700 bars; to allow quick refueling, hydrogen can also be pre-cooled to -40 °C. Mass flow is determined by a pressure-ramp rate that depends on initial pressure, available volume and temperature. These conditions place considerable strain on the testing equipment dedicated to flow measurement. Flow meters that can be operated in this kind of environment have been available for several years now and have been the subject of studies during which mostly water or non-explosive gases were used to observe steady-flow values. However, new methodologies for testing hydrogen flow meters during type approval need to be developed to prevent tests from being conducted at operational refueling stations. Testing the equipment at pressures of up to 700 bars in a laboratory is complicated, especially because of the need for safety precautions.

METROHYVE: OBJECTIVES AND FINDINGS The MetroHyVe project is nearing its end, as it will conclude this June. Meanwhile, the challenges posed by metering hydrogen flow have been addressed in different ways. First of all, we conducted laboratory analyses to evaluate the performance of Coriolis mass flow meters supplied by various manufacturers specializing in hydrogen flow metering. We used fluids safer than hydrogen to conduct these tests under controlled conditions by varying temperature and pressure levels, which resulted in densities and mass flow rates that are broadly representative of in-field conditions. The effect of changes in temperature was also investigated during this time.

Considering hydrogen refueling stations not only need to meet certain measurement requirements but must also be tested and verified, several portable field-testing standards based on gravimetric analysis have been developed by partners in the MetroHyVe project. First, the mass provided by fuel dispensers is collected in pressure vessels identical to those installed in hydrogen-powered cars. These vessels are then weighed on a scale before and after refill, and the results are compared to the numbers on the dispenser display. What may look like a simple procedure is, in fact, a relatively complicated process influenced by several factors. In addition, all measurements require an accuracy level of at least 0.4 percent. Factors such as wind, the placement of the scale (which moves the center of mass), convection currents because of temperature changes on the surface of the pressure vessels, and the condensation of ambient humidity on the cold pipes of field-testing devices during refill need to be considered in order to guarantee the reliability of results. At the end of refueling, between 3 and 4 kilograms of hydrogen, i.e., the amount stored in the vessels, is released into the atmosphere under controlled conditions. Light hydrogen that comes in contact with oxygen could explode because of its very broad flammability range and the little energy required to ignite the hydrogen-oxygen mixture, and such a scenario must be avoided at all costs. For this reason, a notified body carries out a risk analysis and monitors compliance with gravimetric standards based on the ATEX guidelines for explosive environments.

Initial field tests conducted based on METAS' gravimetric standard have demonstrated the reliability of the measuring equipment. However, the use of this gravimetric system to perform onsite measurements proved to be time-consuming and turned out to be quite a logistical challenge as well. A possible solution would be to develop a portable set of measurement tools that use a thoroughly characterized flow meter placed in series between a dispenser and a car during refill. The gravimetric standard could then become the foundation for calibrating these types of flow meters. A follow-on EMPIR project named MetroHyVe 2 has been scheduled to address this issue. ||

PRESSURE VESSELS TESTED AT UP TO 1,050 BARS
Composite pressure vessels are lightweight fuel containers installed in vehicles powered by compressed hydrogen. They are lined with high-density polyethylene that has been reinforced with carbon fibers.

Reference(s)

- [1] International Organization of Legal Metrology (2007). *Dynamic measuring systems for liquids other than water – Part 1: Metrological and technical requirements* (Standard No. OIML R 117-1).
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TURQUOISE HYDROGEN: A GAME CHANGER?

Pyrolysis as a hydrogen production pathway

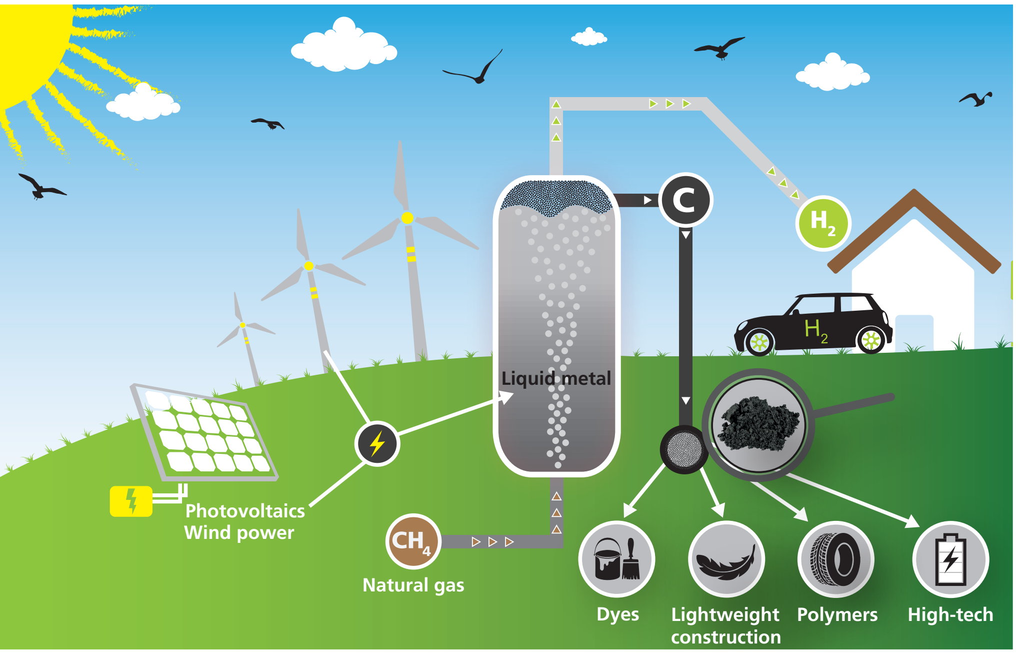

Fig. 1: Methane pyrolysis [Source: Leon Kühner, KIT]

The German government has announced it is planning to pass a national hydrogen strategy this year, with the aim of establishing a regulatory framework for the sector. The transportation, heat, energy storage and transfer, and chemical manufacturing markets could benefit from its implementation very quickly.

According to current scenarios focused on the fight against climate change, our future energy system will no longer rely on centralized fossil fuel-fired power plants but on distributed generation devices delivering clean electricity. Even now, hydrogen is highly sought after, and the industry will continue to grow in the years to come. Sector experts estimate that hydrogen, as one of several sources in the future energy mix, could meet up to 24 percent of electric power demand across the European Union in 2050.

An appropriate strategy will be required to make the industrial production of the gas economically viable. Above all, we will need to develop mature technology, but we will also have to showcase relevant applications, expand the hydrogen infrastructure and create a suitable legal framework.

Hydrogen is considered a clean alternative to fossil fuels. However, current production methods are either relatively expensive or create carbon dioxide emissions. One method that has been growing in importance besides electrolysis and steam reforming is pyrolysis. It uses heat to break down natural gas into gaseous hydrogen and solid carbon.

HYDROGEN FROM METHANE The idea of using heat to split methane is not new. Russian energy conglomerate Gazprom has been working on the technology, also called methane cracking or methane decarbonization, at its research facilities in Tomsk for many years. The main issue preventing real-world application used to be the very short life of demonstration plants. Often, the carbon residue left behind by the process eventually clogged up the reactor.

$$CH_{4\,gaseous} \rightarrow C_{solid} + 2\,H_2 \qquad \Delta H = 298\ K = +\,75.6\ kJ/mole$$

Pyrolysis takes place in a bubble column reactor, filled with a liquid metal such as molten tin. The crack reaction occurs after fine methane bubbles are introduced through an opening at the bottom of the system and start rising inside the column. Carbon then separates on the surface of the bubbles. When they disintegrate, black, elemental carbon is deposited in powder form at the top end of the reactor.

GONE ARE THE SOLID PARTICLES The Karlsruhe Institute of Technology (KIT) and the Institute for Advanced Sustainability Studies (IASS) in Potsdam took advantage of their expertise in liquid metal technologies to improve the process, developing a new approach to generating hydrogen through pyrolysis. The main feature that sets their method apart from previous ideas is that the solid carbon is continuously split off and removed from the reaction zone. As soon as the methane bubbles reach the surface of the liquid metal inside the column, the carbon powder is collected by commonly available means.

KIT tested the new method by running a reactor without interruption at temperatures of around 1,200 °C for a total of two weeks, in which hydrogen was produced with an up to 78 percent conversion efficiency. Pyrolysis creates only high-value resources and, in contrast to other industrial methods, zero carbon dioxide emissions. Compared to electrolysis or steam reforming, pyrolysis is inexpensive, practical, scalable and climate neutral.

Both the hydrogen and the carbon could be used, for example, in the steel industry. Demand for replacing coke with hydrogen could be 140 terawatt-hours in 2050 in Europe alone, since blast furnaces need around 300 kilograms of the fuel and 200 kilograms of coal dust for producing one ton of raw steel. Carbon serves as an additional reductant in steelmaking and is blown into the lower section of the furnace. Replacing it with hydrogen as well would lower emissions by up to 20 percent. Additionally, metal fabrication businesses could make good use of the elemental carbon, the second product of methane pyrolysis, when coating, drilling, engraving, galvanizing, polishing or welding materials.

In short, pyrolysis is the method of choice for anyone in search of a cheap, well-scalable, carbon-neutral and easy-to-implement solution for producing hydrogen. ||

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Category: Stocks | **Author:** Sven Jösting |

ENTER THE HYDROGEN DECADE

Sven Jösting's market analysis

Since the beginning of the year, the fuel cell stocks covered in this issue had seen a fast uptrend, which ended with the spread of Covid-19 around the world. Fears over the impact of the disease on the global economy meant some gains were quickly lost. Still, in light of increased news coverage, multiple project announcements and the growing popularity of green hydrogen, it has become clear that hydrogen and fuel cells are entering the mainstream and their breakthrough into the market is approaching rapidly.

One of the many potential uses for fuel cells is the electric transportation sector, where they primarily compete with batteries. What is often overlooked in this context is that the world's biggest vehicle market, China, is not focusing on a single technology but a great variety of them to meet its future transportation needs. Moreover, the support and funding it provides for fuel cells in particular means the country is no longer putting that much effort into developing new battery technology.

As for the stock market, companies such as FuelCell Energy, believed to have gone under, are expecting to make a comeback and rise like a phoenix from the ashes. Other stocks are also benefitting from the overall good mood in the industry. The new-found enthusiasm is the result of hydrogen and fuel cell systems becoming an important weapon in the fight against climate change, for example, as part of the EU's Green Deal. Most systems showcased to the public these days are prototypes, in testing, parts of living labs, or made in small numbers. However, it will only be a matter of time until they spawn new trends, and new megamarkets in particular.

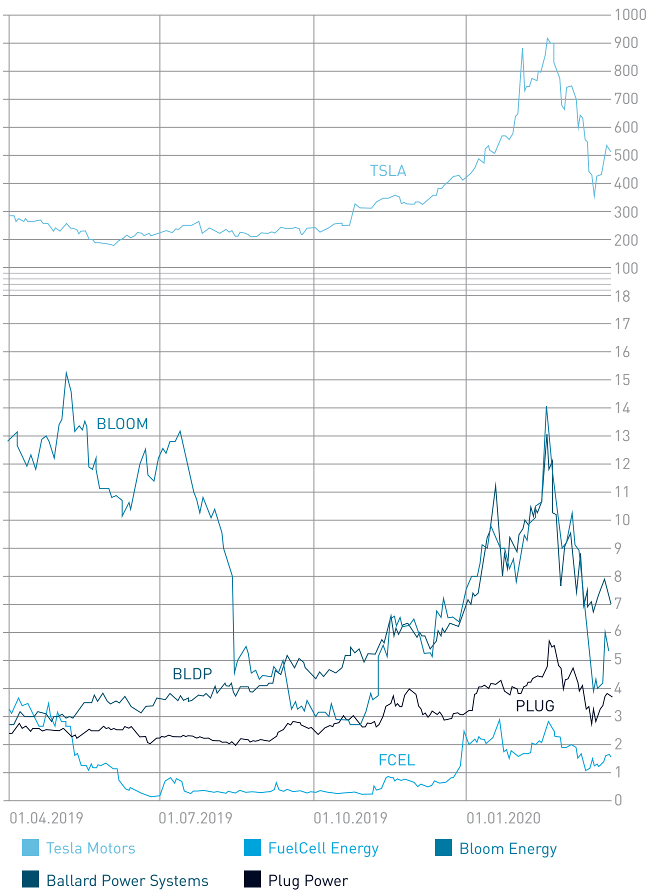

Fig. 1: Historical price data on the five companies covered in this issue [Source: wallstreet-online.de] Retrieved March 23, 2020

Fuel cell companies, as well as their stocks, are sure to benefit from recent developments and, if the Democrats win back the White House, could garner support in the United States based on the party's agenda to pour massive amounts of cash into the clean energy sector. Additionally, the frenzy and hype that has surrounded businesses such as Tesla and has led to record-breaking market rallies will begin to fade away as soon as hydrogen and fuel cell manufacturers achieve economies of scale and a hydrogen infrastructure is up and running. When that time comes, we are talking about no more than a few years, fuel cell suppliers will be giving battery producers a good run for their money.

Fuel cells used in heavy trucks and buses have already reached a level of technological maturity that is becoming a detriment to progress in the all-electric market. The important thing here is to look at the entire range of direct and indirect costs included in the cost of ownership. Hybrid trucks, which use fuel cells and small batteries, have a clear advantage over their all-electric counterparts, since they are not equipped with heavy, space-consuming battery packs. Take Nikola Motors, for example. Its IPO will provide fresh impetus for growth and be a positive influence on other stocks such as Ballard's. Simply put, this year will see hydrogen and fuel cell technology making a breakthrough around the globe. Last year, I believe, was only the beginning.

BALLARD POWER – WELL-PREPARED, STILL GOING STRONG

The manufacture of the new powerful LCS stack, through a Weichai-Ballard joint venture in China, will start in the second half, or around the middle, of 2020. In my opinion, it will lay the foundation for high, long-term growth in revenue and profit. Considering what month it is, we will not have to wait long to find out. The positive news coming from this will form the basis for price trends throughout the year. I estimate a big jump, as Ballard Power is the global leader in manufacturing fuel cells.

ENCOURAGING RESULTS IN 2019 – MORE ON THE HORIZON The numbers for fiscal year 2019 turned out well. Fourth-quarter results were in line with expectations. Revenue was USD 41.9 million, bringing year-on-year growth to 47 percent, more than USD 10 million above forecast. Full-year revenue came to USD 106.3 million; the net loss per share was USD 0.04. Ballard also had a healthy reserve of USD 147.8 million in cash. Regarding 2020, the company anticipates a total revenue of USD 130 million. It also said it would raise fresh capital from time to time through an at-the-market equity program, which could rake in up to >>


Fig. 2: Telecommunications mast in Thailand

USD 75 million. This puts Ballard [Nasdaq: BLDP] in a good market position, since it will not need new loan facilities or more than a small amount of the cash it has on hand. Maybe, though, it wants the USD 75 million for something else, like buying another company?

FUEL CELLS FOR RADIO TOWERS In January, SFC Energy and adKor placed an order with Ballard for 500 fuel cell systems, to be deployed at radio tower sites in Germany. Another 1,000 may be added at a later date. This is a highly intriguing piece of news, as the company once planned to branch out into the sector in China. It was reportedly in talks with China Tower, which owns over 35,000 towers, though the talks were going nowhere. Now, Ballard will finally be able to enter a market that it has had an eye on for a long time.

Those who listened to the company's conference call about the latest financial results or read the transcript of it could be forgiven for getting excited about the prospects for fuel cells. The chief executive of Ballard, Randy MacEwen, painted a perfect picture of the future. He said the fuel cell market "experienced remarkable momentum" and was certain that "we are entering the hydrogen decade." He gave six reasons why hydrogen and fuel cell technology would attract a great deal of investment in the coming years:

1. In all, 66 countries are planning to transform into zero-carbon societies by 2050 and the governments of 18, which generate 70 percent of global GDP, have announced hydrogen and fuel cell road maps. Additionally, government energy departments from around the world have said they were committed to implementing a 10-10-10 strategy, i.e., 10 million fuel cell vehicles and 10,000 hydrogen fueling stations in 10 years.
2. Large corporations, including Bosch, Cummins, CNH, Daimler Trucks, Hyundai and Michelin, are planning a massive increase in hydrogen and fuel cell investments. The Hydrogen Council has grown to 81 members, all of which combined employ 6 million people and generate a revenue of more than USD 18 trillion.
3. Mass production has begun. Use cases in near-term markets include trucks, buses, trains and ships. At some point in the next 10 years, the total cost of ownership for fuel cell vehicles will be lower than for any other kind of vehicle, be it an ICE or an all-electric car. In the long term, fuel cells will have significant advantages over batteries, even if they have to make do without government support. This is because economies of scale will reduce the cost of vehicles and infrastructure.
4. There are many new markets and applications to explore. One example of this is the use of fuel cells in forklift trucks. There are now around 18,000 FCEVs in use globally and 400 hydrogen fueling stations are up and running, with another 200 stations to be put up this year. China already has 6,300 fuel cell units powering trucks and buses and 3,000 of them were installed by Ballard. The country also has 44 hydrogen fueling stations and another 41 are under construction. In close partnership with UPS and Kenworth, Ballard is likewise working on developing fuel cell delivery and drayage trucks.
5. The cost of manufacturing fuel cell stacks has dropped a great deal. The new LCS stacks are 35 percent cheaper than Ballard's previous fuel cell systems.
6. A growing number of people in politics and investor circles are putting environmental and climate issues at the top of their agendas. This has led to an outpouring of cash to fund hydrogen and fuel cell projects.

My conclusion is that those who can be patient will earn good money with this stock. A jump like what we saw in 2001 and 2003, when the price shot from USD 5 to over USD 130 per share, is not a realistic assumption, in my view. However, an uptrend over the next three years is. Additionally, reports from China suggest that Covid-19 seems to be gradually under control and an end to the pandemic is in sight, which is very good news for Ballard.

BLOOM ENERGY – A RESTART IS IN ORDER

Bloom Energy stock rose for a good while, to around USD 14, before falling dramatically. The plunge was a result of the company's relatively weak performance in the fourth quarter of 2019 and the same-quarter restatement of managed service agreements entered into between 2016 and the end of last year. Instead of over the duration of the contract, the revenue for managed services transactions had been recognized upfront. But as this affected only around 10 percent of total revenue over the specified period, the impact on overall results was negligible. An analyst working for investment firm Cowen did not see the earnings restatement as a good enough reason for changing his outlook on the company.

WEAK NUMBERS BUT DESTINED FOR GROWTH The results for the fourth quarter of 2019 seemed disappointing. Instead of around USD 260 million, as estimated, revenue came to USD 213.8 million, an increase of 35.8 percent year over year. Instead of turning a profit, the company incurred a net loss of USD 67.1 million, although most of it was the result of stock-based compensation, i.e., accounting losses. Despite these issues, product and install backlog increased by an impressive 43.3 percent.

Considering how much the stock has been worth lately, Bloom's troubles have been good news for those shorting around 18 million of its shares, from a float of 70 million. But like the above-mentioned analyst, I rather want to focus on the company's bright outlook. Bloom [NYSE: BE] now has a USD 4 billion backlog. The contract value of this backlog is USD 1.1 billion for product and installation revenue, USD 1.1 billion for revenue from new service agreements and USD 2.1 billion for revenue from agreements already in place, assuming all service contracts are renewed over the full contract term. The business also had a year-end cash balance of USD 377 million, though it wants to refinance its existing debt this year. This likely means its 6-percent convertible notes, total par value USD 289 million, will be exchanged for new notes or a long-term loan facility. In any case, the company is planning to complete the refinancing process in the first six months of 2020.

[Update: On 2 April, Bloom announced it would amend the 6-percent notes due in 2020 by raising their interest rate to 10 percent a year, extending maturity to December 1, 2021, and setting the conversion price to USD 8.]

Bloom also reported a substantial increase in new orders, seeing bookings jump by over 40 percent in the fourth quarter of 2019. As its new energy servers reportedly provide more than 50 percent more output as well, it is safe to assume that the stock will rise again.

GOOD PROSPECTS FOR SECOND HALF OF 2020 Bloom's chief executive expects "a solid 2020," with a first-quarter reduction in revenue to somewhere between USD 140 million and USD 160 million because of how projects are won, implemented and included in the balance sheet. Each project needs around three months for assessment and approval and nine to 12 months from award to completion, so you can already see why there is going to be, in his words, "a far better second half."

The company's board believes that following the first quarter, which will show a loss, Bloom will break even in the second and return to "pretty decent profits" in the third and fourth. In my opinion, current prices could be an opportunity to purchase shares at a discount if you are looking for a medium-term investment. Short sellers will continue to try to get the price down by taking advantage of the latest financial results, but this doesn't affect the prospects for Bloom's clean, off-grid solutions. By the way, an analyst with JP Morgan recently (on March 17) lowered his price target from USD 16 to USD 14. Right now, the stock is trading below USD 4!

FUELCELL ENERGY – THE MOMENT YOU REACH THE GROWTH CEILING

How quickly things can change. Just a few months ago, FuelCell Energy [Nasdaq: FCEL] risked bankruptcy due to questionable financial practices. With the help of a highly committed and successful consulting firm, the business then righted the ship. At one point, its price soared from around USD 0.13 to an intraday high of over USD 4.00 as it saw its market cap jump from USD 40 million to USD 500 million. The latest stock crash then put an end to it all and the stock took a nosedive, finishing below USD 1.00. It will certainly take some time before the price averages out to reflect business growth. Daily trading volumes of up to 150 million shares let me assume FuelCell stock is of great value to gamblers and day traders but is less of an opportunity for those who think strategically. Still, I believe things will change for the better in the not-so-distant future, when institutional investors take over the reins and put money into the company long term. Big corporations could also see a business such as this one as an attractive acquisition target. Such was the case for Hydrogenics, the Canadian fuel cell manufacturer that was bought by Cummins.

FuelCell's new board must now leap into action, focus on fulfilling existing orders, generate new bookings and acquire new customers and, above all, make the manufacturer profitable. The company does frequently report that it is making progress, for example, in constructing a fuel cell power plant for Toyota in California to produce hydrogen for FCEVs, among other things. Also, if the joint venture with E.ON Energy Solutions is to make any sense, it needs to attract some large orders from Europe soon.

FAVORABLE OUTLOOK Good reasons for expecting an uptrend to return are the results for the first quarter ended Jan. 31, 2020. During the first three months of 2020, revenue totaled USD 16.1 million. Operating expenses decreased by 51 percent year over year, whereas loss from operations was USD 3.1 million, compared to USD 15.2 million in the prior-year quarter. The net loss per share was USD 0.20, though you will need to bear in mind that the calculation includes warrants issued at the same time capital was raised. These non-cash charges, more than USD 37 million, were added for tax purposes. Cash and cash equivalents, whether restricted or freely available, amounted to as much as USD 73.9 million.

Additionally, USD 120 million is still available from the credit facility provided by major shareholder Orion Energy Partners. Backlog at the end of the reporting period was USD 1.36 billion, an increase by over USD 117 million. I assume that the revenue from service agreements was spread over the length of the contracts. In conclusion, I would say that current prices should be seen as an opportunity for buying FuelCell stock, even though purchases still deserve the label of "highly speculative" at this point, that is, until the restructuring of the company has borne fruit. Nevertheless, prices of USD 2 and more are in sight should second-quarter results indicate an upward trend, which I expect they will.

PLUG POWER – NOT YET WHERE IT SHOULD BE

Cashing in around the USD 5 mark, as I recommended, may have been a bit premature, seeing that the price rose as high as USD 6, but was ultimately a prudent move. At present, Plug Power's stock again trades around USD 3. You may wonder what happened in the meantime. Simply put, expectations were too high. The net loss per share amounted to USD 0.06 in the fourth quarter of 2019. Revenue rose to USD 91.7 million, compared to USD 59.8 million generated in the prior-year quarter, which means there is some good news. The company also announced new bookings would hit USD 300 million this year. But I still don't know how Plug [Nasdaq: PLUG] intends to earn money. Maybe via service agreements? Ideally, it would turn a decent profit from selling hydrogen. Furthermore, I am cautious about investing in Plug because it has granted both Amazon and Walmart more than 100 million warrants. Their low exercise price of around USD 1 could mean a substantial increase in shares, diluting the stock. >>

WIKIFOLIO: BZVISION STILL SHOWS MORE THAN 200 PERCENT PROFIT

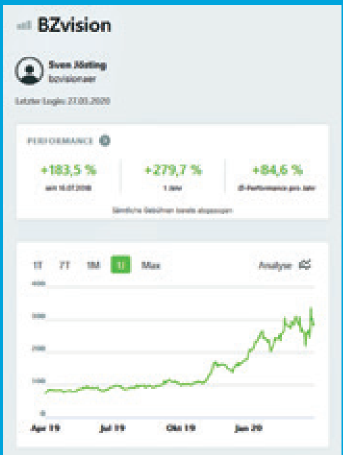

Fig. 3: The virtual portfolio [Source: Wikifolio]

My virtual portfolio BZVision on wikifolio.com has stood up well despite the turbulent times (crash!). After Tesla's stock rallied to over USD 800, I added five thousand EUR 5 HSBC put options, each with a USD 600 strike price and a December expiry, to my Tesla puts with a USD 380 strike price due Sept. 15, 2020. I bought them to protect my portfolio and because I speculated the stock would fall, as I didn't believe that there were good reasons for the rally and that it was rather the result of hedge funds playing the market. The stock's subsequent plunge from more than USD 800 to USD 450 confirmed my suspicions, leading to a sizeable increase in the value of the puts. I immediately reinvested the realized gains in Bloom, Ballard, FuelCell and, for the purposes of position trading, Plug. Fortunately, I had also profited from selling Ballard and Bloom shares when they were around USD 13 or USD 14. I felt their uptrend between December 2019 and February 2020 was too fast and too high. As of this writing, I still expect that Tesla will fall below USD 400 but, more importantly, that fuel cell stocks will start rising again. Tesla has turned out to be the perfect anti-fuel cell investment, considering Elon Musk has called fuel cells "fool cells." Had I waited just a few more days, my portfolio would have been worth EUR 100,000 more because of the added gains from Tesla options alone. This way, though, I was able to buy fuel cell shares at low prices. There are two sides to everything.

The method Plug is using to record major customers and their orders is opaque to me. It is called vendor financing and could, conceivably but not necessarily, lead to restricted cash in excess of USD 210 million. I remain skeptical despite the stock's current low. For the sake of trading, I added a small number of shares on wikifolio. Considering by how much the stock dropped, from USD 6 to below USD 3, it could see a short-lived rebound to USD 4 or USD 5 as soon as most of the market recovers from the current crisis.

TESLA – THERE IS THE SHORT SQUEEZE

In the previous H2-international issue, I wrote that the price rally from USD 250 to more than USD 430 already represented a short squeeze. However, I was quickly disabused of that notion when I saw Tesla's stock hitting an intraday high of USD 1,000 before pulling back in recent weeks. I was not able to find anything that could, even remotely, justify the massive increase in market capitalization to USD 180 billion. It's not to the detriment of Elon Musk, to be sure, as he has achieved one of his milestones, a cap of over USD 100 billion. As far as I can tell, he could be rewarded with a payout of more than USD 300 million.

According to a list of stock market filings exceeding USD 100 million, multiple hedge funds invested big in the carmaker at or around the time of the rally. I can only speculate whether they all agreed on this, that is, if it was a joint, targeted effort, but I would not be able to prove it. I suspect, though, that the aim was to put pressure on short sellers, who had shorted over 22 percent of Tesla's shares. The rally was losing them money. Still, even subsequent quotes of over USD 700 seemed inflated to me.

Mark Spiegel, a well-known and successful short seller, considers Tesla [Nasdaq: TSLA] to be a large stock bubble. He said he had often been wrong in the past, making losses from shorting the company's stock, but will keep his short position. He also expects much lower prices in the future, citing the company's debt and its purchase and lease obligations. These could be as high as USD 30 billion, including what Tesla owes its suppliers. Additionally, the electric carmaker was about to face a huge onslaught of competition.

In January and February, Tesla's models no longer ranked among the top-selling vehicles in Norway. Model S, X and 3 cars came in 18th place or lower. And Adam Jonas, an analyst with Morgan Stanley, now believes General Motors will come out ahead thanks to an electric vehicle budget of more than USD 20 billion and batteries that reportedly enable a range of 400 miles (more than 640 kilometers).

RAISING CAPITAL ON THE GO At the end of 2019, Musk proclaimed in an interview that Tesla did not need to raise capital, though it did just that, you might say in passing, through an offer priced at USD 767 a share, for a total of USD 2.3 billion. This did look good on the balance sheet after banks in China had also loaned the corporation USD 2 billion for putting up the Gigafactory in Shanghai. One can only congratulate Tesla on its achievement. Here is a toast! Now, it has to earn money with the factory, since it agreed to start paying a minimum amount of taxes in a few years' time.

It is certainly a plus that Tesla has gotten a foot in the door of the world's largest auto market, as U.S. President Donald Trump has threatened to escalate the trade war with China. Time will tell if the company made the right decision at the right moment, since China is exploring the potential of hydrogen and fuel cells and is starting to zero in on the technology – at the expense of batteries.

Because of Covid-19, production at the electric carmaker was halted temporarily, which will affect its financial results for the first quarter. One positive development, though, has been that Tesla reached its ambitious sales targets for 2019. In all, it generated USD 7.4 billion in revenue in the fourth quarter, making a profit of USD 105 million. It delivered more than 365,000 vehicles and expects to ship 500,000 this year.

Tesla's outstanding convertible bonds, par value around USD 3 billion, could be exchanged for shares with the aim of lowering the company's debt, since current prices are notably above the conversion rate. Debt could be turned into equity this way, depending on bond terms. However, the huge amount of new shares would end up diluting current shareholders' stock.

The fourth quarter of 2019 ended with a profit that was considerably higher than expected. And yet, I would like to

Fig. 4: Tesla Roadster [Source: Tesla]

advise caution, as most of it came from selling zero-emission vehicle credits, not all-electric cars. I believe the more important quarter for Tesla will be the first of this year. The Covid-19 virus and the drop in sales in China could dampen the mood. Additionally, the reduction or end of funding opportunities and subsidies could spell trouble in many markets in which Tesla operates and where it has so far managed to sell a great many vehicles.

What should give pause too is the weak sales performance of the highly profitable Model S and X cars. Model 3 will be manufactured in greater numbers, but what about Tesla's profit margin? Model Y, which is based on the Model 3, will reportedly provide fresh impetus for growth. Still, some analysts believe Tesla runs the risk that many of those who ordered a Model 3 will rethink their decision and go for a Model Y instead.

Plus, the competition has not been asleep at the wheel and will likely enter the market with hundreds of new models soon. This year may be no more than a transition period for those manufacturing fuel cell hybrid electric vehicles. When looking at the road maps developed by Hyundai, Toyota and others, the hydrogen era will begin in 2021. Thanks to economies of scale, prices for fuel cell electric vehicles have begun to fall drastically. Sadly, German automakers will not start until 2022 or later to manufacture FCEVs, as batteries have taken priority.

Meanwhile, Tesla is not even thinking about adding fuel cells to its cars in some way or another. It has more than USD 5 billion in the bank, at least for now. Its new factory in the German state of Brandenburg will reportedly cost around USD 4 or 5 billion to build, so the company will need to ask for more loan facilities, use the cash it has on hand, or raise capital again through another stock offering.

To explain Tesla's market cap, people often point to the sales potential of self-driving cars. But will everything go as quickly as envisioned by Musk? Will the company be making money with new technology right from the start? I have my doubts and I see them confirmed by current prices. The stock is following a pattern similar to what we saw happening in the first half of 2019, when it dropped from USD 350 to as low as USD 170. This year, it went from USD 700 down to USD 350. Some analysts, though, have set a target of USD 7,000 or more. The average price will be somewhere in between, I believe at the lower end of the range or even lower. ||

RISK WARNING

Share trading can result in a total loss of your investment. Consider spreading the risk as a sensible precaution. The fuel cell companies mentioned in this article are small- and mid-cap businesses, which means their stocks may experience high volatility. The information in this article is based on publicly available sources, and the views and opinions expressed herein are those of the author only. They are not to be taken as a suggestion of what stocks to buy or sell and come without any explicit or implicit guarantee or warranty. The author focuses on mid-term and long-term prospects, not short-term gains, and may own shares in the company or the companies being analyzed.

Category: Global market | **Author:** Nicola Bottrell Hayward

UK GEARS UP FOR HYDROGEN HEATING

Gas engineers prepare for the future

In June 2019, mere weeks before stepping down as British prime minister, Theresa May committed the United Kingdom to an ambitious new target of net-zero carbon emissions by 2050. The amendment to the Climate Change Act made the UK the first G7 nation to enshrine net-zero emissions in law. This toughened stance has resulted in carbon dioxide reduction becoming a more pressing issue than ever. Providing heat to domestic and commercial properties currently accounts for a third of the country's carbon footprint. And with more than 80% of homes using natural gas for heating, hydrogen is now receiving considerable attention as an alternative energy carrier. Yet few in the gas industry have a full understanding of its properties.

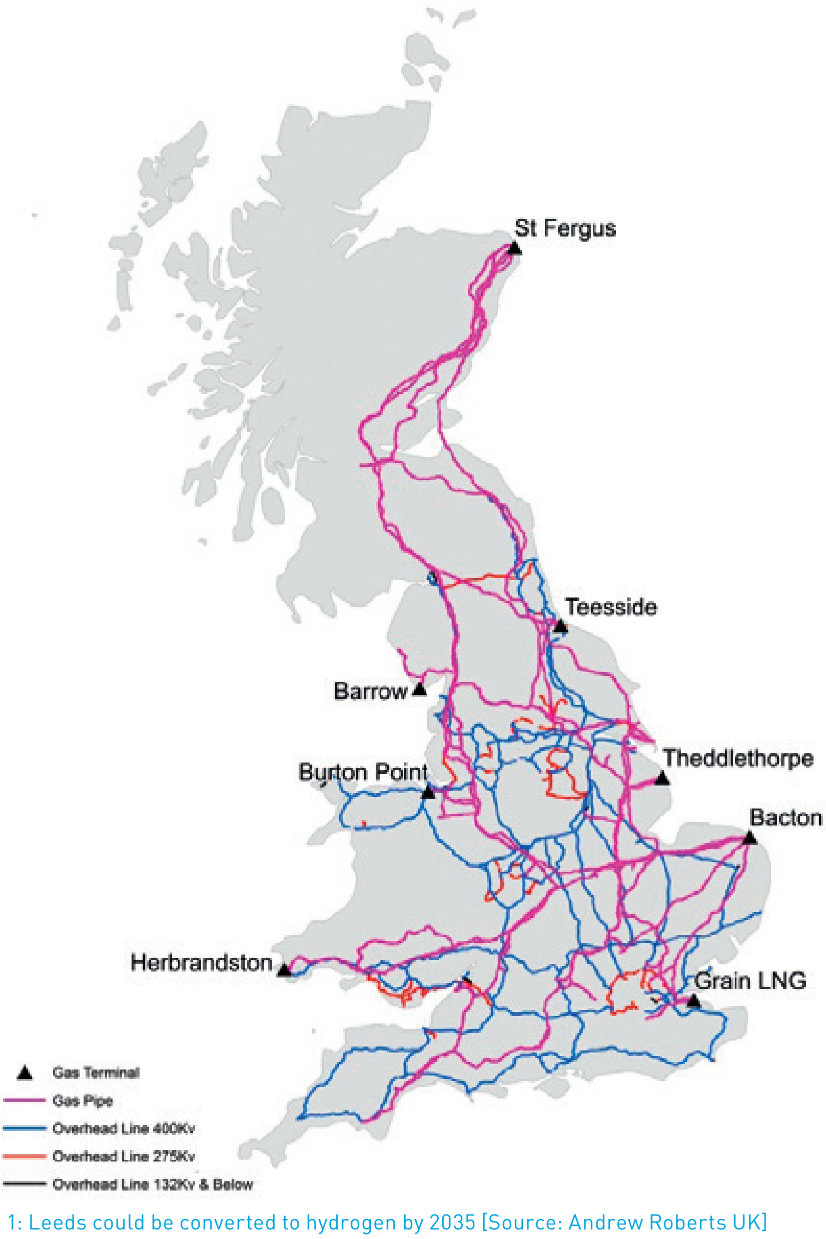

Fig 1: Leeds could be converted to hydrogen by 2035 [Source: Andrew Roberts UK]

Seeking to address this knowledge gap, members of the UK's gas industry gathered at the Institution of Gas Engineers & Managers (IGEM) near Derby on October 1, 2019, for an in-depth training session on "Hydrogen and the Natural Gas Network." The course was delivered by Mark Crowther and Paul McLaughlin of Kiwa Gastec, a leading testing and certification body. The company has been involved in multiple studies investigating the potential conversion of the UK's domestic gas supply to hydrogen, including the H21 Leeds City Gate project (see H2-international, July 2018).

Safety was high on the agenda and the course facilitators were able to use their expertise to drill down into the detail of hydrogen's combustion characteristics and potential hazards. The possible problem of leakage was also raised. Attendees learned that although hydrogen is 76% of the diameter of methane, any pipe that is completely tight with natural gas will also be tight with hydrogen. Reassurance was given that polyethylene (PE) piping can be repurposed for the transportation of hydrogen. Good news for the country's 176,000 miles (284,000 kilometers) of gas mains.

The UK's low and medium pressure gas distribution network is currently being upgraded so that by 2032 all cast iron gas mains will be replaced with PE, making the existing infrastructure substantially hydrogen ready. Transmission of hydrogen at high pressures would, however, necessitate a new, dedicated hydrogen pipeline due to the propensity for hydrogen embrittlement in high strength steels.

HISTORY ON REPEAT Switching the domestic supply from one gas type to another would be nothing new for Great Britain. Up until the discovery of natural gas reserves (made up predominantly of methane) in the North Sea in the 1960s, the country depended on town gas for street lighting, heating and cooking. Manufactured from coal, town gas contained 60% hydrogen by volume and was fed to 13 million homes. A full-scale switchover of the network to natural gas, including the conversion of 40 million appliances, was successfully completed between 1968 and 1976. Changing over to a different gas type for the 21st century is therefore not inconceivable.

Prior to this, it would be technically feasible to inject a small proportion of hydrogen into the existing infrastructure without noticeable disturbance, allowing the country to start bringing down its carbon emissions at an earlier date. For example, blending a 20%

volume of hydrogen with natural gas could cut around six million metric tons of carbon dioxide from the UK's carbon emissions every year. This is equivalent to taking 2.5 million fossil-fueled cars off the road.

HYDROGEN PRODUCTION Of course, any environmental gain from decarbonizing the heat sector will depend on the way the hydrogen is sourced. The training session outlined hydrogen extraction from natural gas using steam methane reforming (SMR) as the preferred option for the UK at scale today. The carbon dioxide released during this process would then be captured and sequestered in disused North Sea oil and gas fields. The current emphasis on blue hydrogen comes down to two main factors: cost and lack of electricity from renewable energy sources.

The country has traditionally lagged behind nations such as Germany in power generation from wind, biomass and solar. But things are changing. In the third quarter of 2019, more electricity was generated in the UK from renewables than fossil fuels [1]. A recent wave of new offshore wind farms has contributed to the increase in renewable capacity, with 20% of electricity generated from wind in July, August and September 2019. There is still a long way to go before renewables-powered electrolysis could be considered a viable alternative. In the meantime, SMR combined with carbon capture and storage would provide a vital stopgap, allowing the rollout of hydrogen while waiting for further electricity generation from renewable energy sources to come online.

STORAGE A key issue is how to ensure the correct quantity of hydrogen is available in the right place at the right time. The course highlighted the extremely variable nature of energy consumption in the UK depending on the time of day and the season. During peak winter demand, natural gas transmits more than four times as much energy as electricity. Ensuring enough fuel reaches the nation's 23 million gas connections at times of highest demand is therefore an immense challenge. Intraday storage can be partially provided by linepack, whereby the pressure in the transmission pipeline is increased or reduced in order to store or release additional gas.

However, a larger-scale approach is required for inter-seasonal storage. The H21 Leeds City Gate project proposed the use of salt caverns as one way of building up hydrogen reserves during the summer. Covering the needs of the city's 660,000 residents would require a 702,720 MWh storage capacity. As many as 30 salt caverns are already used to store natural gas in the UK, making it a proven and favored method for balancing out the peaks and troughs in seasonal load.

NEW-GENERATION APPLIANCES Besides hydrogen generation and distribution, the training session delved into preparations for end use. The government's Hy4Heat program, which runs until 2021, is examining whether it is safe and feasible to replace natural gas with hydrogen in residential and commercial properties. Commissioned by the Department for Business, Energy & Industrial Strategy (BEIS), the scheme oversees a number of work packages designed to investigate the technical and safety aspects of hydrogen conversion. This includes the design of gas appliances. One common misconception is that the lower calorific value of hydrogen (about a third of the value of methane by volume) would necessitate a larger pipe diameter. As the Kiwa Gastec trainers explained, the difference in energy density can, in fact, be offset by tripling the flow rate.

One hurdle facing the UK in the design of domestic appliances is the size of its housing stock. According to analysis by flooring company Find Me A Floor, the country has the smallest homes in Europe. The average floor space in England is 234 square feet (71.2 m^2) compared to 304 square feet (92.7 m^2) in Germany [2]. A small house or flat in the UK typically has a boiler fitted in a kitchen cupboard without a hot water storage cylinder. These spatial conditions need to be taken into account when engineering the next generation of hydrogen-ready appliances.

Currently, nine out of ten boilers are installed on a baseplate frame. If hydrogen boilers used a common baseplate design this would not only ensure the appliance can be positioned within the same limited space but also allow fitters to exchange an appliance in as little as 15 minutes. As part of the Hy4Heat initiative, well-known manufacturers such as Baxi and Worcester Bosch have been tasked with developing hydrogen-fueled boilers, cookers and fires. Engineered on a like-for-like basis, safety-certified prototype appliances are expected to be ready for demonstration trials by early 2020.

CHALLENGES AHEAD With all UK gas companies to some extent investigating the possibility of piping hydrogen directly to domestic properties, there is much work going on behind the scenes to prepare the UK for a transition to hydrogen. However, considerable challenges lie ahead. Conversion to 100% hydrogen would require a strong commitment from central government, especially in terms of large and expensive infrastructure projects such as carbon capture and storage. And while the safety, technical and economic aspects are well understood, the level of acceptance by consumers is largely unknown. In this regard, the introduction of hydrogen trains and buses and the incremental injection of hydrogen into the gas grid could help normalize the technology and alleviate concerns.

This much is clear: Despite Theresa May's landmark pledge on carbon emissions, swift action is needed if the United Kingdom is going to hit its targets. According to a report published by the Science and Technology Select Committee in August 2019, the UK is not on track to meet its fourth (2023 – 2027) and fifth (2028 – 2032) carbon budgets, based on current plans and policies [3]. It states: "The decarbonisation of heating will be critical to the UK achieving its long-term emissions reductions targets." Such warnings could serve as the necessary impetus for an ambitious solution. ||

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[1] Carbon Brief, Analysis: UK renewables generate more electricity than fossil fuels for first time, October 14, 2019

[2] Find Me A Floor, Where in the World Do You Get the Biggest Home, 2017

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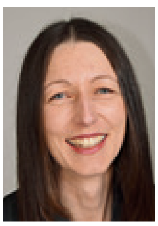

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CH$_2$ILE – THE HIDDEN HYDROGEN CHAMPION

A redemption story for Chile's economy

In 1883, the War of the Pacific, also known as the Saltpeter War, ended with the victory of Chile over Peru and Bolivia and Chile's annexation of the Tarapacá and Antofagasta regions. But why go to war over the world's driest desert? The area was rich in gold, albeit not the traditional kind. The resource the three countries were after was white gold, or Chilean saltpeter. With the support of the British Empire, Chile became the world's biggest exporter of the compound, commonly referred to as sodium nitrate, a natural fertilizer and if mixed with a reducing agent, an explosive. The country held a virtual monopoly on the substance for almost four decades, which led to the creation of new businesses and communities and attracted investment from around the globe.

And wherever there is money to be made, a German will get involved at one point or another. This time, it was Henry B. Sloman, a German businessman born in 1848, who went off to Chile to set up a saltpeter business in Tocopilla. In 1889, he returned to Hamburg as a wealthy man and was considered to be one of its richest citizens in 1912. In 1924, seven years prior to his death, he commissioned the construction of a 10-story office building. Called Chilehaus, it is now a UNESCO World Heritage site.

The saltpeter exports gave the Chilean economy an unprecedented boost. But nothing lasts forever. In 1904, Fritz Haber, who worked at Technische Hochschule Karlsruhe, known as KIT these days, was able to synthesize ammonia directly from hydrogen and nitrogen. Between 1910 and 1913, Carl Bosch then managed to scale up the process at BASF in Ludwigshafen. These discoveries would later earn both men the Nobel Prizes in Chemistry. For the first time in history, it became possible to bind nitrogen to a stable ammonia molecule: Haber and Bosch had figured out a way to synthesize a cheaper chemical replacement for Chile's white gold.

In 1914, early into the First World War, the new production technique proved crucial to Germany's war efforts. The same British Empire that had supported Chile in the War of the Pacific now began to block Germany's import routes for saltpeter, putting the country's agriculture and explosive powder sectors at risk. The German Empire considered the lack of saltpeter a crisis that needed solving, and with scarcity came innovation. A deal reached between the German government and the chemicals industry heavily subsidized new ammonia production facilities. As a result, Germany and its allies were able to produce explosives and fertilizers without having to rely on imports of saltpeter.

With the availability of synthetic alternatives and because of a lack of innovation in Chile's industry, it was just a matter of time until the country's saltpeter monopoly would collapse. It ultimately did so during the Great Depression, primarily from 1929 to 1932. A severe drop in demand and the rise of industrial urea production effectively killed the industry. Chile did not use its revenues from white gold sales to diversify the country's industrial base; neither did it invest in new research and development capacity. Its lack of foresight ultimately crashed the economy.

CHILE'S ECONOMIC REVIVAL Almost 100 years later, the technique that put Chile out of business could lead to a major revival of its economy. Only this time around, the country can count on cutting-edge technology, clean energy and green hydrogen. It is Chile's biggest redemption story.

The South American country has one of the largest potentials for renewable energy production in the world. Spanning over 4,200 kilometers (2,600 miles) from north to south, a distance on par with that from northern Scandinavia to northern Africa, Chile lies between the Pacific Ocean and the Andes Mountains. The 2018 Bloomberg New Energy Finance Climate Scope ranked Chile as the most attractive country for clean energy investment (out of 103 emerging markets) with the potential to generate a total of 1,380 to 1,860 gigawatts from renewable sources of energy, including solar PV, CSP and wind. This is close to 70 times the electric generation capacity it has currently available, prompting the World Energy Council Germany association to call Chile the "hidden champion" in their 2018 report "International Aspects of a Power-to-X Roadmap."

HOW TO GET A CHAMPION OUT OF HIDING Hydrogen is not new to Chile. It has, for several decades, been used in industrial applications, such as refining petroleum, manufacturing flat glass and hardening vegetable oil. But the recent appreciation of green hydrogen in Chile is the result of a collaborative effort between technical support agency GIZ, acting on behalf of the German environment ministry, the Chilean energy ministry, and its industrial development agency CORFO. Since mining is Chile's most important industry, the Solar and Energy Innovation Committee of CORFO began co-financing two industrial hydrogen projects in the sector in 2017. The first has seen huge 300-ton mining trucks being equipped with dual fuel engines that run on diesel and hydrogen. The second aims at using fuel cells in large underground mining vehicles. The GIZ also played a pivotal role in organizing initial international hydrogen seminars in Chile in May 2017 and September 2018, attended by key figures from the worlds of politics, industry and academia. Private-private partnerships are starting to appear as well. For example, as collaboration will be needed to scale up the technology, French utility Engie and Enaex, a Chilean importer of ammonia used in mining explosives, have joined forces to set up the first green ammonia project in Chile.

The founding of the Chilean hydrogen association H$_2$ Chile in January 2018 was definitely a highlight of this call to action. Its objective is to establish green hydrogen as a sustainable energy carrier that can help decarburize the national energy sector and, in the long run, provide Chile with the means to supply clean energy globally by shipping hydrogen and all its derivatives overseas, creating a brand-new chemical industry supported through greenfield investment. The last two years have seen an increase in the number of training sessions, congresses, seminars, newspaper and journal articles, and reports, including interviews on TV, where the "old newcomer" hydrogen was presented and promoted among members of the public.

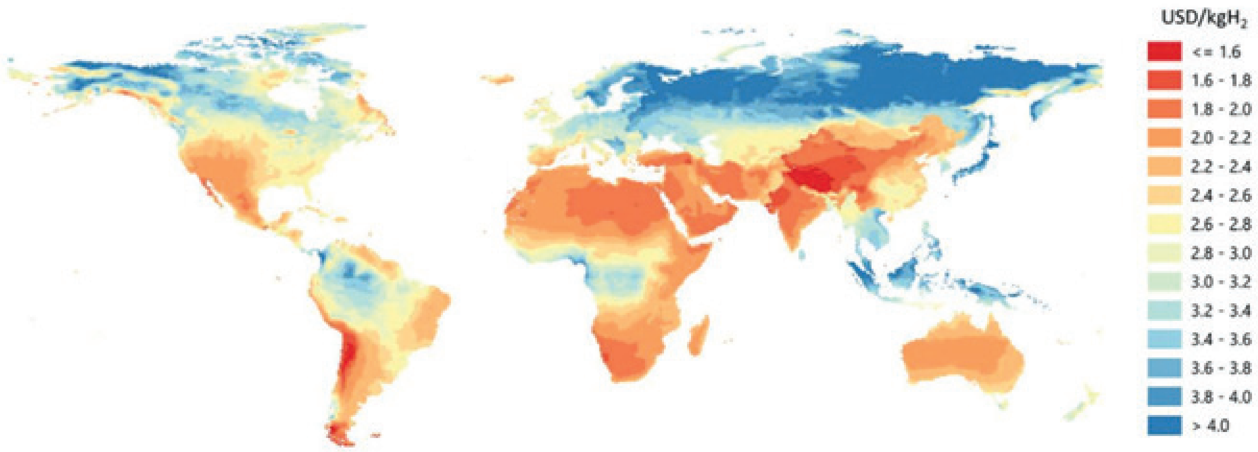

Fig. 1: IEA cost estimate of global green hydrogen production [Source: IEA]

CHILE'S HYDROGEN OUTLOOK In its June 2019 report "The Future of Hydrogen," the IEA said Chile could produce hydrogen at the lowest cost worldwide (less than USD 1.60 per kilogram), made possible by its extraordinary solar irradiation levels. This is especially true for the northern Atacama Desert, where the cold Humboldt Current leads to an absence of cloud cover during more than 300 days and nights a year, so that over 70 percent of the worldwide sky observatory capacity is located there. Meanwhile, the southern part of Chile, including the ever-windy Patagonia region, offers phenomenal conditions for installing onshore wind farms. By using geothermal energy, the country could also generate renewable electricity, considering it is part of the Pacific fire rim, a large string of volcanoes often throwing up hot lava to the surface. Additionally, Chile's around 5,000 kilometers (3,100 miles) of coastline allow the addition of wave and tidal power capacity, total potential being 240 gigawatts. Likewise, there is considerable potential for biomass and hydropower in the central southern regions.

As for green hydrogen, Chile could produce up to 200 million tons of it per year based on its renewable energy potential. This would be nearly three times the current quantity of about 70 million tons of hydrogen produced each year around the world. A basic clean source of energy, hydrogen could be worth several hundred billion dollars annually, the equivalent of Chile´s current GDP.

In 2017, an article in the Washington Post compared Chile's potential for renewable energy to that of Saudi Arabia's oil exports. Every year, Saudi Arabia sells 2.7 billion barrels of crude oil to customers abroad. When converted to electrical energy, 16.5 EJ of thermal energy results in 5.5 EJ. Considering Chile's estimated solar potential of 6.1 PWh per year, this would be 22.1 EJ stored as green hydrogen annually. From this, 12.1 EJ of renewable electricity could be generated annually by fuel cells. This is more than twice the amount of thermoelectrically generated power produced from Saudi Arabia's current exports. As an added benefit, Chile's green hydrogen would emit no greenhouse gases and because it is a renewable energy source, no one would have to be concerned about wells drying up.

WHAT IS NEXT? 2019 saw numerous hydrogen initiatives for Chile being pushed by COP25, originally scheduled to take place in the country. The conference featured a notable number of seminars on hydrogen, during which the Chilean Hydrogen Strategy was discussed as well. After countrywide working sessions with stakeholders from industry, academia, government and civil society, a strategy was announced by the Solar and Technical Innovation Committee of CORFO, the government agency in charge of promoting industrial initiatives. Although COP25 had to be moved to Madrid, Chile managed to organize a novel side event, chaired by H_2 Chile's executive director, where a large number of specialists discussed the pros and cons of hydrogen.

This year, a series of seminars and workshops was launched under the name of Misión Cavendish to honor the discovery of electrolytic hydrogen two-and-a-half centuries ago, with the aim of encouraging hydrogen project development and giving attendees the opportunity to fill knowledge gaps. Supported by the GIZ and consultants from all around the world, the Chilean energy ministry is also drafting a hydrogen standard, which should be ready sometime this year, and has joined forces with CORFO and Chile's science ministry to organize an International Hydrogen Summit in June 2020. Another highlight over the next months will be the Clean Energy Ministerial and Mission Innovation Ministerial (CEM11/MI-5) meetings, which are scheduled to take place in Viña del Mar, Chile from June 2 to 4, 2020.

TIME TO ACT Chile could play a vital role in helping Germany meet its clean energy targets. The recently published German hydrogen strategy calls for green hydrogen imports in order to speed up the decarburization of its economy. Chile has the potential for producing clean, sustainable green hydrogen at the lowest cost possible. There is a huge clean energy industry to be had in Chile, for which German technology, knowhow and capital is paramount. Further down the road, there will also be a brand-new sustainable chemical industry to develop, so Chile can export, for example, green ammonia and fertilizers. We invite all the industry's visionaries to come to Chile to follow in Henry B. Sloman's footsteps and use the Haber-Bosch process once again, this time to produce today's new kind of gold: green hydrogen. ||

Authors:
Hans-Werner Kulenkampff, President of H_2 Chile

Dr. Erwin Plett, President of the Energy Commission, Chilean Engineering Society; Low Carbon Chile SpA

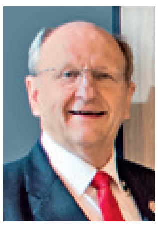

Fig. 1: H2Future 6-MW-electrolyser at the steel plant in Linz, Austria [Source: voestalpine, H2Future]

Category: Global market | **Author:** Bart Biebuyck

EUROPE DRIVES AHEAD WITH HYDROGEN-POWERED VEHICLES

Overview of FCH JU activities

Europe is leading the way in developing the breakthrough technologies needed to realise hydrogen's energy potential. With hydrogen-powered buses and taxis being used across major cities, we have demonstrated that the technology can be used on a large scale.

Europe is a global leader for renewable energy, and fuel cells and hydrogen (FCH) technologies are a major part of that mix. Hydrogen can contribute up to 24 % of Europe's energy needs, reduce annually CO_2 emissions by 650 million tonnes, create 5.4 million jobs and generate 820 billion Euro annually in Europe by 2050, according to an FCH JU study.

"Hydrogen will become key for industrial sectors," said European Commission President Ursula von der Leyen in her recent BusinessEurope Day 2020 speech. "We want to stimulate investment and we want innovation all across the value chain. We want to involve industries, be they large or be they small. We want to create lead markets for new technologies."

And this is exactly what our partnership has been doing. As a public-private partnership between industry and the EU, Fuel Cells and Hydrogen Joint Undertaking (FCH JU) has co-funded over 260 cutting-edge research and demonstration projects since 2008 to bring the technology to the point where it is being used successfully across different sector.

BETTER ELECTROLYSERS The advance made to develop innovative electrolyser technology is one example of the success in delivering breakthrough hydrogen production technologies to the market. Electrolysers store renewable energy through a process whereby electricity splits water into hydrogen and oxygen.

Electrolyser technologies are key to the production of green hydrogen energy, paving the way for the large-scale rollout. To help achieve this, FCH-JU-funded projects are developing more affordable, efficient and reliable electrolysers.

The NEPTUNE and PRETZEL projects are developing breakthrough solutions for proton exchange membrane (PEM) and solid oxide (SO) electrolysers. Europe is a world-leader in these technologies, as shown by a recent analysis of relevant publications and patents.

H2Future is showing how PEM electrolysers can power the European steel industry (see fig. 1). Meanwhile, DJEWELS is demonstrating the operational readiness of the world's largest high-pressure alkaline electrolysis (AE) electrolyser, to be used for the large-scale production of hydrogen and also green methanol.

ACCELERATING THE ROLLOUT OF HYDROGEN BUSES The FCH JU has been funding several projects focused on the demonstration of hydrogen fuel cell technology for transport, while at the same time expanding the hydrogen refuelling infrastructure network. In this area, projects such as Clean Hydrogen in European Cities (CHIC), 3EMOTION and High V.LO-City, have demonstrated the suitability, sustainability, reliability and financial viability of hydrogen fuel cell technology for buses in many cities. This has made an important contribution to their commercialisation in Europe.

The recent JIVE (Joint Initiative for hydrogen Vehicles across Europe) projects are planning to roll out more than 300 hydrogen buses in 22 cities across Europe, the largest deployment to date. Given the potential size of the European market, estimated recently by FCH JU at around 2.3 billion Euro, this could expand to over 1,000 buses by 2025.

Through its demonstration projects, FCH JU has built a sound business case for hydrogen fuel cell buses as a means of decarbonising public transport. The partnership brought together manufacturers, operators and public authorities. As a result, a new generation of hydrogen buses is being developed, involving up to ten bus manufacturers. FCH JU projects are also currently deploying 2,000 light-duty vehicles, including taxi fleets in Paris and Brussels.

REFUELLING STATIONS Although hydrogen-powered vehicles can travel up to 400 kilometres without refuelling, there is a need to extend the network of refuelling stations across Europe. FCH-JU-funded projects are working to overcome the barriers to deploying refuelling stations, to facilitate the uptake of fuel cell electric vehicles.

Currently 67 new hydrogen-refuelling stations have been deployed in twelve countries, including a mobile one for buses and commercial vehicles. There are also 55 car-only refuelling stations in ten countries. As the number of stations increases, it brings significant reductions in their footprint and cost. It's worth mentioning here that FCH JU projects are using approximately 90 % green hydrogen to fuel the vehicles deployed through them.

However, we did not stop there. A key long-term aim is to establish a common European system that gives drivers real-time information on the availability of hydrogen refuelling stations. (see https://h2-map.eu/)

ABOUT THE FCH JU

A unique public-private partnership, the FCH JU contributes to the development of sustainable and globally competitive FCH technology in Europe. By bringing together a wide range of industrial and scientific partners, it supports EU approaches on sustainable energy and transport, climate change and industrial competitiveness.

"Through its demonstration projects, FCH JU has built a sound business case for hydrogen fuel cell buses as a means of decarbonising public transport."

→ www.fch.europa.eu

HYDROGEN VALLEYS Finally, we wanted to put all these pieces together, to demonstrate how hydrogen technology can foster economic growth in the European regions while answering to the local energy needs and reducing pollution. Hence the concept of 'Hydrogen Valleys' – which are geographical locations where activities encompassing the entire hydrogen value chain, from production to end-use, are integrated to improve the economics of FCH technologies.

Entry the recently funded project Heavenn, which is establishing Europe's first 'Hydrogen Valley' in the Northern Netherlands. Here, it will connect the entire hydrogen chain, with the involvement of 31 public and private parties from 6 European countries.

The 2020 Call for Proposals will take this one-step further. Among other topics, the new Call is looking to fund projects that apply the 'Hydrogen Valley' approach to islands and island regions, to meet the specific challenges of decarbonising island economies. The deadline for submissions is April 21, 2020. ||

Author:

Bart Biebuyck, executive director of the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)

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Category: Global market | **Author:** Michael Jensen

SOLAR, HYDROGEN AND FUEL CELLS COMBINED

Public housing project goes off-grid in Sweden

Fig. 1: The renovation and energy retrofit of these buildings put up in 1975 was a major undertaking and included the installation of highly insulating facades and a unique off-grid energy system, which runs off solar panels and seasonal hydrogen storage. The images show the apartment complex during (left) and after renovation (right). [Source: Vårgårda Bostäder]

Vårgårda, a small town in the south west of Sweden, took a crucial step toward more sustainable public housing when it turned six apartment blocks into energy-independent buildings by using a combination of PV solar panels, batteries and hydrogen fuel cells.

The buildings, jointly known as the Backgårdsgatan housing project, were erected in the mid-1970s with support from Sweden's public housing program "miljontalsprogrammet" (program for the millions) and contain 172 apartments. Before renovation, they hadn't met modern building codes for quite some years. Something had to be done about their interior and amenities, as well as their indoor climate and energy efficiency, not least because their age and a slew of social issues had given them a bad reputation.

HIGH ENERGY COSTS, LOW FINANCIAL HEALTH Outdated technology and high operating, maintenance and energy costs meant the real estate value of the buildings was low. This limited the financial health of Vårgårda Bostäder, the housing provider that owns and operates Backgårdsgatan and similar communities in Vårgårda, a town of 11,500 people.

Realizing the gravity of the situation, Jan Thorsson, CEO of Vårgårda Bostäder, decided, together with the town's council, that it was time to act. Thorsson started looking for ways to improve and upgrade the buildings, raise their energy efficiency, lower maintenance and operating expenses and stabilize energy costs. Early on, he identified the ever-rising prices for electricity and district heating as significant and unpredictable factors in facility management, noting that they could seriously jeopardize ROI and real estate values after modernization. As a result, he turned his attention to onsite energy generation, with the aim of creating an energy-independent apartment complex.

SAFE INVESTMENT, RISING PROPERTY VALUE The increase in real estate value through renovation and retrofit has now bolstered the financial health of the municipal housing provider. Throughout the process, Thorsson and his team did not focus on just one option but remained open to new ideas for creating an efficient, long-lasting and eco-friendly facility management solution that would cut costs and offer more predictable energy pricing.

INEXPENSIVE BUT FUTURE-PROOF It just so happened that PV solar panels combined with batteries, fuel cells and seasonal hydrogen storage fulfilled all the criteria mentioned above and allowed the business to disconnect the buildings from the expensive district heating grid and use onsite energy generation devices to power installations in the common areas, such as stairwell lighting, elevators and ventilation.

Besides general architectural and technical improvements, the complex now features interlinked energy devices, which form a microgrid that runs off PV units, battery storage and fuel cells. This grid meets all the hot water and heating needs at the complex and powers geothermal heat pumps that supply energy to a conventional central heating system.

The hydrogen energy system, which comprises an electrolyzer, a compressor and storage, was installed at a central location (fig. 3, left-hand side) and provides the six buildings with gas for their 5-kilowatt fuel cells. It can additionally store excess energy transferred to the electrolyzer and compressor from rooftop solar panels.

Each building also has its own equipment to produce electricity and heat. It consists of 500 square meters of solar panels installed on the roof, a power inverter, an off-grid hub, a 5-kilowatt fuel cell, hot water storage, central heating (through a geothermal heat pump), a power distribution unit controlled by an RE8760 system and battery storage allowing uninterrupted 48-hour operation (fig. 3, right-hand side). When the batteries are fully charged, surplus solar electricity is redirected to the centralized hydrogen storage, which stores the energy in hydrogen through electrolyzation. The electricity generation device in each building is connected to those in the other five buildings and together, they form a microgrid that provides the redundancy and flexibility needed to supply energy to all six apartment blocks in the event of a power failure or a temporary shutdown of parts of the grid for maintenance purposes.

In the cold season, when there is little or no solar energy available, electricity for things such as stairwell lighting, elevators and heat pumps in the common areas is produced by fuel cells, which run on centrally stored hydrogen. The hydrogen is generated by electrolysis through the use of surplus power transferred from the rooftop solar panels during the long Swedish summer from May through September. The waste heat produced by this process is redirected to the central heating system.

For now, each apartment still receives and pays for grid power delivered by a utility company. The solar-hydrogen solution, however, will be ready to incorporate demand from the apartments when it has run long enough to provide necessary operational data and has proven its reliability after meeting greater, more fluctuating demand. And yet, as mentioned before, it has already demonstrated that it can supply heating and hot water to all households throughout the year.

BUILDING RENOVATION Besides thoroughly modernizing the exterior of the buildings, which included adding new roofs, windows and top-notch, highly insulating facades, the housing provider also had a whole floor put in to create 54 new apartments. The original apartments and stairwells have been upgraded too; for example, elevators have been added to the hallways.

The substantial visual and technical transformation of the entire apartment complex raises its standard of construction to a new level and exceeds the requirements of most contemporary building codes on public housing. The standard established with this renovation even surpasses that of many newbuilds in terms of comfort, energy efficiency, sustainability and carbon emissions reductions.

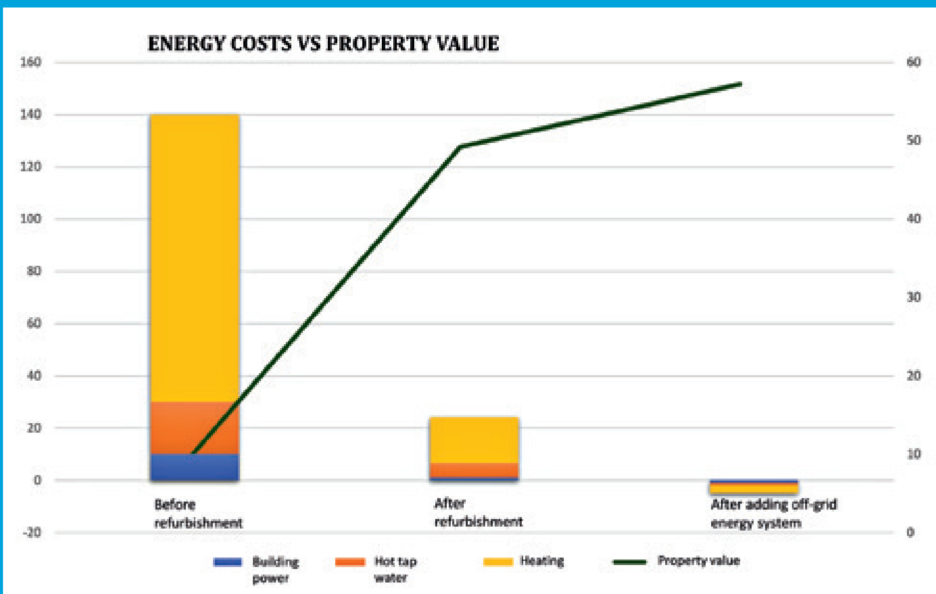
ENERGY GENERATION The roof of each renovated building has been covered with 500 square meters of PV solar panels. These provide 109 kilowatts of peak power and 98,000 kilowatt-hours a year. Inverters in the basement transfer direct current from the PV system or the fuel cell to the battery and convert DC into AC for transmission along the microgrid, while additional inverters change DC from the panels and the fuel cell directly into AC for transfer along the grid.

Energy is stored in a 48-volt lithium-ion battery made by Tesvolt. It has a capacity of 187 kilowatt-hours and can provide heat and electricity for up to two days. The battery storage takes priority when surplus solar power is available; this means that once the battery is fully charged, excess solar energy is directed to the alkaline electrolyzer (which produces 60 Nm^3 an hour) to replenish the hydrogen storage system. The total capacity of the hydrogen tanks is 50,000 normal cubic meters, or 4,560 kilograms, at a pressure of 300 bars, which is enough to supply all six buildings with heat and electricity in wintertime.

When the PV solar panels produce little or no energy, a typical scenario in the cold season, a 5-kilowatt fuel cell manufactured by PowerCell generates electricity by retrieving hydrogen from central storage, while the battery is used for grid balancing. Hot water is provided by a geothermal heat pump, which feeds into the central heating system that serves the apartments and the common areas. The waste heat produced by the fuel cell is transferred to central heating as well, in order to ensure a CHP efficiency of 90 percent.

A unique energy center, based on proprietary RE8760 technology, decides when to use solar electricity directly, when to charge batteries or produce hydrogen as well as when to retrieve energy from battery or fuel cell storage. The center and its control unit were developed by Nilsson >>

Fig. 2: Key figures on one of the six apartment blocks [Source: Vårgårda Bostäder]



- Previously, this Backgårdsgatan building (left column) was valued at SEK 7 million, while annual energy purchasing (AEP) reached 140 kWh per square meter.

- Following renovation, its value rose to SEK 47 million, at 25 kWh of AEP per square meter.

- After the off-grid energy system was added, the building was worth SEK 55 million, at 4 kWh of AEP per square meter (the target being 0 kWh).

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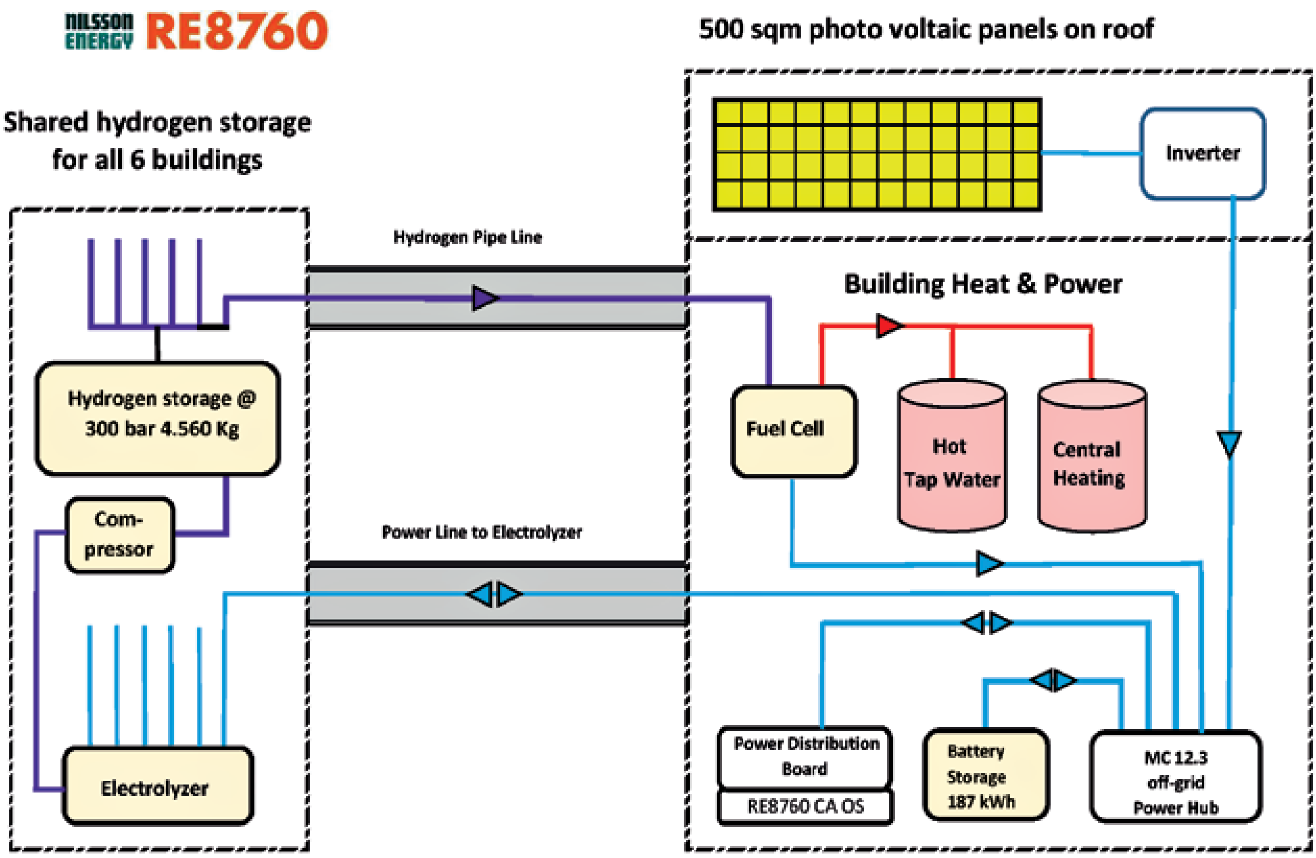


Fig. 3: One of the energy generation devices installed in the Backgårdsgatan buildings

Energy, which was also in charge of designing, integrating and installing the equipment.

LESSONS LEARNED "You need a holistic approach to implementing a project like Backgårdsgatan. You have to meet people's expectations of architecture, building design, operations, living environments, the future, the economy and environmental protection," Thorsson explained. "Think long term," he added. "Build something new and do so sustainably."

"Dare to be entrepreneurial and expand your business model by generating your own energy. Investing in smart technology is profitable; it raises real estate values and future-proofs your properties," he said, noting that it was important to develop solutions that are "efficient and independent of external energy providers."

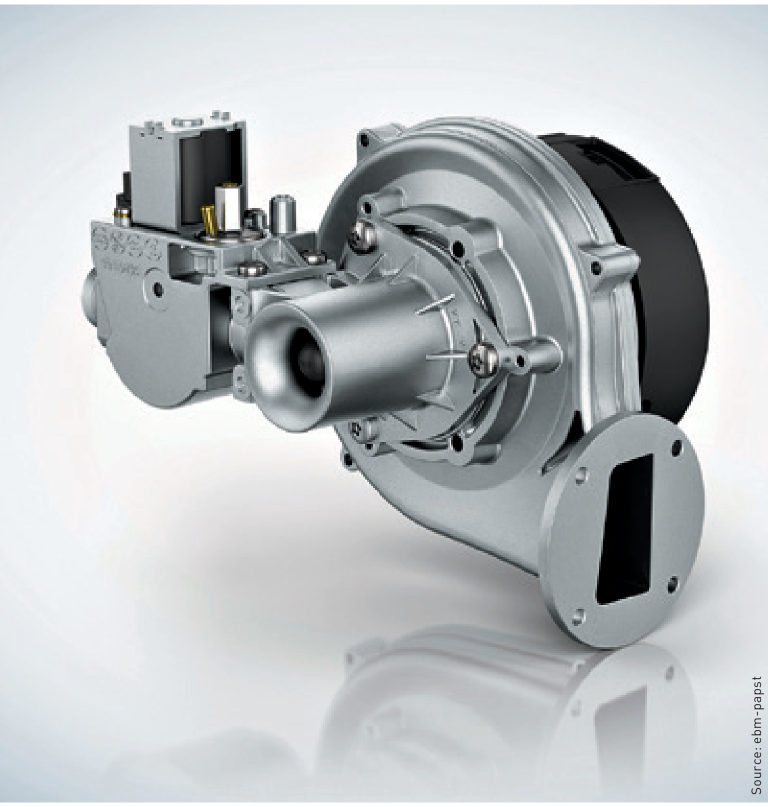
"An important lesson for us was to involve the Fire and Rescue Department early on, as we were the first ever to use this kind of system in a public housing project in Sweden and, in fact, the world. Fire safety approval took a long time, as the FRD had no previous experience in judging the safety of a hydrogen storage unit of this size within a densely populated area."

FOSSIL FUEL-FREE PUBLIC HOUSING The Backgårdsgatan housing project is an internationally renowned example of how to build and operate sustainable apartment blocks using a holistic approach that honors the principles of social responsibility and environmental and climate protection and meets residents' expectations of modern living.

Several international delegations have already toured the site; many more visits have been scheduled in the meantime. Vårgårda Bostäder has proved that it is perfectly possible to build sustainably and offer a pollution- and fossil-free energy generation system that also improves the overall economics and real estate value of a building.

No need to burn coal, biomass or household waste in huge district heating boilers: You can provide your buildings with free and clean energy throughout the year by using only solar panels, battery storage and the simplest element in the universe: H_2. ||

BLOWER ASSEMBLY SUITED FOR 100 PERCENT HYDROGEN


Source: ebm-papst

Most current-generation heating systems run on natural gas, some of them also on LPG. And yet, it is becoming clear that several stationary systems will eventually use nothing but hydrogen. Many suppliers have already been preparing for when this happens. One of them is ebm-papst, a ventilation manufacturer based in Mulfingen, Germany. In March, the family-run business presented a new assembly called NRV 118 Hydrogen, which provides the required fuel-air mixture for condensing boilers. Originally, it wanted to unveil its new product at MCE Mostra Convegno Expocomfort, a Milan-based HVACR show. However, the event has been postponed to later this year.

The blower assembly has been designed for use with 100 percent hydrogen. Few adjustments to the base version had been necessary to make that possible, the company stated. Although the flame speed of hydrogen was eight times that of methane, it was manageable by checking and controlling the ignition timing in burner management systems. The difference in gross heat content was not an issue either, as the values for hydrogen and natural gas were about the same according to the Wobbe Index, an important measure of fuel gas interchangeability.

The ebm-papst Group also said it had conducted initial component tests without using the complicated control lines needed when running devices at positive pressure. Likewise, it had succeeded in adjusting blower speed to match boiler output to heating demand with relatively high accuracy, since negative pressure made it easier to control the gas valve. A spokesperson told H2-international that "all large heating manufacturers are determined to transition to a hydrogen economy. Some of the larger projects are the EU's THyGA, Avacon in the German state of Saxony-Anhalt, and the UK's Hy4Heat and HyDeploy." ||

SWITCHING FROM ICES TO FUEL CELLS

While we are seeing a transformative change in technology as the market transitions from internal combustion engines to electric motors, not all components found in gasoline and diesel vehicles will all of a sudden become useless. One of those repurposing some of the parts is Pierburg, a Rheinmetall Automotive subsidiary based in Neckarsulm, Germany. The company, whose main business is pumps and valves, is working on several systems to provide air and hydrogen for fuel cell electric vehicles, offering a leak-tight governor, a coolant pump and a hydrogen recycle blower, among other things.

A recycle blower can, for example, recover off-gas from a fuel cell anode. The key is to ensure safe and efficient recirculation even at high hydrogen concentrations. Pierburg used side-channel technology but no dynamic seals to guarantee the continuous, reliable and leak-tight operation of its device. The blower can run on up to 48 volts of DC power or considerably more in the case of stationary systems.

The coolant pump has been designed to run on up to 800 volts. As an addition to longstanding products such as 12-volt to 48-volt pumps, it has been developed specifically with fuel cell applications in mind. The pump is powered by an electronically commutated BLDC (brushless direct current) motor and offers relevant diagnostic functions via a LIN/CAN communication bus. It can be used with deionized water and different types of coolants.

Pierburg's multi-purpose valve has been engineered for use at fuel cell cathodes. It is resistant to both deionized water and hydrogen and can serve as either a blow-off or bypass valve in air compressors or a pressure relief or shutoff valve in fuel cell stacks. It allows operation at relatively high flow rates, provides notable leak-tightness, and keeps pressure loss to a minimum. It is compact, weighs relatively little and can be adjusted to meet very specific requirements. ||


Source: Rheinmetall

EVENTS 2020

Due to the current situation, we will refrain from announcing events this time, as most of them will not take place in the near future anyway. But here are some online events as well as some events scheduled for fall 2020:

RENPOWER H2 Sub-Saharan Africa 2020
Online-Conference by Euroconvention Global
May 19 to 20, 2020
www.euroconventionglobal.com

Green Hydrogen at Industrial Scale
Online-Forum by Scottish Development International
May 20, 2020
www.scotent.co.uk

RENPOWER H2 Latam 2020
Online-Conference by Euroconvention Global
June 3 to 4, 2020
www.euroconventionglobal.com

Hypothesis XV
HYdrogen POwer THeoretical & Engineering Solution International Symposium
June 3 to 5, 2020, online, South Africa
www.hypothesis.ws

f-cell + HFC
September 9 to 10, 2020, in Vancouver, Canada
www.hyfcell.com

North America Smart Energy Week
with Hydrogen + Fuel Cells International
September 14 to 17, 2020, Anaheim, USA
www.solarpowerinternational.com

f-cell
September 29 to 30, 2020,
in Stuttgart, Germany
www.f-cell.de

Hydrogen Online Conference
24-h-Conference by Mission Hydrogen
October 8, 2020
www.hydrogen-online-conference.com

European SOFC & SOE FORUM
EFCF-Conference with Exhibition
October 20 to 23, 2020, in Lucerne, Switzerland
www.efcf.com

Due to coronavirus emergence and the consequent lockdown in South Africa as well as in many other countries, HYdrogen POwer THeoretical & Engineering Solutions International Symposium has been rescheduled as an online conference to give the authors of the abstracts the opportunity to present their recent works and to give all the others the opportunity to discuss with them.
For further information have a look to www.hypothesis.ws or contact coordinator@hypothesis.ws.

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COMMUNICATION & MARKETING

Mission Hydrogen GmbH, Lise-Meitner-Str. 20, 71364 Winnenden, Germany, Phone +49-7195-904390-0, +49-162-2109822, *www.mission-hydrogen.de*

mummert – creating relations, Uta Mummert, German-French Communication Services – Media, Events, Marketing, 85 Chemin du Vignal, 07230 Lablachère, France, Phone +33-652980552, *info@mummert.fr, www.mummert.fr*

COMPRESSORS

Mehrer Compression GmbH, Rosenfelder Str. 35, 72336 Balingen, Germany, Phone +49-(0)7433-2605-0, Fax -7541, *www.mehrer.de*

J.P. Sauer & Sohn Maschinenbau GmbH, Brauner Berg 15, 24159 Kiel, Germany, Phone +49-(0)431-3940-0, *sales@sauercompressors.de, www.sauercompressors.com*

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Haas Engineering GmbH & Co. KG, Reinhold-Schneider-Str. 18a, 79194 Gundelfingen, Germany, Phone +49-(0)761-503649-0, Fax -69, *info@haasengineering.de, www.haasengineering.de*

DISTRIBUTION

Hydrogenious LOHC Technologies GmbH, Weidenweg 13, 91058 Erlangen, Germany, Phone +49-(0)9131-12640-220, Fax -29, *www.hydrogenious.net*

Kälte- und Systemtechnik GmbH, Refrigeration systems for cooling hydrogen according SAE, Heavy duty refueling, Strassfeld 5, 3441 Freundorf, Austria, Phone +43-2274-44109, *office@kustec.at, www.kustec.at*

Reuther STC GmbH, Fabrikstr. 8, 15517 Fuerstenwalde, Germany, Phone +49-(0)3361-694-0, Fax -852, *www.reuther-stc.com*

Wystrach GmbH, Industriestr. 60, 47652 Weeze, Germany, Phone +49-(0)2837-9135-0, Fax -30, *www.wystrach-gmbh.de*

ELECTROLYZERS

Areva H_2Gen GmbH, Eupener Strasse 165, 50933 Köln, Germany, Phone +49-(0)221- 2919073-0, Fax -9, *www.arevah2gen.com*

Cummins Inc., Am Wiesenbusch 2 – Halle 5, 45966 Gladbeck, Germany, Phone +49-2043-944-133, Fax -146, *powersales@hydrogenics.com, www.cummins.com*

Enapter srl, Pisa, Berlin, Chiang Mai, Via di lavoria 56G, 56040 Crespina Lorenzana (PI), Italy, Phone +39-5064-4281, *www.enapter.com*

Giner ELX, Inc., 89 Rumford Avenue, Newton, Massachusetts 02466, USA, Phone +1-(0)781-529-0500, *information@ginerelx.com, www.ginerelx.com*

GreenHydrogen.dk ApS, Platinvej 29B, 6000 Kolding, Denmark, Phone +45-(0)7550-3500, *www.greenhydrogen.dk*

H-Tec Systems GmbH, PEM electrolyzers for industry application, Am Mittleren Moos 46, 86167 Augsburg, Germany, Phone +49-821-507697-0, Fax +49-451-399-41799, *info@h-tec-systems.com, www.h-tec.com*

iGas energy GmbH, Cockerillstr. 100, 52222 Stolberg, Germany, Phone +49-(0)2402-9791600, *info@igas-energy.de, www.iGas-energy.de*

Kraftanlagen München GmbH, Ridlerstr. 31 c, 80339 München, Germany, Phone +49-89-62370, *www.kraftanlagen.com*

Nel Hydrogen, 10 Technology Dr, 06492 Wallingford CT, USA, Phone +1-203-9498-697, Fax -016, *info@nelhydrogen.com, www.NelHydrogen.com*

thyssenkrupp Uhde Chlorine Engineers GmbH, Vosskuhle 38, 44141 Dortmund, Germany, Phone +49-231-547-0, Fax -2334, *info-uce@thyssenkrupp.com, www.thyssenkrupp-uhde-chlorine-engineers.com*

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Prüfrex Innovative Power Products GmbH, Egersdorfer Str. 36, 90556 Cadolzburg, Germany, Phone +49-(0)9103-7953-0, Fax -55, *www.pruefrex.com*

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Eugen Seitz AG, Leading H_2-solenoid valve technology from 10 to 1,000 bar, Spitalstr. 204, 8623 Wetzikon, Switzerland, Phone +41-44-9318190, *h2info@seitz.ch, www.seitz.ch*

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OMB Saleri SpA, Via Rose di Sotto 38/c – 25126 Brescia, Italy, *hydrogen@omb-saleri.it, www.omb-saleri.it*

PTEC – Pressure Technology GmbH, pipelines, screw connections, filters, valves, regulators, TPRD, Linde 11, 51399 Burscheid, Germany, Phone +49-2174-748-722, *mail@ptec.eu, www.ptec.eu*

FUEL-RECIRCULATION AND AIR-SUPPLY

Gebr. Becker GmbH, Hölker Feld 29-31, 42279 Wuppertal, Germany, Phone +49-(0)202-697-255, Fax -38255, *info@becker-international.com, www.becker-international.com*

Busch Clean Air S.A., Chemin des Grandes-Vies 54, 2900 Porrentruy, Switzerland, Phone +41-(0)32-46589-60, Fax -79, *info@buschcleanair.com, www.buschcleanair.com*

Haskel International, LLC, 100 E Graham Place, 91502 Burbank, CA, USA, Phone +1-818-84-34000, Fax -14291, *www.haskel.com*

sera ComPress GmbH, sera-Str. 1, 34369 Immenhausen, Germany, Phone +49-5673-999-04, Fax-05, *info-compress@sera-web.com, www.sera-web.com*

Vairex air systems, 3048 Valmont Road, Boulder, CO, 80301, USA, Phone +1-303-994-2047, *info@vairex.com, www.vairex.com*

GAS DIFFUSION LAYERS (GDL)

MeliCon GmbH, Metallic Lightweight Construction, Porschestr. 6, 41836 Hückelhoven, Germany, Phone +49-(0)2433-44674-0, Fax -22, *www.melicon.de*

SGL Carbon GmbH, Werner-von-Siemens-Str. 18, 86405 Meitingen, Germany, Phone +48-(0)8271-83-3360, Fax -103360, *fuelcellcomponents@sglgroup.com, www.sglgroup.com*

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Framatome GmbH, Paul-Gossen-Str. 100, 91052 Erlangen, Germany, Contact: Mrs. Gemmer-Berkbilek, Phone +49-(0)9131-90095221, *www.framatome.com*

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Henze-Hauck Prozessmesstechnik / Analytik GmbH, Wasserstoffanalysatoren, ATEX zertifiziert, Sicherheitstechnik, Dünnhauptstr. 14, 06847 Dessau, Tel. 0340 5169363, *info@henze-hauck.de, www.processanalytik.de*

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hySOLUTIONS GmbH, Steinstrasse 25, 20095 Hamburg, Germany, Phone +49-(0)40-3288353-2, Fax -8, *hysolutions-hamburg.de*

National Organisation Hydrogen and Fuel Cell Technology (NOW GmbH), Fasanenstr. 5, 10623 Berlin, Germany, Phone +49-(0)30-3116116-15, Fax -99, *www.now-gmbh.de*

ORGANIZERS (EVENTS)

Hydrogen + Fuel Cells Europe, Hannover Messe 2021, April 12-16 Tobias Renz FAIR, *tobias@h2fc-fair.com, www.h2fc-fair.com*

European Fuel Cell Forum, Obgardihalde 2, 6043 Luzern-Adligenswil, Switzerland, Phone +41-(0)4-45865644, Fax 35080622, *forum@efcf.com, www.efcf.com*

Peter Sauber Agentur Messen und Kongresse GmbH, f-cell, September 29 to 30, 2020, Haus der Wirtschaft, Willi-Bleicher-Str. 19, 70174 Stuttgart, Germany, Phone +49-(0)711-656960-55, Fax -9055, *www.f-cell.de*

Peter Sauber Agentur Messen und Kongresse GmbH, f-cell + HFC, The Hydrogen and Fuel Cell Event, September 9 to 10, 2020, Vancouver Convention Centre, Canada, *www.hyfcell.com*

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WS Reformer GmbH, Dornierstrasse 14, 71272 Renningen, Germany, Phone +49-(0)7159-163242, Fax -2738, *www.wsreformer.com*

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Fraunhofer ISE, Heidenhofstrasse 2, 79110 Freiburg, Germany, Phone +49-(0)761- 4588-5208, Fax -9202, *www.h2-ise.de*

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