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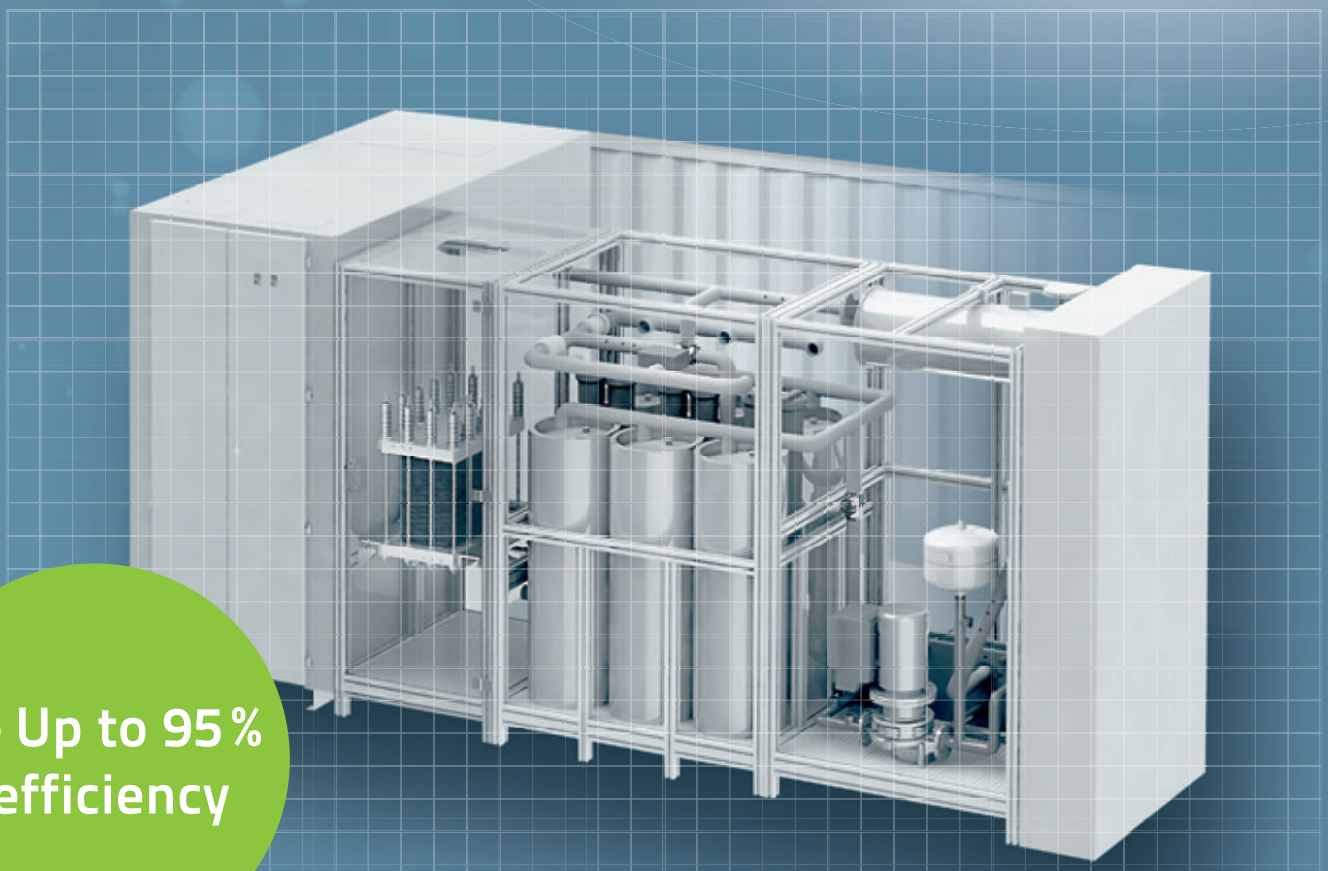

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H2-international

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NEWFOUND OPTIMISM

Dear readers,
Considering we are confronted with new facts almost every day, it should come as no surprise that the controversy surrounding nitrogen oxides and fine dust, blue badges and diesel bans in German cities shows no sign of letting up. Likewise, automakers are a recurrent subject on the evening news, whether they want to or not. Despite, or probably because, every news cycle delivers more information about how the industry cheated during emission tests, it has become increasingly difficult to keep up with the latest developments.

Ultimately, there is one thing that stands out to me when watching all this back and forth about driving restrictions and financial compensation. Finally, we are talking about what path we want to take and no longer about what we have and how we could keep the internal combustion engine running. Finally, we are discussing new avenues, the value of good air quality and the chance for a clean environment.

Those days when no one dared to question the wisdom of clinging to conventional combustion technology seem to be over. The current debate about the path to more electric transportation may be a fierce one. Thankfully, though, arguments no longer revolve around whether electric cars have a future at all. The past months have proven beyond a doubt that they will be needed moving forward.

Of course, there are still widely varying opinions on what the next step should be. Should the government restrict the use of old technology? Should automakers offer useful alternatives and let consumers decide if they want the market to change? This competition of sometimes opposing ideas is vital to a society that cherishes democratic values. In the end, the majority will decide on the course, without being pressured into taking certain actions.

What counts right now is not so much whether we will quickly see the implementation of a blue badge system or the banning of diesel cars from downtown areas. Instead, the key to progress will be a public discussion to encourage road users to contemplate their choice of transportation, a discussion to have owners of real estate think about their options for water and space heating, a discussion to get tenants to reflect on alternative power sources for all those electrical devices at home.

In short, as soon as there is a general feeling that everyone's actions have at least some kind of impact on shaping the future of our planet, we know we will be on the right path. At that point, I believe consumers will voluntarily opt for the more sustainable engine. It will be their choice and theirs alone to buy the kind of car that will still have a place in cities and towns in two decades' time. Maybe then, business leaders will start looking past quarterly financial results and make decisions based on what will give their companies long-term, and not short-term, prospects for growth.

Considering the above, there is more than one way to interpret the number of fuel cell vehicles that have been put on the market. In February, the European Hydrogen Association announced that nearly 6,500 hydrogen fuel cell cars had been delivered to customers since 2013. More than half of them ended up in the United States, mainly in California, and fewer than one-tenth in Europe. But is that figure reason for ease or apprehension?

Frankly, I don't have an answer to this question and I'm not sure that the figure means much without context. It seems like an alarmingly low number compared to the targets that should have been meet years ago. But you could also say that it is quite a feat to accomplish, given the vehicles' high price tags and no mass market to speak of yet.

Where does this leave us? Can we be satisfied with the way things are?

I do believe that it's not looking all that bleak right now. Perhaps, the past and the following months and years could go down in history as the time when we succeeded in transforming the market. They could become known as the era in which changes initiated in the power industry gradually spread to the transportation and heat sectors as well.

The process has been started, that much is clear. Now, it's time to work toward achieving all those ambitious goals.

One last thing. Those 6,500 fuel cell cars? Every single one of them was made in Asia.

Best wishes,

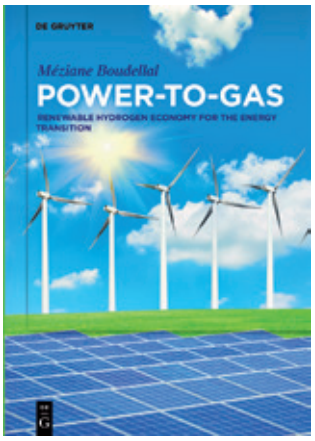
Sven Geitmann
Editor of H2-international

GASTEIGER JOINS PAJARITO POWDER'S ADVISORY BOARD

Hubert Gasteiger

Pajarito Powder, a catalyst manufacturer based in Albuquerque, USA, can now draw on Austrian expertise to further its business. Late last October, it announced that Hubert Gasteiger had joined the company's technical advisory board. Webb Johnson, who also advises Pajarito, told H2-international that the manufacturer had made great progress in designing engineered catalyst support materials and entire catalysts not made from precious metals. Gasteiger chairs the electrochemical technology division at the Technical University of Munich. He is considered one of the leading experts in electrocatalyst research. He said, "I am very much excited about joining Pajarito Powder's technical advisory board to assist them in their mission to accelerate the adoption of electric vehicles through better electrocatalysis." Pajarito's CEO, Thomas J. Stephenson, added that Gasteiger's joining the board was a remarkable honor for Pajarito Powder and an indication of the importance of his company's work in reducing the overall cost of fuel cells. ||

'POWER-TO-GAS' AVAILABLE IN ENGLISH



Méziane Boudellal is the author of several books about hydrogen. His 2016 title "Power-to-Gas – Renewable Hydrogen Economy for the Energy Transition," originally written in French, was published in English this February. The book offers an in-depth look at electrolyzer technologies, power-to-gas implementation strategies, pilot projects and business models. ||

Boudellal, M. (2018). *Power-to-Gas.* Berlin: De Gruyter. 212 pages. ISBN 978-3-11-055881-4; store price: EUR 69 / USD 79.99 ISBN 978-3-11-055981-1; e-book price: EUR 69 / USD 79.99

SIMONE PETER ELECTED PRESIDENT OF BEE


Source: BEE

BEE-Präsidentin Dr Simone Peter

The BEE, the German Renewable Energy Federation, has a new president, former Green Party co-chair Simone Peter. After stepping down from her party leadership position in January 2018, she was unanimously elected to head the umbrella organization the following month. She replaced Fritz Brickwedde, who had presided over the BEE since October 2013 and resigned for personal reasons.

Peter used to work for Eurosolar and the German Renewable Energies Agency before going into politics. As a member of the Saarland state assembly, she led the state's environment ministry from 2009 to 2012. She said, "We need to expand renewable power production, establish clear pathways to increase the use of renewable heat and transportation, and further the integration of these sectors. […] In the long run, a minimum nationwide carbon price offers the chance for effective climate protection and cost cuts for consumers, especially if we coordinate its implementation with other countries in Europe."

The Renewable Energy Federation represents 48 associations and companies, speaking for 30,000 people altogether. As recently as August 2017, Peter Röttgen became the organization's new CEO, which means that the rebranding and reshaping of the BEE is kicking into high gear. ||

H2 ENERGY ON TRACK FOR EXPANSION

H2 Energy, a Swiss corporation based in the Glattpark industrial area in Opfikon, near Zurich, is gradually expanding its reach. CEO Philipp Dietrich said that the company would now concentrate its efforts on the German market. In mid-January, it formed a joint venture with Global Automotive Partners. Reportedly, the new business, called H2 Energy Deutschland, will sell renewable hydrogen produced in Pliening, northeast of Munich, and develop systems to make use of the gas. Prior to the venture, H2 Energy had set up a subsidiary in Norway.

Rolf Huber, H2 Energy's chairman, said that Germany offered an ideal environment for growth. The country had great potential to become a major renewable hydrogen consumer and provided good access to other EU markets.


Source: Pionierpreis

Rolf Huber

Michael Spitznagel, CEO of both Global Automotive Partners and the joint venture, added that the collaboration with H2 Energy was a great opportunity for Global Automotive Partners to strengthen its role in the industry and broaden its product portfolio.

H2 Energy has also succeeded in attracting a new shareholder. In late January, family-owned oil producer Osterwalder St. Gallen announced a strategic shift toward renewable energies. Its intent to establish a line of hydrogen products was said to have been the reason for its investment in H2 Energy. The investment gave Martin Osterwalder, who sits on Osterwalder St. Gallen's board of directors, a seat on the directors' board of the hydrogen technology supplier. He said he was convinced that hydrogen would have a bright future in heavy-duty transportation. His company is part of Avia, formed in 1927 as a group of independent Swiss importers of petroleum products. According to him, Avia was planning to add hydrogen refueling sites to its gas station network at some point in the future. ||

SWISS HYDROGEN TURNS FRENCH

Swiss Hydrogen, a manufacturer of fuel cell systems, has a new owner. Groupe E, an energy provider based in Switzerland, announced in late 2017 that it had sold its stake in the company to Plastic Omnium, a French supplier of auto parts. The latter also acquired the shares held by others, namely entrepreneur Marco Simeoni, venture capital firm Capital Risque Fribourg and the Paul Scherrer Institute, also known as PSI.

Nevertheless, Swiss Hydrogen's CEO, Alexandre Closset, said in an interview that his company would continue to work in close collaboration with the institute. "In fact, our business only survived because we were able to assemble and test systems at the Paul Scherrer Institute. […] PSI is recognized for its fuel cell expertise not just in Switzerland but all around the world. The partnership with the institute will remain our most important research collaboration." Swiss Hydrogen was founded in 2008 as a subsidiary of Belenos Clean Power. It offers both electrolyzers and fuel cells for mobile and stationary applications. One example of its work is the hydrogen truck used in a project by Swiss retail chain Coop (see H2-international, October 2017). ||

DWV IN FAVOR OF JOINT H_2 COMPANY

On Feb. 7, 2018, the DWV, also known as the German Hydrogen and Fuel Cell Association, held an extraordinary general meeting in Berlin. During this meeting, it was decided that the group would be joining forces with the BVES, that is, the German Energy Storage Association, and possibly also with the DVGW, the German Technical and Scientific Association for Gas and Water, to create a new company to better coordinate the introduction of new hydrogen technologies.

The stated aim was to get hydrogen faster onto energy markets. The DWV was said to have dropped its original idea of hiring a full-time CEO, as it would have put a strain on the budget of the small but hard-working association. Instead, it decided on founding a GmbH, the German counterpart of an LLC in the United States. The DWV and the BVES would both retain their status as non-profit organizations, but commercial transactions would be handled by the new company.

The special meeting had been announced, on rather short notice, in the January issue of the DWV member magazine. Management had been discussing a professionalization of the association for years but had made little progress in implementing changes. Barely over 30 people found their way to the Siemens Forum in Berlin for the meeting, but the company representatives who did had been given the powers to decide on the way forward. After extensive discussion, there was a clear majority in favor of establishing a jointly operated GmbH. According to initial plans, the company would have about half a dozen employees and an annual budget in the mid-six figures. Since preliminary talks have reportedly gone well, the board members are said to be now fervently working out the details among themselves.

Werner Diwald, chair of the DWV, said, "Hydrogen is undoubtedly one of the keys to achieving the clean energy transformation." He added that the BVES, DWV and DVGW had not been the only ones coming to that conclusion. The CDU, CSU and SPD, Germany's major political parties, had done the same in their negotiations about a new coalition government. The three associations were convinced that, at last, those political parties had realized how important it was to develop storage technologies such as hydrogen, batteries and heat pumps and expand the heat storage and gas infrastructure in order to transform the energy markets.

After a series of talks with the BVES in mid-December 2017 prompted the DWV's board to take on the establishment of a GmbH, the DVGW indicated in mid-January that it, too, was interested in a closer partnership. As a result, the DWV and the DVGW agreed to further strengthen sector integration through power-to-gas, hydrogen storage and the shared use of the gas infrastructure and aim for greater acceptance of hydrogen and fuel cell technology among politicians and the public. The two associations had signed a cooperation agreement for this purpose shortly before the DWV meeting took place. ||

EZELLERON CHARGES FILED AGAINST EZELLERON'S KÜHN

In April 2016, eZelleron, a German startup, filed for bankruptcy protection (see H2-international, August 2016). Now, its former CEO, Sascha Kühn, was charged with violating accounting principles, committing fraud and deepening the company's insolvency, the Dresdner Neueste Nachrichten newspaper has reported. Kühn left Germany for the United States to head kraftwerk Inc. and eZelleron Inc. based in Silicon Valley. He is alleged to have filed balance sheets too late and not petitioned the court for bankruptcy protection in due time, despite knowing about the impending liquidity shortage because of his position in the company. The prosecution further claimed that he had put intellectual property in the hands of his parents. Kühn disagreed, saying that those patents had only been used as collateral, but that they were still owned by the German business.

Kühn also said that he had reached an agreement with the trustee. Whether the many customers who crowdfunded the startup will ever get their chargers is anyone's guess at this point. Kühn told the Bild, another German newspaper, that the devices "will definitely be put on the market, but there is no set timetable for their launch. First, we will need to find new investors." ||

Theme: Trade shows | **Author:** Sven Geitmann

PUTTING THE SPOTLIGHT ON INFRASTRUCTURE

Hannover Messe remodels Energy show

Change is coming to energy, industrial and transportation sectors all over the world. Everywhere, countries are looking for future-proof solutions to transform their economies into something more environmentally sustainable and energy efficient. Hannover Messe, taking place April 23 through 27, will offer them ways to accomplish their goals. The center of attention will again be the Energy, one of the five lead shows. This show alone is said to be attracting about 100,000 attendees to Hanover.

Hannover Messe goers were starting to lose interest in electric vehicles in recent years. The hype around electric transportation and the exponential growth of MobiliTec 2012 seemed like a long time ago. MobiliTec, previously the lead show on hybrid and electric engines, saw a dwindling number of exhibitors each time, so Deutsche Messe decided to replace it in 2018. From now on, this part of the show grounds will be known as Electric Transportation Systems.

Like the Renewable Energies section, which includes the Integrated Energy Plaza, and the exhibit space for Decentralized Energy Supply, Electric Transportation Systems will put the spotlight on infrastructure and the debate surrounding the profound changes to manufacturing and trade. Deutsche Messe's Benjamin Low said that attendees would learn in the Energy halls what was needed for a sustainable electric transportation infrastructure and what the market had to offer at this point. The new show area would focus on the integration of electric vehicles into energy markets.

ABB's latest products seem to fit the occasion, reportedly promising a drastic reduction in charging times. At the show, the corporation will unveil a fast charger to replenish batteries within a few minutes, equal to a short stop at the gas station for conventional refueling.

THE THRILL OF A TRANSFORMING MARKET There is renewed interest in electric transportation, driven in part by the multiple news articles uncovering some automakers' repeated manipulation of emission tests and the subsequent court decision imposing restrictions on driving diesel cars into German cities. Many businesses, especially small and midsize ones, have begun to adjust their strategies. For example, ElringKlinger's Peter Renz stressed that his company had been

Fig. 1: Public Forum in hall 27 – the meeting point for all those interested in hydrogen and fuel cells

working on battery and fuel cell systems for years. He said that an automotive supplier rooted as deeply in tradition as ElringKlinger was witnessing an exciting moment in the market's history, a transformation that would have an impact on the entire automobile industry. The chairman of the company's board, Stefan Wolf, added that batteries and fuel cells, with their qualities and benefits, were both sensible solutions to upcoming challenges. In combination, they would be even more powerful.

MICROBIAL FUEL CELL PROJECT WINS AWARD 2018 marks the 24th year of Hydrogen + Fuel Cells + Batteries, a shared exhibit expected to feature more than 150 organizations this time around. Tobias Renz was especially proud that two large automotive companies had announced booths in the shared space this year. One is Faurecia, a globally operating supplier that employs 110,000 people. Last September, it inked a five-year cooperation agreement with CEA-Liten, which had partnered with French automaker PSA on the Genepac® fuel cell project from 2003 to 2010. The other is Plastic Omnium, the new owner of Swiss Hydrogen (see p. 6). Together with Anleg and ZBT Duisburg, it will present a new mobile refueling system in Hanover. Likewise, Daimler is said to be showing its GLC F-Cell three booths down the aisle.

One more exhibitor coming back to the premises in 2018 is Eisenhuth. Last December, it won the German Sustainability Award in the Research category as part of a consortium including the Clausthal University of Technology's Cutec Institute, the Braunschweig Technical University and the Karlsruhe Institute of Technology. The consortium had developed a fuel cell that generates renewable power at sewage plants while cleaning the wastewater. It then set up a pilot system at Goslar's sewage treatment plant operated by Eurawasser Betriebsführungsgesellschaft. Professor Michael Sievers from the Clausthal University of Technology said that the microbial fuel cell provided an off-grid, low-maintenance method for improved wastewater treatment. The system produced little sewage sludge, but generated electricity and hydrogen, for example, to power electric vehicles.

Eisenhuth, however, will have more than just this fuel cell to present. There are also the company's redox-flow batteries. Like the fuel cell, they need graphite plates, one of CEO Thorsten Hickmann's fields of expertise. The company will further offer an in-depth view of specialized insulation and 3D parts manufacturing, be it from rubber, plastic, silicone or steel.

DEFINITE PLANS TO SWITCH OVER TO RENEWABLES The German Technical and Scientific Association for Gas and Water (see also p. 7) has indicated his rising interest in hydrogen through renting its own, albeit small, booth in Tobias Renz's exhibition area. Among other things, booth E70/1, located right next to the Technical Forum in hall 27, will present the association's bookazine, a hybrid of a book and a magazine, published in January. Titled "Energie-Impuls konkret," it describes numerous best practice examples to change to a renewable economy. On 100 pages, it illustrates in precise terms how to implement a market transformation project, even in today's environment.

Nevertheless, the association's CEO, Professor Gerald Linke, said that the bookazine's authors did write about the hurdles on the way to successful showcase projects. Current policies were stalling progress in the deployment of economically sensible technologies, such as power-to-gas. Likewise, they made it difficult to increase the adoption of synthetic mixtures in natural gas-powered goods and passenger transportation. The aim was and had been to overcome those challenges and work in concert with politicians and the energy industry to succeed in building a sustainable future.

Besides 25 organizations from France, another exhibitor that will arrive from outside Germany is Haskel International, based in Burbank, close to Los Angeles. Robert Kelly, Haskel's new global business development manager for hydrogen, will represent this American manufacturer of high-pressure products in hall 27 in Hanover. He intends to establish relations with companies along the entire hydrogen value chain and explore market options for hydrogen refueling and power-to-hydrogen applications. ||

→ Eisenhuth in Hanover: booth D53, hall 27
→ Haskel in Hanover: booth D70, hall 27

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Hydrogeit Verlag is offering readers of HZwei and H2-international free Hannover Messe tickets online. Go to hannover-messe.de and use the following promo code during registration: wmv3r

Theme: Trade shows | **Author:** Sven Geitmann

HYDROGEN CONFERENCE IN RIO DE JANEIRO

Source: Fotolia, Dominik Ruso

This year, the hydrogen community will meet June 17 through 22 in Rio de Janeiro, Brazil, for the 22nd World Hydrogen Energy Conference. Three of the speakers who have confirmed their participation are Bart Biebuyck, Fuel Cells and Hydrogen Joint Undertaking, Brussels; Sunita Satyapal, Department of Energy, USA; and Yoshihiro Mizutani, Ministry of the Environment, Japan. Other conference contributions are said to be coming from Pierre-Etienne Franc, secretary general of the Hydrogen Council, and renowned managers working for Ballard and Hydrogenics. In all, around 200 presentations and more than 330 poster sessions will be vying for the attention of attendees.

The traditional exposition that runs alongside the conference will include an exhibition space organized by the German Hydrogen and Fuel Cell Association and the National Organization Hydrogen and Fuel Cell Technology. Workshops take place on three of the five days. For example, the Canadian Hydrogen and Fuel Cell Association is planned to hold a scientific seminar on the technology, while UFSCar, the Federal University of São Carlos, is going to inform attendees about metal alloys for hydrogen storage. In partnership with the European Hydrogen Association, the UN's Climate Technology Center & Network will additionally offer a workshop titled "Energy Transition Now to Mitigate Climate Change." The schedule also includes four technical tours. One will be a visit to the LabH2 hydrogen research facility of the Alberto Luiz Coimbra Institute at the Federal University of Rio de Janeiro. Another will offer insights into the work at the federal science ministry's National Institute of Technology. The third will be a tour of the National Institute of Metrology, Quality and Technology, and the fourth will take place at the Itaipu Dam, the world's most productive hydropower plant.

The organizer of the conference, Peter Sauber, expressed his delight when the subject came up during a conversation with H2-international: "Rio is lovely – much lovelier than expected." The conference is going to be held south of the city, almost directly on the beach. H2-international will be reporting live from the event. ||

www.whec2018.com

ENERGY STORAGE EUROPE GROWTH GRINDS TO A HALT

The Energy Storage Europe show, which took place March 13 through 15 in Düsseldorf, Germany, had more than 200 leaders in science, business, government and civil society present the latest developments in five series of parallel sessions at two co-located conferences, the 7th ESE and Eurosolar's 12th IRES. The show no longer featured a Power-to-Gas conference, since OTTI had filed for bankruptcy protection in late 2016. It was replaced by a Power-2-X workshop, headed by Fraunhofer ISE's Christopher Hebling and organized in cooperation with the German Hydrogen and Fuel Cell Association, the German Energy Storage Association and the Embassy of Canada.

Electrochaea, based in Planegg, close to Munich, took this first-ever opportunity to show attendees its range of bioreactors. Based on standardized biocatalyst storage technology, the systems use single-cell microorganisms, called archaea, to convert power into methane. The organisms' level of activity can be controlled through the withdrawal and addition of hydrogen and carbon dioxide. Mich Hein, CEO of Electrochaea, said that the company's bioreactors provided turnkey solutions for storing renewable energies and carbon dioxide in the form of synthetic gas for either on-site use or pipeline injection. The technology promised lower operating costs at increased competitiveness thanks to standardized components and a subsequent reduction in planning and construction times. With capacities ranging from 1 megawatt to 50 megawatts, the units could be employed at landfills, sewage treatment and waste-to-energy plants, geothermal sites and industrial facilities. A more detailed report will follow in this year's October issue.

This year's show attracted 170 exhibitors, a bit more than last year and somewhat more than the 142 that had come in 2016. The rapid 50 percent growth in exhibitor numbers, typical of the show's early years, has given way to a period of stagnation. ||

Theme: Stationary systems | **Author:** Sven Geitmann

FUEL CELL POWER PLANTS COMPARED

MCFCs, PAFCs, PEMFCs and SOFCs

Fuel cell power plants are the top class of stationary applications. They are the most difficult systems to design and the market for them is the toughest to survive. Companies engaging in this business have often come crashing down or were saved in spectacular fashion by mere chance. But there are some which have mastered the market's ups and downs and new entrants who are willing to try. The following will offer readers an outline of market players, projects and technologies, in addition to the table on pages 16 and 17.

There are now over half a dozen companies that manufacture stationary fuel cell systems ranging from 100 kilowatts to 10 megawatts. The power source for these systems used to be either a solid oxide or a molten carbonate fuel cell, but proton exchange membranes have made headway in recent years. Even phosphoric acid fuel cells remain an option, despite receiving scarce news coverage at times.

BLOOM ENERGY Bloom Energy, a globally operating provider of interconnection services, began to develop solid oxide fuel cells, or SOFCs, in 2001. But the company, based in Sunnyvale, USA, became more widely known no earlier than the beginning of 2010. Even now, details about Bloom's systems are few. This strategy has allowed CEO KR Sridhar to build a broad knowledge base on high-temperature fuel cells without being constantly in the public eye.

Eight years ago, the cash-strong business started producing one Bloom Box each day. Meanwhile, its systems have been installed on the premises of many large corporations. In July 2008, Bloom delivered a first 100-kilowatt installation to Google. Over the following two years, it set up units at eBay's headquarters in San Jose. Other big customers collaborating with Bloom during that period were Coca-Cola, FedEx and Walmart.

> "There is no greater compliment and validation of our energy platform than to have our existing customers continue to expand their deployments of Bloom Energy Servers, and today, Equinix is doing that in a big way."
> *K. R. Sridhar, CEO of Bloom Energy*

In August 2017, the company announced that Equinix and one of Southern Company's subsidiaries had signed a 15-year energy supply contract. This contract is said to involve the installation of Bloom Boxes at 12 Equinix International Business Exchange™ (IBX®) datacenters in the United States. Until 2019, Bloom's off-grid systems are expected to power 15 datacenters and other facilities around the world, at a total capacity of more than 40 megawatts.

CONVION Another company focused on SOFC development is Finnish Convion, founded in 2012. Its ceramic stacks >>

Source: DEMOSOFC

Fig. 1: DEMOSOFC system at a wastewater treatment plant in Turin, Italy

Fig. 2: Bloom Boxes at customer FedEx

come from suppliers such as Elcogen, a fuel cell manufacturer based in Tallinn, Estonia. Established by CEO Enn Õunpuu in 2001, Elcogen has grown into an R&D facility employing 28 staff members.

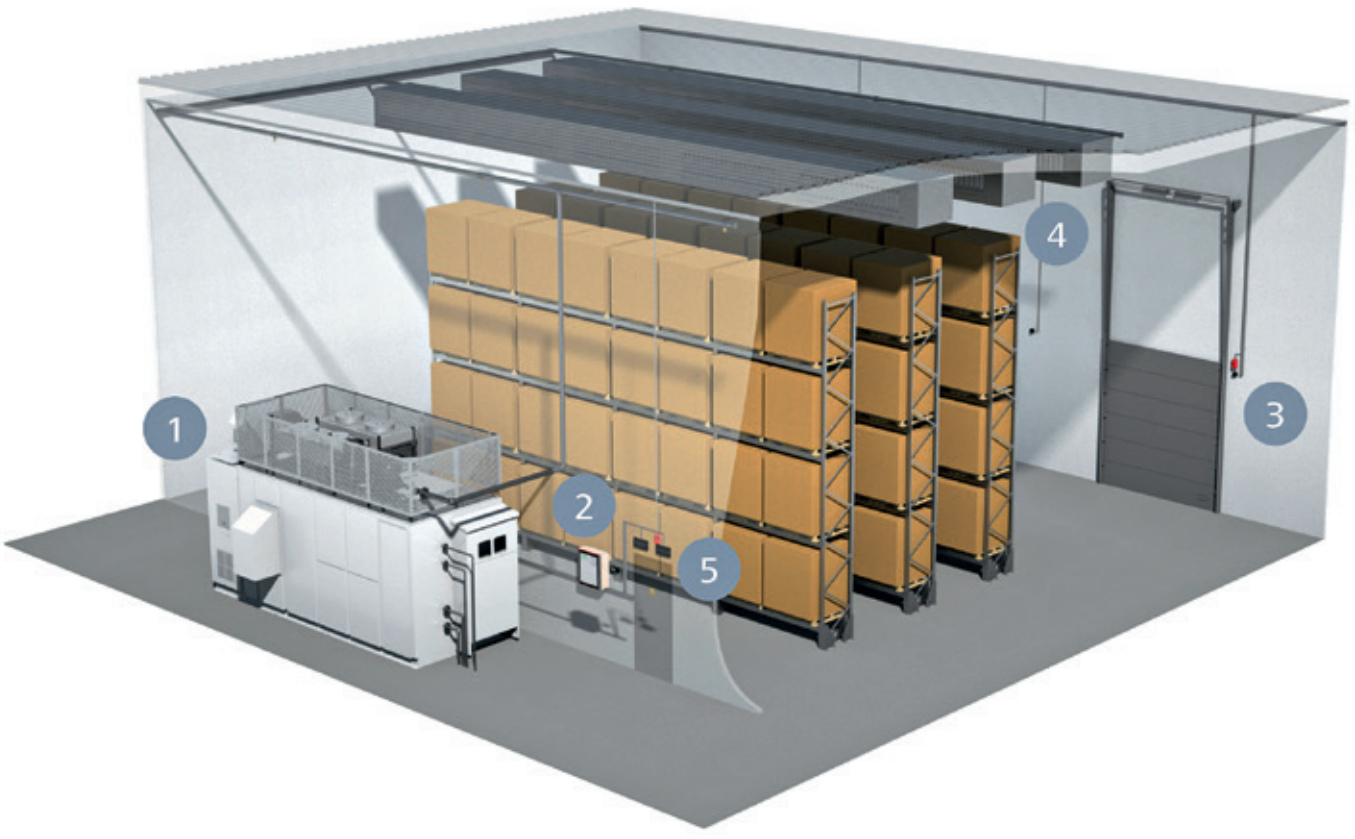
The Estonian business said that its fuel cells had operating temperatures of as low as 600 °C to 650 °C, showed more than 74 percent efficiency and cost less than EUR 500 per kilowatt. Typical SOFC systems operate at 750 °C to 900 °C. The lower temperature threshold is said to allow for the use of inexpensive materials and lead to reduced degradation.

The stacks are incorporated into fuel cell power plants ranging from 50 kilowatts to 300 kilowatts of capacity. Some of the expertise has been sourced from Wärtsilä, whose fuel cell division Convion acquired in January 2013. The business has cooperation agreements with the Fraunhofer Institute for Ceramic Technologies and Systems, Plansee and mPower. Convion's technology is being tested in projects such as the EU's DEMOSOFC, launched last October (see fig. 1). The project's waste-to-energy system, which generates electricity from a byproduct of the wastewater treatment process, is today's biggest biogas-based fuel cell installation in Europe. It consists of three modules, each producing 58 kilowatts of alternating current power. The total electricity generation capacity amounts to 174 kilowatts, meeting around 30 percent of the energy requirements to operate the wastewater treatment plant connected to the installation. Additionally, waste heat recovered from the exhaust provides part of the power to run the anaerobic digester tanks on-site.

The organizations participating in the DEMOSOFC project estimate that 90 percent of all wastewater treatment plants in Europe, or more than 26,890 facilities, could make use of the technology.

The potential of SOFCs is also being explored by LG Fuel Cell Systems, based in the United States. In September 2017, the U.S. Department of Energy greenlighted more than USD 5.7 million in funds for installing one of the company's 250-kilowatt SOFC systems powered by natural gas at the Stark State College in North Canton, Ohio.

Then, there's General Electric. In 2014, the energy corporation established a subsidiary named GE Fuel Cells, based in Saratoga County, New York. In late 2016, the business was integrated into GE Global Research and about two dozen of CTO Johanna Wellington's employees were let go. Fuel cell research was subsequently relegated back to the laboratory to test a 1-megawatt pilot system. The original aim was to put an SOFC unit on the market in 2017, but nothing seems to have happened so far.



Source: Minimax

Fig. 3: Oxeo EcoPrevent FC – 1: Fuel cell; 2: Control room; 3: Oxygen sensors; 4: Pipes for nitrogen gas feed; 5: Screen and alarm system

Source: Hydrogenics

Fig. 4: Several R120 racks combined

MITSUBISHI Meanwhile, Mitsubishi Hitachi Power Systems announced that it had received an initial order for its combined fuel cell and gas turbine system. The hybrid power plant, which runs on natural gas, consists of a solid oxide fuel cell and a mini gas turbine. Electricity is generated first in the fuel cell, through the reaction of hydrogen and carbon monoxide with air, before the hot exhaust reaches the turbine to produce more power and push electrical efficiency above 65 percent. The use of waste heat brings the plant's total efficiency to 73 percent. The system will reportedly come online in February 2019, at Mitsubishi Estate's Marunouchi Building in Tokyo. Previous tests of 250-kilowatt prototypes in 2016 have been a success, prompting Mitsubishi to launch a marketing campaign last summer.

FUELCELL ENERGY One influential market player is FuelCell Energy, an American manufacturer that started developing molten carbonate fuel cells, or MCFCs, more than 20 years ago. In Germany, the corporation initially entered into partnership with MTU Friedrichshafen before the latter outsourced its fuel cell division to MTU CFC Solutions and from there to MTU Onsite Energy. The division was then incorporated into the Tognum Group, which ultimately abandoned the business altogether. Eighteen months later, FuelCell Energy acquired the remaining assets and founded a German subsidiary, FuelCell Energy Solutions. Its longtime CEO Andreas Frömmel left in April 2017 and was replaced by Klaus Ullrich the following month. In the meantime, the position has become vacant again.

FuelCell Energy's main markets besides Germany are the United States and Asia. One of its latest projects is the construction of a multi-megawatt system at the Port of Long Beach in California, in collaboration with Toyota. Starting in 2020, the trigeneration unit called SureSource™ is expected to produce 2.35 megawatts of electricity and 1.2 tons of hydrogen per day to supply an on-site fleet of Mirai cars and new Toyota hydrogen trucks. The revenue from feeding the power into the public grid is intended to secure the economic viability of the system.

FROM UTC TO DOOSAN United Technologies Corporation began researching phosphoric acid fuel cells, or PAFCs, half a century ago. In 1985, UTC Power partnered with Toshiba to establish International Fuel Cells. The joint venture and Toshiba then founded ONSI Corporation in 1991. The >>

new business set up more than 150 fuel cell power plants, type ONSI PC25. But the plants were too costly, stack lifetime too low. Following years of uncertainty, ClearEdge Power, a company backed through venture capital, acquired the expertise originally sourced from UTC. ClearEdge, however, had to file for bankruptcy protection in 2014. Its PAFC technology lives on, as Doosan Fuel Cell America took over the reins the same year and has since been manufacturing the 400-kilowatt PureCell® Model 400. Doosan Fuel Cell is a subsidiary of South Korean Doosan Corporation, which employs 43,000 people in 38 countries.

The subsidiary has installed around 40 power plants in the United States, with a total fuel cell capacity exceeding 240 megawatts. It has invested over USD 50 million in production facilities in the state of Connecticut and in Iksan in South Korea. Up to now, systems have been primarily designed to run on biogas or natural gas, but Doosan is said to be working on LPG and hydrogen systems. Its first combined hydrogen and fuel cell power plant is scheduled for completion in 2019. On behalf of Hanwha Energy, it plans to install 114 of the company's 50-megawatt units in the Daesan industrial zone in Seosan, South Korea. During the FC Expo in Japan (see p. 57), the South Korean manufacturer was seeking out operators of datacenters to assess the potential of this part of the market.

FUJI ELECTRIC Fuji Electric is another PAFC manufacturer. In Germany, at least, the company's offering is mainly known among fire safety professionals. In 2015, it acquired N_2telligence, a small northern German startup that has been in the fuel cell business for years. N_2telligence uses the low-oxygen air exhaust from its fuel cells to reduce the oxygen content inside a building and prevent fires from breaking out. Since it became a Fuji subsidiary, it has signed cooperation agreements with businesses such as Minimax, which offer several types of fire protection systems. Minimax's Oxeo EcoPrevent FC was recognized with the Product of the Year award in the Fire Protection for Industrial Equipment category in January 2018.

HYDROGENICS Hydrogenics, a Canadian manufacturer listed on the stock exchange (see p. 50), is a long-standing player on the market for proton exchange membrane fuel cells, or PEMFCs. It not only has a variety of stationary and vehicle systems for sale but offers scalable fuel cell solutions. The product portfolio ranges from 10-kilowatt R10s to R20s, R30s and R120s and goes up to multi-megawatt systems, for which the corporation combines several 120-kilowatt racks.

TOSHIBA Toshiba seems to be one step ahead of its competitors. The Japanese manufacturer began work on PAFCs in 1978 and put into operation its fifth H2One™ system in April 2017. This off-grid system, which produces renewably sourced hydrogen via electrolysis and converts the gas into power via fuel cells, supplies a Japan Railways station in Kawasaki City. It reduces the amount of energy needed from the public grid and serves as an off-grid uninterruptible supply system to provide the station with hot water and electricity. In winter, the hot water is also being directed through the station's benches to keep them warm. Hiroyuki Ota, project manager at Toshiba Energy Systems & Solutions, said that the aim was to help implement a low-carbon economy that primarily uses hydrogen produced without carbon dioxide emissions. Similar systems have been installed in the ports of Kawasaki and Yokohama. ||

Theme: Stationary systems | **Author:** Eva Augsten

FUEL CELL POWER PLANT MARKET OVERVIEW

As part of an online survey, H2-international has asked 12 suppliers of fuel cell power plants to provide information about their product portfolio and the market. Unfortunately, only four of them filled out the questionnaire, describing four products in total. Datasheets available elsewhere were used to add more systems to the table below. Because of the small number of respondents, we have decided not to perform any statistical analysis and will focus on some commonalities instead.

The three suppliers that responded had a list of relevant target markets, namely Europe and the Asian high-tech tigers South Korea and Japan. Not one of them believes that the United States was of interest to their business. They also agreed that renewable energies and hydrogen could push each other to new heights. In their opinion, it would make sense to increase public funding for fuel cell power plants.

One of the respondents would like hydrogen technology to have a higher public profile to make installation figures go up and prices go down. Another criticized the fact that hydrogen produced from renewable energies was subject to the same regulations as diesel fuel. "It's the biggest obstacle to growing demand for fuel cell power plants," he wrote. (see overview on page 16/17) ||

Theme: Stationary systems | **Author:** Sven Geitmann

TRANSPORTATION MINISTRY FUNDS OFF-GRID FUEL CELL UNITS

The National Innovation Program Hydrogen and Fuel Cell Technology is now providing financial support for off-grid fuel cell systems. Christian Schmidt, acting federal transportation minister, said in February 2018 that the government intended to guarantee the eco-friendly, uninterrupted supply of critical and remote off-grid infrastructure. The program had been extended to include fuel cell units to increase their market adoption and cost-effectiveness. He added that fuel cells were vital infrastructure components, especially when used to power traffic control installations and the government's public safety communications network.

Funds from the EUR 5 million budget are available for off-grid fuel cell units not exceeding 20 kilowatts of capacity. In total, the measure is hoped to lead to the installation of up to 600 devices in public safety communications and traffic control. The maximum reimbursement is 40 percent of the added capital costs compared to a conventional unit. The deadline for applications is May 31, 2018. The relevant documents can be submitted online at https://foerderportal.bund.de/easyonline ||

Christian Schmidt

NOW in Hanover: booth B59, hall 27

Theme: Stationary systems | **Author:** Eva Augsten

FUEL CELL POWER PLANT MARKET OVERVIEW

	BLOOM ENERGY CORP.*	DOOSAN FUEL CELL AMERICA, INC.*	DOOSAN FUEL CELL AMERICA, INC.*
COMPANY			
PRODUCT	Energy Server 5	PureCell 400	PureCell Hydrogen
DEVELOPMENT STATUS	commercial	commercial	pre-commercial
MAIN APPLICATION	on grid power generation, UPS or back-up service	on grid power generation, UPS or back-up service	on grid power generation, UPS or back-up service
TYPE OF FUEL CELL	SOFC	PAFC	PAFC
FUEL	natural gas, bio gas	natural gas, bio gas	hydrogen
NOMINAL ELECTRICAL OUTPUT	250 kW	460 kW	440 kW
HEAT OUTPUT [KW]		301 kW / 212 kW	
AC OR DC	AC	AC	AC
FREQUENCY	60 Hz		
ELECTRICAL EFFICIENCY	53 bis 65 %	43 %	45 %
TOTAL EFFICIENCY		90 %	90 %
VOLTAGE	480 V		
OUTPUT TEMPERATURE		60 °C / 120 °C	120 °C
HEIGHT		250 cm	250 cm
WIDTH		300 cm	300 cm
DEPTH		830 cm	830 cm
WEIGHT	14300 kg		
OPERATION TEMPERATURE	-20 to 45 °C		

*: product data sheet
**: manufacturer's own instructions

			
FUELCELL ENERGY SOLUTIONS GMBH**	**FUJI N2TELLIGENCE GMBH****	**FUJI N2TELLIGENCE GMBH****	**HYDROGENICS CORP.****
SureSource	QuattroGeneration	HyCoGeneration	Fuel Cell MW Power Plant
commercial	commercial	commercial	commercial
on grid power generation, UPS or back-up service, Carbon Capture	on grid power generation, fire prevention	on grid power generation	on grid power generation, UPS or back-up service
MCFC	PAFC	PAFC	PEM
natural, bio, landfill gas, LNG	natural gas, LNG	hydrogen	hydrogen
1400 kW	100 kW	100 kW	1000 kW
750 kW	120 kW	100 kW	1500 kW
AC	AC	AC	AC
50 Hz / 60 Hz	50 Hz	50 Hz	50 Hz / 60 Hz
47 %	42 %	48 %	49 %
	92 %	92 %	
400 V	400 V	400 V	380 to 480 V
	75 °C	90 °C	70 °C
700 cm	340 cm	340 cm	292 cm
15000 cm	590 cm	590 cm	243 cm
20000 cm	220 cm	220 cm	1219 cm
50000 kg			32000 kg
-20 to 50 °C	-20 to 40 °C	-20 to 40 °C	

Theme: Stationary systems | **Author:** Sven Geitmann

IBZ REORGANIZED

Kehler and Lücke become spokesmen for the initiative

The beginning of this year saw wide-ranging changes to the Fuel Cell Initiative, or IBZ for short. What used to be a group of manufacturers and energy suppliers collaborating to promote fuel cell heaters was integrated with the BDH, Germany's national heating industry association, and Zukunft Erdgas, an advocacy group representing the interests of over 100 gas utilities and pipeline operators. The heads of both organizations, Andreas Lücke and Timm Kehler, are now also the new spokesmen for the initiative.

Reportedly, the changes had been made to keep pace with market developments and new challenges. While the BDH will concentrate its efforts on the political arena, Zukunft Erdgas will focus on the market itself. Partners are the German Technical and Scientific Association for Gas and Water and the National Organization Hydrogen and Fuel Cell Technology. Both began coordinating activities with the IBZ last March.

The initiative was founded by EWE, MVV Energie, Ruhrgas and VNG in 2001, with the intent to develop and test smaller fuel cells powered by natural gas. As many as 12 organizations – energy suppliers, device manufacturers and the German Energy Agency – had been part of the collaboration at some point. Six of those have remained, all of them heating equipment manufacturers. They are Bosch, SenerTec, SOLIDpower, Vaillant, Viessmann and Elcore, which was recently acquired by Freudenberg (see p. 5). In March 2017, the companies decided to work together with influential associations for the gas and appliance manufacturing industries to create an effective communications strategy that would support the market launch of new technologies. Kehler said that the decision had marked the end of the first stage and that an increase in the uptake of fuel cell heaters was the collaboration's next objective.

Source: SOLIDpower

SOLIDpower produced and installed its 1000th BlueGEN unit at the turn of the year.

Fuel cells, however, were nowhere to be seen when the BDH, Zukunft Erdgas and the plumbing trade started a marketing campaign this March. Zukunft Erdgas would only say that one aim of the Replace-It-Now Weeks certainly was to address the vast number of building retrofits needed today and the condensing technology that came with such a task. ||

VAILLANT'S NON-EXIT

When H2-international asked Alexander Dauensteiner why Vaillant continued to be involved in the initiative, although it was said to have turned its back on fuel cell technology in early 2017, he replied:

"Vaillant would like to emphasize that it never 'exited the sector.' What we did do at ISH 2017 was to announce that the Vaillant Group will reduce its fuel cell R&D activities and halt the market launch of its residential fuel cells for single-family homes. This decision was made in response to the government's decarbonization strategy and was based on the conclusions we drew from it. We are still actively participating in all relevant fuel cell associations, such as the new fuel cell initiative."

Zukunft Erdgas' Michael Schaarschmidt told H2-international that Vaillant had always been very committed to the initiative, something that would not change moving forward. Should politicians, competitors and the trade be successful in establishing more than a niche application, Vaillant would be sure to rethink its position and start contemplating whether and how to re-enter the market.

FREUDENBERG INCORPORATES ELCORE

In the January issue, we reported about Elcore's preliminary bankruptcy. Beginning the new year it was told that Freudenberg Sealing Technologies, a subsidiary of the Freudenberg group of companies, based in Weinheim, Germany, is the new investor. In mid-December last year, it struck a deal with the interim trustee to purchase several of Elcore's assets.

Elcore, Elcomax and Efficiencity are now defunct. What began with a re-evaluation of warranty liabilities and a rather unsuccessful financing round ended in a bankruptcy case on Jan. 1, 2018, and the liquidation of the companies involved.

Manfred Stefener, CEO of Elcore, Elcomax and Efficiencity, said that he had taken on a management position at Freudenberg. Production of the Elcore 2400 is planned to continue and, reportedly, the name of the system will not change. But "opportunities for synergy," as the bankruptcy administrator put it, mean that about half of the more than 100 staff members previously employed by the three companies will be let go. ||

Theme: Energy storage | **Author:** Sven Geitmann

ONCE ACTA, NOW ENAPTER

Interview with Sebastian-Justus Schmidt about Heliocentris Italy

So far, we've closely followed the developments unfolding at Berlin-based fuel cell supplier Heliocentris and the takeover of its locations in Germany (see H2-international, May 2017 and January 2018). We also reported about the comeback of FutureE and the spin-off of Home Power Solutions. And recently, we sat down with Sebastian-Justus Schmidt, owner of Enapter, to find out what happened to Heliocentris' subsidiary in Tuscany.

Sebastian-Justus Schmidt

Mr. Schmidt, the story is that it all started in Pisa, with an Italian business named Acta. First, please tell us what became of this company.
Schmidt: Acta, which was later renamed Heliocentris Italy and is now Enapter, entered AIM, the Alternative Investment Market of the London Stock Exchange, in 2004. At the end of 2014, it lost a court case and was ordered to pay EUR 1.35 million. Since the company had already slipped into the red, it filed for "concordato preventivo," Italy's version of Chapter 11 bankruptcy protection in the United States. After all, it had burned through more than EUR 35.9 million in vital cash reserves from AIM gains and various other investments.

What had Acta been working on?
Schmidt: With a small team made up of chemical engineers, Acta had begun to develop fuel cells, but refocused its attention in 2007, turning instead to alkaline water electrolysis. Initial results looked promising, and in 2010, management decided to make electrolyzers the company's only line of business. One year later, Acta started delivering units to a few institutes and signed a distribution agreement with German supplier Heliocentris Energy Solutions.

It seems that working with Heliocentris was rather beneficial for Acta, at least initially.
Schmidt: Yes, it was. After Acta had filed for bankruptcy protection, Heliocentris set up a subsidiary, Heliocentris Italy, which rented Acta's assets for a year. In early 2015, the subsidiary acquired all of the company and signed an agreement with the trustee.

What followed?
Schmidt: Unfortunately, the next thing that happened was the bankruptcy filing of the parent corporation in October 2016. But Inabata, a Japanese trading company in business with both Acta and Heliocentris, had secured a floating-rate loan and a minority stake in Heliocentris Italy, so it received some of the shares.

Odasco's alleged rescue attempt did not work out as planned, did it?
Schmidt: In January 2017, the trustee managing Heliocentris' bankruptcy case signed an agreement with Odasco, based in Dubai in the United Arab Emirates, to allow the corporation to establish Odasco Heliocentris Europe, registered in Düsseldorf, Germany, and take control of Heliocentris Italy. Odasco Heliocentris brought in fresh capital for a few weeks, but then, payments suddenly stopped, without notice, leaving the Italian offshoot unable to meet its financial obligations. Since Odasco had paid less than the full amount for the takeover, the trustee declared it "not consummated" in October. He asked me whether I was interested in purchasing most of the shares – an offer I just couldn't resist.

Why was that?
Schmidt: Since 2015, I've been using Acta's electrolyzers for my sustainable living project, Phi Suea House [phisueahouse.com]. I have seen how the devices work, know their benefits and drawbacks. Also, I strongly believe that hydrogen will be big in the coming years.

And Heliocentris?
Schmidt: We retained all 11 employees and hired five more for our headquarters in Pisa. We likewise hired new staff and contracted freelancers for our Software, UX and UI division. We got started on extensive and urgently needed renovations, some of which have already been completed. In March, we will begin planning for our Berlin office, and we will introduce our new company, Enapter, to Hannover Messe goers in April (Hall 27, Booth D57). We've been very pleased with how everything, including the company and the team, has turned out. But, of course, there is still a lot of work to be done. ||

Theme: Energy storage | **Authors:** Andreas Kunz, Julia Witte, Serge Biollaz and Tilman Schildhauer

60 PERCENT MORE METHANE FROM BIOGAS

Using renewable hydrogen in direct methanation

Until 2030, Switzerland's heat generation from renewable gas is to increase from today's roughly 1 percent to 30 percent. To achieve greater efficiency in the use of raw gas sources, Zurich-based energy supplier Energie 360° and the PSI – Paul Scherrer Institute have been working on developing a new power-to-gas technology. Together, they created a prototype, put through a long-term test cycle in the lab, that meets the requirements for unrestricted pipeline supply and produces 60 percent more renewable gas from sewage and solid waste treatment. The findings mark an important milestone in meeting the 2030 target.

Despite major growth in domestic biogas production over the past decade, non-imports add up to only around 1 percent today. Increasing Switzerland's biogas share to 30 percent in slightly more than a decade will be a challenging task. Energie 360° and the PSI have now brought the country one step closer to its renewable goals by devising a system that makes use of the 40 percent of carbon dioxide contained in raw biogas and released through sewage and solid waste treatment. Conventional plants will remove this carbon dioxide from the biogas before injecting the remainder, 60 percent of almost pure methane, into the national pipeline system. If, however, hydrogen were added, the mixture could be put through a power-to-gas cycle and lead to a 60 percent increase in methane output.

If all the existing Swiss sewage and solid waste treatment plants that produce biogas close to a pipeline received a power-to-gas upgrade, today's renewable gas total in the national transmission system could be increased to 1,400 gigawatt-hours. In 2016, output was at 308 gigawatt-hours per year. Thus, the retrofit would make it possible to store more than 900 gigawatt-hours of electricity in the network.

Nearly 100 potential power-to-gas sites can be found across the country. The majority, 64 to be exact, are at sewage treatment plants. Most of these plants do not yet possess any injection station but use CHP technology to generate power and heat from sewage gas. CHP may be suitable for this purpose, but there are more effective and efficient processes that would likewise provide greater environmental benefits.

ECONOMIC FEASIBILITY Biogas is an eco-friendly alternative to natural gas, but its cost of production is higher. The difference is not a concern to customers, who are willing to pay more to protect the environment. Biogas is also exempt from fuel taxes and carbon fees, which has made it possible to operate conventional waste-to-energy plants without the need for public funding. This is the kind of milestone that power-to-gas should be able to reach. The aim of our feasibility analysis was to determine whether power-to-gas systems could achieve economically sustainable operation at similar or lower capital and operating costs per kilowatt-hour of gas produced.

The exemption from taxes and fees was changed in 2016 to include methane sourced from renewable hydrogen, provided that the carbon dioxide produced during the process was not used specifically for methanation. As a result, syngas is now competing on an equal footing with today's biogas. Thus, we assumed that it will eventually achieve the same price levels as the latter does on today's market.

The price for biogas that can be injected into the pipelines was set to between 9 and 10 cents* for each kilowatt-hour, before distribution, trade or sale. This price includes the cost of production and the environmental benefits being offered. Increasing competition on the market could make our assumption a rather optimistic one, and we expect the price to drop at some point. The sample system chosen for comparison was a mid-size installation producing 200 normal cubic meters of raw biogas per hour. This type of plant, which will achieve a production of 11 gigawatt-hours a year, is very common in Switzerland.

Employing power-to-gas systems to make use of the carbon dioxide that raw biogas contains can increase the injection quantity to 160 percent. Capital expenditures, including the total investment in gas cleanup equipment, will rise by a factor of 1.9 if unrestricted supply to the transmission system is required, whereas the higher methane output will nearly close the gap in costs per kilowatt-hour between the new system and a conventional one (fig. 1). Economies of scale are expected to drive down these costs even further.

Fig. 1: Cosyma test container

The 60 percent increase in methane production will cover operating and maintenance expenses, offsetting the higher capital expenditure for a power-to-gas system. Costs per kilowatt-hour are the same for both options when factoring in the initial investment as well as operation and maintenance but excluding the cost of raw biogas and the power required for electrolysis. The economic feasibility of power-to-gas primarily hinges on electricity prices, which need to be below 4 cents per kilowatt-hour to match the cost structure of conventional biogas production and a complete removal of the carbon dioxide. Currently, this kind of scenario is only feasible if there are no grid fees added to electricity charges. Some options to further improve economic sustainability include the utilization of waste heat generated as part of the process and of the oxygen released during electrolysis. What concrete suggestions can be made will depend on the location of the project and local conditions.

TECHNICAL FEASIBILITY A container called Cosyma, short for *Container-based System for Methanation* (see fig. 1), was set up at the PSI to demonstrate the economic and technical feasibility of methanation without prior removal of the carbon dioxide involved. Bottled gas was used to put the system into operation on the PSI's Energy System Integration Platform in late 2016. The following January, it was transported to one of Switzerland's largest waste-to-energy plants, in the Werdhölzli area of Zurich.

The 800 normal cubic meters of methane output from sewage and solid waste treatment at the plant come from raw biogas consisting of around 60 percent methane, 40 percent carbon dioxide and some impurities, such as sulfur compounds. The carbon dioxide is typically removed during amine gas treating through activated carbon before the resulting biomethane is dehydrated and injected into the pipelines at more than 96 percent purity. Each hour, the PSI system receives between 1 and 2 cubic meters of the raw biogas flow prior to amine scrubbing and will later inject it as methane-rich biogas into the network (see *fig. 2)*.

COSYMA CONTAINER The container has four sections (see fig. 3). Inside the first section, raw biogas is compressed to around 6 bars. The next stage removes sulfur compounds and siloxanes that could poison the catalyst used for methanation. The purified gas is then heated, while the system adds to it a certain amount of steam and the hydrogen required for the process. The third section contains the methanation reactor, which produces one-third methane and two-thirds steam, as well as heat, from carbon dioxide and hydrogen supplied at a ratio of 1 to 4.

The reactor has a fluidized bed. The gas let in from below will expand the bed and cause the catalyst particles to swirl around in the reactor, which makes for very effective cooling and allows for the reaction to occur at any given temperature. In the past, this type of reactor has proven to be much more resilient to catalyst coking than other thermochemical devices for methanation.

When reaction has occurred, the system will filter out certain particles and allow the steam to condense. At this point, the biomethane consists of as much as 85 percent to 90 percent methane, 1 percent to 2 percent carbon dioxide and 8 percent to 14 percent hydrogen. The quantity of biomethane created during the process is negligible compared to the amount of gas transported through the national transmission system at any given time. Thus, it can be safely injected into the pipelines, with no impact on gas quality.

To meet the requirements for unlimited quantities to be injected into the network, an industrial system would have a hydrogen membrane installed. This membrane would raise the methane content to more than 96 percent and push the hydrogen share below 2 percent. The hydrogen separated through the process would then be directed back to the methanation reactor, increasing overall efficiency.

PROCESS ENHANCEMENTS The use of nickel-based catalysts in methanation, which requires temperatures between 250 °C and 400 °C, can lead to a minimum 95 percent conversion efficiency. The laws of thermodynamics will not make it possible to convert the entire amount of carbon dioxide and a small quantity of hydrogen needs to remain in the reactor to protect the catalyst from coking and deactivation. Together, these requirements mean that the biomethane will still contain around 10 percent of hydrogen. This value and the high methane >>

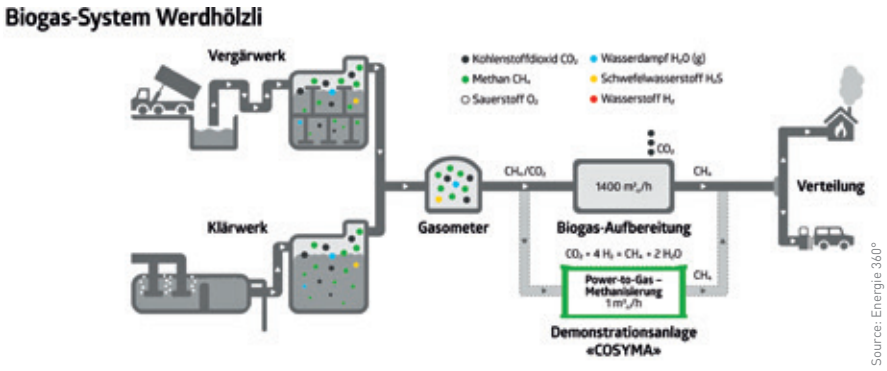


Fig. 2: Schematic diagram of the Cosyma prototype unit

content of 85 percent to 95 percent could be kept constant during the entire 1,000-hour test cycle. It is a testament to the stability of the catalyst and the effectiveness of the gas purification process.

In the first 100 hours especially, we conducted several experiments to determine the most suitable operating point and corroborate simulation results. The limitations of the thermodynamic reaction reduce potential methanation returns at higher temperatures, while low temperatures prevent full use of the catalyst. As shown by our simulations, the system achieves a maximum level of methane purity at temperatures of around 340 °C to 350 °C.

Another crucial operating condition is the ratio of carbon dioxide to hydrogen. The more hydrogen is added, the more carbon dioxide can be converted into methane. However, the hydrogen that is not converted will lower biomethane purity and require the use of a membrane to separate and return it. Conversely, methane returns from carbon dioxide will decrease if the hydrogen quantity is reduced, which also carries the risk of catalyst deactivation. According to both our calculation model and our experiments, the reactor will approach what is thermodynamically possible.

CONCLUSION During our 1,000-hour test cycle in a real-life environment, we have been able to verify our assumptions about the most suitable conditions for reactor operation. Low temperatures will restrict the movement of the catalyst particles, whereas high temperatures will test the boundaries of thermodynamics. Adding a large amount of hydrogen will improve the rate of production but decrease biomethane purity, a disadvantage that could be countered through a membrane for returning the gas to the process. Although the amount of excess hydrogen should be kept as low as possible to allow for smaller membrane surface areas that will keep down costs, it does not seem prudent to add as little hydrogen as possible. Insufficiently large quantities will reduce methane production output and may, at worst, lead to the coking of the catalyst material. The 1,000-hour trial period has demonstrated that stable and optimized fluidized bed methanation can lead to high methane content despite the addition of a comparatively small amount of hydrogen.

In conclusion, the system has provided proof that the use of renewable hydrogen in the above-described methanation process can lead to a 60 percent increase in pipeline injection based on the same quantity of raw biogas as in gas treatment through carbon dioxide removal. The next step will be experiments in pilot size at 100 kilowatts to 200 kilowatts of methane production output, for which a test system is being constructed at the PSI. This pilot installation is hoped to shed more light on certain technical parameters in dynamic operation and CHP and deliver data to validate predictions from our statistical model. Since data on this type of reactor has been available even for megawatt systems, the pilot installation will be used to demonstrate that, together with the findings from the previous test cycle, fluidized bed technology is ready for implementation. ||

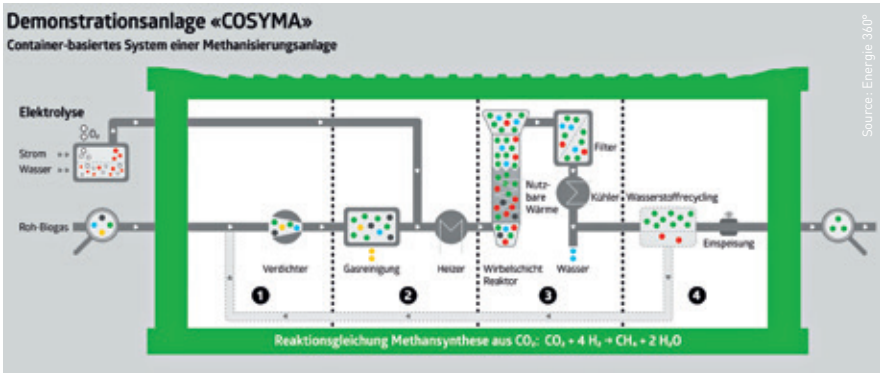


Fig. 3: Look inside the Cosyma container

* all amounts in EUR

Fig. 4: The fluidized bed reactor, one of four container sections

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On Jan. 11, 2018, at the New Year's event of Switzerland's federal energy ministry BFE in Bern, the Cosyma project was recognized with the Watt d'Or award in the Renewable Energy category.

AVL REVOLUTIONIZES FUEL CELL DEVELOPMENT

The tipping point in fuel cell development

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- Intuitive usability thanks to the flexible, real-time AVL PUMA Open 2™ automation software
- Smart fuel cell development support enabled by early online diagnosis of fuel cell degradation
- Time- and cost-effective fuel cell development made possible due to its integrated and proven AVL toolchain for vehicle development

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Theme: Energy storage | **Authors:** Annika Linke and Sven Geitmann

EXTRACTING HYDROGEN FROM WATER

Interview with Traver Kennedy, CEO of Joi Scientific™

The work of Joi Scientific Inc. continues to be shrouded in secrecy. Who are these Americans who have been present on the scene for months, but haven't really explained what they're doing? What does the company, which seems to have already collected millions in investor money, want to offer? A finished product or services only? Moreover, why all this secrecy? H2-international had the opportunity to interview the CEO of Joi, Traver Kennedy, to learn more about the company's plans for 2017 and beyond.

Traver Kennedy

H2-international: Mr. Kennedy, what's the best way to start an interview where you hardly know anything about your interviewee? Maybe chronologically? Joi Scientific was founded in 2009 – with the intent to ...?

Kennedy: Our mission has always been to make hydrogen an affordable fuel, available to all. As your readers well know, hydrogen is simply the best fuel in the world. When generated locally, it doesn't create greenhouse gases or other negative environmental impacts, unlike some of the alternatives. For example, the Netherlands has been experiencing earthquakes because of natural gas extraction, which isn't good for the environment. Consequently, the country will require 200 of its largest companies to transition to an alternative energy source within four years.

H2-international: Who was there from the start?

Kennedy: Joi Scientific's co-founders are Robert Koeneman, our president and senior vice president of technology; James Kirchoff, our vice president of engineering; and myself, as chairman and CEO. Today, we have 27 employees.

H2-international: And what exactly did you do in the first few years?

Kennedy: Our hydrogen research was born out of a series of experiments studying hydrogen extraction techniques at room temperature and without pressure, using water as the primary feedstock for our fuel. The extraction of hydrogen from water is traditionally a very inefficient process. I can't go into the scientific details yet, but we've developed an efficient way of cracking water molecules to liberate hydrogen.

H2-international: What was the reason for setting up your headquarters at the Space Life Sciences Lab of the Kennedy Space Center?

Kennedy: In 2010, I had the opportunity to meet with President Barack Obama at the Kennedy Space Center in Florida to brief him on Joi Scientific's technology and mission. Subsequently, he invited Joi Scientific to relocate to the Space Life Sciences Lab, run in partnership with NASA and Space Florida. This move has proven invaluable in furthering the development of our technology. The lab is a hub of technology innovation, with both great facilities but also an atmosphere of invention, driven by the collective of great minds that work there. Because of the area's rich history of innovation and legacy of exploration, there's a new, critical mass gaining serious momentum along Florida's Space Coast, which includes SpaceX, Blue Origin and smaller companies such as ours. The energy here is akin to the early days of Silicon Valley.

H2-international: More than two years ago, in February 2016, a press release said that Joi Scientific had completed its Series A financing round to commercialize a new technology for producing hydrogen-based fuel. What was this financing round for?

Kennedy: Basically, the Series A round was primarily to take the lab-based research that we had completed and to scale up the process for industrial applications. We also wanted to attract like-minded professional investors to the company. It was good for Joi Scientific to experience their diligence on the technology, our business model and legal organization.

H2-international: Meaning this was the first step into the public arena?

Kennedy: It was part of the ongoing research and development process that is now bearing fruit.

H2-international: At that time, it seemed as if you wanted to get started right away. You had a professionally made website and an image trailer. But in the months that followed, there were hardly any reports about what you were planning. What have you been doing in the last two years?

Kennedy: I think it was Bill Gates who said that we tend to overestimate the change that will happen in two years

and underestimate the change that can be achieved in ten. The last two years have been highly productive behind the scenes, but we made the decision not to talk publicly until we reached certain milestones.

H2-international: In May 2017, you attended Collision, a technology conference in New Orleans. Did you report on your plans there? Until that point, it had only been said that you offer "solutions for clean energy, water and air."

Kennedy: We were selected by Accenture Strategy's Global Sustainability Practice as one of "11 of the world's most impactful startups." We were invited to participate at last year's Collision conference based on five criteria, which included product maturity, growth potential and ability to execute. The 11 startups showcased at the event were chosen precisely for their potential to impact planetary issues through innovative and sustainable clean energy, engineering, packaging and more. From our perspective, we will judge success based on the returns we achieve for our investors, partners and employees and the number of gigatons of carbon we help to eliminate from the atmosphere through our Hydrogen 2.0 technology.

H2-international: After collecting 5 Mio. US-$ in the first round of financing, you received another 2 Mio. US-$ in September 2017. What was this money for?

Kennedy: To further advance the product development and commercialization of our technology. It's not only a fundamentally new process in the production of clean and affordable hydrogen, which can be extracted from water at the point of use. We're also scaling up the process for industrial applications.

H2-international: What has changed so much now that you've suddenly decided to go public with it?

Kennedy: In one word, "customers." We're starting to transition our technology out of the lab and into the commercialization phase and are engaged in several commercial projects. Accordingly, we felt that the time had come to be a bit more open about what we're doing.

H2-international: Let's get to the heart of the matter. What exactly do you want to do? It's about hydrogen production but not about electrolysis or steam reforming. What is it?

Kennedy: Correct – our approach is not electrolysis nor steam reforming. We have found a new way to extract hydrogen more efficiently than conventional processes. We've not yet announced the details behind our technology, but we have been and continue to be extensively vetted and verified by external evaluation groups.

H2-international: You call your concept "Hydrogen 2.0™," but the basic idea behind it is not that new. What is Joi doing differently than others?

Kennedy: The affordable production of clean hydrogen at the point of demand is very new. We're calling that process Hydrogen 2.0, and it's very innovative. Hydrogen 2.0 introduces a novel way to store hydrogen in an aqueous state at room temperature and without pressure before the hydrogen is extracted. Its on-demand and on-board nature mean that hydrogen is converted into a gas at the point of use – thus, eliminating any requirements for specialized storage and transportation. We welcome other players to join us in the new Hydrogen 2.0 era.

H2-international: Why hasn't anyone else been successful so far?

Kennedy: There's plenty of work going on in hydrogen production from biomethane or ammonia. We started with the premise that water is extremely abundant on this planet and contains a lot of hydrogen.

H2-international: Has your process been independently assessed and certified?

Kennedy: Both investors and commercial partners have sent scientific teams in to evaluate our technology. All who have visited our labs have been satisfied that we're delivering the goods. The level of due diligence of our commercial partners and investors has been extremely deep.

H2-international: You say that it would work with salt water too. Does this mean rain or dirty water? What level of water purity do you need?

Kennedy: I am afraid that is still confidential, as we have not yet revealed the scientific details behind our Hydrogen 2.0 technology.

H2-international: Many prominent managers have gotten behind your idea. How did you do that?

Kennedy: Great ideas attract interesting and inspiring people. Many talented people are drawn to the concept of affordable on-demand hydrogen as the clean fuel of the future.

H2-international: Recently, you welcomed Stefan Sjöström, previously a manager at Microsoft (see box p. 26), into your team. How did you get him to join?

Kennedy: Stefan is more than a manager; he's a vastly experienced executive across the technology industry. I believe he saw Joi Scientific not just as another technology company but one that could change the world for the better. Think about it: At Microsoft, he was in charge of a multi-billion-dollar division covering all of Asia and the Pacific – from Australia up through Southeast Asia to China, Japan and South Korea, and west to India, Sri Lanka and Bangladesh. After having done significant diligence himself, Stefan decided to dedicate himself and his career to fulfilling Joi Scientific's mission.

H2-international: As it looks now, the intent is to market your specific know-how about licenses, be it in technology, manufacturing or sales. You've set up offices in Germany and Asia. Have you been able to build business partnerships in these regions to advance your project?

STEFAN SJÖSTRÖM

H2-international:
Mr. Sjöström, why did you decide to join Joi Scientific at this time?

Sjöström: Hydrogen is the fuel of the future, but its adoption has been limited by cost and availability. Joi Scientific has the means to break those limitations and make hydrogen available as an affordable fuel, to be generated at the point of use. Joi Scientific is a company with a technology that could have a profound impact on the world, and I am proud to be joining such an innovative organization.

Kennedy: We have several commercial relationships around the world, at differing stages of progress. We'll be announcing them when they are finalized, but the first should be very soon.

H2-international: What are you planning next?
Kennedy: I think delivering affordable on-demand hydrogen is probably enough to occupy our attention for a while.

H2-international: Okay, last question. When can we see the first results of Joi for ourselves?
Kennedy: The deployment of production systems will depend on our commercial partners. We'll be announcing projects and production systems as we move forward. We think it's exciting. Let's stay in touch.

H2-international: Yes, let's do that. Mr. Kennedy, thank you for our interview.

Theme: Energy storage | **Authors:** Joachim Jungsbluth and Bernd Oberschachtsiek

ENERGY SUPPLY CENTRAL ON WHEELS

MobFuelH2 provides electricity, hydrogen and light

26

As part of a project funded by the German federal state of North Rhine-Westphalia, Anleg and ZBT are constructing a mobile energy station to ensure that even small-scale applications in difficult terrain have a reliable source of power, hydrogen and light. The system base is a box truck, designed for off-road duty, whose cargo area houses the components, from the fuel cell and the hydrogen storage tanks to the compressor and the dispensing equipment. This year's Hannover Messe will see the unveiling of a functional prototype at booth B77 in hall 27.

Most of today's mobile energy and stationary UPS units run on fossil fuels, such as diesel or liquefied petroleum gas. Hydrogen is a viable alternative to these fuels, particularly because it can be turned into a zero-emission energy source if produced from renewables.

However, the lack of a comprehensive infrastructure means that units generating power from hydrogen have so far failed to capture a sizeable portion of the market. First, there is no specialized equipment to create an inexpensive supply chain for stationary systems. Second, there are few mobile fuelers that could be used to demonstrate the technology.

The energy station that is being constructed as part of this project meets several essential requirements and provide a range of vital functions:

1. Delivers hydrogen to stationary systems, e.g., UPS units for critical infrastructure, and vehicles.
2. Offers a stand-alone power grid for the temporary connection of small consumers.
3. Supplies especially off-grid and remote installations in difficult terrain.

DESIGN AND IMPLEMENTATION The station is to utilize as many sources of hydrogen as possible. It has a range of connectors that permit storage fill-ups through pumps at 350-bar hydrogen stations for buses and conventional 200-bar or 300-bar gas cylinder banks. Refueling at 500 bars is also possible.

In principle, the energy-independent system integrated into the vehicle consists of several high-pressure compartment tanks, a PEM fuel cell to produce electricity, an electric-powered hydrogen compressor, outlets for different pressure levels, instrumentation and control equipment, and piping.

The hydrogen to supply the fuel cell and provide fueling capabilities is stored at up to 500 bars in eight type IV tanks, made of carbon fibers and polymer liner. Together, these tanks can hold a total of 50 kilograms of the gas. Each storage compartment can be filled and emptied individually to replenish stationary storage.

To provide mainly high-pressure gas, the electric-powered compressor can be used to transfer hydrogen from one compartment at a very low suction pressure of about 65 bars to the following section at 500 bars, from where it can be delivered through several types of fuel nozzles. This kind of system can supply not only decentralized UPS units with 200-bar to 300-bar hydrogen, but also vehicles, such as buses and trains or FCEVs, with 350-bar or 700-bar emergency fuel.

The vehicle is equipped with a PEM fuel cell to power the controls and the compressor and to produce electricity. The cell's net generation is 4 kilowatts, available for a maximum of 180 hours based on the amount of hydrogen stored in the tanks. The output voltage is 230 V, allowing for the design of a stand-alone system, including battery storage, up to this level.

Source: ZBT

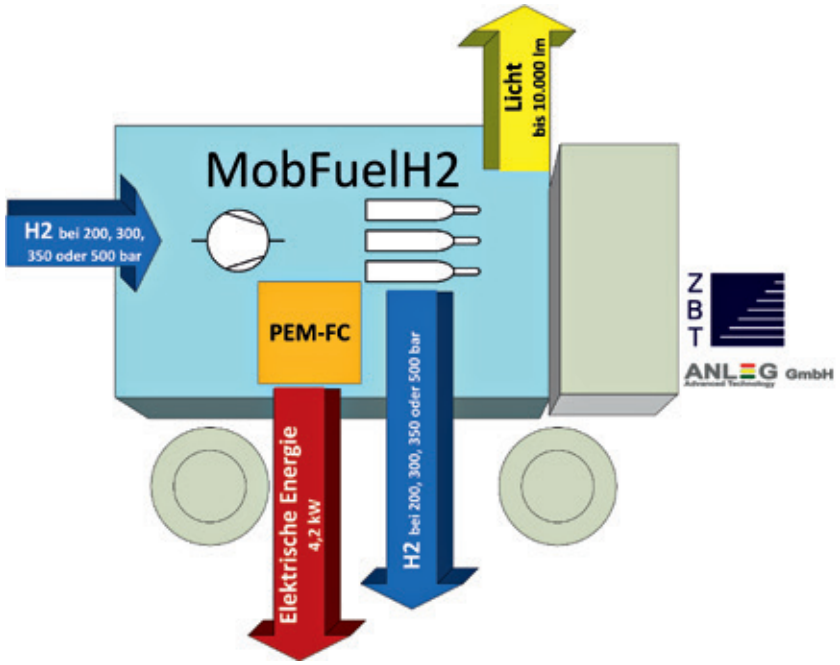

Fig. 1: Simplified diagram of the energy station layout

The system's telescopic LED floodlighting mast gives off a maximum of 10,000 lumens. It can be operated for up to around 2,000 hours. The vehicle base is an off-road automobile to guarantee that challenging terrain poses no difficulty to the supply chain.

RANGE OF APPLICATIONS Research into mobile units to replenish stationary hydrogen storage, with a focus on sustaining UPS operation, began several years ago. What prevented the implementation of earlier concepts was a lack of suitable equipment. The energy station described in this article offers the functionality required for this kind of application.

The station could conceivably be deployed in different types of scenarios. For example, large-scale police or rescue operations need mobile units to power government communications. The combination of significant supply quantities and a technology that produces zero emissions on-site can also prove advantageous when providing energy and light for large entertainment events.

During the duration of this project, the mobile energy station will be tested and analyzed under varied real-world conditions. These tests and analyses will be used to produce reliable sets of data on application options and refueling to estimate required quantities, fill-up times and the amount of additional technical effort that will be needed for a well-functioning system. The findings will help create a data repository that allows for realistic assessments of the economic viability of different operating models in industry and trade.

Moreover, the unit will expand today's range of applications. Not only can it provide an alternative to gas cylinders and cylinder banks, but it will offer the first-ever opportunity to cater to markets for which a hydrogen supply chain has not yet been possible. ||

Vehicle base	Fuso Canter 6C18 4x4; long wheelbase
Gross weight limit	6.500 kg
Load limit	3.665 kg
Design	Rigid box body
No. and size of hydrogen tanks	8 x 211 l
Tank pressure	500 bars
Usable onboard hydrogen quantity	50,4 kg
Compressor	Electric, up to 550 bars
Fuel cell system	PEM, type GreenHub 5000
Electric power at 230 volts AC	4,250 watts
Telescopic lighting mast	10,000 lumens
Dispensing pressures	200, 300, 350 and 500 bars
Length of fuel dispensing hoses	Up to 20 meters
Controller	Simatic S7

Table 1: Technical specifications

The project has been co-funded by North Rhine-Westphalia's HydrogenHighWay program and the European Union. The grant period started April 1, 2017, and will end Dec. 31, 2019. Afterward, the vehicle will be used in other ZBT projects researching hydrogen-based supply.

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Theme: Energy storage | **Authors:** Ahmels, Voß, Gago, Lettenmeier, Voglstätter, Schmitz, Kleinickel, Barsch, Rockmann, Pumpa, Fischer, Voigt

HYDROGEN TO STORE WIND POWER

WESpe project findings

Hydrogen is of central importance to a German market that is becoming increasingly interwoven. What makes the gas the ideal chemical energy carrier is that it can provide not only the heat and power sector with a long-term storage option, but also vehicles with electricity and the chemical industry with a raw material. The authors of studies focused on the overall system estimate the requirements in 2050 to total 110 gigawatts for electrolysis through power-to-gas, or, more specifically, power-to-hydrogen, that is, the electrolyte-based production of hydrogen from renewable energies. Their figures also include possible subsequent methanation and a 90 percent reduction in carbon dioxide levels [1].

What size and technical configuration will wind-to-hydrogen systems have in a future sector-integrated energy network? What will their performance be throughout the year? What needs to be done to maximize their economic viability? These were some of the questions raised during WESpe, a joint research initiative. The closing conference that took place Dec. 4, 2017, on the GLS Campus in Berlin provided an opportunity to present key findings to around 80 business delegates, politicians and researchers.

WESpe dealt with the entire energy conversion chain, from renewable resource management and production via electrolysis to storage in underground facilities and injection into natural gas networks to consumption in a variety of sectors. One focus area was electrolysis research. Other objectives were to advance the development of components for underground storage and pipeline injection and to examine the technological and economic aspects of sample pathways that make use of wind-sourced hydrogen.

The overall aim was to improve processes that are critical to a functioning wind-to-hydrogen supply chain. Detailed simulations of the entire energy network were conducted to determine the economic and technological impact of sample power-to-gas systems, particularly when hydrogen is produced. The research consortium chose eight scenarios, including ones that map strategically essential pathways to transform the market. Two such vital paths are, first, widespread hydrogen-based power production and supply in manufacturing by 2050 and, second, medium-term economic viability of the gas in transportation.

CREATING THE NEXT GENERATION OF ELECTROLYZERS The Brandenburg University of Technology, Fraunhofer ISE and the German Aerospace Center studied and compared PEM and alkaline water electrolysis, with a focus on variable load operation. The German Aerospace Center

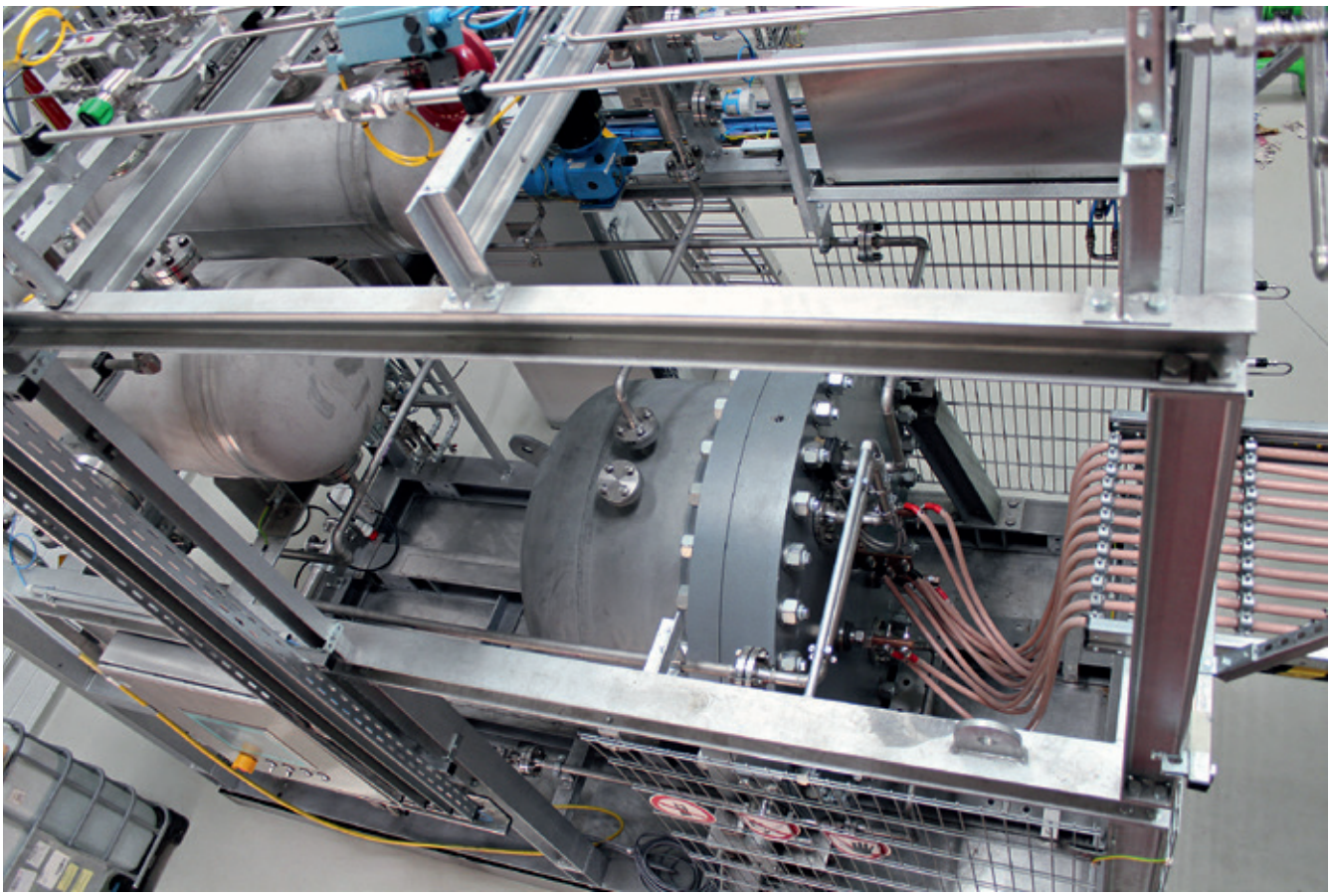

Fig. 1: 60-bar alkaline high-pressure electrolyzer at the Brandenburg University of Technology

primarily investigated the performance and degradation of PEM electrolyzers that are operated under rapidly changing load conditions or above rated capacity. Data generated from laboratory experiments on several fuel cells of up to 1.5 megawatts of capacity was analyzed to devise strategies for enhancement, or, more specifically, opportunities to reduce costs through increases in performance, efficiency and lifetime. Other important milestones were reached in the creation of gas diffusion layers combining a micro- and macroporous structure and the design of anti-corrosion coatings for bipolar plates. In the end, transient operation was not considered to be posing above-average risks.

The 60-bar, and thus high-pressure, alkaline electrolyzer owned by the Brandenburg University of Technology (see fig. 1) underwent a series of tests based on steady-state and transient load profiles as well as several parameters, such as pressure, temperature, current density and solution circulation rate. Whereas temperatures showed a significant impact on the process, pressure levels had marginal influence on efficiency. The 120-kilowatt unit has a rapid response rate, with a current change above 50 amperes per second from hot standby, allowing for its direct connection to wind power stations. Individual elements of the overall system were examined for interrelated factors, for example, in pressure and heat management, during variable load operation and standby mode.

UNDERGROUND STORAGE AND PIPELINE INJECTION The objective of the subproject managed by Gastechnologisches Institut Freiberg, or DBI for short, was to improve and advance the technology for gas injection, underground storage in geological formations and associated equipment. Parameters for a technical and geological assessment of suitable locations were developed based on available data about town gas, current underground storage conditions in Germany and operating requirements for underground hydrogen reservoirs. While there are no concerns about hydrogen storage in salt caverns, natural underground traps require a case-by-case evaluation, including a geological survey, for example, to gauge temperatures and identify the geochemical properties of on-site rocks and fluids.

The materials that are used for above-ground and underground technical installations determine whether a location is suitable for hydrogen storage. An evaluation of available steel grades and an inspection of several types of plugging cement in the laboratory led to recommendations on which materials to replace below and above ground and which to use for new storage sites.

Geological exploration techniques were enhanced to locate new underground storage sites, specifically for the biogeochemical conversion of hydrogen. The means to assess current storage locations and identify new ones, combined with monitoring and surveillance strategies to ensure safe operation, were necessary prerequisites for testing whether geological, technological and operational conditions support the long-term storage of hydrogen and gas mixtures below ground.

The additional modeling of an underground cavern, including the borehole, allowed for the computation of thermodynamic, fluid-dynamic and geomechanical processes during hydrogen storage. The analytical cavern model that was created was subsequently integrated into the overall system and made it possible to map the hydrogen storage cavern within the power-to-gas process chain. Subsystems were the compressor, the withdrawal equipment, the injection system and the transportation pipelines. The model also accounted for system reliability and plant upgrades. >>

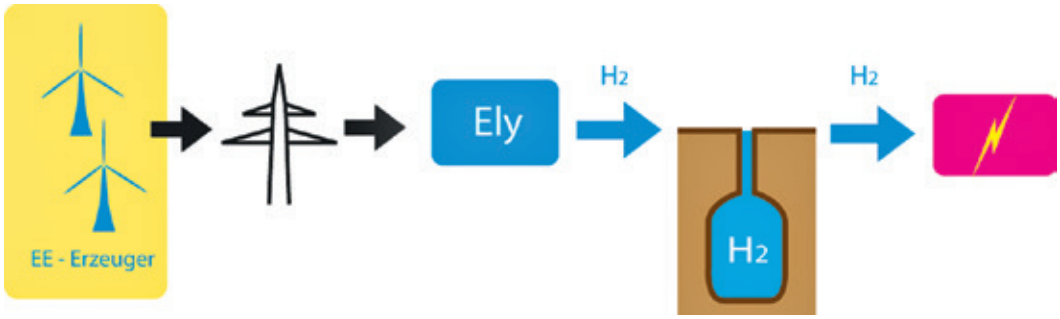

Fig. 2: Pathway including underground hydrogen storage and direct power production through hybrid gas turbine

MODEL 1: CONVERSION TO ELECTRICITY The following will provide a more in-depth description of two simulation models mapping the entire power-to-hydrogen pathway. The first example deals with large-scale power generation from hydrogen in 2030 and 2050. It comprises electrolysis, cavern storage and direct fuel-to-electricity production through hybrid gas turbines (see fig. 2). To identify economically feasible system sizes under variable load conditions, a year's worth of sample data on electrolysis and power generation was taken from a Fraunhofer ISE study [2]. To account for future purchasing and sales activities on the market, this data was used to arrive at the time-related marginal cost of electricity production. The study encompassed more than one sector and its authors employed a model that is focused on the most cost-effective method to reduce carbon dioxide emissions across the German energy network. Among other things, it provides for a time-based simulation of the levels of non-intermittent renewable sources. When there is a renewable surplus, the priority is on charging stationary and vehicle batteries as well as pump storage installations before electrolyzers are used to produce hydrogen. The scenario used for the sample WESpe pathway described in this article aims for an 85 percent reduction in carbon dioxide emissions. In 2050, it will require 201 gigawatts of wind power, 166 gigawatts of PV capacity and 159 gigawatts of solar thermal.

The entire network was simulated based on the alkaline high-pressure electrolysis model developed at the university, the DBI model of a standard-size cavern and, for reasons of dynamic input, gas turbines. The cavern has a size of 500,000 cubic meters and between 60 bars and 190 bars of pressure, at a maximum pressure gradient of around 10 bars per day. A software application called Matlab Simulink was used to conduct the simulations, which showed that 4 gigawatts of electrolysis capacity at 2,270 full-load hours will require eight of these caverns in 2030. In 4.9 cycles, they will temporarily store a total of 180,000 tons of hydrogen throughout the year (see fig. 3) and provide the energy for a 1-gigawatt gas turbine at 2,520 full-load hours. In 2050, these values will increase to 67 gigawatts of electrolysis capacity at 2,130 full-load hours to store 3 million tons of hydrogen in 170 caverns in 4 cycles and provide energy for 26 gigawatts of gas turbine capacity at 1,630 full-load hours.

In 2050, the levelized cost of hydrogen on this pathway will amount to EUR 5.52 per kilogram of hydrogen, absent any regulatory fees and charges. The purchase cost of electricity of EUR 3.40 per kilogram will make up most of the total, whereas the capital and running costs of electrolysis will add up to EUR 1.92 per kilogram. By contrast, the cavern, including the above-ground facilities, will require EUR 0.20 per kilogram, a comparatively low amount. Post-turbine power production, the levelized cost of power in this linear model was EUR 0.429 per kilowatt-hour of electricity. It needs to be noted that a sector-integrated model designed for cost-effectiveness could result in above-average costs for individual electric generation pathways, despite their vital role in the entire system. Those pathways will then have to be supported through suitable incentive policies.

MODEL 2: TRANSPORTATION AND MANUFACTURING Fraunhofer ISE created and optimized the second simulation model described in this article. To improve investment security and increase energy independence, it includes a wind farm that has been directly connected to a large-scale electrolyzer. Electrolysis systems store hydrogen in caverns before delivering the gas through pipelines to large consumers in transportation and manufacturing. Demand for synthetic fuel was assumed to come from 12,500 passenger vehicles and 340 buses in the transportation sector. In manufacturing, consumption was expected to remain at a constant 4.6 tons per hour. The simulation also included real-world timelines from onshore wind power production in eastern Germany.

To map the entire energy network, Fraunhofer ISE's dynamic, and validated, PEM electrolysis model and the DBI's cavern model, including above-ground facilities, were incorporated into the overall system. With a focus on wind-sourced hydrogen meeting demand at any time, Fraunhofer ISE used an optimizer developed in-house to enhance the interplay of wind farm, electrolyzer and storage size, aiming for the lowest possible levelized cost of hydrogen.

A simulation of the overall system showed that the requirements for last year would have been 970 megawatts of peak wind power, 590 megawatts of electrolysis capacity and a large cavern holding 530,000 cubic meters. The electrolyzer would have operated for 7,700 hours throughout the year, at 4,300 full-load hours. Based on a total investment of EUR 1.4 billion, the levelized cost of hydrogen would have been EUR 4 per kilogram and the cost of cavern storage 4.6 percent of the total, again a marginal proportion.

Substituting renewable excess energy for wind farm output could make it possible to lower the marginal cost of hydrogen-sourced power production to EUR 3.7 per kilogram. The cost of electricity wields strong influence over the price, as it contributed around 57 percent to the levelized total. Thus, what price can be achieved in the long-term will very much depend on future power market policies and on changes in the levelized cost of electricity. The use of surplus renewable energy reduced the full-load hours of electrolysis to 2,360 and required that electrolysis capacity be increased to 1 megawatt to meet expected hydrogen demand. The size of the storage cavern and its share in the levelized cost remained roughly the same.

The above shows that cavern-based large-scale hydrogen systems allow for the inexpensive seasonal storage of energy, regardless of whether the system has a connection to the power grid.

Sources: BTU Cottbus-Senftenberg

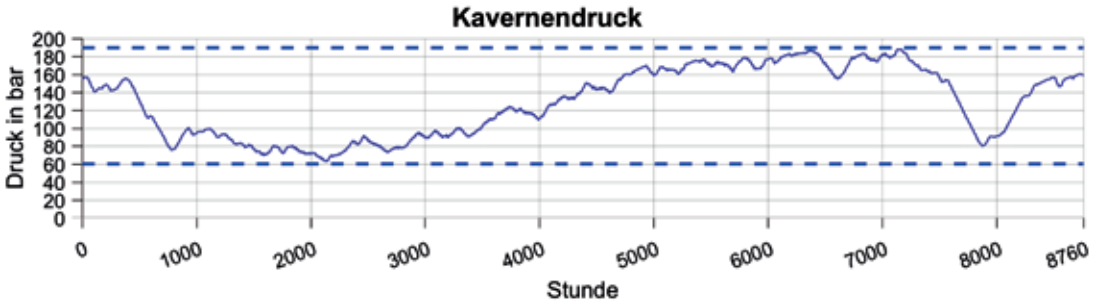

Fig. 3: Change in cavern storage levels throughout 2050

HANDS-ON RESEARCH INTO MARKET ACCEPTANCE Deutsche Umwelthilfe, a German environmental organization, asked the public how to increase acceptance and transparency immediately at the launch of wind-sourced hydrogen projects. The first step involved creating a communications strategy that focused on the following questions:

- What are the market players?
- Where are the main sources of conflict?
- What safety concerns do citizens have?
- Does renewable hydrogen increase acceptance of the technology?
- How can people participate in breaking new ground?

The second step translated theory into practice. In close collaboration with a project consortium led by multi-energy power plant Sperenberg, the association developed and implemented individual elements of the strategy. The consortium had decided on the former German military test facility Sperenberg in Brandenburg for an evaluation of the approach, as the neighboring communities had been advocating for the conversion of the premises into a site for power generation from wind and sunlight. The project is expected to supply 145,000 close-by housing units, convert surplus power into hydrogen via electrolysis and store the gas or inject it into the near-site pipeline network. However, the area is not only home to red kites and sea eagles but also of historical significance.

Experience tells us that large-scale developments in need of special land use approval can be accompanied by less formal types of participation. Early on, this kind of approach will allow for a less complicated resolution to conflicts, which typically arise when the project is well into the planning stage. It was the reason why the environmental organization, the regional government working group and the MEKS project consortium joined forces to organize a roundtable for environmentalists, two public events and a discussion forum about heritage protection. Nevertheless, these commendable ideas cannot replace conventional permitting procedures to weigh competing interests and determine the appropriate course of action. ||

WESpe received financial support from the BMWi, Germany's economy ministry, as part of the federal government's Energy Storage initiative (funding ID: 0325619A-E). The research organizations participating in the project were DBI – Gastechnologisches Institut Freiberg, Deutsche Umwelthilfe, the German Aerospace Center, the Fraunhofer Institute for Solar Energy Systems and the Brandenburg University of Technology Cottbus-Senftenberg.

The final report about the WESpe research project will be published in the second quarter of 2018.

Reference(s)
[1] Ausfelder, F. et al. (2017). Sektorkopplung – Untersuchungen und Überlegungen zur Entwicklung eines integrierten Energiesystems (Schriftenreihe Energiesysteme der Zukunft). Deutsche Akademie der Technikwissenschaften: Munich.
[2] Henning, H.-M., Palzer, A. (2016). Was kostet die Energiewende? Wege zur Transformation des deutschen Energiesystems bis 2050. Fraunhofer ISE: Freiburg.

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Theme: Electric transportation | **Author:** Sven Geitmann

NEXO'S SECOND PREMIERE

Hyundai's new charm offensive in Germany

The second stop for the successor to Hyundai's ix35 Fuel Cell was neither Detroit nor Tokyo but Offenbach, home to the automaker's German and European headquarters. In mid-January, seven weeks prior to its official European premiere in Geneva, the Nexo was shown to a select group of journalists in this city by the river Main in the German state of Hesse. H2-international took the opportunity to get an in-depth look at a car that had just been unveiled Jan. 9 at the Consumer Electronics Show in Las Vegas.

A small but illustrious circle of reporters were able to catch a first glimpse of the matte-gray, hydrogen-powered SUV in Offenbach. The choice of location sent a powerful message, namely that Hyundai views Germany as a crucial target market in Europe. What attracted the automaker's interest was not only the number of hydrogen stations available across the country. According to Frank Meijer, head of Eco Car and Mobility at Hyundai Motor Europe, much progress had been made in the heart of the continent. The public was able to see the new vehicle as early as March, at the International Motor Show in Geneva, Switzerland.

FROM FAST FOLLOWER TO FIRST MOVER In his opening remarks, Meijer took the gathered press down memory lane, back to 2013, when Hyundai was the first automaker to put a fuel cell car on the market. He said, "Until 2013, we were fast followers. Now, we are first movers." The delivery of more than 500 fuel cell cars to European businesses, including 50 rental vehicles to BeeZero in Munich and 75 taxi cabs to Paris-based startup STEP, meant that Hyundai had become the market driver throughout Europe, where about 80 percent of sales now involved a Hyundai-brand vehicle, he said. Toyota, Hyundai's only real competitor thus far, reportedly has over 6,000 fuel cell vehicles in operation worldwide.

Fig. 1: Nexo – the next milestone in the company's strategic evolution

Now, five years after the market launch of the ix35 Fuel Cell, the time seems ripe for a new line of cars to continue the company's vision. But Hyundai didn't just throw in a few upgrades to give the appearance of a state-of-the-art fuel cell vehicle. Instead, it created a whole new product. And this time, it made no compromises – such as integrating the fuel cell system into an available model, the Tucson – but tailored the car to the needs of the engine and the powertrain. The pre-series Hyundai FE Fuel Cell that was showcased last spring in Geneva (see July 2017 issue of H2-international), and last August in Seoul, gave attendees a taste of what the automaker was planning next.

In the Nexo, three same-sized 52.2-liter hydrogen tanks replace the differently sized versions in its predecessor. One of those, along with the high-voltage battery, can be found beneath the trunk compartment cover, while the other two have been placed under the back seats. This kind of design has two advantages. First, it increases cargo space to 461 liters. Second, the standardized dimensions help drive down costs in negotiations with South Korean suppliers.

HOW THE NEXO GOT ITS NAME

Nexø is the name of the second-largest city on the Danish island of Bornholm in the Baltic Sea. The island has become known for its exemplary efforts to advance research in sustainability and has been dubbed the country's clean energy laboratory, or the "Bright Green Island." Now, there's a renewably powered car named after one of its cities. According to a spokesperson for Hyundai, the name was likewise chosen because it had "a nice futuristic ring to it."

The novel 95-kilowatt fuel cell stack, this time the automaker's own creation, is supported by a lithium-ion buffer battery offering 40 kilowatts of power. Together, they drive a 120-kilowatt electric engine that will take the five-seater to 100 kilometers, or 62 miles, per hour in 9.5 seconds, shaving 3 seconds off the ix35 Fuel Cell's acceleration time. The maximum speed is 179 kilometers, or 111 miles, per hour.

So far, Hyundai has provided no details about how much fuel the car will need. Oliver Gutt, head of product management, said that it would "certainly not require more than its predecessor." The target was a range of around 800 kilometers, or 497 miles, based on the New European Drive Cycle, to be achieved, among other things, by a more effective fuel cell design at 60 percent efficiency. Despite several attempts to ask about the price of the new model, there was no answer to this question either. There wasn't even a hint as to whether the list price for the Nexo will be below the EUR 65,000 for an ix35 Fuel Cell. The market launch in South Korea is scheduled for July, and the car will reportedly be available to both private and commercial customers in Germany starting in August. It's one more sign that Hyundai's charm offensive is focused on Germany and

Fig. 2: Dashboard with 7-inch display and 12-inch touchscreen

Europe, as the new model will not be for sale on the US market by then.

The car has some intriguing features, such as retractable door handles. There is also a self-parking mode, so the driver can get out of the vehicle before the car maneuvers into tight parking spots. Other things worth mentioning are the use of voice commands to activate dashboard functions and the anti-sleep alarms integrated into the seats.

Regarding batteries, the company followed a two-are-better-than-one approach. The high-voltage accumulator is complemented by a 12-volt unit, as Gutt said, to prevent starting problems because of a dead battery, as had sometimes happened with the ix35. If someone were to leave open the trunk now, the interior lights would no longer drain the battery to a point where the car could not be started. There would always be enough power reserves to get the fuel cell up and running in 5 seconds, so it could generate electricity, he said.

HYDROGEN FIRST Meijer explained that the initial plan was to put a comparatively small number of cars up for a sale until demand picked up. He reassured us that there was enough production capacity, since the car was no longer being manufactured separately from the standard assembly line process.

A spokesperson also named Norway as another important target market because of the country's attractive incentive programs. Denmark, on the other hand, is being pushed to the sidelines after it changed vital regulations.

The Nexo is proof of how important this engine technology has become to Hyundai. "It's a flagship project for us," Bernhard Voß, a spokesman for Hyundai, said. There was no mention of any possible breakthroughs by the corporate group's other two brands, Kia and Genesis. The only thing that the company's representatives were willing to reveal was that all findings from corporate research would be made available to each sister company within the group.

AUTONOMOUS FUEL CELL CARS

Originally, the Nexo had been announced as only a semi-autonomous car with self-parking capabilities. But in early February, the automaker reported that three of its new fuel cell vehicles had successfully completed a 190-kilometer, or 118-mile, trip from Seoul to Pyeongchang based on level 4 autonomous driving standards for cars "designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip."

The above doesn't mean Hyundai has left the development of battery electric vehicles to its competitors. It even believes that BEVs will offer a much more attractive sales environment than FCEVs over the coming years. But one of the aims of the automaker's worldwide offices, especially its German one, is to continue improving the public image of the gas and the conditions for wind-sourced hydrogen and counter the many falsehoods that are still circulating. Additionally, the corporation wants to be prepared should oil prices rise again. "We're branching out," Voß said. Hyundai's strategists have been keeping an eye especially on the light commercial vehicle and truck markets. ||

Government sources have told Reuters that Hyundai was planning to invest a total of EUR 17.6 billion in new technologies. The automaker is said to be hiring around 45,000 new employees to take on the challenge of developing new hydrogen, battery and autonomous cars as well as artificial intelligence in the next five years.

LEXUS KNOWS NO LIMITS

In mid-January, during the North American International Auto Show in Detroit, Lexus unveiled its LF-1 Limitless car. It's the luxury brand's latest crossover product, designed to accommodate a range of lifestyles and engine options. The concept car can be equipped with a conventional motor or with fuel cell or hybrid technology. In short, it's supposed to provide "limitless opportunities." ||

Source: Lexus

KIA EYES FCEV PRODUCTION IN 2020

Kia, part of Hyundai Motor Group, is planning to produce fuel cell vehicles of its own, though customers will have to wait until the end of 2020. Like the competition, the automaker is said to be using an SUV, presumably the successor to the Sorento, as the basis for its first commercially available FCEV model. Production will start at around 4,000 units per year, similar to what its sister company Hyundai is putting on the market. ||

Theme: Electric transportation | **Author:** Dr. Marius Herr

LIMITED IN THE EXTREME

Real-life experiences with hydrogen-powered transportation

Special edition vehicles produced in only small numbers: It's what luxury car manufacturers do to cultivate an air of exclusivity and add value to their brands – and their methods seem to work. They could also be a model for German OEMs to establish new technologies promoting sustainability. At least, that's what it looked like to employees of TesTneT when they were searching for German automakers that could provide them with a fuel cell vehicle. What they found was not even worthy of a special edition: "There are some prototypes available and many, many announcements, but not one car that any ordinary citizen could drive, let alone buy – neither flattery, nor a well-filled wallet will get you anywhere." The following paragraphs describe their experiences over the past months.

We really wanted to add a fuel cell vehicle to our carpool, so we compared available options to figure out which items we could cross off our wish list. In the end, we decided to look for an ix35 Fuel Cell by South Korean automaker Hyundai. It was surprisingly easy to find one. We called up a popular car website and typed in "hydrogen" in the Fuel field to get in touch with a dealer that sold us a model, including a temporary license plate, for around EUR 40,000. It took only few days until the future of driving had reached our offices.

Car registration and insurance gave us no trouble at all. We can probably thank Linde and its BeeZero fleet for that. Its carsharing program had laid most of the groundwork for the use of hydrogen vehicles in Germany. After getting a few CEP fuel cards, we were ready to take the car out for a spin. Fast forward nine months and our meter shows about 24,000 kilometers, or 14,913 miles, travelled. During all this time, neither the vehicle itself, nor the refueling infrastructure posed any problems.

Of course, we had to make a few adjustments to some routes, so they match up with a refueling network that is growing but still limited. Some business trips required that we take a conventional vehicle, as the drive from one hydrogen station to the next exceeded the range of the car. That's the price you pay for owning an FCEV, of which there are only about 300 in Germany. There are still some minor issues. For example, there is no cruise control and the small battery size will lead to an early loss of engine braking when driving downhill. But, as said, these are minor problems, which we believe will be solved in the next vehicle generations.

All in all, the car has been a positive surprise. We expected higher hurdles and greater drawbacks.

THE GREAT UNKNOWN What has been just as much a surprise to us were the comments from colleagues, business partners and friends. While people from the hydrogen community in Germany showed excitement and genuine admiration at the sight of our latest carpool addition, many others did not know what to say or what to think of our choice. It's remarkable how many technically minded people can't tell you that, for example, fuel cell vehicles have electric motors and not internal combustion engines, that hydrogen is stored in a gas tank and not in liquid form inside the vehicle, that refueling takes a few minutes and not several hours, and that an FCEV is the natural partner to and not the sworn enemy of a battery vehicle.

It's understandable how people came to these views, since we feel that the public is not being sufficiently informed. Most of them grew up in a time dominated by internal combustion engine cars and even the ones who have a very limited interest in technical details have developed a minimum understanding of how conventional engines work. But moving forward, a keen interest in the technology, or intimate knowledge of it, should no longer be a deal breaker, since the cars will need to be sold to more than a small group of engineers working in the field.

To purchase or not to purchase could then be a decision based on well-known and common criteria such as design, price, usability and brand image. The successes of the past show that automakers have been able to rise to the challenge on the conventional car market. What's keeping them from trying the same strategy to sell FCEVs?

SOME IDEAS The chicken-and-egg dilemma of what to increase first, the number of filling stations or the vehicles sold, is starting to lose importance as more refueling sites are being set up. Germany had over 60 operational hydrogen stations at the end of 2017. Expectations are that the oft-heard magic number of 100 stations will be reached soon. Big cities, such as Berlin, Frankfurt, Hamburg, Munich and Stuttgart, and conurbations, such as the Ruhr area and the Rhine-Neckar region, have already seen the installation of a reasonable number of hydrogen stations for public access.

The transition from conventional to fuel cell vehicles should be easy enough when it comes to design, operation and functionality. The same marketing and distribution networks that have served the ICE car market so well could also be used for FCEVs, something that OEMs will surely view as

a plus, since for them, nothing will really change. The added benefit is that the cars can be marketed as sustainable and eco-friendly alternatives.

For several years, the public has been on the lookout for new modes of transportation. Great efforts are being made to figure out which of the many concepts would be the most promising. There are no signs that people will lose interest in the issue anytime soon. On the contrary, the recent negotiations about a new government coalition in Germany, and the differing views of the parties involved, have given it renewed attention. It would be an ideal time to unveil automotive technology aiming for sustainability – the public will be eager to read all about it. But some marketing departments may still need some time before they realize what's happening. The part of the public interested in those technologies will surely not be impressed by another news piece about the latest acceleration record of a 1,500-horsepower Bugatti.

In our case, the purchase price and running costs were at a relatively modest level. Of course, we could have gotten a better package deal for a conventional car. But considering the limited number of available units, the purchase price seems fair, although we suspect that manufacturers are still pumping much money into subsidizing those cars. As for the running costs, the difference is not as great as we may have thought. It's clear that there is room for improvement in hydrogen generation and supply and the refueling infrastructure. Also, today's EUR 9.5 for one kilogram won't cover the entire cost of production and distribution. But studies have shown that it's rather a question of economies of scale. As in Toyota's case, the long-term investment in a new type of engine can pay off. It's the reason why nowadays, hybrid vehicles are economically viable for both the customer and supplier.

While policies can help, it will be the media which can make or break a brand's popularity. Reports about BEVs have shown up in newspapers and magazines where you would have never expected to see them so quickly and so often. Maybe that's why most people have nice things to say about them. The sheer number of those articles is in stark contrast to the few FCEV reports that have been published in the mainstream media. Typically, the latter also make it clear that the journalists responsible for them didn't research or understand some or most of what they were writing about. But it's not their fault alone. More than ever, they will need help from the professionals and experts who make up the hydrogen community to popularize the technology, raise awareness and dispel doubts about its usability. Other natural partners to the effort would be the automakers. They could and should provide a lot of support, and not just because they are well known and will be vital to advancing the technology. There is a certain self-interest involved in promoting new types of engines.

Regarding usability, people often point to range and trunk size as the main issues in fuel cell cars. The question is why both of those should be a problem. The layout of an SUV-type vehicle will have around 7 square meters, or 75 square feet, of space available, at an average height of 1 meter, or 3 feet. Can it be that difficult to find enough room in there for the driver and passengers, their bags and suitcases and a few kilograms of hydrogen? Theoretically, you need a bit over 10 kilograms of the gas to offer a 1,000-kilometer, or 621-mile, range. If you compress the hydrogen at 700 bars, or 10,000 psi, you'll end up at about 0.25 cubic meters, or 9 cubic feet. Now, double these values to account for the size of related components and you can see that much less than 10 percent of the above-mentioned space is required to install the system. That may still be a problem when trying to power older models with hydrogen and can lead to such curious ideas as integrating the tank into the transmission tunnel. But the days of having to make it fit somehow somewhere have passed since new models were specifically built around the new engine technology. We have the proof and it is driving on the streets of Korea and Japan.

WHAT WE THINK With our nearly 20 years' experience in hydrogen tank and component testing, we know about the complexity of the technology, especially the 700-bar compression. We also know that it sometimes can be an arduous and challenging journey to put this new technology on the market. And, of course, much time will pass before enough fuel cell vehicles have been sold and you can talk about a sizeable market. Still, we hope that today's all too common focus on limited numbers will soon be replaced by the kind of normality we experienced when driving and operating a fuel cell car and that many people will be able to share in the technology's benefits very soon. But if what we hope comes true, it would be great to see it happening not just in Asia. ||

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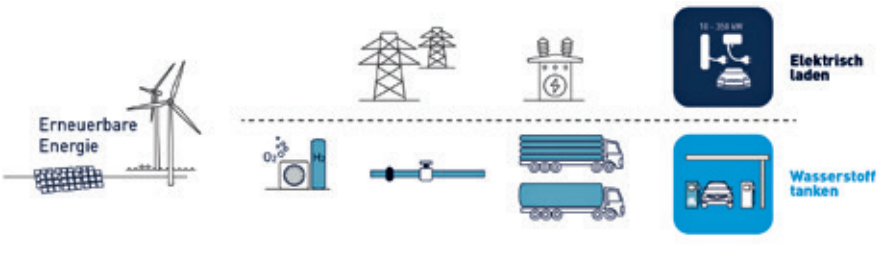
Theme: Electric transportation | **Author:** Dr.-Ing. Martin Robinius und Prof. Dr.- Ing. Detlef Stolten

POWER SUPPLY IN TRANSPORTATION

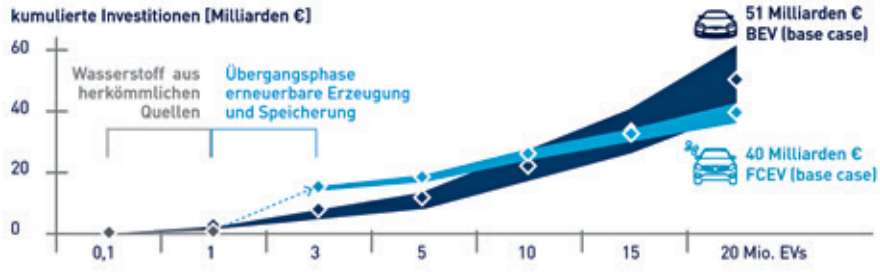
Hydrogen refueling vs. electric charging

Electric motors are the key to sustainable transportation. One of the features that all-electric and fuel cell vehicles have in common is the absence of local emissions. Their lack of harmful pollutants can improve people's quality of life, especially in highly populated conurbations. What is needed now is a supply chain to exploit the potential of those technologies.



Source: H2 Mobility / FZ Jülich, Robinius et al.

Fig. 1: Illustration of the supply chains examined in the study



Source: H2 Mobility / FZ Jülich, Robinius et al.

Fig. 2: Total capital costs for infrastructure development

Source: H2 Mobility / FZ Jülich, Robinius et al.

Fig. 3: Carbon dioxide emissions and electricity consumption per kilometer at 20 million vehicles

The Jülich research center has conducted an in-depth analysis of the supply chains for battery electric vehicles and hydrogen fuel cell cars. The study document contains a detailed description of several scenarios, which serve markets of several hundred thousand to several million vehicles, and lists their capital and running costs, efficiencies and emission levels.

Both technologies are still in early development. There is little clarity about what the supply chain for each pathway should look like and which adjustments need to be made based on the size of the relevant market. Likewise, there would need to be options for dealing with surplus electricity, certain to be a frequent occurrence in energy sectors primarily based on renewable power production.

Besides a detailed description of the necessary infrastructure and means of distribution, the paper reveals all the assumptions that served as the starting point for subsequent discussion. This level of transparency is hoped to facilitate an open exchange of information and a fact-based debate, which can lead to improvements to the current knowledge base.

FINDINGS The scenarios analyzed as part of the study show that both pathways require nearly identical amounts of investment if the size of the relevant market does not exceed several hundred thousand vehicles. During the transition period, hydrogen producers are assumed to make increasing use of the renewable surplus energy and of seasonal storage space designed to bridge a gap in supply for up to 60 days. This concept would allow for green hydrogen to meet demand, although it would be more expensive in the short-term compared to a charging infrastructure.

Seasonal storage is missing from the all-electric scenario, although it could guarantee that production is sourced entirely from renewables. The total capital costs required for supplying 20 million vehicles through an electric infrastructure is EUR 51 billion. The cost of the hydrogen system, on the other hand, is much lower and adds up to around EUR 40 billion (see fig. 2).

High market penetration rates result in similar costs per kilometer for both pathways. On average, they add up to 4.5 cents* for electric charging and 4.6 cents for hydrogen. What nearly offsets the reduced efficiency of the latter is the use of electrolysis to produce hydrogen from the surplus available on-site and, thus, store energy that would otherwise have been lost. [* all amounts in EUR]

The scenario assuming the availability of 20 million fuel cell vehicles requires 87 terawatt-hours of surplus energy for electrolysis, as well as another 6 terawatt-hours from the grid to transport and distribute the hydrogen. Charging 20 million all-electric vehicles consumes 46 terawatt-hours, taken from the transmission lines. Both the charging infrastructure and the all-electric cars show higher efficiencies, but on-demand power is limited to shorter intervals. In energy sectors dominated by renewable production, the excess power required for the two pathways in the high-penetration scenario exceeds demand by a factor of three to six.

The decision to replace fossil fuels with excess renewable power and largely renewable grid energy leads to a drastic reduction in carbon dioxide emissions per kilometer. The existence of seasonal storage means that the hydrogen supply chain can incorporate a higher proportion of surplus energy, resulting in lower emissions. However, the carbon dioxide levels associated with the all-electric pathway can be decreased if charging is timed to coincide with increased renewable power output.

CONCLUSION It needs to be noted that both supply chains described above are vital to implementing eco-friendly, clean and renewable transportation. Combining the strengths of a hydrogen supply chain and those of an electric charging infrastructure can prevent the emergence of less promising individual solutions, which may prove to be little convenient or efficient. One option to meet that objective could involve the widespread implementation of overnight charging for all-electric vehicles in short-distance travel, a goal that is more easily achievable. Hydrogen systems, on the other hand, could be employed to take on the challenges of long-distance and heavy-duty transportation. This sort of hybrid strategy could result in significantly reduced carbon dioxide levels across a large part of the transportation sector.

The amount of investment required to pursue either strategy is low compared to other measures, such as an increase in renewable power capacities or road construction and upkeep. Whereas the charging infrastructure is more energy efficient than the hydrogen pathway, the latter is seen as a chance to utilize the seasonal surplus for other purposes, for example, in manufacturing. Overall, hydrogen allows for the implementation of a supply chain that can provide benefits to more than one sector. ||

Download the study: http://hdl.handle.net/2128/16709

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H_2ESLA FROM HOOGEZAND

In late 2017, the Holthausen Group, a Dutch gas supplier based in Hoogezand, east of Groningen, unveiled a Tesla car running on hydrogen instead of battery power. More specifically, the company had replaced the battery in a Tesla Model S, owned by 18-year-old Max Holthausen, with a fuel cell and a hydrogen tank. The upgrade more than doubled the range of the vehicle and drastically cut refueling times. It made sense that the company's CEO and founder, Stefan Holthausen, who is also the father of the car's driver, would call it H²esla.

The conversion was not that simple, but Stefan Holthausen said that a family member had reprogrammed the car's computer to make it compatible with the new fuel system. What helped the family-owned corporation in their endeavor was an abundance of experience from delivering other hydrogen-powered vehicles, through Holthausen Clean Technology. Max Holthausen, who has since been nominated as an "green technology pioneer", told H2-international that a Tesla car was an option, but not one typically offered by his father's enterprise. He said that the business specialized in garbage trucks, street sweepers, transit buses and vans.

Almost instantly after news about the blue-color H²esla made the rounds online, Holthausen received multiple requests for more information. Time will tell whether these requests can be turned into orders. An initial estimate put the cost of conversion at EUR 50,000. ||

Theme: Electric Transportation | **Author:** Sven Geitmann

KLIXBÜLL AND SPRAKEBÜLL SHOW HOW IT'S DONE

Communities discover their love for electric carsharing

Sprakebüll is a small German village, west of Flensburg, where wet meadows extend as far as the eye can see. Most of the village's population of 240 has worked in agriculture for decades. About 20 years ago, 24 of them pooled their resources to fund a community wind farm. The investment was seen as a risky venture, as the technology was still new, but wind is one thing the region has in abundance. The farm became a full-on success, especially because of Germany's Renewable Energy Sources Act. Today, local wind farms produce more electricity than needed. The search for ways to make use of all this excess energy ended when electric cars and electrolyzers came into the picture.

Thanks to the Renewable Energy Sources Act, or EEG for short, the people of Sprakebüll can be laid back about all those times when the turbines in their area stop running. If wind power plants are shut down temporarily because the electrical grid is filled to the brim with eco-power, operators continue to earn money based on the law's 20-year feed-in tariff and preferential treatment clause. But for many in the region, money was not the main concern when they invested in these installations. Rather, they wanted to make sensible, that is, eco-friendly, use of the energy that the plants produce.

SURPLUS GOES INTO CAR BATTERIES Several years ago, the plants began to generate more electricity than the region could consume. When looking for ways to deal with the excess capacity, the population in northern Germany discovered the benefits of electric transportation. In December 2016, people living in Sprakebüll bought a total of 15 electric vehicles. Last May, the inventory increased to 20, earning the community the top spot on the list of Germany's towns and cities with the most electric cars per head.

The people of the village can lease vehicles at favorable terms, which the e-Mobiles Dorf Sprakebüll association and GreenTec Campus, based in Enge-Sande, negotiated with manufacturers. The rates that association members pay are comparatively low. For example, a Renault Zoe costs EUR 2,000 upfront and EUR 299 per month over four years. The monthly payment for a Nissan Leaf is EUR 281.

The cars are leased through eE4mobile, a 2010-founded cooperative of more than 200 individuals, businesses and institutions. The cooperative has entered into collaboration with GreenTec Campus, which is both the name of the company and the premises it owns. The primary aim of GreenTec is to promote electric transportation based on fully renewable power. Among other things, it offers a track for free test drives. But there is more happening across the region.

A VILLAGE SHOWS THE WAY One village down the road, in Klixbüll, there is a similar kind of commitment to electric transportation. In 2016, Klixbüll unveiled its Dörpsmobil, an electric vehicle standing in the center of town, available for rent at any time. The service is an offer by the local council to all villagers and their guests, especially to those who have no electric car of their own. The Dörpsmobil is not straining the budget, as the community of 1,000 has made a small fortune from local taxes on wind energy production. There was enough money left over to install nine charging points, including a fast charger.

The car can be booked online. People can also enter their destination to see whether others would like to join, for example, to get to Flensburg, the closest city. Sharing a ride with the mayor of the village, Werner Schweizer, had been a particularly popular choice, Hans-Christian Andresen and Christian Andresen, the initiators of the project, told H2-international during an interview at their company's office in Sprakebüll.

Hans-Christian and Christian Andresen are father and son and share the role of CEO at Solar-Energie Andresen in Sprakebüll. The company's main business is the sale of solar systems. But considering that the Andresens live in the wind-rich north of Germany, it should come as no surprise that they have also invested in several citizen-funded energy parks and associated companies. In fact, their entire business life seems to revolve around energy. They, themselves, seem to have plenty of it. They need that energy, as they have a lot of ideas for starting new ventures. So far, neither challenges nor unforeseen hurdles have stopped them from implementing their projects. Thanks to their relentless efforts, Sprakebüll and Klixbüll have become models for the rest of the country.

Stephan Wiese, project manager at GreenTec Campus in Enge-Sande, said that Schweizer's motto was "not to complain but do something about it. After all, he succeeded in bringing electric carsharing to his small village." His success has prompted several other communities to initiate similar projects. Now, there are even instructions to facilitate the installation of similar infrastructures in other areas. Wiese said that Schweizer had partnered with the Akademie für die Ländlichen Räume Schleswig-Holsteins, the association representing the rural regions in the northernmost German

state, to create a guidance document on project setups. "You could say it's a how-to guide on electric carsharing for all communities in Schleswig-Holstein."

The 80-page book is available for free and states precisely how much of the Klixbüll concept can be implemented elsewhere and what is needed to complete a project in three months' time. In the presence of Kristina Herbst, the minister for the state's rural regions, the guidebook had its official launch at the International Green Week, held in mid-January 2018 in Germany's capital, Berlin.

Meanwhile, the high demand in Klixbüll has led to the lease of a second Dörpsmobil. Members of the association founded specifically for this purpose can rent the car for only EUR 3.5 an hour, at an annual membership fee of EUR 60. The revenues are said to be enough to cover the running costs. According to village officials, the breakeven is at 90 hours of car use a month. Last year, Sprakebüll, too, decided to lease a Dörpsmobil and rents it to members of its own association for a fee of EUR 3.5 per hour.

SHOWING INITIATIVE

The work of Hans-Christian and Christian Andresen and their project partners has already borne fruit beyond Schleswig-Holstein. Their enthusiasm has spread to H2-international's editorial team in Brandenburg. Intrigued by the idea, the Hydrogeit Verlag publishing house is now supporting the implementation of similar electric carsharing projects in Kremmen and Oberkrämmer, two villages to the northwest of Berlin.

HYDROGEN PRODUCTION INSTEAD OF PIPELINE INJECTION Currently, however, there are not nearly enough electric vehicles to make use of all the surplus energy available throughout the region. The villages neighboring Sprakebüll and Klixbüll began looking for other eco-power consumers a long time ago, and they will need those alternatives. In four to five years, some wind systems will no longer be subject to the 20-year feed-in tariff that has so far provided their owners with a great deal of planning security.

Together with his father, Hans-Christian Andresen, and several other stakeholders, Christian Andresen has now embarked on a new journey. In partnership with Greenpeace, a 6-megawatt electrolyzer is to be set up to provide long-term hydrogen storage of the abundant wind resources in the region.

Father and son told H2-international that federal regulations had limited the feed-in from wind power systems in their community to about 30 percent of the total capacity. Elsewhere, it was around 40 percent. The plan is to use hydrogen to store at least part of the energy that could be generated. Andresen said that 6 megawatts of wind power capacity could be added for each megawatt required by the electrolyzer.

If past developments are any indication, it probably will not take long until their idea becomes reality. ||

Delays in installation meant that the citizen-funded project by wind energy pioneer Reinhard Christiansen (see interview in H2-international, January 2018) was completed no earlier than 2000. But the project's six turbines, installed near Ellhöft, directly on the Danish border, were technologically so advanced that they did not need later repowering, that is, replacement. They will be the first to lose the feed-in guarantee in a few years.

Christian Andresen

HYDROGENIOUS GETS NEW PARTNER IN BROAD OCEAN

Daniel Teichmann

Hydrogenious Technologies, based in Erlangen, Germany, has succeeded in bolstering its global partner network over the past months. In mid-January, it said that it had signed a cooperation agreement with a Chinese supplier, Zhongshan Broad Ocean Motor Co., while South African mining corporation Anglo American Platinum, also known as Amplats, had increased its investment in the company. In late 2017, during Hydrogenious' third round of financing, both Broad Ocean and Amplats decided to pour money into the clean technology manufacturer to expand the hydrogen infrastructure in China.

Daniel Teichmann, CEO of Hydrogenious, announced that the business's first-ever LOHC hydrogen station in China would be set up in early 2019. Charles Lu, founder and chairman of Broad Ocean, said that the 2016 license agreement with Ballard Power Systems had been his company's entry to the hydrogen market. Together with Hydrogenious, Broad Ocean was now ready to take on the next challenge. According to Andrew Hinkly, CEO of Anglo American Platinum's corporate venturing unit, Amplats believes that the strategic partnership with Broad Ocean will accelerate the market adoption of fuel cell vehicles in China. ||

Theme: Electric transportation | **Author:** Sven Geitmann

THE BRITISH ROAD TO FUEL CELL CARS

Riversimple tries crowdfunding

Source: Riversimple

Riversimple, based in Llandrindod Wells, a Welsh town of 5,000 people, is venturing into uncharted territory. Crowdfunding a new fuel cell car is not the only thing that sets the company apart from its competitors. The small creative powerhouse will also take another route in distribution.

Riversimple's first crowdfunding campaign, which ended last April, netted the 23-staff business over EUR 1.28 million, money it used to develop its Rasa car. The vehicle will now have butterfly doors and a chassis made from biocarbon, with layers of flax woven into it. Power for the Rasa's four small in-wheel electric motors will come from Hydrogenics PEM fuel cell stacks, type HyPM HD 8-200, as well as supercapacitors. The stacks' 8.6 kilowatts are enough to take the two-seater, which weighs as little as 580 kilograms, to its top speed of around 97 kilometers, or 60 miles, per hour in a total of 10 seconds.

Riversimple's founder, Hugo Spowers, put a great deal of effort into maximizing the impact of regenerative braking. Currently, the brakes recapture more than 50 percent of the car's kinetic energy, with the target being 70. It makes the Rasa comparatively efficient and allows for an acceptable range, though the vehicle has been designed primarily for trips around town. Prospective customers, however, are not supposed to worry about possible issues such as refueling, insurance, maintenance and price. Riversimple said that it would be taking care of all those things and make the car available for rent only.

Spowers, who used to design and build race cars, told the Welt newspaper that the big automakers might think it is business as usual, but that they were wrong. "You can't market a hydrogen car in the same way you would a conventional one," he said. Instead, he intends to create a completely sustainable vehicle. It will be one that is used frequently throughout its average 15-year life, to recover the comparatively high production cost. He estimates the total cost of ownership at around EUR 560 per month.

In all, Spowers has invested over EUR 12.5 million in his idea. The European Union has pledged EUR 2 million toward a 12-month test of 20 Rasa cars in Monmouthshire, UK. To receive funding and be able to construct the first half of the beta prototypes, Riversimple launched another crowdfunding campaign some time ago. The campaign's GBP 1 million goal has since been reached.

As early as 2009, the company had unveiled a similar vehicle. The corporation supplying the 6-kilowatt fuel cell had been Horizon Fuel Cell Technologies, which created a division called Horizon Educational Group a few years thereafter (see HZwei, July 2009). ||

Rasa is short for "tabula rasa," the Latin term for "scraped tablet" – or, "clean slate."

HYDROGEN TO PLAY BIGGER ROLE IN 2020s

The 50-station target, originally set for 2015, has not yet been achieved, but it will be soon, according to the H2 Mobility Germany consortium. On behalf of its founding partners, it is setting up and putting into operation new hydrogen stations across the country.

One new station was opened by the parliamentary state secretary for transportation, Norbert Barthle, in mid-February in Wendlingen. Shell invested a total of EUR 1.4 million in the installation southeast of Stuttgart, along the A8 freeway. Half of the money came from public funds. Thomas Bystry, chairman of the Clean Energy Partnership, said during the opening ceremony that starting in the 2020s, hydrogen would play an increasingly stronger role in markets such as Germany, the Benelux countries, the UK and the United States.

Germany's number 44 went into operation March 5 in Ingolstadt, also in the presence of Barthle. This one is a Total station on Manchinger Strasse, not far from the Ingolstadt Süd exit on the A9 freeway. In late 2017, another system – supported with EUR 900,000 – came online at a Total truck stop at the A5, near Hirschberg an der Bergstraße. Soon, drivers of fuel cell vehicles will have even more opportunities for refueling near the A5 freeway. Bad Homburg, in the state of Hesse, was H2 Mobility's choice during its second request for applications, for which 13 regions had submitted papers. The effort put in by Gaertner & Roesebeck Unternehmensberatung, a German consultancy, had tipped the scales in favor of the location. The consultancy had campaigned vigorously for the use of hydrogen fuel and convinced many stakeholders of the technology's benefits for transportation. Additionally,

P.-E. Franc, Air Liquide; N. Iwan, H2 Mobility, K. Bonhoff, NOW; S. Mißlbeck, Mayor Ingolstadt; T. Strauß, Total Deutschland; M. Spieß, Total (v. l., Source: CEP)

Bad Homburg had announced that it intended to make hydrogen vehicles part of its carshare portfolio. Financial support for the endeavor is also coming from the EU project Hydrogen Mobility Europe, or H2ME (more on the project will follow in the July 2018 issue).

Lorenz Jung, head of project management at H2 Mobility, said that despite the rather tight application deadline, the regions had succeeded in mobilizing their citizens and companies. "The results have far surpassed our expectations. There's no getting away from it, there's definitely a market for hydrogen out there now," he said. Not only was he impressed with the level of commitment, but also with the quality of the applications. "Systems integration, hydrogen production based on renewable sources and transportation concepts are all clear indicators of the important role hydrogen is set to play in our energy system's transformation." ||

MATTES REPLACES WISSMANN AS HEAD OF VDA

Bernhard Mattes

On Jan. 30, the German Automotive Industry Association, or VDA for short, elected a new president. By unanimous vote, Bernhard Mattes was chosen to head the Berlin-based organization. On March 1, he took over for Matthias Wissmann, president since June 2007, whose contract had expired. Mattes was the chairman of Ford-Werke between 2002 and 2016. He was also a member of the VDA's board of directors during that time and served as the association's vice president from 2002 through 2004.

Arndt G. Kirchhoff, the current vice president of the VDA and CEO of Kirchhoff Automotive Holding, said that the decision on Mattes had the backing of all three groups of automotive companies whose representatives were sitting on the board of directors and the executive committee. One reason why the association was such a strong voice for the industry was that it represented both automakers and suppliers. It was a constellation with which Mattes was very familiar, as he had been with the VDA for many years.

Asked about the association's plans, Mattes said that the automotive industry was on the verge of a historic transformation, driven largely by the electrification of vehicles, growing digitization, advances in autonomous driving and new transportation modes, but also by the challenges of further reducing fuel consumption and GHG emissions. The aim was to guarantee and raise the global competitiveness of an industry that was of paramount importance to the success of the German manufacturing sector. ||

Theme: Letters from readers | **Author:** Dr. Artur Braun

REALLY NOT MUCH TO WORRY ABOUT

Re: H2-international editorial, May 2017, "H_2 Refueling, the German Way"

Recently, I hit the 5,000-kilometer, or 3,107-mile, mark for business trips with a hydrogen-powered Hyundai ix35 Fuel Cell. In my case, the question has always been, "Is an FCEV only a short-range option for driving around a city?" What can I say, I went from Zurich in Switzerland to Lausanne, on to Basle, Berlin and Luxembourg until I reached Strasbourg and, lastly, Darmstadt in southern Germany.

Sure, organizing a longer trip needs some planning. Without a CEP fuel card, I would have never made it to Berlin. But I did get one and it worked every time.

I was offered a no-cost fill-up at ST@RT Hürth, located in the Knapsack industrial park in Hürth, near Cologne. I had to refuel at 350 bars and pick up the phone first. But it worked. The hydrogen produced on-site is a byproduct of chemical processes.

In Hunzenschwil in Switzerland, at the Coop Pronto station, you can use a credit card for 700-bar refueling. The security deposit is 150 francs, or around 138 euros. The gas is generated at a hydropower plant in neighboring Aarau. It is clean hydrogen from renewable production.

In Freiburg, the hydrogen produced at Fraunhofer ISE comes from solar energy. To fill up, you will need a CEP fuel card.

At my place of work, the Swiss Federal Laboratories for Materials Science and Technology, or Empa for short, parking lot staff takes care of the refueling. We have our own filling station, equipped with an electrolyzer.

So much hydrogen and not a single barrel of oil needs to be transported on the Schatt al-Arab river or pass through the Suez Canal.

Source: Artur Braun

I am glad that the employees of the Coop Pronto station and the Shell one in Geisingen, near the A81 freeway in Germany, instructed me on how to refuel the vehicle. I learned something new about cars – and I am very interested in learning new things about cars!

We, the "second generation of first movers," who only drive their vehicles and have not presented any plans for, let alone started the construction of, new infrastructure, need to stick together right now. I think a lot has been accomplished so far, and hydrogen is indeed the future.

I did not have to stop for long at some charging point in Geiselwind. Whether you fill up a tank with hydrogen or gasoline, neither takes much time. Also, my FCEV runs as quiet as a mouse.

Over the weekend, I calculated how much energy the Hyundai ix35 consumes when you travel a certain number of miles and then fill up the tank with either super or hydrogen. Pick the gasoline model – actually, any car with an internal combustion engine – and the outcome will be devastating. Fuel cells, on the other hand, could not achieve higher grades.

Hyundai's FCEVs have become a familiar sight at car dealerships. Not only that: You can drive them across almost all of Europe, from Bergen to Bolzano, from Berlin to the United Kingdom. Toyota sells the Mirai. Honda has put its own fuel cell version on the market and Hyundai is already announcing its next models.

While I was writing my dissertation at the Paul Scherrer Institute, I was able to gain some insight into the fuel cell research on cars in our department. But it was never my field of research or line of work. I still remember how, during my sabbatical in Hawaii in 2010, I smirked at a Chrysler FCEV that had been loaded onto a carrier instead of being driven on the road.

Now, after ten years' research into clean hydrogen, I'm amazed by the fact that FCEVs have made it onto the streets and have found their way into the hearts of vehicle drivers, their target group.

I brought measuring equipment along for the ride from Zurich to Germany's capital, where I worked on BESSY experiments involving solar-sourced hydrogen. I needed only one stop for gas in Geiselwind, near Würzburg. Later, in Berlin, I used the opportunity to drive with my South Korean colleagues and guests to the H2 Mobility station on Sachsendamm street to learn about the latest technological advances.

H2 Mobility's goal is to have a total of 400 hydrogen stations up and running by 2023. Other people have told me that a German carmaker was about to put a large number of FCEVs on the road.

In hindsight, a sense of normality is settling in when driving a hydrogen car these days.

At this very moment, I am downloading the H2.Live station app onto my iPhone.

I am thrilled! ||

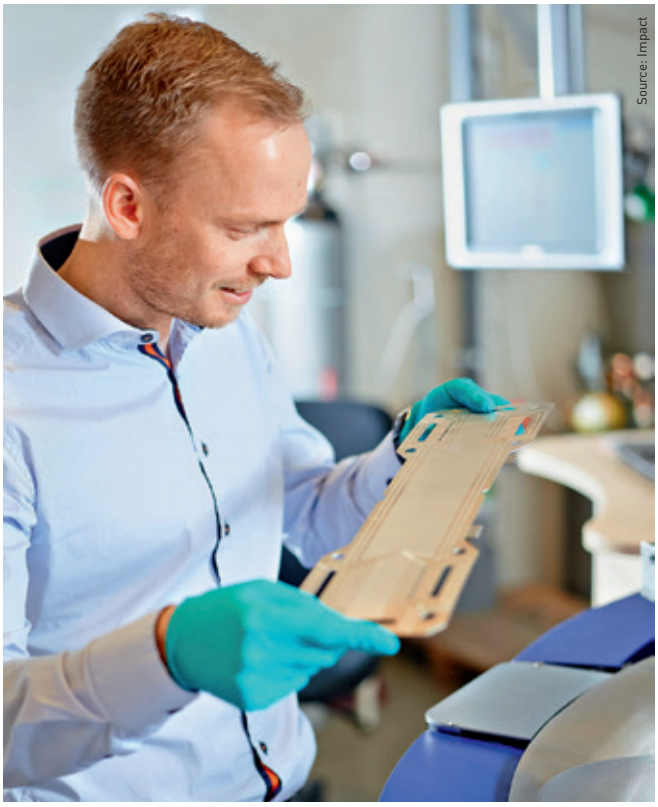
IMPACT COATS FOR MICHELIN

French tiremaker and automotive supplier Michelin has placed its first order with Impact Coatings, a coating manufacturer based in Linköping, Sweden. According to a mid-February press release, the order was received after the successful completion of initial tests on Michelin fuel cells. In late 2017, Impact had also signed a cooperation agreement with Telos Auto Power Systems, a fuel cell manufacturer based in Foshan, China.

Impact uses physical vapor deposition, a method to produce thin metal and ceramic films and coatings in a vacuum chamber. Under the MaxPhase™ brand, the company offers products for fuel cells, electrical connectors, reflectors and other components.

Henrik Ljungcrantz, CEO of Impact Coatings, said that not only had the cooperation with Michelin been going extremely well, but it had also been a clear sign that the European fuel cell market was picking up speed. The French automotive supplier had certified and approved the coating and was convinced that it showed the best performance to increase fuel cell system efficiency.

Michelin develops fuel cell systems for a range of vehicles, from trucks to buses and passenger cars, and is planning to step up its involvement in the market. ||

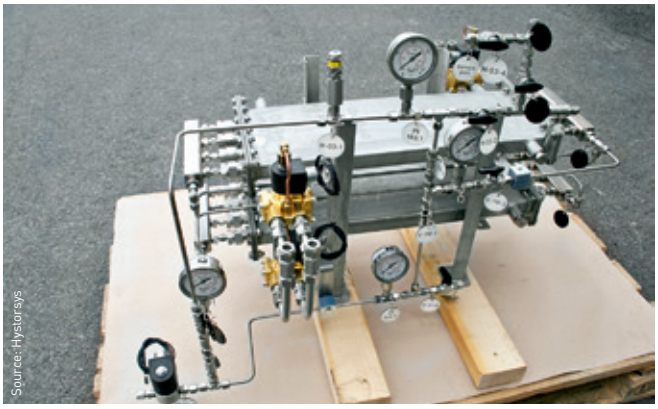


Source: Impact

HYSTORSYS LAUNCHES COMPRESSOR PRODUCT LINE

Following years of development, Norwegian manufacturer Hystorsys, a spinoff of the Norwegian Institute for Energy Technology, has begun shipping metal hydride compressors to customers. Three years ago, it put into operation a proof-of-concept unit at the refueling station that is part of the institute's test facility in the municipality of Skedsmo. Big advancements have been made in the meantime and today's HYMEHC is a thermocompressor designed for a throughput ranging from 0.5 to 20 normal cubic meters per hour. It's comparatively small and has almost no movable parts, keeping noise to a minimum. It is particularly suited for industrial and geothermal applications, or for use in any other environment providing sufficient access to heat.

With water temperatures of 5 °C to 20 °C at the cold end, 80 °C to 95 °C at the hot end, and a temperature difference of at least 70 °C, the unit can achieve a compression ratio of 1 to 10. For example, the use of the system in two-stage compression can turn 10 bars of inlet pressure into 200 bars at the outlet. ||



Source: Hystorsys

PRESSURE TRANSMITTERS FOR HYDROGEN APPLICATIONS

Source: Prignitz

Pressure sensing is of paramount importance to the entire hydrogen and fuel cell sector. But making sensors hydrogen-proof may not be enough. Prignitz Mikrosystemtechnik has designed a pressure transmitter called SPT H2 to account for all the factors crucial to successful measurements of hydrogen pressures.

The one-piece product has no welding seams, making the metal surface impervious to embrittlement through ionized hydrogen molecules. It is vacuum-sealed and is produced without the use of elastomers to prevent material wear and tear from causing leaks in the internal insulation.

Its dry piezoelectric sensing element made of stainless steel does not contain any liquids to transmit pressure, nor does it have comparatively large pressurized areas. What it does have is a robust, vibration-proof membrane, allowing for measurements in a low-temperature environment over longer periods. The new series offers several process connections, a variety of thread standards and devices based on ATEX, IECEx and CSA for use in potentially explosive atmospheres, including Zone 0. ||

Theme: Research & Development | **Author:** Sven Geitmann

SOLAR FOR A CLEAN ENERGY FUTURE

Photo-electrochemical cells to produce hydrogen

Each day, the sun sends vast quantities of energy to the earth. During millions of years, our planet has adapted to this steady stream of power, developing clever ways to make efficient use of the solar resources it receives. Scientists have been trying to do the same in a rather minuscule amount of time. Over the past 20 years, they succeeded in using photocells to convert sunlight into electricity, a process marked by relatively high efficiency today. Not long ago, they began to redouble their efforts to capitalize on the potential that sunlight has for hydrogen production. It remains a challenge, though, to design both small systems, such as the ones described below, and large-scale installations, as depicted on page 46.

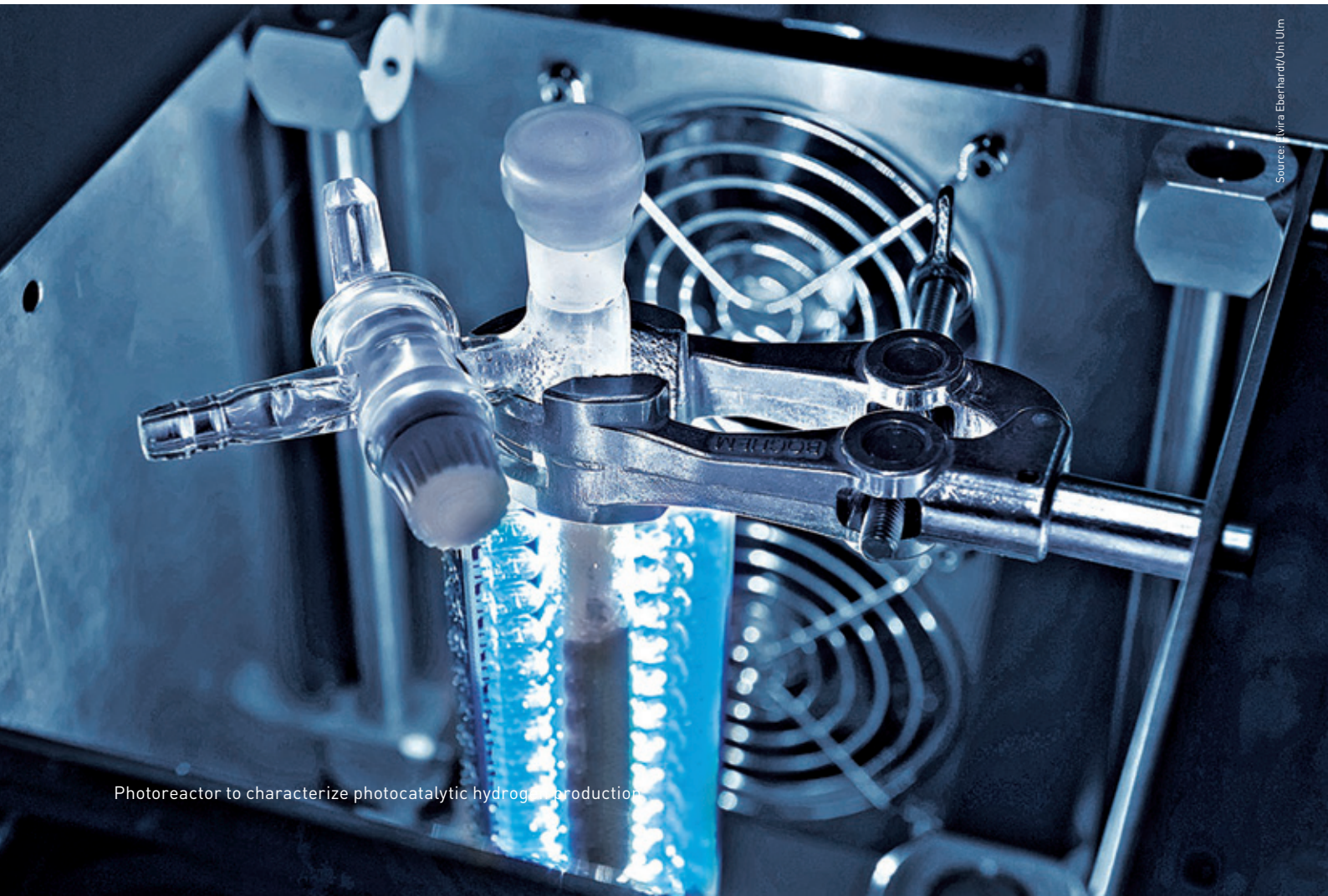
Helmholtz-Zentrum Berlin, a research institute based in Germany's capital, is at the helm of a European research endeavor called PECSYS. The objective is to design an economically viable method for solar-powered hydrogen production in four years' time. Achieving this objective will require an efficient combination of photocells and electrocatalysts to split water into its elements, hydrogen and oxygen.

There have been some breakthroughs in this field in recent years, but many questions have gone unanswered. For example, whereas photovoltaic systems have seen their share of advances, researchers have yet to figure out which technology will show the most promising results for water splitting. One of those crucial but unsolved issues is the choice of material for system construction.

What has been defined so far are the aims of the endeavor, supported with EUR 2.5 million from the EU's Horizon 2020 program. Within four years, the project partners from Germany, Italy and Sweden are to develop the technology to a point at which several modules adding up to 10 square meters, or 108 square feet, can be set up for testing purposes. The subsequent testing period would be used to demonstrate that even large installations can provide the desired reliability and output.

The organizations participating in the project are said to be examining photovoltaic cells manufactured from materials such as silicon and chalcogenides or tandem cells made of perovskite and silicon, alongside electrocatalysts and appropriate sealing technologies. The outcome is hoped to be a space-efficient unit that can be operated in the harshest environments.

The prototype is to convert more than 6 percent of the incoming sunlight into hydrogen through chemical means and operate reliably over a pe-



Source: Elvira Eberhardt/Uni Ulm

Photoreactor to characterize photocatalytic hydrogen production

riod of at least six months. The cost of hydrogen produced by the system is to remain below EUR 5 per kilogram. Current market prices are around EUR 8. Sonya Calnan, who works for the Berlin-based Helmholtz-Zentrum and manages the project, said that those aims were very specific and very ambitious.

PECSYS
The organization coordinating this EU venture is the Helmholtz-Zentrum Berlin's center of excellence for photovoltaic technology. Other partners are the research center in Jülich, Germany; Uppsala University, Sweden; Consiglio Nazionale delle Ricerche, Italy; and two companies, the Swedish arm of Solibro Research, based in Germany, and Italian 3Sun. The project was launched in January 2017.

SCIENTIFIC INVESTIGATIONS ALL AROUND Helmholtz-Zentrum Berlin is not the only organization looking into solar-sourced hydrogen production. It is not even the only Helmholtz-Zentrum to do so, as research by the one in Geesthacht shows. On top of this, a small interdisciplinary team, led by Sven Rau, a professor working in Ulm, is intent on advancing both artificial photosynthesis and water-splitting photocatalysis in the German cities of Ulm, Munich and Kaiserslautern. Their efforts seem to be paying off. Rau explained that it would have taken up to 10 years to complete a series of tests in the past. Nowadays, researchers could identify photocatalyst properties in a few days while gathering clues to help maximize efficiency.

Scientific exploration is also not restricted to Germany, as evidenced by the great efforts undertaken in the Netherlands and Switzerland. In summer 2017, scientists from TU Delft and the AMOLF Institute said in an article in the Nature Communications journal that they had been able to design a stable, highly efficient photoelectrode to split water directly into its basic components. Previously, one had to choose either high efficiency or long life, which meant that stability decreased as soon as efficiency increased and vice versa.

The Dutch researchers examined both processes individually and merged them at a later stage. They designed an insulating layer of aluminum oxide to stabilize the silicon photoelectrode and used nickel and platinum for the electrode to increase the photovoltage. The employment of a metal-insulator-semiconductor junction not only raised efficiency but also extended the life of the unit. Previous systems had lasted for no more than a few hours, TU Delft's Wilson Smith said. The new system, on the other hand, can run up to 200. Likewise, the light-absorbing silicon wafers that are part of the unit could cut costs and make the process less expensive than other approaches.

In Switzerland, at the École Polytechnique Fédérale de Lausanne, Carlos G. Morales sought to advance the development of catalysts increasing the rate of solar-sourced hydrogen production in a photochemical cell. These catalysts must be transparent and guarantee a stable electrical contact. Morales developed them specifically with those requirements in mind, and some have led to record-breaking efficiencies in electrolysis. His dissertation "Coupling of electrocatalysts to photoabsorbers for solar fuels production" was recognized with an ABB Research Award in 2017.

Across the Channel, like-minded researchers have conducted their own studies over the past decades. When writing his dissertation, Samuel Harrison, from Lancaster University in the UK, observed a great need for much more experimental work on solar-powered hydrogen production in the field of quantum technology. Nanostructures seemed like a promising avenue to raise the maximum photovoltage in a photoelectric cell and increase the output of water splitting, he said. But as Manus Hayne from the university's physics department explained, that kind of increase required innovations in material research and system design. ||

PEC
PECs, or photo-electrochemical cells, are small solar cells used in electrolysis to split water into hydrogen and oxygen by directing light at the anode.

Theme: Research & Development | **Author:** Dr. Martin Roeb

TWO-STEP HIGH-TEMPERATURE WATER SPLITTING

Solar tower to be field-tested in Almería

Hydrogen certainly has the potential to become a mainstay across all kinds of energy markets. It can be produced entirely from renewable energy, requiring not even a tiny amount of carbon-based fuel. It is currently being brought to market to power cars, buses, trucks and trains through fuel cells driving their engines. It is likewise used in ground and material handling equipment for logistics and airport operations, in stationary units, such as CHP installations, and in uninterruptible power supply systems.

The gas also continues to be in high demand as an intermediate product in industrial settings. Around the world, several hundred billion cubic meters of it are consumed each year in the plastics, petrochemical, glass and metal fabrication, and fertilizer industries, as well as in agriculture and food processing. Additionally, the plans to inject hydrogen into natural gas pipelines are becoming more concrete. The aim is to replace part of the fossil fuel stored and transferred throughout the network with a non-carbon alternative produced from sustainable and renewable resources.

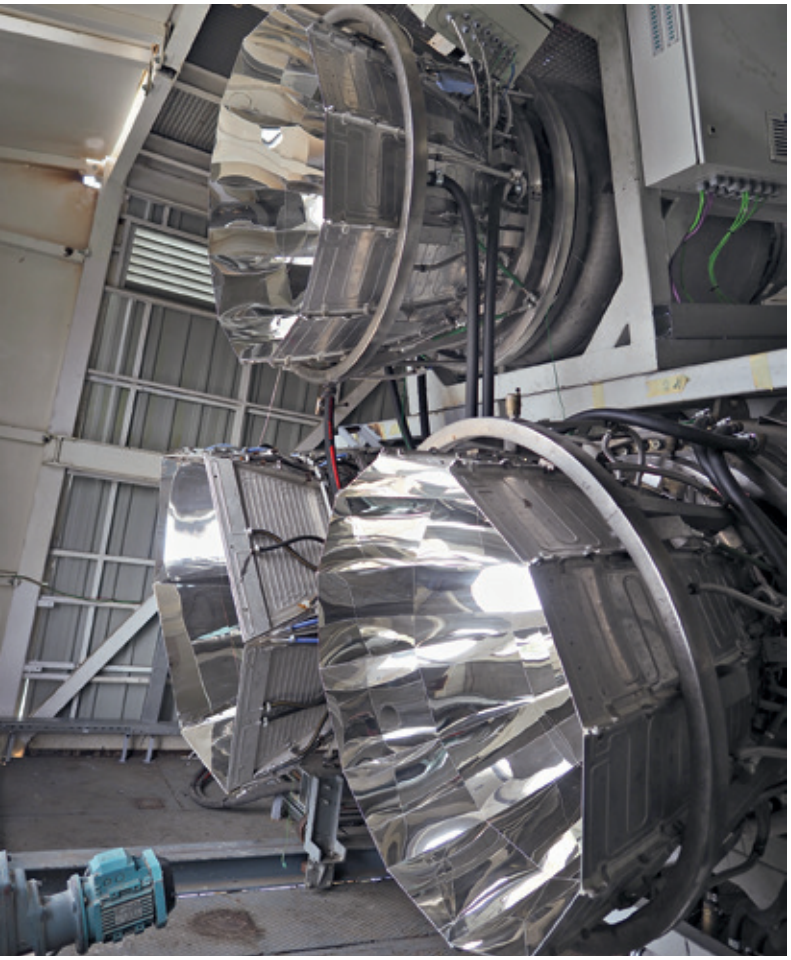


Fig. 1: Front view of the three reaction chambers installed on the solar tower at the Plataforma Solar de Almería

JAPAN, THE PRIME MOVER Despite Japan's very ambitious strategy, the country has not wavered in its years-long commitment to make hydrogen the country's main energy source. In April 2014, Japan's cabinet approved a roadmap, revised in March 2016, to sketch out the path it intends to take to become a prime example of a hydrogen society. The roadmap outlines not only technical aspects of manufacturing, transport and storage but also societal factors, such as market adoption and public acceptance. It is not surprising then that it has been and is being developed in close collaboration between research organizations, manufacturers and suppliers, the government and the public.

Japan's way to a hydrogen-based economy is divided into three stages. The first has already been set in motion and is planned to last until the end of this decade. The aim of this stage is to expand the range of fuel cell applications to realize energy savings and secure a position on the global market. The 2020s, on the other hand, are to see the buildup of a supply infrastructure based on imported hydrogen, mainly from renewable production. A prominent example is hydrogen generated by solar installations in Australia and elsewhere. The principal objective is supply security.

The third stage, until 2040, involves creating a zero-carbon hydrogen infrastructure throughout the entire country. Japan could serve as a template for introducing the technology in other regions worldwide, not least in Europe.

WHEN HYDROGEN TURNS RENEWABLE Hydrogen benefits from a wide production base. The fact that it can be generated using a broad range of renewable sources turns it into a hub for meeting the requirements of a variety of energy-hungry processes while releasing little or no harmful emissions. It would give countries and regions blessed with vast and inexpensive renewable resources the chance to export the gas generated from them. Examples include Canada's and Norway's hydropower stations, the wind power systems in the whole of northern Europe, and renewable energy installations in northern Africa, the Middle East, Chile and Australia.

Today's most advanced renewable method to produce hydrogen is the electrolysis of water. There are, however, several options, particularly solar-based ones, that could eventually outcompete electrolysis in terms of efficiency. One of them is the thermochemical water-splitting cycle.

HOW A SOLAR POWER TOWER WORKS Solar alternatives to water electrolysis are closely associated with the use of concentrating technologies, especially power towers. The solar thermochemical system, or its later industrial version, will include an array of mirrors focusing the sun's rays onto what is called a receiver at the top of the tower. The high temperatures reached at the focal point will then be used to convert energy into heat. Solar power towers have already been available on the market and are in operation in many sun-rich countries, where they generate heat and, subsequently, electricity.

Source of all figures: DLR

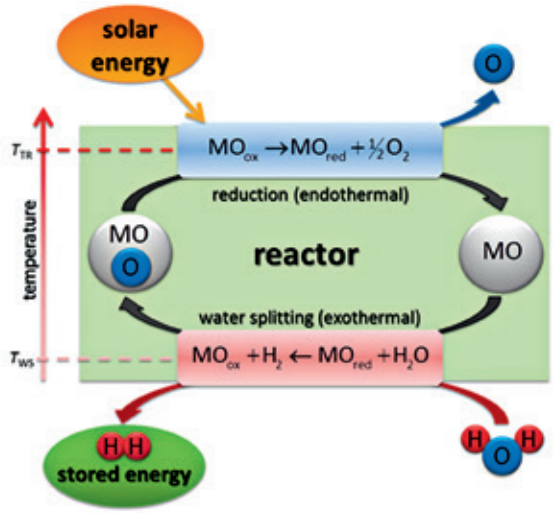


Fig. 2: Illustration showing the solar thermochemical water-splitting cycle

These towers also make it possible to meet the heat requirements of energy-intensive chemical processes, for example, when splitting water into oxygen and hydrogen. During the first step in the thermochemical cycle, the sun heats a metal oxide in a reactor on the tower to around 1,400 °C. Consequently, oxygen is removed from the substance, a chemical process known as reduction.

The second step occurs at temperatures between 800 °C and 1,000 °C. Steam enters the reactor, re-oxidizing the metal compound to produce hydrogen. The cycle ends with a complete oxidation of the substance before it is led back to the first step in the process to be returned to its initial, i.e., low-oxygen, state (see fig. 2). The use of concentrated solar energy to supply the process heat in a thermochemical water-splitting cycle will bring carbon dioxide levels down to zero.

In partnership with other organizations from across Europe, the Institute of Solar Research at the German Aerospace Center has developed and "solarized" a two-step thermochemical cycle over the course of several EU projects. This means that it has devised and validated a method to inject solar-sourced high-temperature heat into the cycle. The reactor design envisioned as part of these projects consists of porous ceramic components coated with metal oxide or parts made entirely of the metal compound. They both provide the reactive surface area for water splitting and function as solar absorbers.

More specifically, concentrated sunlight is used to heat the ceramic absorbers to the required temperature inside a closed reaction chamber. Feeding the gaseous reactant, the steam, into the chamber will start the two-step process of splitting water into its elements. If purified, the oxygen generated as a byproduct during the second step can be marketed alongside the hydrogen.

VALIDATION PROVES SUCCESSFUL Over the last years, researchers from the German Aerospace Center have been engaged in several collaborative projects in Europe, playing a crucial role in advancing the development of redox materials, the thermochemical cycle technology and operational guidelines. Its efforts have resulted in a successful validation of the new method in the real-life environment of a solar furnace and a solar tower.

In 2014, as part of the Hydrosol-Plant project, co-financed by the EU's Fuel Cells and Hydrogen Joint Undertaking, the center and its partners began to scale up the process and the relevant components. The system can now be field-tested at around 750 kilowatts of capacity. Late last November, at the Plataforma Solar de Almería in southern Spain, the consortium unveiled the world's biggest installation for solar thermochemical water splitting. The participating researchers and industrial companies had put in great effort to improve hydrogen production from sunlight. Enhanced metal oxides and a carefully chosen reactor design promising much higher efficiencies have made it possible to construct this new system. It is much larger than the 100-kilowatt prototype operated during the previous stage.

In the coming months, research will focus on the choice of materials. Improvements to the solar reactor design have reduced heat losses, further preventing the hot absorber structures from releasing thermal energy into the atmosphere. In all, the field test now consists of three reactor units operated simultaneously (see fig. 1) to allow for the time alignment of water splitting and metal oxide reduction. Additionally, the curved quartz windows give the focused solar beam optimal access to the structure at minimal reflection losses. The aim of the tests, however, is not only to demonstrate that hydrogen can be produced during a solar thermochemical cycle inside a reactor but also to show that it can be separated, purified and stored. The relevant gas purification equipment has been integrated into the installation. ||

RECOGNIZED FOR EXCELLENCE
The validation has also netted the project partners several scientific awards, such as the EU's Descartes Prize.

The project is being coordinated by the Aerosol and Particle Technology Laboratory based in Greece. Other partners are the German Aerospace Center, Spanish research organization Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Dutch company HyGear and Greek energy supplier Hellenic Petroleum. The German Aerospace Center has been the driving force behind the development of the solar reactor, the system design, and the instrumentation and control equipment.

Written by

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Theme: Research & Development | **Author:** Niels Hendrik Petersen

HYDROGEN-ENRICHED TURBINE GAS

Combustion diagnostics at the German Aerospace Center

Scientists working for the Institute of Combustion Technology at the Stuttgart-based German Aerospace Center, also known as the DLR, are developing new laser-based methods to investigate combustion processes in gas turbines. Their progress may help reduce the dangers associated with hydrogen-rich blends, which could destroy a turbine's combustion chamber. Research and development in this field will be crucial to the success of Germany's energy transformation. The mixtures make it possible to store surplus energy from intermittent renewable sources in the national pipeline system, from where it can be reconverted into power through gas turbines. Perfecting the technology could mark a major milestone in cutting carbon dioxide emissions and stabilizing the electrical grid.

Isaac Boxx and his team stand behind a large window pane made of fused quartz, observing a flame burning on the other side of the room. Several instruments analyze the green laser beam passing through the test rig. New equipment, developed to allow for rapid measurements at high time resolution, helps to keep track of the entire process. The scientists intend to improve the laser-based method further. "The human eye wouldn't be able to identify the fluctuations in the turbulent flame," Boxx says. The rig, designed to closely resemble real-world operation, is thought to change all of that. The Stuttgart-based laboratory is one of only a few facilities in the world to have the equipment and the know-how to even attempt these kinds of experiments.

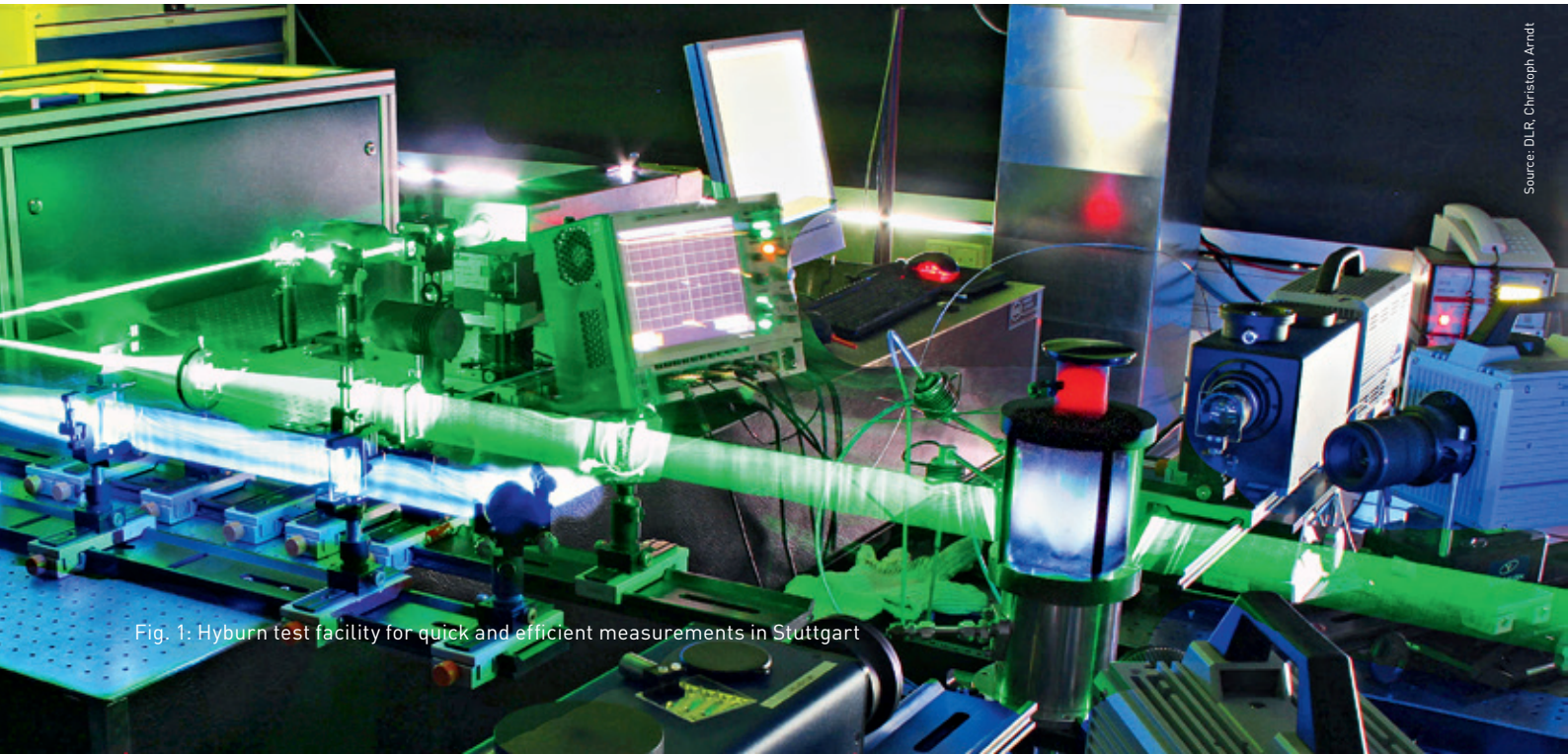
Ten years have passed since Boxx started his research into gas combustion at the DLR. He is the manager of the project Hyburn, a short acronym for a rather long title: Enabling Hydrogen-Enriched Burner Technology for Gas Turbines through Advanced Measurement and Simulation.

The combustion processes he and his team observe happen in the span of milliseconds. To make them visible at all and aid in understanding what goes on inside the chamber, the new system delivers 10,000 frames per second. Boxx points out that it provides a highly accurate picture of both the flame structure and the flow field.

SOFTWARE TO ANALYZE COMBUSTION PATTERNS The data from these laser-based measurements serves as a basis for simulating combustion processes that can be analyzed in detail on a computer. "The software application we developed is perfect for studying the impact of a higher percentage of hydrogen on flame behavior," Boxx says, cheeringly. His project is being supported with what the European Research Council calls a consolidator grant, to support researchers who excel in their fields. In this case, the grant total is about EUR 2 million over five years.

Hyburn's role in Germany's energy transformation cannot be overstated. In late 2017, the proportion of electricity produced from renewable sources across the country added up to more than 33.1 percent, according to preliminary estimates by the German Energy and Water Industries Association. Wind and solar systems had contributed 217 billion kilowatt-hours to the total, nearly enough eco-power to achieve the federal government's 2020 target of 35 percent. Their numbers, however, need to rise significantly if renewable energies are to make up between 80 percent and 95 percent of Germany's electricity production by 2050 at the latest.

According to the association, gas turbines had supplied 13.1 percent of the total. They are a very good fit for renewable sources, as fast startup and shutdown allow for quick responses to output fluctuations. In the future,



Source: DLR, Christoph Arndt

Fig. 1: Hyburn test facility for quick and efficient measurements in Stuttgart

electrolysis could be used to store a growing amount of renewable power in the form of hydrogen in natural gas pipelines. This hydrogen could replace fossil fuels and help meet climate targets.

ENORMOUS TURBULENCE DURING COMBUSTION To advance on-demand power production from blends of hydrogen and natural gas, the DLR scientists are examining the combustion patterns of these mixtures. The key difference between a combination of the two gases and pure natural gas is that hydrogen is highly reactive. "The flame will change its shape and pattern, which may damage the chamber," Boxx explains. He admits, "We, the researchers, have yet to gain a sufficient understanding of the processes involved before blends can be used safely in gas power plants." Data and experience are still not at the required level.

The project has relevance far beyond Germany. The country may have seen a strong increase in renewable power being fed into its national grid. But other countries will have to transform their energy markets too. Boxx affirms that turbine manufacturers from across Europe have expressed great interest in enriched natural gas. None of them are directly involved in the project, however. The findings from Hyburn are planned to be made available at no cost to the entire industrial sector in the hope that they will prompt innovations in gas turbine technology.

Manufacturers have put a variety of turbine designs and setups on the market, making it impossible to give universally applicable statements on thresholds for enrichment, Boxx says. Several producers have been certified to use 10 percent blends, and more hydrogen could be added, in his opinion. No one, however, can currently say exactly where the limit should be.

MITSUBISHI TESTS 30 PERCENT ENRICHMENT Japanese corporations are at the forefront of research into hydrogen combustion. Mitsubishi Hitachi's power systems division has set the bar relatively high. It announced that the gas in a turbine installed in Takasago, around 40 kilometers, or 25 miles, away from Kobe, had been enriched with as much as 30 percent hydrogen. Stable operation had been achieved by a redesign of the combustion chamber. The 30 percent blend had led to a 10 percent reduction in carbon dioxide emissions compared to pure natural gas. Reportedly, Mitsubishi was planning to enrich the gas in its power plants at 20 percent for now. But it was working on increasing the proportion, as it had already done for testing purposes.

The research in Japan, as well as the one at the aerospace center in Germany, is focused on small and midsize turbines used in CHP systems. Turbines of up to 1 megawatt capacity, installed in conventional, decentralized power stations, show relatively low levels of electrical efficiency. Enriching the natural gas with hydrogen could benefit those plants, since none of the components, except for the combustion chamber, need to be replaced.

The chambers, on the other hand, must guarantee proper blending. A nozzle will provide the air for thoroughly mixing both gases before the blend is being burned. Mitsubishi Hitachi said that its combustion test had been conducted using a J Series turbine at an inlet temperature of 1,600 °C. The result had been 700 megawatts of output and 63 percent of electrical efficiency.

HYBRID SYSTEMS MAKE ECONOMIC SENSE In Boxx's opinion, it would be a great technological and economic challenge to use nothing else than hydrogen for powering a large turbine. It is one reason why the attempt has yet to be made. Besides, there are clear advantages to enrichment, he says, as the process makes economic sense, allowing for the efficient conversion of any surplus in renewable electricity. Likewise, storing this electrical energy could balance supply and demand in the following months and keep the grid stable.

Despite all the challenges, gas manufacturers are optimistic about the prospects of hydrogen-only combustion. It will require more research and development, though. Enrichment is giving research organizations the time to investigate the use of pure hydrogen. In comparison with natural gas firing, blends have also become a technologically feasible and economically viable option, offering a way to reduce carbon dioxide emissions. The first steps have been taken. In their lab in Stuttgart, Isaac Boxx and his team are now working toward the market readiness of gas turbines with an even greater proportion of hydrogen in the blend. ||

ITM AND SHELL TO BUILD 10 MW ELECTROLYZER

REFHYNE
CLEAN REFINERY HYDROGEN FOR EUROPE

Water electrolysis is starting to make inroads into the refinery sector. Shell has revealed plans for the construction of a 10-megawatt electrolyzer at its Wesseling refinery site in Germany. The project, called Refhyne, is supported with EUR 10 million in funds from the EU's Fuel Cells and Hydrogen Joint Undertaking. It will see British manufacturer ITM Power forging ahead with the design of a system having more capacity than any other in the world.

By steam-reforming natural gas, Shell's Rheinland Refinery produces around 180,000 tons of hydrogen per year. The quantity that will be generated through electrolysis is said to be going into, for example, petroleum processing. The Refhyne plant is scheduled to come online in 2020.

Graham Cooley, CEO of ITM Power, said: "Decarbonizing hydrogen production in the chemical and refining industries worldwide is potentially a very large market. This pioneering project with Shell aims to demonstrate what can be achieved using our industrial-scale electrolyzers, which can also use low-cost renewable energy and help to balance electricity grids."

Tudor Constantinescu, principal adviser to the European Commission's director general for energy, added that renewable power could help decarbonize the energy sector and, through sector integration, other carbon-intensive industries, such as refining. Considering the EU's emission reduction and renewable energy targets, renewable hydrogen was certain to play a key role in the process.

Another company exploring the potential of renewable electrolysis is British Petroleum. In partnership with Uniper, it may set up a power-to-gas system for diesel production in Lingen, in the German state of Lower Saxony. It has already signed the relevant cooperation agreement. ||

Theme: Stock market | **Author:** Sven Jösting

TECHNOLOGY'S POTENTIAL FAILS TO MAKE AN IMPACT

Sven Jösting's stock market analysis

Technological breakthroughs and rosy prospects for growth may have raised expectations of the fuel cell companies described below, but their grossly undervalued stocks haven't followed suit. Zooming out for a moment, there should be a greater focus on sustainability if the goal is to up the stock price. Instead, too much emphasis is placed on current financial results, specifically on the reports published each quarter. A pessimistic view of the next two years seems especially unjustified considering that sectors such as electric transportation are making increased use of both fuel cells and hydrogen and that manufacturers of these technologies are starting to give battery producers a run for their money. The countries leading the charge are China and Japan.

HEDGE FUND TAKES ON BALLARD – THE NEW STOCK MARKET THRILLER?

Ballard Power's stock recently came under pressure for not fulfilling all the expectations of market analysts. The last quarter of 2017 didn't see a net loss of USD 0.01 but USD 0.02 per share. The net loss for the whole of last year was as much as USD 0.05, although on a non-adjusted basis. It means that despite a considerable leap toward breakeven in 2017, Ballard was still around USD 8 million in the red. Nevertheless, the outlook is bright, for fuel cells in general and Ballard Power in particular.

Total revenue in 2017 grew to USD 121.3 million, a 42 percent increase compared to 2016, while the company was able to raise the gross margin by another 6 percentage points to 34 percent. The year ended on a positive EBITDA of USD 3.3 million, making Ballard the industry's only company to have had a positive one for all of 12 months. Cash reserves added up to a healthy USD 60.3 million. Backlog reached USD 221 million, of which USD 91.4 million alone is expected for delivery in 2018.

> "So let's drive on."
>
> *Randall MacEwen, CEO of Ballard*

MULTIPLE REASONS FOR AN OPTIMISTIC OUTLOOK THIS EARLY IN 2018 Ballard announced several cooperation agreements and bookings in the first few months of 2018. When the company had its conference call about the last-quarter results, participants agreed that many more would follow. The company will

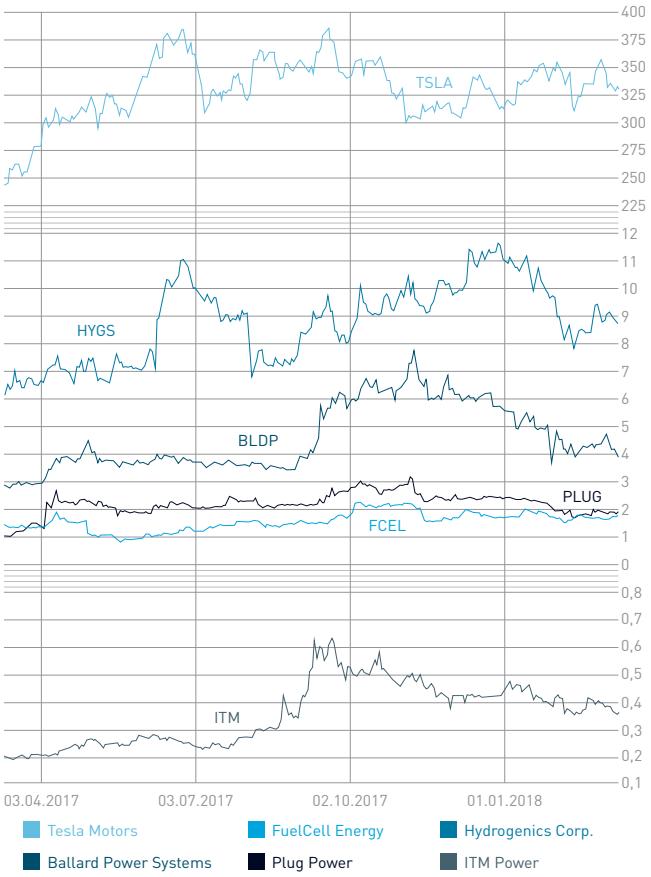


Fig. 1: Historical stock prices of the six companies mentioned in the articles below

1. Install fuel cells in 500 Dongfeng-owned trucks in Shanghai.
2. Collaborate with ABB on a fuel cell system for a Royal Caribbean cruise ship.
3. Team up with Siemens for train research (EUR 12 million in funds from German economy ministry).
4. Develop air-cooled fuel cell stacks for forklift trucks in USD 4.2 million program.
5. Research for partner Nisshinbo Holdings into replacing precious metals.
6. Expand fuel cell vehicle development on behalf of Audi and other automotive companies.
7. Cooperate with fuel cell system supplier Re-Fire in Shanghai.
8. Build 40 fuel cell bus engines for Van Hool (signed letter of intent) – largest individual order yet.
9. Deliver fuel cell equipment to the U.S. Army, via Protonex, for a respectable USD 1.6 million.
10. Test drayage trucks at ports in California in partnership with Kenworth, a Paccar subsidiary.

HEDGE FUND PUTS STOCK UNDER PRESSURE Ballard Power (Nasdaq: BLDP) has been the subject of an extremely negative report published by a hedge fund, which seems to have taken a

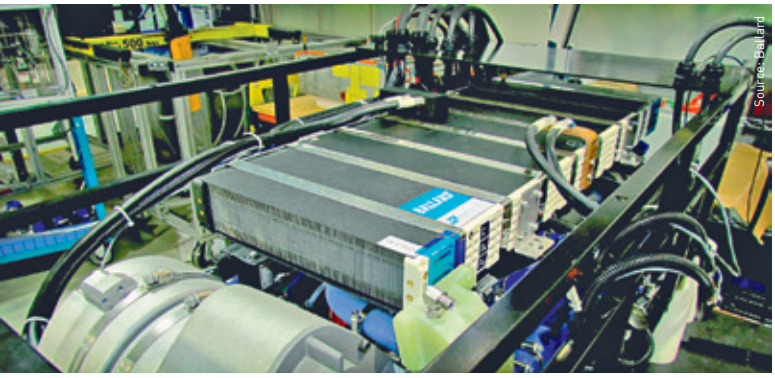


Fig. 2: Ballard stacks for commercial vehicles

Fig. 3: Installation in Bridgeport, USA

strong interest in the company. The authors said that the company had made false or misleading statements about its strategy for the Chinese market. They claimed that the Chinese partners were far from reputable and that some fuel cell buses were not operational. They also zeroed in on the currently low number of hydrogen stations in China. The 2030 target is 4.2 million charging points and 3,000 hydrogen stations. Ballard responded immediately, stating that the report contained unsubstantiated claims and that the authors got the details wrong too.

I think this hedge fund is a short seller that wrote the document to prompt shares to fall and profit through buying back stock at a lower price level. That is exactly what happened, as the stock fell from more than USD 4 to under USD 3. On the other hand, the fund may regard Ballard shares as a long-term investment and use the negative news to cause the price to drop and purchase shares when they are traded at lower levels. Who knows. The long-term scenario is supported by the fact that only around 5 million of Ballard's shares have been sold short, a miniscule number compared to a total of more than 170 million outstanding. In the meantime, several law firms have filed class action suits, since the price dip lost shareholders a lot of money. Ballard has taken measures to respond.

What's more important are the facts "on the ground" and they put the company in a very favorable light. For example, Dongfeng, based in Shanghai, China, placed an order for the delivery of 500 fuel cell truck systems. Unfortunately, there is no information about the contract value in dollars, but I suspect it to be in the mid-eight figures. I think the contract is part of an existing framework agreement on equipment parts, or, more specifically, membrane electrode assemblies. Nevertheless, it has been the first large booking for truck equipment and will dramatically expand the market for Ballard fuel cell stacks.

Protonex was able to snatch up an initial USD 1.6 million order by the U.S. Army, which should be viewed as a good first sign. Expectations are that the United States Army could potentially buy between USD 150 million and USD 250 million worth of Protonex products over five years. Furthermore, an unknown corporation – my guess is Toyota Tsusho – is said to have tasked Ballard with developing the latest generation of air-cooled fuel cells, capable to power forklift trucks for more than 20,000 hours. The contract, which is hoped to lead to considerably reduced fuel cell system costs, is valued at USD 4.2 million (see Plug).

Plus, the two German mass transit companies responsible for public transportation in Cologne and Wuppertal commissioned Van Hool to construct 40 fuel cell buses and Ballard seems to be delivering the fuel cell stacks for the project. At least, it has signed a letter of intent, with an order sure to be next. Other communities and cities may follow their example – London comes to mind – and outdo their booking, the largest individual one for fuel cell buses in Europe to date.

In short, Ballard is the leader in the design of advanced fuel cell systems across several markets, applications and partnerships. The company's stock will retain its volatility, but whoever can wait a bit and watch the fuel cell market over the next years will benefit from his or her stake in Ballard. Maybe, this is the time to adapt an old stock market adage: Buy on bad news. If prospects are good, keep what you have.

FUELCELL ENERGY – CARBON CAPTURE OFFERS GREAT POTENTIAL

FuelCell Energy (Nasdaq: FCEL) has announced its financial results for the first quarter in 2018, ended Jan. 31. Total revenue amounted to USD 38.6 million, up from USD 17 million in 2017. The company posted a loss of USD 8.4 million, including USD 3.5 million in deemed dividends on preferred stock. Financial liquidity on the balance sheet date added up to USD 115.4 million, part of which is a USD 40 million revolving project financing facility by NRG Energy, a strategic partner. Contract backlog reached a record high of around USD 638.5 million. The inclusion of announced project awards will drive up the sum to USD 1.6 billion.

> "Strong revenue, tremendous backlog and a strong balance sheet."
>
> *Chip Bottone, CEO of FuelCell Energy*

FuelCell Energy recently finished a 20-megawatt fuel cell power plant that it had built on behalf of Kospo in South Korea. The company could announce other fuel cell projects over the next months (see p. 12). For example, it is working on a 40-megawatt installation for the Long Island Power Authority.

CARBON CAPTURE ExxonMobil is pinning its hopes for the sector on carbon capture and FuelCell Energy technologies, which promise 90 percent lower carbon dioxide and more than 70 percent lower nitrogen oxide levels. Success in the current pilot stage could lead to Exxon placing monumental orders that could generate nothing but excitement among fuel cell enthusiasts, I bet.

Overall, FuelCell Energy is in a good market position. Through a series of warrants that are yet to be converted, it is planning to build a financial cushion for large projects. The company's portfolio consists of industrial equipment support, which generates revenue through parts delivery and service as well as maintenance contracts, and fuel cell system operation, to sell >>

power, heat and cooling and carbon capture capabilities. This portfolio allows for potentially very notable growth rates and returns, which should have a positive impact on the stock price.

PLUG POWER EXPECTS STRONG SECOND QUARTER

Plug Power (Nasdaq: PLUG) has moved into a strong position on the forklift truck market. Many A-list customers have come to rely entirely on fuel cells and signed impressive multi-year contracts for more than 19,000 hydrogen-powered forklift trucks and 15,000 hydrogen fill-ups per day. Plug is also designing fuel cell systems for courier vans and is pushing into China, which is not an easy task, I might add. It has asked Barclays Bank for help in finding suitable partners to gain a foothold in the Chinese market.

One positive piece of news is the United States' extension of the 30 percent investment tax credit (see p. 60) and the continued financial support for fuel cells. Considering these developments and the statements by CEO Andy Marsh, I could see Plug expecting one of this year's quarters to exceed USD 50 million in revenue and reach a positive EBITDA. In 2017, revenues added up to USD 130 million. In 2022, the figure is said to grow to more than USD 500 million, two years later than had been predicted earlier.

ENTHUSIASTIC MCKINSEY CONSULTANTS What's clear is that the global fuel cell market shows strong and sustained growth. McKinsey puts the investment in fuel cell technology at more than USD 275 billion in the coming years. It added that the global market for fuel cells, including hydrogen production, could reach USD 2.5 trillion in size in 2050. Regarding forklift trucks and material handling equipment, McKinsey sees fuel cells beating batteries by a mile and a half in the long term.

On March 7, Plug announced its fourth-quarter results, with gross revenues adding up to USD 33.7 million. Over the entire year, the figure grew to USD 132.9 million, a 55 percent increase compared to 2016. Plug has installed GenDrive systems in 16,600 forklift trucks and set up the required infrastructure, between four and six hydrogen pumps each, at more than 60 locations. The company had a year-end cash position of USD 68.1 million. The fourth quarter saw the completion of new bookings worth USD 125 million, which brought the 2017 total to USD 285 million. In all, though, Plug posted an adjusted loss of USD 18.5 million or minus USD 0.08 per share. Revenues for 2018 are expected to be somewhere between USD 155 million and USD 180 million. In the meantime, the company is continuing to work on fuel cell stacks reported to last much longer than previous versions, so it can realize cost savings in the foreseeable future.

All in all, the company's outlook remains positive. Nevertheless, I think Ballard Power and FuelCell Energy are more promising targets for investment and easier candidates for short-term assessments. I view Plug as a Hold until it becomes a bit clearer when the company can break even. I'm not entirely certain at this point how to rate the warrants to big customers, such as Amazon and Walmart. These warrants, which are tied to cash payments, will see their exercise price adjusted after a certain number has been vested and this adjustment and tax considerations will affect quarterly results. I will explain the situation in more detail in one of the next issues of H2-international.

HYDROGENICS VS. ITM POWER

Canadian producer Hydrogenics (Nasdqaq: HYGS) and British manufacturer ITM Power (London: ITM) aren't entirely comparable, but they use similar technologies. There are some commonalities in the form of power-to-gas projects, hydrogen stations and powerful electrolyzers to generate the gas. Their market caps aren't as far apart as I would expect based on the number and contract value of bookings. Both stocks have experienced severe price drops. ITM Power's shares have fallen from more than GBP 0.56 to under GBP 0.40, while Hydrogenics' have dipped from more than USD 12 to around USD 8. The two companies have several first-rate customers, but in contrast to ITM, Hydrogenics has also been involved in projects to design road vehicles, or, more specifically, fuel cell trucks, and trains, in collaboration with Alstom. Likewise, it has a considerable foothold in China, as a Chinese corporation has become one of its major shareholders.

Fig. 4: Simon Bourne in the ITM container

In short, I recommend Hydrogenics over ITM, although the British manufacturer's price decline will possibly come to a halt soon. However, ITM's stock of over 320 million shares seems a bit excessive to me and the contract value of bookings is merely a fraction of Hydrogenics'. Moreover, I see the Canadian producer as a takeover target because a partner such as Alstom could be interested in acquiring the company's railroad know-how. Ballard would be another ideal buyer, in my opinion. Both Ballard and Hydrogenics hail from Canada, have made major investments in China and possess top-notch fuel cell expertise. Additionally, Hydrogenics' range of electrolyzers would be a good addition to Ballard's portfolio, since the latter could offer customers hydrogen production facilities following the acquisition of the former. Hydrogenics is shaping up to be the much better deal, especially after the price drop.

2017 RESULTS The fourth quarter ended on Dec. 31, 2017, with a surge in revenue to USD 19.5 million, a 124 percent increase compared to the same period the previous year. The revenue total for 2017 was USD 48.1 million, a 66 percent increase over last year. Cash, cash equivalents and restricted cash added up to a healthy USD 22.4 million, while backlog reached a record-like USD 144.6 million, of which more than USD 55 million is expected to be recognized in 2018. The company senses great potential for growth in China.

TESLA: LIVIN' IN MY OWN LITTLE WORLD

This or a similar sentiment could describe in a nutshell the content of the tweets and comments by Elon Musk, the charismatic CEO of Tesla (Nasdaq: TSLA). Reality is a bit of a world apart. In the fourth quarter of 2017, Tesla lost around USD 675 million despite strong growth in revenue to USD 3.3 billion. The average share loss was either USD 4.01 based on GAAP, which I prefer, or USD 3.04 per share based on non-GAAP.

Losses should be seen in relation to the extraordinary income of around USD 180 million from the sale of zero-emission vehicle credits, tax credits tied to an electric car quota in the United States. Similarly, financial liquidity leaves much room for interpretation. The last quarter had cash flow in the negative by as little as USD 277 million. This figure, however, includes the USD 180 million in credit sales and customer deposits for future models. The latter range from prepayments of between USD 50,000 and USD 150,000 for the roadster to USD 20,000 for a semitruck to the amounts deposited for the company's flagship vehicles, Model S and Model X.

The delay in Model 3 production leads me to believe that the first quarter of 2018 will see the company again incurring high losses, equal to what had been posted in the previous one, or even worse. Zero-emission credit sales should not be overlooked as a factor in all of this. Likewise, some critics suspect that Tesla will first serve customers who were willing to fork over USD 45,000 to USD 60,000 for a car. Preferring those who spend more on extras over the people who pay only the USD 35,000 list price would certainly boost revenue. But some people who made a deposit might request their money back as soon as they have to wait for more than a year and competitors start to offer models that look just as good as a Tesla car, may be much less expensive and have a higher range.

It's not getting any easier for the corporation. Even USD 3.4 billion on the bank is nothing if cash is used up as quickly as it has been in the past. Theoretically, the amount could be gone in three to four quarters. The next capital raise will get more difficult, as institutional investors especially want to see some benefits from investing in the company. It is very likely that the next time a raise is announced, you will see a discount on the stock price.

CEO MUSK'S COMPENSATION PLAN Musk is his usual old self. He intends to stay on as CEO for another 10 years and the only thing he asked for when renewing his contract was not a salary but a compensation package of performance-based warrants and stock. This package is tied in with the company's market valuation, which he could imagine reaching USD 650 billion. That Tesla's shareholders would agree is clear, just as clear as Musk's major influence as an owner in the company. Through his 37 million shares and in cooperation with five large funds, unanimous decisions on capital raises are a foregone conclusion. Refusing an annual paycheck of USD 56,000 for his role as CEO isn't really a big deal. Since he took out a loan on part of his shares, he must already have several billion dollars on his personal bank account.

Speaking of payments, launching a roadster on a rocket into space was most likely not done to attract new buyers but to grab the spotlight. It would be interesting to know who paid for it. SpaceX? Elon Musk? Or Tesla's stockholders?

Fig. 5: Recharge, please

THE COMPETITION ISN'T DRAGGING ITS FEET The semitruck, which Tesla itself is showering the most praise on, could get serious competition in the near future. I'm talking about the battery-fuel cell hybrid by Nikola Motor Company. The corporation said that it would soon be making an important announcement regarding one of its partners. It is also planning to set up several hundred hydrogen stations to ensure that there are enough refueling options available to some of its truck customers.

Jaguar, on the other hand, just unveiled its I-Pace. It offers a range of 480 kilometers, or 298 miles, is less expensive than a Tesla and will reportedly cut down on recharging times. Other manufacturer will be sure to announce their own models soon. Hyundai is also stepping on the gas, as is Porsche, which presented a concept study to make 15-minute recharging a reality. Again, others will certainly follow in their footsteps. Meanwhile, expectations are that Tesla will "refresh" its Model X and Model S, a kind of relaunch with product enhancements. Stay tuned.

What I can say is that much, way too much, hinges on the production figures of Model 3. Production schedules are being updated time and again, of course, with milestones of between 5,000 and 10,000 units per week. I am certain that Tesla's revenue will continue to grow at a rapid pace. But will the vehicle earn the company money? Some reports forecast sky-high profits, but what about the new roadster and the semitruck? Or the SUV named Model Y? Does the setup of new production lines for these vehicles come at no cost? When will they be ready for production, let alone delivery? Why are top executives leaving the company in droves?

I do think that the next capital raise will have a stock price discount attached to it. ||

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 ones, i.e., they may experience high stock volatility. This article is not to be taken as a recommendation of what shares to buy or sell – it comes without any explicit or implicit guarantee or warranty. All information is based on publicly available sources and the content of this article reflects the author's opinion only. This article focuses on mid-term and long-term prospects and not short-term profit. The author may own shares in any of the companies mentioned in it.

Theme: Education & training | **Author:** Robert Steinberger-Wilckens

EDUCATING TOMORROW'S FUEL CELL RESEARCHERS

The European summer school's fuel cell course offerings

Fuel cells are highly productive systems for converting energy from hydrogen into electricity. Their conversion efficiency of 50 percent to 60 percent has made them a subject of intense interest among stakeholders in the EU's current and past research framework programs. However, if there is to be a concrete implementation strategy to introduce zero-emission power generation throughout Europe, one will need not only systems based on the technology but also skilled personnel to operate them.

The increasing amount of electricity that is generated through renewable energies, particularly wind and solar, has prompted growing demand for storage technologies. This demand can be met by hydrogen, through electrolyzers and fuel cells, and batteries, both of which will offer options for electrochemical storage and subsequent electricity generation. Moreover, power-to-gas and power-to-fuel technologies have opened up new opportunities to provide, in the form of hydrogen, renewably sourced power for other energy markets, such as fuel production and trade or, through pipelines, the gas sector. Hydrogen can contribute a great deal to decarbonizing our energy network – if there are enough people with knowledge of the associated equipment.

The Strategic Energy Technology Plan, created by the European Commission in 2014, put the number of people in need of proper training and employment in the field by 2030 at 200,000 technicians, engineers and researchers. Considering the duration of training and the rapid deployment of battery, fuel cell and hydrogen units, the current number of available professionals must see a dramatic increase, even if many technicians and engineers who have already found work today will have to shift their attention to the design and operation of battery or hydrogen and fuel cell systems.

JESS PROGRAM To educate tomorrow's specialists, JESS, the Joint European Summer School, offers university graduates high-quality courses on fuel cells, electrolysis and batteries. These courses originate with a 2004 training program that was part of the EU project Real-SOFC. At the time, education focused on solid oxide fuel cells only, but the scope of the sessions was extended between 2010 and 2012, during TrainHy, to include a class on low-temperature fuel cells. Batteries and electrolyzers were added a while later.

The Joint European Summer School, which will again take place this year, has been available in its current form since 2013. What once was a one-week seminar has been turned into a two-week event. In the second week, attendees acquire specialized knowledge of, for instance, hydrogen safety and fuel cell vehicles.

JESS will be co-organized by the University of Birmingham and the Jülich Research Center, in cooperation with RWTH Aachen University and the Technical University of Denmark.

Source: University of Birmingham

JESS is mainly targeted at university students who have obtained their bachelor's, master's or PhD degree. But experienced researchers and engineers are likewise invited to participate and benefit from a more in-depth look at new technologies, build a knowledge base for a new employment position or collect points for the Continuing Professional Development program.

WEEK 1 – BASICS JESS has been tailored to the needs of a broad audience, including newcomers, experienced students, young professionals and experts in fuel cell, electrolysis and battery applications. In the first JESS week, Sept. 10 through 14, 2018, there will be three separate introductory modules about

- High-temperature fuel cells and electrolyzers, i.e., SOFCs and SOEs;
- Low-temperature fuel cells and electrolyzers, i.e., PEM and alkaline systems;
- Battery technology.

Classes will focus on the science and technology of the entire range of materials, designs and peripheral, or balance of plant, components based on electrochemical and thermodynamic principles.

WEEK 2 – ADVANCED CLASSES The following week, Sept. 17 through 21, will offer four courses on

- Fuel cell electric vehicles;
- Business development and innovative technologies;
- Hydrogen safety;
- Advanced modelling.

The emphasis of the second week, which will be conducted independently of the first, will be on technology and innovation. The second-week courses are especially aimed at older students and engineers who would like to acquire more specialized expertise. Building on students' experience, the modules will focus on vehicle technologies, starting a business and the safe handling of hydrogen.

During the course, there will be presentations, exercises, debates and Q&A sessions. In addition to the seminar modules, attendees will participate in a project to put theory into practice. This hands-on part will have learners apply the knowledge they gained during the seven days to a case study, with an award for the best presentation of findings at the end of the week.

The first week's modules, which carry 3 credit points each in the European Credit Transfer System, have been accredited by the three summer school universities. The classes in the second week also carry 3 ECTS points, or 10 credits based on the British system, and have been accredited by the University of Birmingham.

The Introductory Classes will offer a bird's eye view on the entire branch of electrochemistry, including system manufacturing and applications. Lectures will be combined with cross-subject study units, during which everyone will gather for presentations on aspects common to all three technologies. The courses on low- and high-temperature fuel cells, electrolyzers and batteries will be structured as follows:

- Introduction to electrochemistry and thermodynamics and their basic concepts;
- Materials;
- Components, design and manufacturing;
- Systems and applications.

The specialized course content can be of use not only to students of fuel cells and hydrogen, for example to receive a doctorate in the field, but also to other university graduates and to professionals researching or working on these technologies.

The Fuel Cell Electric Vehicles module will comprise theoretical and student-managed exercises, ranging from the choice of electrical and fuel cell powertrain components to the history and future of fuel cell electric vehicles. This module is suited for learners who have already participated in seminars on fuel cell technology and electrochemical devices. It will provide insights into basic FCEV design research and associated technologies. Attendees will learn about technology selection, state-of-the-art equipment and the beginnings of FCEV research. Topics will include:

- Hybrid powertrain technology and components, fuel cells and batteries;
- Vehicle design and lightweight construction;
- Environmental impact of FCEVs and the history and future of fuel cell electric vehicles.

Business Development and Innovative Technologies will combine theory and practice. The objective is to help participants develop viable business ideas and acquire the investment capital for different growth stages. It will consist of five interrelated components:

1) The Ideation/Creativity unit will teach attendees how to develop business ideas, including the Design Thinking approach and other ways to build early prototypes.
2) Innovation Management will explain how the Business Canvas concept can help create a viable business model, clear possible barriers to growth and identify target markets.
3) In Early Stage Finance, participants will study and discuss alternative methods of financing available to companies in an early stage of development.
4) The Growth Finance Class will introduce attendees to financial mechanisms that large corporations use to grow.
5) The Business Development and Intellectual Property unit will show, for example, how to create a university spin-off and protect its intellectual property. It will also address the subsequent paperwork challenges that management will have to face.

The Hydrogen Safety module will provide an in-depth look at an important but often overlooked and misunderstood topic, namely the safe handling of hydrogen. Each fuel cell vehicle requires a hydrogen tank, which will soon turn the gas into a commodity. Many people, however, are not used to operating hydrogen equipment, a frequent response being questions about how safe it is. Educating the public on how to deal with the real risks, in contrast to imagined ones, and take necessary precautions will facilitate the introduction of hydrogen and fuel cell system and improve public acceptance.

This module is aimed at first and second responders, government and administrative staff involved in the issuance of construction and operating permits for hydrogen systems, and site safety managers. It will draw on a broad scientific and industrial knowledge base. Topics will include:

- Rules, codes and standards;
- Effects of hydrogen release, fires and explosions;
- How to handle liquid hydrogen;
- How to handle hydrogen at repair garages, including first-hand experience with a Toyota Mirai car;
- Safety strategies and engineering solutions.

The Fuel Cell and Systems Modelling Master Class will blend theoretical knowledge, exercises and student project presentations. It will offer insights into several modelling techniques and software platforms to assist learners in broadening their know-how of modelling and programming tools. It is suited for anyone who has experience with rendering fuel cell and electrochemical equipment models. The module will teach the basics of modelling software packages, their differences and application, including Open Source codes. Topics range from mathematical principles and thermodynamic calculations to computational fluid dynamics >>

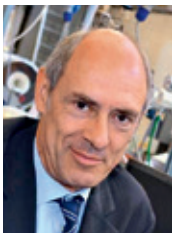
JESS will take place in Vouliagmeni, south of Athens, directly on the coastline. The hotel that houses the school is located 100 meters off the beach, 17 kilometers away from Athens' inner city. It is also 19 kilometers away from the international airport, which is easy to reach using public transportation. The flight and accommodations will be handled by a well-established Greek travel agency. Course fees are EUR 1,435 per module. This price includes study fees, a single room for six nights and three meals a day. The early bird discount will be available until the end of April and participants sharing a double room can get a discount too. For more information, please contact John Hooper at the University of Birmingham.

simulations and finite element analyses, that is, from Zero-D to 3-D models. One of the key points will be multi-physics modelling. All this will serve to provide attendees experienced in computer modelling with a better overview of possible alternatives and generate valuable suggestions to adjust their project approaches.

The second part of the module will have participants present their own modelling and simulation projects, offering them a chance to receive feedback and comments from instructors and fellow students. The overall aim is to address modelling issues and, possibly, to discover new approaches and solutions based on discussions with colleagues and renown experts.

NETWORK OF EXPERTS Informal networking is a key element of science and research. JESS offers ample opportunity to get to know colleagues and experienced scientists. At the start of a course, learners will introduce themselves briefly and present their current and planned research activities. JESS draws on the knowledge and expertise of a select group of instructors who are leaders in fuel cell, hydrogen and battery research and development in Europe. All of them have an extensive net of contacts at universities, national research institutions and businesses. Since JESS is a summer school, participants will have enough free time to relax in the afternoon, enter into conversations with instructors or discuss projects, future collaborations and general issues. ||

www.jess-summerschool.eu.



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UNITED STATES EXTENDS FUEL CELL FUNDING

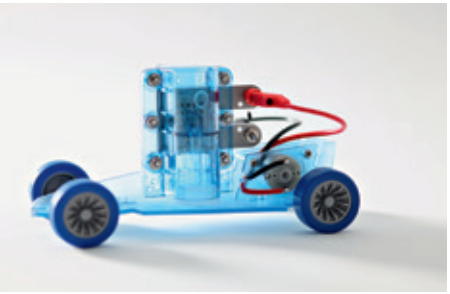
The United States Congress has restored the 30 percent investment tax credit for fuel cell power generation and forklifts, extending it through 2022, with a reduction in the final two years. The credit would be 26 percent in 2021 and 22 percent in 2022. This brings the fuel cell incentive in line with incentives for other advanced and renewable energy technologies.

The tax credit was a significant factor for the fuel cell industry. Companies said that its lapse on Dec. 31, 2016, had materially affected their business, although significant sales continued in 2017. Congress restored it effective Jan. 1, 2017, so there will be a windfall for people who purchased systems in 2017, in addition to a boost for buyers going forward. In an odd turn of events, Congress also approved a one-year retroactive credit for fuel cell vehicles and hydrogen infrastructure purchased or installed in 2017, providing a windfall for early adopters.

President Donald Trump's budget proposal for the vehicle-related fuel cell and hydrogen program is USD 58 million for fiscal year 2019. The president's proposal has little practical effect given recent congressional actions, but it does reflect the administration's view that the program – like all renewable energy and energy efficiency programs – should be scaled back and that the focus should be on long-term research. This shift is certainly reflected in recent presentations by Department of Energy staff.

There is still no nominee to be Assistant Secretary for Energy Efficiency and Renewable Energy, another sign of the government's priorities. But it has been reported that Scott Pruitt, who heads the Environmental Protection Agency, would visit a hydrogen generation facility during a planned trip to Japan. No doubt the visit was included at the urging of the Japanese. Nevertheless, it may have some impact. ||

SYNERGY IN EDUCATION



In February 2017, the Czech member of Singapore-based Horizon Educational Group acquired Heliocentris Academia, or at least some portion of it (see H2-international, May 2017). Other assets, or, more specifically, part of the sales, advanced manufacturing and back-office divisions, went to the group's companies in China and the United States. What remained in Berlin, where Heliocentris Academia has its headquarters, were engineering and quality control as well as some of the sales and production capacities.

The Czech business, located in Prague, is an independent entity within the Horizon Educational partner network, specializing in learning programs and technical training in renewable energies, energy storage and energy management systems. It provides a wide variety of services, from demand analysis to customized solutions and installations to seminars and after-sales support.

CEO Timo Lukkarinen told H2-international that Heliocentris Academia's previous management team had never been able to make the company profitable. He was confident, though, that he could turn the tide of negative financial results. Horizon and Heliocentris Academia employed similar technologies, he explained, which offered the opportunity to develop a synergy in purchase and manufacturing. Since both businesses' product lines were a good match, the same, and more, could be said for sales, where as little as 20 percent of the products would need to be sold through separate distribution channels.

He added, "The longer-term goal of Horizon Educational is to supply middle and high schools with science kits and STEM programs. Heliocentris Academia, on the other hand, will concentrate on providing educational resources to job training facilities, universities and research institutions." ||

Theme: International | **Author:** Professor Birgit Scheppat

JAPAN, THE RISING STAR

Birgit Scheppat reporting from Tokyo's FC Expo

Source: Peter Sauber Agentur Messen und Kongresse

Fig. 1: Big crowd at the German Pavilion

The 14th International Hydrogen and Fuel Cell Expo took place Feb. 28 through March 2 in Tokyo, Japan. According to the organizers, it is the largest hydrogen and fuel cell show in the world. One regular exhibitor over the past several years has been H2BZ-Initiative Hessen, the hydrogen and fuel cell initiative from the German state of Hesse. It shared space with other organizations at the German Pavilion, which Peter Sauber Agentur organizes each spring. Professor Birgit Scheppat, who chairs the initiative, has been a longtime FC Expo attendee. Below is her report on the pavilion and the entire show.

On three days, FC Expo provided a forum for discussing hydrogen and fuel cells, batteries and smart grids. In 2018, the exhibition space seemed to have grown in size compared to previous years. It was teeming with attendees right on the first day. Every exhibit attracted a throng of them, and seemingly endless streams of people dressed in dark-colored business attire moved around the premises. I think Hannover Messe is the only other event at which I have ever seen such a crowd, once or twice.

INTRIGUING CLASH OF IDEAS: JAPAN VS. THE UNITED STATES

Today was my day for presentations. First, I listened to what Tadashi Mogi from the Japanese economy ministry had to say about the future of hydrogen. Immediately thereafter, Daniel Simmons from the U.S. Department of Energy took the stage. Simmons, with his illustrious title of principal deputy assistant secretary, was the one who presented President Donald Trump's view. It was fascinating, watching this clash of ideas. On the one hand, you have a society that has a clear vision for its future. On the other, you have a country that wants to revive the past.

But let us stick with the commonalities for a moment. The aim of both countries is to make every sector, be it transportation, housing or production, more energy efficient. However, the plans to achieve efficiency targets seemed to be short on details. The two representatives talked about minimizing fine dust and emission levels, although Simmons regarded these things as less relevant. Hydrogen was one source to warrant consideration, but it was hardly a vital item on his agenda. What was much more important to him was that the United States, which used to be an importer of crude oil in 2000, had turned into an exporter of the black gold and that low-cost shale gas was helping America's industries. He added that technological progress had led to cheap energy resources. No, not merely affordable or inexpensive resources – cheap ones!

He said that 10 percent of the power generated in the United States was from renewable energies, 29 percent from natural gas, 37 percent from petroleum, 15 percent from coal and 9 percent from nuclear energy. All the while, the number of kilometers travelled by citizens in the United States had increased by 190 percent and total energy consumption by 44 percent. The level of pollutants, however, had decreased by 73 percent. You notice that these outcomes look impressive, but Simmons avoided mentioning anything else than percentages throughout his presentation.

He did announce a new government strategy to improve energy efficiency. It would focus on early research and development, especially battery technology, and include lightweight vehicle design.

Simmons said that there would be an opportunity for deploying hydrogen and fuel cells if, and only if, the prices for these technologies came tumbling down. Then, the United States could see the deployment of 40,000 hydrogen vehicles, limited to California, since no other state is adding hydrogen stations in significant numbers. The federal government >>

also has its eyes set on expanding the country's outdated electrical grid and enhancing old technologies such as natural gas liquefaction to drive sales abroad. I quote, "Exporting energy is exporting freedom."

Let us come back to Japan. The 2020 roadmap was said to be revised and refocused in the weeks following the show. There was no definite statement on what would happen after the Olympic Games in 2020, although a few objectives had crystallized. One of them was to catch up to countries such as Germany and Spain regarding the use of renewable energies. Another was to improve energy efficiency, whether at home, where it is still low, in transportation or manufacturing. By 2030, these objectives are planned to be implemented, so that all sectors could become virtually decarbonized by 2050. Many challenges lay ahead, it was said, but there were some concrete plans on how to expand renewables.

Mogi also mentioned a project in Australia, where hydrogen is produced from dirty brown coal and is planned to be transported to Japan in liquified form. The dirt will stay in Australia and only the extremely cold gas will be shipped.

AUTOMAKERS AND THEIR APPROACHES TOWARD THE MARKET In the afternoon, I attended a series of presentations by Jörg Wind, Daimler; Sae Hoon Kim, Hyundai; and Jürgen Jablonski, Audi. Daimler's new SUV model called GLC has a hydrogen-based range of, exactly, 437 kilometers, or nearly 272 miles, and can run 49 kilometers, or around 30 miles, on battery power if the battery is charged through the plug-in connector. The latter is thought to alleviate fears that drivers may find hydrogen stations in their area to be non-operational. The car was indeed being manufactured, but there were still some issues to resolve, he said. One of them was the lack of a widespread network of refueling stations. Complaints were plentiful, but he gave no clear statement on when and how the car would become available.

In a similar vein, Audi's presentation would have needed to be dubbed, "I'd like to say something, but management won't allow it." Jablonski explained that within the VW conglomerate, it was Audi which manufactured parts of the fuel cell system at several sites, while its Neckarsulm location was coordinating all activities. Improvements had been made over the past months, but there was no commitment to any figures. Then, he showed the audience an image depicting a hydrogen tank in an entirely curious spot in the car. When asked, he replied that the image merely sketched out a prototype. He added that the system to be installed in the sixth generation would have an entirely different look and that you would have only two tanks. It was just one example of the many confusing things that were said.

Had it not been for the Hyundai representative and his presentation about the new Nexo, you would have started to develop doubts about how feasible hydrogen-based transportation really was. Suddenly, figures and components (if one was permitted to show them; see p. 32) were fair game. The car was in the final prototype stage, Kim said. He added that ramping up production solely depended on demand and the available infrastructure. He didn't want to put a price tag on the car, but he said that some customers had waved off the price question and would get it regardless. What was more important to him was to talk about production capacity to deliver the cars.

That the costs of fuel cells and tanks especially need to go down was on the minds of all three representatives for the automotive industry. Other aims were to make BOP components more reliable and drastically reduce system complexity. They agreed that there were a lot of ideas swirling around to deal with those issues and that the infrastructure needed to be expanded.

I'd like to conclude my report regarding the first day of the show with a quick observation about what couldn't be overlooked by anyone. The Chinese are here.

THEY AREN'T COMING, THEY'RE ALREADY HERE On the second day, I visited a lot of exhibits to get an overall picture of the show. After a while of walking from booth to booth, it occurred to me that the Chinese aren't coming – they're already here. Need materials to design a fuel cell? You can get them from China, just like tanks. Additionally, I saw an intriguing system by Chinese manufacturer Re-Fire. While its fuel cell model, ranging from 30 kilowatts to 70 kilowatts, contained a stack by Ballard, it was probably the most compact system I had seen in a long time. I'm looking forward to receiving an offer for it and knowing how much it will cost.

Not only did you find everything you need to construct an entire fuel cell system, but there was also the matter of government funding. In several conversations with Chinese exhibitors, company representatives repeatedly mentioned that China had showered its businesses in money. Whoever failed to seize the moment would pass up a great opportunity. China's provinces are currently in a fierce fight for pieces of the pie. I got to know Ruiming Zhang, CEO of Telos Auto Power Systems. He said that his company was constructing between 100 and 200 fuel cell buses and had already built several prototypes. The endeavor had been almost fully funded by the Chinese government. If more money was needed, sending a request was all it took.

China showed just as much strength on the battery market. From lithium production to power management systems and more, the country offered all that is needed to set up, test and accredit battery production facilities. Such a facility may not look like a prime example of modern design, but it was robust and all of it seemed to be working properly.

JAPAN READY TO MOVE AHEAD The Japanese, too, are looking to boost sales. Initially, their strategy has been to concentrate on the domestic market, but I'd be surprised if it stays that way. Japan's companies have enough products, from hydrogen stations to components to tanks, to increase their market presence. Need to measure hydrogen quantities at a gas station? Just talk to Tatsuno. There were still some technical issues to resolve, but the company's fancy app at least helped read metering data via Bluetooth connection. There was a truck for refueling. The Japanese make the things we are only talking about in Germany.

Likewise, people have taken to the idea of using brown coal in Australia to produce hydrogen and ship it in liquified form to Japan. Several times, I was also asked about NH3, better known as ammonia. It is said to be another way to produce more hydrogen.

It's a big show, bigger than the one last year. Booths had been crammed into the space as much as possible. There are

Funny side note: One corner of the exhibition space had been reserved for the last bit of the battery exposition. There, you could see a Tesla car with butterfly doors – pushed to the sidelines, where it belongs. Of course, you looked at it. But you immediately saw in people's faces whose heart was beating for hydrogen.


Source: Presscontact

Fig. 2: Birgit Scheppat

numerous pipe manufacturers, and exhibitors offer valves, components to recirculate the hydrogen, humidifiers and much more. Had you wanted a compressor, the question would have been, "Which size and pressure level do you need?" Whether large or small, any type of unit up to 1,200 bars, or nearly 17,500 psi, was available. What was equally noticeable was the number of on-site staff members of fuel cell suppliers such as Axane and ElringKlinger. Plus, there were tank systems, nearly all of them designed for 700 bars, or 10,000 psi.

In short, Japan is ready to move forward, and the country is a beehive of activity. No longer is it a matter of whether the era of hydrogen will come, but when and at which gas quality. Who will be the one leading the others? Interest in the technology was huge and the German Pavilion was almost always full. So many had come that, sadly, I had no more of our brochures for the next day – I handed out the last ones that evening. One presentation by NOW's Klaus Bonhoff alone attracted more than 1,000 people.

WHEN QUALITY MAKES A DIFFERENCE The buzzing at FC Expo didn't start to die down until around one hour before the end. At our German Pavilion booth, many Japanese attendees were asking questions such as "What's happening in Germany?" or "How are things going?" Those questions were mostly followed by apologies for the slow growth of renewables in Japan and a statement that the country was now fervently trying to catch up.

Japanese businesses are still focused on the domestic market when it comes to hydrogen and fuel cells. But they are aware of the tough competition growing in neighboring China and South Korea. Both countries take a different approach toward the market and I got the impression that they wanted to make the difference clear for all to see. Six Chinese companies, two of them based in Taiwan, had fuel cells on display. Not all cells looked like high-quality products, but the businesses' representatives told me that they had been designed using in-house materials, which could also be custom made.

Most of the units had between 1 kilowatt and 3 kilowatts of capacity and all of them were built akin to a Ballard model. There was no mention of open cathodes or recirculating the hydrogen, that is, returning the gas from the end of the bipolar plate to the main loop. Many systems were sold in small numbers and were not offered in combination with control equipment. One of the fuel cells had a basic surface area of around 5 centimeters to 10 centimeters, at a height of about 10 centimeters. It was said to have a capacity of 1 kilowatt, which would be at least twice the power density of products made by well-known companies such as Elring-Klinger and Axane.

By the way, the two businesses mentioned last had their hands full at the show. Booth personnel were repeatedly in conversations with potential customers, with others already lining up behind them. ElringKlinger, based in Dettingen, Germany, had a small stack on display. In conversation with a representative for the company, I was told that a complete system, meaning a stack and all necessary components, would be available at the end of the year. Production was in high gear, while demand for the company's diverse range of products was shaping up the same way. French manufacturer Axane didn't have anything to complain about either.

China is a horse of a different color. Quality is not the criterion that seems to be cherished the most. I wouldn't use many of the tanks that Chinese businesses were exhibiting for any type of application. They just couldn't dispel my doubts about reliability and robustness. It's not like there were many concrete statements on tests. The valves and channels didn't inspire confidence either. The majority were products to ride the wave – replicas and imitations, nothing truly original.

SOUTH KOREA, JAPAN'S OLD AND NEW COMPETITION

This means that the real competition does not hail from Japan or China but the Korean Peninsula. South Korea is supporting its industry in any way it can. When talking to a producer of electric bikes, I was told that South Korean delivery services using scooters, bicycles and other similar means of transport now intended to employ fuel cells to get around battery charging, which was burdensome and time-consuming. An employee of Sunbike told me that no one had the nerve for long charging times or the money to keep several batteries in store and that the supply chain was a horrible piece of logistics. On the other hand, the South Koreans are proud of their vehicles. They seem to have stolen the show from the Japanese at this year's Winter Olympic Games. In response, Japan will have to make its case for a hydrogen society during the 2020 Summer Olympics.

Many booths exhibited hoses and fuel dispensers. New connection technologies offered up to 1,000 bars, or 14,500 psi. The Japanese products looked very robust, but there were no plans yet to ship them to customers abroad. Large corporations such as Iwatani and Tatsuno had set up refueling systems. However, the units were not what you would call design showcases and no significantly new features were announced. Still, all companies had heard about the dangers of particles from hoses and internal surfaces. These particles could apparently spell trouble for fuel cells if they entered the hydrogen part of the system. ||

10-YEAR ANNIVERSARY

Two Japanese dressed up as yodelers from the German state of Bavaria were part of the event celebrating the 10th year in which Peter Sauber Agentur organized the German Pavilion (see fig. 1). When thinking about what relevant hydrogen and fuel cell developments originated in the state in southeastern Germany, I sadly couldn't recall any. The only excuse I could come up with was that those yodelers were from Japan. I guess that made it all right.

EVENTS 2018

April 23th to 27th, 2018
Hannover Messe
Group Exhibit "Hydrogen, Fuel Cells, Batteries" and MobiliTec
Hannover, Germany
Hannover Messe, www.h2fc-fair.com

May 9th to 11th, 2018
EV Expo – International EV Industrial Ecology Chain Exposition & Global Electric Vehicle Leadership Summit
in Guangzhou International Sourcing Center, China
www.evexpovip.com

May 14th to 15th, 2018
5th Residential Energy Storage Forum
organized by Dufresne
Berlin, Germany
www.energystorageforum.com

May 15th to 17th, 2018
The Battery Show
in Hanover, Germany
www.thebatteryshow.eu

THE BATTERY SHOW
EUROPE 2018

May 15th to 17th, 2018
Electric & Hybrid Vehicle Technology Expo Europe
in Hannover, Germany
www.evtechexpo.eu

May 16th to 18th, 2018
11th Energy Storage World Forum
organized by Dufresne
in Berlin, Germany
www.energystorageforum.com

June 17th to 22nd, 2018
22nd WHEC
in Rio de Janeiro, Brazil
www.whec2018.com

June 19th to 21st, 2018
Electrify Europe
Messe Wien, in Vienna, Austria
www.electrify-europe.com

June 19th to 22th
ees Europe & Power2Drive Europe
Europe's largest exhibition for batteries and energy storage systems
The exhibition for charging infra-structure and e-mobility
Conference: June 19th to 20th, 2018, in Munich
Fair: June 20th to 22nd, 2018, in Munich
together with *Intersolar Europe*
www.ees-europe.com
www.powertodrive.de

July 24th to 27st, 2018
Hypothesis XIII
HYdrogen POwer THeoretical & Engineering Solution International Symposium
in Singapore
www.hypothesis.ws

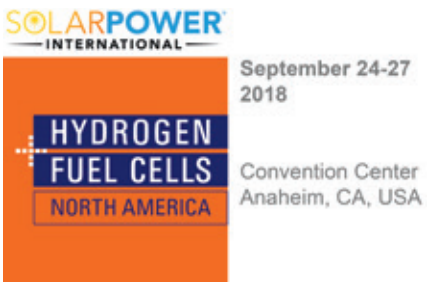
July 26th to 28th, 2018
China International Hydrogen and Fuel Cell Exhibition (CHFCE)
China International Exhibition Center
organized by China Machinery Industry Federation
in Beijing, China
http://en.chfce.com

September 10th to 14th, 2018
European Summer School on Hydrogen Safety (ESSHS 2018)
Week 1 – Introductory Classes
in Athens, Greece
www.jess-summerschool.eu

September 17th to 21st, 2018
European Summer School on Hydrogen Safety (ESSHS 2018)
Week 2 – Advanced Classes
in Athens, Greece
www.jess-summerschool.eu

September 18th to 19th, 2018
f-cell
in Stuttgart, Haus der Wirtschaft
www.f-cell.de

September 24th to 27th, 2018
Hydrogen + Fuel Cells NORTH AMERICA
Part of SOLARPOWER International (SPI)
Convention Center Anaheim, California, USA
www.h2fc-fair.com/usa



DISCOUNTS + TICKETS

April 23th to 27th, 2018
Hanover Fair in Hanover, Germany
Free Tickets for the fair
www.hannovermesse.de/ticketregistrierung?wmv3r

May 14th to 18th, 2018
11th Energy Storage World Forum
5th Residential Energy Storage Forum
in Berlin, Germany
10% Discount for the conference
Code for registration: H2Int18
http://energystorageworldforum.com

May 15th to 17th, 2018
The Battery Show Europe
in Hanover, Germany
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www.thebatteryshow.eu

June 20th to 22th 2018
electrical energy storage ees – Inter-solar Europe in Munich, Germany
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Code: H2ees2017
www.messe-ticket.de/INTERSOLAR/Fairevents

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ENERGY STORAGE

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HPS Home Power Solutions GmbH, Carl-Scheele-Str. 16, 12489 Berlin, Germany, Phone +49-(0)30-5169-5810, mail@homepowersolutions.de, *www.homepowersolutions.de*

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

MicrobEnergy GmbH, Specialist in Methanisation, Bayernwerk 8, 92421 Schwandorf, Germany, Phone +49-(0)9431-751-400, Fax -5400, info@microbenergy.com, *www.viessmann.co.uk*

EVENT ORGANIZERS

Group Exhibit Hydrogen + Fuel Cells + Batteries
Hannover Messe 2018, April 23 – 27
Hydrogen + Fuel Cells NORTH AMERICA
Solarpower 2018, September 24 - 27
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, Wankelstr. 1, 70563 Stuttgart, Germany, Phone +49-(0)711-656960-55, Fax -9055, *www.f-cell.de*

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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*

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