Hydrogeit Verlag / www.h2-international.com / October 2018 / 10$

H2 international

THE E-JOURNAL ON HYDROGEN AND FUEL CELLS

→ INTERVIEW WITH ROBERT HABECK

→ BIOLOGICAL HYDROGEN PRODUCTION

2018 EUROPEAN ZERO EMISSION BUS CONFERENCE

LEARN WHAT'S NEXT IN CLEAN TRANSPORT

Accelerating the adoption of battery & fuel cell electric transit buses.

November 27 & 28, 2018 in Flora, Cologne, Germany

Technology and policy experts will lead a two-day conference to drive forward the realisation of zero emission public transport for Europe.

Agenda overview:

- Technological readiness
- Zero emission bus deployment
- Lessons learned from policy makers and operators
- New business and financing models
- Scaling up – going from small bus fleets to complete zero emission bus fleets

Details & registration:

www.zebconference.com/eu

Follow the ZEB on Twitter:

@EUZEBconference #ZEB2018

Organisers

Hydrogen Europe · elementenergy · ZERO EMISSION · Stadt Köln

Partners

FCH · ElektroMobilität NRW · EnergieAgentur.NRW · HyCologne

Sponsors

MICHELIN · Linde · ITM POWER · nel · VANHOOL · BALLARD · McPhy · NOW · RK · EMCEL · Safra

CONTENT

7 Ten-year NOW anniversary

8 WHEC2018 in Rio de Janeiro, Brazil

14 Robert Habeck at GreenTEC Campus

H2-international
H2 international E-JOURNAL ON HYDROGEN AND FUEL CELLS

ISSN 2367-3931
Years/Issue No. 4, October 2018

Publisher Hydrogeit Verlag
Sven Geitmann, Gartenweg 5
16727 Oberkraemer, Germany

VAT ID No. DE 221143829
Legally Responsible for Content Dipl.-Ing. Sven Geitmann
Phone / Fax +49 (0)33055 213 ext. 22 / 20
Email info@h2-international.com
Web www.hydrogeit-verlag.de, www.h2-international.com

Editorial & Research Sven Geitmann, Alexandra Huss, Niels Hendrik Petersen, Sven Jösting, Jörg Staude

Design Dipl.-Des. Andreas Wolter, Weimar
Typesetting Dipl.-Des. Robert Müller, Berlin
Adverts Kirsten Laasner Projektmanagement, Bad Segeberg
Translation Björn Vrooman, Pirna

Frequency 4 digital issues per year

Single issue (DE) USD 10 / EUR 8 (excl. VAT)
1-year sub (DE) USD 40 / EUR 35 (excl. VAT)
Shipping D: USD 2.50 / EUR 2.00, World: USD 5.00 / EUR 4.00
Students 50 % off standard prices
Termination At any time

Cover image Robert Habeck (Source: Dennis Williamson / www.williamson-foto.de)

SUSTAINABLE ECONOMY

Dear readers,

The task of politics is to create an environment in which society and the economy can thrive. That is, if there is consensus about which direction to take.

In democracies, this means much to debate and argue about. In doing so, people often find a solution that many can get behind. What can be very irritating, however, is when a handful of politicians start ignoring consensus and do what they think is best over the objections of most citizens and almost all scientists.

Interest groups may likewise try to influence decision-making. Their attempts have been with us since the days of Rome, long before business representatives began intercepting politicians in the hallways, or lobbies, of the British Houses of Parliament. And sometimes, their efforts to gain legislative support have paid off: In February, the German Government Accountability Office said that the national auto industry had "played a pivotal role in the government's decision to create an electric vehicle incentive and wielded much influence over how the program was designed."

In short, there is consensus, not only in Germany but around the world, about the need to implement policies that will curb fossil fuel consumption and protect our environment from the effects of human intervention. Some heads of governments may beg to differ. But in light of recent population growth, smog and extreme weather patterns, it seems to be the only sensible path.

Yet, some businesses, even large corporations, have – or at least appear to have – a different opinion. The chief executives of those may deep down agree with the majority. But they are often paid a hefty sum to make and defend decisions that will have the opposite effect. One of their responsibilities is to put representatives in lobbies to try and persuade politicians to pour cash into the coffers of whoever has them under their sway.

Considering the above, it seems quite fitting what Tesla's chief executive, Elon Musk, wrote in a letter in August, when trying to explain why he wanted to delist the electric carmaker (see p. 51):

"The reason for doing this is all about creating the environment for Tesla to operate best. As a public company, we are subject to wild swings in our stock price that can be a major distraction for everyone working at Tesla, all of whom are shareholders. Being public also subjects us to the quarterly earnings cycle that puts enormous pressure on Tesla to make decisions that may be right for a given quarter but not necessarily right for the long term."

He added, "We are at our best when everyone is focused on executing, when we can remain focused on our long-term mission, and when there are not perverse incentives for people to try to harm what we're all trying to achieve." He was seeking to accomplish an outcome that allowed Tesla to be "free from as much distraction and short-term thinking as possible."

By trying to buy his company back, Musk again proves that he is an unconventional thinker. And even though there are legitimate questions about how much thought he had put into his privatization idea, his letter could be a starting point to pondering and debating if some kind of long-term strategy could be more sustainable and reasonable than the approach taken by other automakers, which are clinging to diesel and combustion technology to protect their shareholders' dividends.

That is, until those shareholders miss the opportunity to sell their stock in a company that is going the way of Kodak*, which probably didn't intend to end up where it had ended up several years ago.

Best wishes,

Sven Geitmann
Editor-in-chief of H2-international

* In 2012, Kodak filed for bankruptcy protection because of its inability to see digital photography as a disruptive technology.

H_2 WELL LAUNCHED IN SONNEBERG

A new coalition has formed in middle Germany to instigate an era of structural change in the region stretching from northern Franconia in Bavaria to the south of Saxony Anhalt. The goal of "H_2 Well – a source of hydrogen and added value along the Main and Elbe river" is to establish a decentralized hydrogen economy in several states. The project is being supported by the science ministry and started with a kickoff event on May 17 in Sonneberg in Thuringia.

As part of WIR! – Innovating Regional Change, the ministry has been backing 32 coalitions to promote creative solutions, sustainable ideas and new opportunities. H2 Well is one outcome of the program. Mark Jentsch, an associate professor at Weimar's Bauhaus University, which is coordinating the endeavor, said, "H2 Well is not unlike Hypos, although the geographical area and size of our project is much smaller. We see it as an addition to Hypos. We're currently bringing together leaders from the worlds of business, science and society to devise an innovative road map that we can use in the implementation stage." ||

→ www.h2well.de

PLANSEE SHUTS DOWN FUEL CELL DIVISION

Plansee SE, which specializes in high-temperature materials and is based in Reutte, Austria, will discontinue its fuel cell business. Early this year, management had announced that the company intended to refocus attention on core operations, namely molybdenum and wolfram production, and abandon research on metal-supported fuel cells. It is said, however, that Global Tungsten & Powders, a fully owned Plansee subsidiary headquartered in Towanda, USA, will continue and expand the work on passive high-temperature fuel cells, which involves the development and manufacture of metal powders for fuel cell components such as CFY interconnects. ||

FUELCON TURNS JAPANESE

In mid-August, the Horiba Group purchased FuelCon, a test station manufacturer founded in 2001 and based in Barleben, near Magdeburg. It is now part of Japanese subsidiary Horiba Automotive Test Systems, which – in its own words – is a leading supplier of equipment to test engines, drivelines, brake systems and exhausts. Robert Plank, the chief operations officer of Horiba Europe, said that the deal allowed for "a broader range of test and validation equipment to cover all kinds of vehicle powertrain technologies, from combustion engines to electric motors. By incorporating FuelCon into the Horiba Group and turning the Magdeburg site into a global center of excellence for fuel cell and battery tests, we are taking another step toward future-proofing our auto business." The chief executive of FuelCon, Mathias Bode, hopes that the agreement will give his company easier access to the Japanese market. ||

AVX BUYS KUMATEC

In mid-May, an AVX Corp. subsidiary, AVX Interconnect Europe, signed a EUR 12.5 million agreement to acquire Kumatec Sondermaschinenbau & Kunststoffverarbeitung, a German plastic components manufacturer based in Neuhaus-Schierschnitz, near Coburg. As a U.S. supplier of advanced electronic parts, interconnect solutions and sensor products, AVX bought Kumatec to benefit from the latter's expertise in automation. The chief executive of AVX, John Sarvis, stated that the "acquisition of Kumatec and our joint venture into the hydrogen market will provide us with additional manufacturing capabilities and create new opportunities for business." ||

HYDROGEN EUROPE OPENS MAIN OFFICE

On July 10, the Hydrogen Europe association opened its new main office. The event to mark the occasion took place in the White Atrium building on Avenue de la Toison d'Or in Brussels. Among the guests were prominent figures such as Miguel Arias Cañete, the EU's commissioner for climate action and energy. The building is also home to the Fuel Cells and Hydrogen Joint Undertaking. ||

Source: Hydrogen Europe

5

ELCORE BUSINESS CONTINUES

Following Elcore's acquisition by Freudenberg, many former business partners didn't know what would happen to the fuel cell heaters manufactured by the company. Manfred Stefener, formerly Elcore's chief executive and now the head of its 40-staff office in Munich, told H2-international that Elcore would continue selling 2400 Plus devices as well as support existing installations. One of the only changes had been the logo, which now showed the symbol of the new owner, Weinheim-based company Freudenberg Sealing Technologies, one of the largest business units of the Freudenberg Group. It had acquired Elcore and Elcomax early this year and customers had already been informed of the situation, he said. On elcore.fst.com, a website put together for the new venture, a statement reads, "Fuel cells will play a key role in transforming the market and ensure sustainable and future-proof energy generation."

Freudenberg is a family-owned company in its eighth generation. It mainly produces seals, filters, humidifiers and lubricants. To make it into the ninth, the business based in the German state of Baden-Württemberg has spent considerable time on researching innovative technologies. It started work on fuel cells in 1996. ||

Category: News | **Author:** Sven Geitmann

BRUSSELS ONE STEP CLOSER TO PASSING RED II

'Clean energy for all Europeans'

After three years of negotiations, the RED II bill was accepted by the European Commission, Parliament and Council in mid-June. Now, the parliament and council will need to make the agreement legally binding by approving the text of the renewable energy directive.

The bill will then be signed by both lawmaking bodies and appear in the official journal of the European Union. When the regulations take effect 20 days later, member countries will need to start transposing new elements into national law within 18 months, that is, before the end of 2021. Via RED II, the commission will implement four of its eight suggestions included in a 2016 package called Clean Energy for all Europeans.

The directive is hoped to help propel the EU to a renewable energy future and a minimum 32 percent target of clean energy by 2030. The main objectives are to increase energy efficiency by 32.5 percent, become a leading force in renewable energy use around the world, and reduce the reliance on fossil fuel imports. In other words, the aims are to reduce carbon dioxide emissions by, at least, 40 percent by 2030, overhaul the EU economy and create more jobs and growth for all European citizens.

Miguel Arias Cañete, the European Union's commissioner for climate action and energy, said, that "renewables are good for Europe, and today, Europe is good at renewables." He called RED II a hard-won victory in an effort to explore the true potential of Europe's transforming energy market. The agreement would help the EU meet the targets set in the Paris climate accords, as well as create more jobs, cut energy bills and reduce imports. He was especially pleased about the new 32 percent aim, noting that it would provide greater investment security as it was a binding target. He then called on the parliament and the council to continue their negotiations with the same level of commitment and implement the other proposals from the package.

Somewhat satisfied, the German Energy Storage Association, also known as BVES, said that "those who worked on RED II clearly regard an increase in storage devices as crucial to meeting the European Union's new, binding 32 percent renewable target by 2030. More specifically, they conclude that a widespread use of energy storage units will be the only way to achieve that goal." Similarly, the association noted that the European Commission had highlighted decentralized systems as drivers of market transformation and identified the double burden of charges and fees on on-site consumption as a discriminatory practice.

It also pointed to parallel talks about the Electricity Market Design Directive and negotiations about governance rules thought to offer a legal basis for comparing national climate action plans. Countries would need to submit draft plans at the end of the year and finalized documents at the end of the next. ||

Fig. 1: Miguel Arias Cañete

Category: Conferences & Trade Shows | **Author:** Sven Geitmann

TRANSPORTATION MINISTER IS A NO-SHOW AT CELEBRATION

NOW turns 10 years old

Fig. 1: Steffen Bilger, parliamentary state secretary at the federal transportation ministry

Fig. 2: An overjoyed Bonhoff stands next to Christopher Hebling from Fraunhofer ISE (left).

On June 11, scores of industry representatives arrived at the headquarters of the transportation ministry in Berlin to celebrate the 10-year anniversary of the National Organization Hydrogen and Fuel Cell Technology, better known by its German acronym NOW. However, one prominent figure was conspicuously absent from the event, and that someone was Andreas Scheuer, the head of the department. He was in the building that day but had made other plans: Daimler chief Dieter Zetsche had been invited to talk about the diesel scandal and nitrogen oxide emissions. Be as it may, in no way did the minister's absence dampen the mood at the celebration.

NOW was founded as a federal government organization in 2008 to offer a platform for exchanging ideas and knowledge between the worlds of politics, industry and science about how to introduce clean and sustainable ways to power vehicles and produce energy. At first, it had been tasked with supporting hydrogen and fuel cell development but later took on additional responsibilities, namely to popularize electric vehicles and implement the government's fuel strategy. It used to have nine staff members in addition to a chief executive officer, Klaus Bonhoff, and a chief financial and operations officer, Kai Klinder. The number has since grown to 40 employees, who occupy four floors in the office building on Fasanenstrasse in Berlin. In 2011, Wolfgang Axthammer joined the company and replaced Klinder as the second member of the executive board.

"In partnership with industrial businesses and the scientific community, we intend to demonstrate the viability of hydrogen and fuel cells. This will not only benefit the environment but also create future-proof jobs here at home. [...] The founding of NOW will allow the design of marketable, energy-efficient and globally competitive products for use in transportation, the energy sector and the consumer market."

Wolfgang Tiefensee, then minister of transportation, speaking in 2008

"I am glad that, at the time, people had the courage to take those risks [that is, found a company owned by the federal government]."

Klaus Bonhoff, chief executive of NOW, in 2018

ALL'S WELL THAT ENDS WELL The 10-year anniversary celebration, held in the courtyard of the ministry building, bore the slogan "Batteries and fuel cells for transportation and energy – RD&D, commercialization, future challenges," and was attended by many professionals well known throughout the industry. Among them were two professors who used to be employed at the ZSW, Jürgen Garche and Werner Tillmetz, and Nilgün Parker, administrator in the department while it was headed by Tiefensee. Each of them played a crucial role in the creation of the National Innovation Program Hydrogen and Fuel Cell Technology, or NIP for short.

This, you might say, sentimental, throwback revealed how much foresight the organization's founders had. But it also made clear how much progress had been achieved. Many echoed that sentiment as they concluded their speeches. For instance, Steffen Bilger said on behalf of the transportation ministry that "electric power and hydrogen are the fuels of the future" and that "NOW had a reliable track record." He admonished German carmakers, saying, "Automakers will have to do their fair share. We call on the auto industry to lead the charge in developing new technologies. […] Carmakers really need to do more. […] Those who don't act soon will put a lot of jobs at risk."

As the event was held in the transportation ministry, it strongly focused on, well, means of transportation. Still, when it was Bonhoff's turn to speak, he tried to cover more ground, saying that "transportation and energy are two sides of the same coin. [...] Overall, we are well on track with our objectives, although we need to continue with our integrated approach to public sector support for renewables." He added that NIP had "contributed to the accelerated growth in the market and an increase in value-added process chains." Likewise, he was pleased to note that Germany had been able to defend its technological leadership role. He ended his speech by saying, "What we need to meet our carbon reduction targets are innovative technologies and public acceptance." ||

Category: Conferences & Trade Shows | **Author:** Sven Geitmann

FULL STEAM AHEAD

22nd World Hydrogen Energy Conference

Fig. 1: Video message by T. Nejat VeziroĐlu

Attendees from Europe, Asia and even North America had a long way to travel to this year's World Hydrogen Energy Conference. In the end, however, more than 550 came to the event, which took place June 17 to 22 in Rio de Janeiro, Brazil. They were rewarded with a lot of interesting material. What caught the imagination of many was the story of natural hydrogen, about which geologist Alain Prinzhofer reported that it came out of the ground in several places around the world.

The WHEC 2018 kicked off with a speech by its chairman, Professor Paulo Emílio Valadão de Miranda, the head of the Hydrogen Laboratory at the Alberto Luiz Coimbra Institute of the Federal University of Rio de Janeiro and president of the Brazilian hydrogen association ABH2. The subsequent video message from the president of the International Association for Hydrogen Energy and initiator of the WHEC, T. Nejat Veziroğlu, marked a highlight of the event schedule. Being 93 years of age, he had been unable to participate in the conference due to health reasons but wished everyone his best and, in a voice imbued with the unrelenting spirit he had become known for, called on the hydrogen community to "fight the global problem!"

While talking about the state of the market, he mentioned with pride that early last year, 13 globally operating corporations had joined forces to tackle the world's environmental problems and, instead of Climate Council or Green Council, they had named their initiative Hydrogen Council (see H2-international, May 2017). He told the audience not to be discouraged by a possibly long road ahead, exclaiming, "Your dreams will come true. Go full steam ahead into a hydrogen society!"

While he could only attend digitally, his wife Ayfer Veziroğlu, the executive vice president of the international hydrogen association over which he presides, was among the guest speakers at the WHEC. She recounted the beginnings of the hydrogen community and the first-ever WHEC in Miami Beach, over 40 years ago. Much had been accomplished since then, she said, before announcing that cell phone giants AT&T and Verizon would, as early as this year, offer a fuel cell-powered smartphone on the market. Named RED Hydrogen One, the limited-edition model will reportedly carry a price tag of USD 1,595.

Danny Epp, a fuel cell pioneer and longtime employee of Ballard, took attendees on another trip down memory lane, into the 1980s. He, too, said that a lot had been achieved, especially when it came to platinum amounts in fuel cell production and the power density of stacks. Platinum content had shrunk by a factor of 50 in 30 years, while power density had risen by a factor of 10 during the same period.

Edson H. Watanabe, who works at the Alberto Luiz Coimbra Institute, also known as Coppe, alongside Miranda, told attendees that Brazil had large amounts of renewable sources, be

ITAIPÚ

For a long time, Itaipú's 14 gigawatts of capacity made it the world's largest hydropower plant. It subsequently lost out to the Three Gorges Dam, a 22.4-gigawatt installation that was completed in China in 2012. Itaipú was built on the border between Brazil and Paraguay in 1974. In 2016, it generated 103 million megawatt-hours, a record that has yet to be broken.

it hydropower, wind or biomass, such as sugar cane. He said that he had bought a flexible-fuel vehicle in 2006 but that ethanol was not the final step of development. Rather, he encouraged everyone to use hydrogen and urged with a wink: "I am 65 years old, so I implore you to hurry a little. I would like to be around when the technology is ready to use."

OVER 80 PERCENT RENEWABLES In 2016, the proportion of renewable energy in total electricity consumption was 81.7 percent, or 43 percent of all energy consumed in Brazil. Most renewable electricity was generated at hydroelectric power stations. Sugar cane has likewise become a popular source of energy for ethanol production. In 2016, the share of flexible-fuel vehicles amounted to 29 percent. It is expected to rise to 43 percent by 2030.

A major challenge faced by the country is bridging the gap between a wet September and a dry April. Hydrogen is currently regarded as a serious contender for the job because electrolyzers and storage systems would make it possible to transfer the rainy season's large energy resources to the dry summer months. Hydrogen and fuel cell technology could also allow for the creation of microgrids, eliminating the need for power lines across long distances – the country's huge landmass demands no less. Additionally, energy could be generated, stored and used locally in a relatively efficient way to replace generators running on imported diesel.

The government has already installed an electrolyzer at the Itaipú dam to explore the idea. This demonstration system in the Parque Tecnológico Itaipú produces 10 normal cubic meters of hydrogen an hour. Gas is stored in 46 pressure vessels before being reconverted into electricity in a 6-kilowatt fuel cell.

HOT TOPIC: NATURAL HYDROGEN Alain Prinzhofer, geologist and scientific director at Brazilian company Geo4U, generated a lot of buzz when he presented findings that show hydrogen seepage in places around the globe. The purity of this so-called natural hydrogen depended on local conditions. One oft-shared characteristic, he said, was a circle in which vegetation differed markedly from the rest of the environment. Up to 353,000 cubic feet (10,000 cubic meters) of the gas seeped from each of those locations per day.

He was clearly enamored with the idea of using natural hydrogen as a renewable and sustainable resource and began drawing parallels to the oil boom of the 1850s, though opinions in the audience ranged from enthusiasm to surprise to caution.

Together with Eric Philippe Deville from the IFP School, based in the French city of Rueil-Malmaison, Prinzhofer, who at one time worked at the University Pierre and Marie Curie in Paris, published a book about the discovery in 2017. It is titled "Hydrogène naturel – La prochaine révolution énergétique." There have been earlier reports about hydrogen seepages, though. In 2015, researchers found rocks containing up to 1.25 percent of molecular hydrogen at a depth of 3.9 feet (1.2 meters) throughout the European part of Russia. Klaus Bonhoff, the chief executive of NOW, who attended WHEC 2018 and knew about the find, told H2-international, "That hydrogen is being extracted [in small quantities through few boreholes] from the ground in Mali and used in local energy production seems to be a true story. Reportedly, these sources were discovered by accident. The managers of the project are now looking for investors to expand operations. We will keep a close watch on developments."

DIGITAL POSTER SESSION The conference was accompanied by an exhibition, at which 35 organizations showcased products and services on 4,628 square feet (430 square meters). The poster session took place at the same location, although vertical monitors had replaced the paper posters of previous years.

Aside from a few small issues, the entire event received relatively good grades from attendees. One thing that could have used some work was the way in which information about the schedule had been made available to WHEC participants. The organizers had put a lot of effort into creating an app for the occasion. But neither the app nor a printout made clear who among the 350 speakers was going to be in which session. Overall, though, everyone seemed satisfied with how everything went. ||

Fig. 2: Emilio Valadão de Miranda and Ayfer VeziroĐlu

9

AWARD GOES TO GERMAN SCIENTIST

The second conference day concluded with what you might describe as a cultural exchange: a Brazilian-themed evening to enjoy samba and South American beverages. It was also an opportunity – one that, sadly, the public barely took notice of – to present the William Grove Award. This year, the winner was Professor Peter Strasser from TU Berlin. The German scientist was honored for his research into new kinds of electrocatalysts, especially his nanostructure material consisting of a nickel core surrounded by an atom-thin mantle made of platinum. He said that the shell and core design was multiple times more efficient than pure platinum, which would lead to a severe reduction in the quantity of precious metal needed for designing catalysts.

WHTC AND G20 IN JAPAN

Multiple times during the event, the director of international cooperation at the environment ministry in Japan, Yoshihiro Mizutani, could be heard advertising the World Hydrogen Technologies Convention, to be held June 2 through 7 in Tokyo. It will reportedly include a special edition called FC Expo Summer. He also said that the G20 summit, which will take place June 28 and 29, 2019, in Osaka, would create an opportunity to demonstrate the technological readiness of hydrogen solutions.
www.whtc2019.jp

Category: Conferences & Trade Shows | **Author:** Sven Geitmann

EUROPE FINALLY FORGES AHEAD

H2Congress shows China widens gap

Every two years, the H2Congress takes place in North Rhine-Westphalia's state office in Berlin. And if there is one technology that has grown in popularity throughout past conferences, it was hydrogen. So it seems only fitting that this year's event, held June 6 and 7, placed the emphasis on electrolysis and power-to-gas, that is, the economic implications of hydrogen use in transportation and energy markets.

Fig. 1: A visibly relaxed Stijn van Els giving one last presentation shortly before his retirement.

Around 200 attendees witnessed an exciting event, which included several thoroughly intriguing presentations. Right at the beginning, representatives for large businesses from the energy-intensive steel and cement and oil industries outlined their strategies for the coming years. Stijn van Els, who had served as the chairman of Shell Deutschland until July, said, "We want to act today to have an impact tomorrow. Our aim is to instigate change in the energy markets." Reinhold Achatz, the chief operations officer of thyssenkrupp, added that his company had undergone successful restructuring over the past years and increased its standing in the climate protection ranking by the Carbon Disclosure Project, where it jumped from D to A. He likewise pointed to Carbon2Chem®, a project that was launched this fall (see H2-international, October 2017, and p. 22). Achatz said thyssenkrupp did not see hydrogen technology confined to a niche market but, on the contrary, sparking a major trend.

CHINA SPEEDS AHEAD The presentation that generated the most discussion was the one by Tobias Brunner, a former BMW employee and the current chief executive of Hynergy, a German consulting firm founded in Grasbrunn in 2016. He talked about his months-long experiences as an adviser to Great Wall Motors, one of China's biggest carmakers and a partner to Hynergy. Brunner confirmed what most people in Germany could only read about: that the People's Republic has been churning out policy after policy to pour massive amounts of cash into advancing renewables and alternative engines. He gave a row of examples to illustrate to which extremes China had gone, so that the national market was developing at a much more rapid pace than many believed.

In 2017 alone, the country saw the installation of about 53 gigawatts of photovoltaic capacity, with some of the systems floating on lakes, created by flooding coal mines. At the end of the year, total PV capacity amounted to more than 130 gigawatts and wind power rose to nearly 190 gigawatts, compared with Germany's 43 gigawatts and 56 gigawatts, respectively. An abundance of eco-power – unused wind energy totaled 150 terawatt-hours in 2017 – has provided a strong impetus for increasing the number of electric vehicles. Reports show 90,000 electric buses sold on the Chinese market last year and as many as 32,000 new electric cars registered by April 2017. Many of the 20 best-selling car models were manufactured in the country. Only Tesla's Model X, which came in 17th place, and Model S, in 19th, were makes from abroad (see also the report about China on p. 52).

EAST-WEST CORRIDOR TO DELIVER HYDROGEN However, progress is happening in not only the East but also the West. Jorgo Chatzimarkakis, secretary general of Hydrogen Europe, said that, for example, France's (former) environment minister had announced a program to promote hydrogen-focused projects across the country (see p. 55). He added, "The importance of hydrogen as an economic factor beyond a niche market will depend on whether it is possible to use a system of pipelines to transport the gas in large quantities as part of a natural gas blend or possibly on its own through a converted network."

He suggested a route through the North Sea and the Baltic States to connect eastern and western Europe from Helsinki to Rotterdam (see fig. 2). The idea could lead to many new hydrogen and fuel cell projects along a path strongly endorsed by Catherine Trautmann, the European Union's coordinator for the North Sea-Baltic network corridor. This corridor includes 3,695 miles (5,947 kilometers) of railroad tracks, 2,504 miles (4,029 kilometers) of roads, and 1,358

Fig. 2: Route through the North Sea and the Baltic States

miles (2,186 kilometers) of waterways. The gas pipelines and electric power lines along the route could likewise be used to deliver hydrogen.

Chatzimarkakis, however, stressed that he would rather talk about "sector integration than sector coupling," as the latter sounded "much too easy to accomplish." He then pointed at a chart (see fig. 3, following page) to make it unmistakably clear why the endeavor involved considerably more than adding a new technology to an existing system.

RED II ON ITS WAY Chatzimarkakis also confirmed the European Parliament's intention to go ahead with approving the Renewable Energy Directive RED II, which it did in mid-June (see p. 7). He said that the next item on the agenda was to get actively involved in drafting Germany's action plan, which will lay out the government's plans to transpose EU regulations into national law, with the deadline set for 2021. He was extremely pleased that the key points had been communicated to high-ranking officials and that those mostly responsible for blocking new initiatives had left in the meantime. He said, "Some members of the Greens in Germany are fighting the adoption of hydrogen with much religious zeal, while some in France will support it, even if that means going against the party line." Apparently, they had been concerned that greater acceptance would lead to gray or blue instead of green hydrogen, so they had tried to delay draft laws. "But now," he said, "the important thing is that the largest member of the EU is taking hydrogen seriously."

The chairman of the German hydrogen association DWV, Werner Diwald, said that it "took only 24 months to have hydrogen become a hot topic in Brussels." He added that the industry viewed the recent negotiations about RED II as a success. Many of the DWV's suggestions had found their way into the draft. As the bill was passed in July, the organization now "seeks to play an active role in transposing the directive into national law." >>

Klaus Bonhoff, the chief executive of NOW, picked out the railroad sector as a prime example of hydrogen use. For instance, BetHy, supported by the transport ministry with EUR 7.9 million, was instrumental in developing Alstom's hydrogen-powered railcar Coradia iLint, he said. A EUR 1.14 million follow-on project named BetHy 2 was in the works. It would validate BetHy's findings and prepare the vehicle for receiving an operating permit. Bonhoff concluded by saying that "the funding situation for vehicles and gas stations couldn't be better."

In the evening of the first day, Steffen Bilger, parliamentary state secretary at Germany's transport ministry and Andreas Rimkus, a member of the Bundestag, assured attendees during a panel discussion they would continue their work to get more hydrogen on the market. ||

"Not all projects about power-to-gas and energy systems integration may be economical, but they certainly are good for the economy."
Thomas Hüwener, chief technology officer of Open Grid Europe

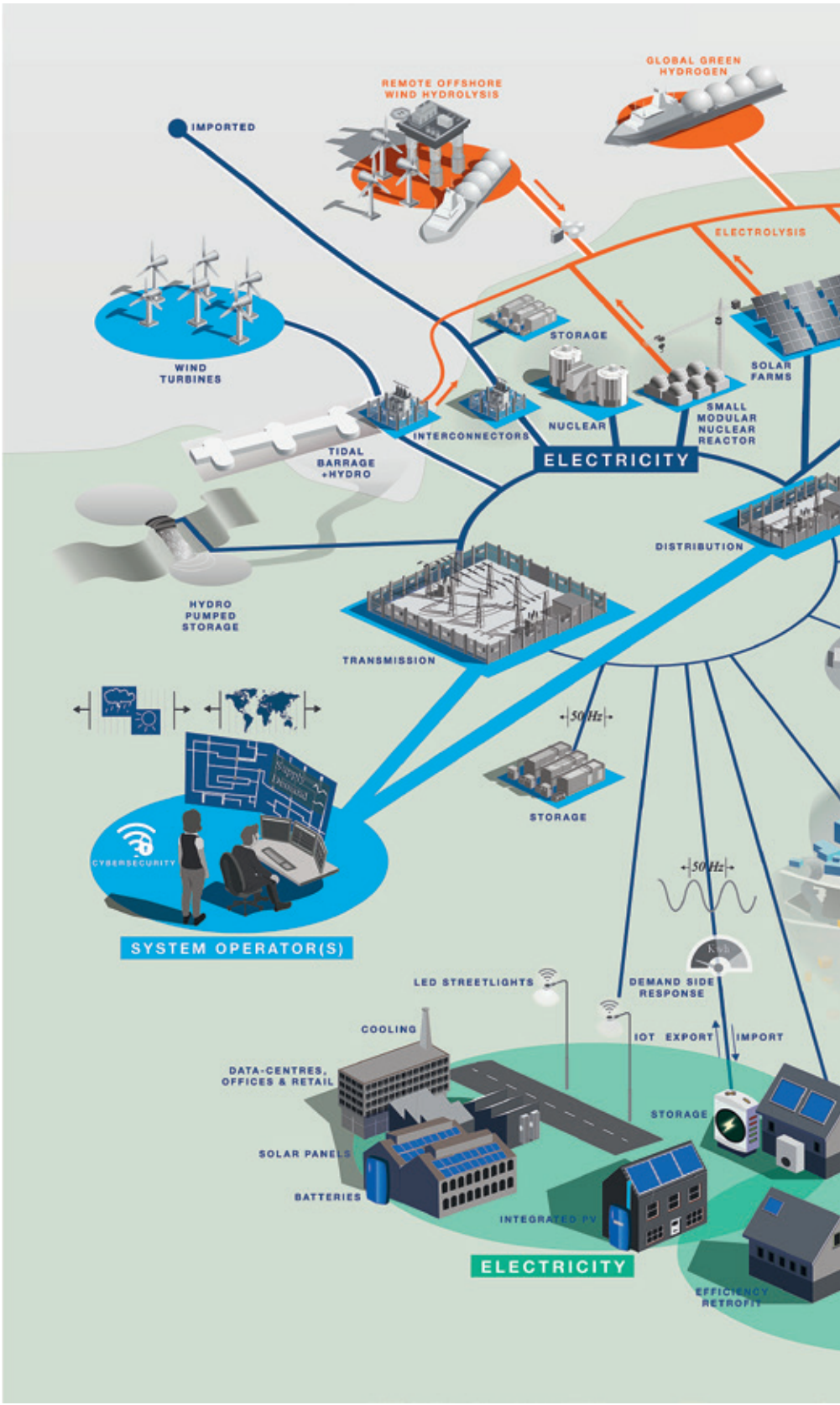
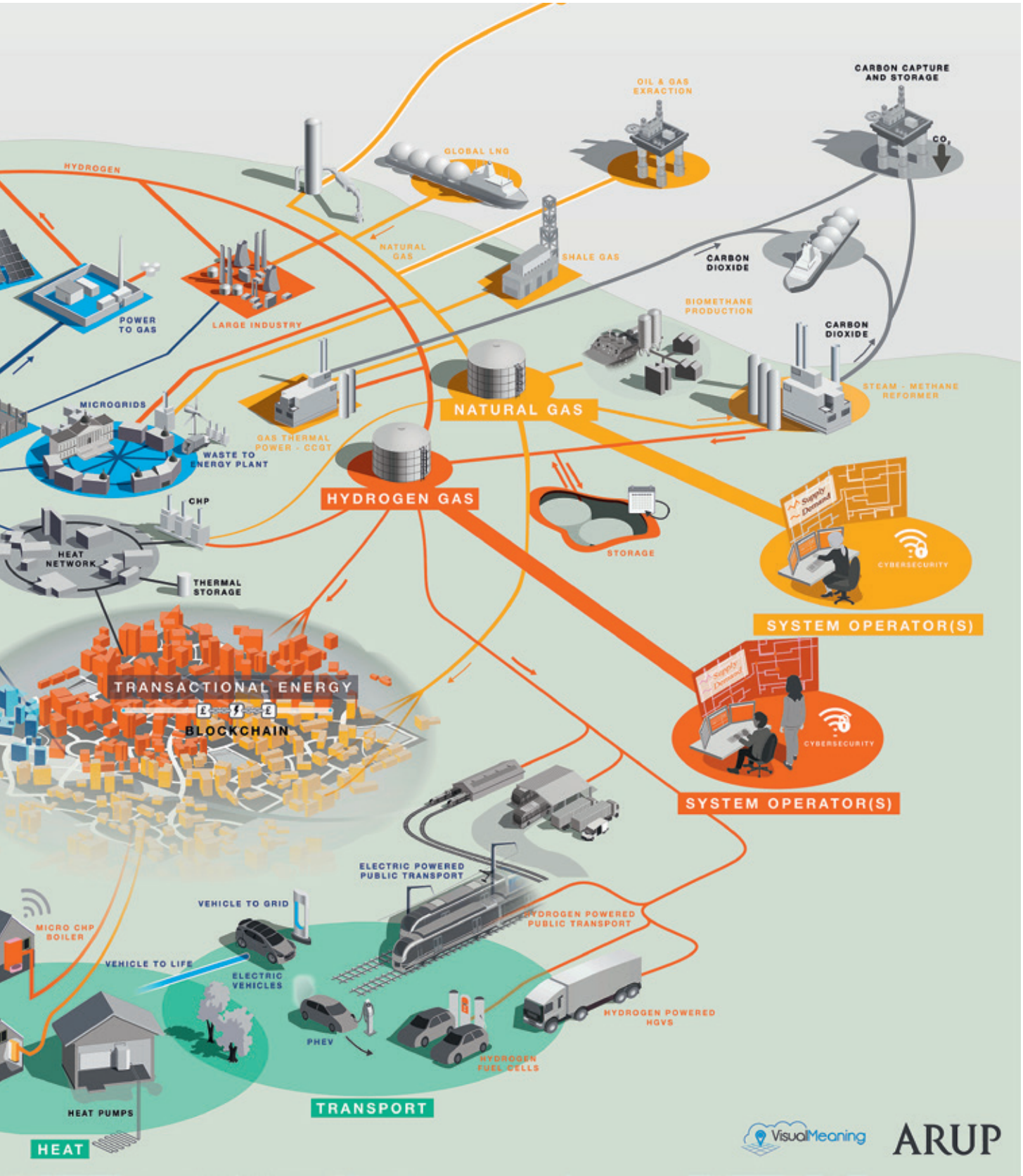


Fig. 3: Energy system in 2035


CARBON CAPTURE AND STORAGE
OIL & GAS EXRACTION
GLOBAL LNG
HYDROGEN
NATURAL GAS
SHALE GAS
CARBON DIOXIDE
BIOMETHANE PRODUCTION
CARBON DIOXIDE
POWER TO GAS
LARGE INDUSTRY
STEAM - METHANE REFORMER
MICROGRIDS
NATURAL GAS
GAS THERMAL POWER - CCGT
WASTE TO ENERGY PLANT
HYDROGEN GAS
CHP
STORAGE
HEAT NETWORK
THERMAL STORAGE
CYBERSECURITY
SYSTEM OPERATOR(S)
TRANSACTIONAL ENERGY
BLOCKCHAIN
CYBERSECURITY
SYSTEM OPERATOR(S)
ELECTRIC POWERED PUBLIC TRANSPORT
VEHICLE TO GRID
HYDROGEN POWERED PUBLIC TRANSPORT
MICRO CHP BOILER
VEHICLE TO LIFE
ELECTRIC VEHICLES
HYDROGEN POWERED HGVS
PHEV
HYDROGEN FUEL CELLS
TRANSPORT
HEAT PUMPS
HEAT
VisualMeaning
ARUP

13

Category: Energy Storage | **Author:** Sven Geitmann

HOW TO RAISE HYDROGEN OUTPUT

Interview with Robert Habeck, co-chair of the German Green Party

Robert Habeck is not your typical politician. It may be easier to picture him as a band member of Green Day than a member of a political party. This January, he entered the national stage after having been voted in as one of two co-chairs to lead the Greens in Germany. As a result, he needed to give up his post in the cabinet of Schleswig-Holstein, where he had served a second term as the state's environment minister upon his confirmation in summer 2017. The party went as far as changing bylaws to fulfil his request for an orderly transition from the state to federal level, granting him eight months in which he was able to keep both jobs. H2-international spoke with Habeck about his experiences at both tiers of government.

H2-international: Mr. Habeck, 2018 was your third straight year of attending the Green Electricity show in Enge-Sande in your role as Schleswig-Holstein's environment minister. What's your motivation for visiting a regional event such as this one?

Habeck: It is not your average regional show. Rather, it is a showcase for sustainable transportation throughout northern Germany. At this event in Enge-Sande, you have many incredibly dedicated people who really want to see the transformation of the energy market take shape. And it is a good opportunity for me to meet them and talk to them.

You have spoken with plenty of citizens over the years. What is the mood in Schleswig-Holstein?

Habeck: As you know, life in the north is a bit on the quiet side. People in other states may have gotten used to heated debates, but the rhetoric up here is pretty tame. I think we need this kind of attitude if we want to stay focused on the issues, particularly if they are of grave concern to many.

What about the energy industry? What is on most people's minds?

Habeck: First of all, the expansion of the power network is in full force. Half the middle section is finished and the transmission line on the west coast will be completed before the next election. One issue that is weighing heavily on people's minds is wind power generation across the state. Our governing coalition has arrived at a sensible and workable compromise without losing sight of climate protection goals. I truly hope that the wind power market will pick up soon, as capacity is trailing expectations at the moment. The market is also a testing ground for a lot of important and innovative ideas, from the integration of renewables into existing systems to smart energy management and the construction of an electric highway. And we're trying out new methods for energy storage and energy systems integration in general. I could go on, but the point is that we are adopting a wide variety of approaches to establish a future-proof energy network.

Almost no other region in the world is as blessed with wind resources as Schleswig-Holstein, not to mention the access it has to funds from the Renewable Energy Sources Act. The state, it seems, has allowed both wind farm developers and many citizens to profit from market growth over the past years. How did this come about?

Habeck: People around here quickly realized that they can benefit from the changes in the market by working together. The result is that a significant part of the value chain that was created through the transformation in the state remains in Germany, especially in the countryside. The success has brought about prosperity and joy, but there is great potential for conflict and that should not be ignored. If you want to transform a market, you need help from citizens, so they should have a say in what the future is going to look like. It is why we set up a citizen fund to support projects at a very early stage, when the banks don't dole out cash for them. Up to EUR 200,000 are available for each project.

However, the first wind power plants will lose support from the feed-in tariff program over the next years. How are people in the region preparing for the shortfall in funds?

Habeck: The industry is ahead of the curve and has already launched multiple NEW 4.0 projects. What deserves a mention as well is power-to-X. It involves trial runs to figure out how best to prepare for the upcoming lack of money from feed-in tariffs. Though the legal underpinnings could still use some revisions.

Northern German Energy Transformation – NEW 4.0 is a project that was launched jointly by Schleswig-Holstein and Hamburg. Could you give us a short explanation of its purpose?

Habeck: The aim of the NEW 4.0 showcase, which was set up by a coalition from the worlds of business, science and politics, is to demonstrate how entire regions can meet their energy needs by renewable electricity only. It underlines the importance of smart energy management and consumption.

In mid-June, one-and-a-half years into NEW 4.0, you and your colleague Bernd Buchholz, the economy minister of Hamburg, discussed current progress. How far are you?

Habeck: We've reached a good number of milestones. The program is gaining traction, especially because more and more projects have entered the testing stage. Take the tests conducted at an aluminum factory, where the aim is to find a way to align consumption, and thus production capacity, more closely with power generation. A project at Flensburg's public utility, in contrast, is making use of surplus electricity to produce heat. And several months ago, Europe's largest electric power storage came online in Jardelund [in Schleswig-Holstein]. We need these types of hands-on projects to be better prepared for what's to come.

When you were in Hamburg, both you and the city's economy minister criticized that hydrogen had not been an oft-discussed topic when debating future energy storage and that there were legal issues too. What exactly is it that you don't like about the current situation?

Habeck: We had to curtail power production, wasting nearly 3,000 gigawatt-hours across the region in 2017. It was perfectly good electricity that we could have used if the federal government had attempted to consider all options or had established experimental provisions. It didn't. I believe that the instinct to protect the fossil fuel industry is still there. But it is detrimental to progress. For example, the electricity surplus generated from wind power could be stored as hydrogen. It is an option we would be able to implement on a larger scale across the region.

What does this mean in terms of objectives?

Habeck: Don't curtail wind power plants and make people pay for electricity that was never generated. Instead, connect devices such as hydrogen systems, heat storage and batteries. This way, consumption pays off and can be credited based on Germany's renewable energy law. Consequently, you will see lower electric power prices. It will certainly shift the balance of power in the industrial sector.

Your state-level position has allowed you to implement your ideas, which you once said was the thing you liked most about your job. Your move to Berlin, scheduled for September, will likely involve less decision-making and more debating. What energy-related issues do you intend to highlight in the future?

Habeck: My co-chair Annalena Baerbock and I will be calling for instantly effective climate protection policies, a coal exit strategy, a shift to sustainable transportation and carbon pricing.

And what about hydrogen in particular? Will you advocate for a more thorough discussion of energy storage options after moving to the country's capital?

Habeck: I have spoken about them before, and I will continue to do so. In the past years, we have filed petitions at meetings of state and federal ministers and in the Bundesrat to introduce experimental legislation. My move to Berlin will not change that. To transform the market through renewables, it is crucial that we offer solutions for storing the energy we generate and that we expand the power network. >>

The previous federal minister for the economy, Sigmar Gabriel, expressed no interest in discussing opportunities for energy storage. Do you think Peter Altmaier is a bit more open to speaking about those?

Habeck: So far, I have heard nothing that would suggest Peter Altmaier has a strategy for how to transform the market. I am not sure what's going on in his department. He looks tired and exhausted.

Why have I basically not seen any Green Party support for hydrogen? In 21 years of covering the hydrogen and fuel cell industry, I have heard few party members say good things about the technology.

Habeck: I have rarely experienced someone refusing to consider the technology outright. But there have been many unanswered questions concerning technological development, energy efficiency and cost-effectiveness. Meanwhile, the situation has changed somewhat. In some regions, we have a surplus of renewable electricity and we can use that surplus to produce relatively low-cost and environmentally friendly hydrogen. We should see this as an opportunity.

Regarding real-life solutions, I am often told that, for the most part, the Free Democratic Party is more open and committed to testing and introducing new energy technologies. Could it be that your members have grown a bit too conservative, so that others now feel that they have to step up to the plate?

Habeck: Without trying to spark a political debate, the Free Democrats were the ones who wanted to stop the transformation in its tracks during the talks to create a coalition at the federal level.

In the 1980s, your party's popularity grew because of your focus on energy. Have your predecessors missed the opportunity to elevate the issue to its former status? Could they have underestimated the potential of a debate over transforming the market?

Habeck: Why would you ask such a question? In all states where we are part of the governing coalition, we are supporting renewable energy in any way possible. We are preventing coal power stations from being built. We are the driver behind the nuclear power phase-out. In short, we are not the ones discouraging initiative. This is true in Hesse, Baden-Württemberg, North Rhine-Westphalia and Lower Saxony. The issue is even more obvious in Schleswig-Holstein. What we lack is representation at the federal level. But we are in the process of changing that, finally.

What would be your answer to the question of which energy source should replace nuclear and coal?

Habeck: I sincerely believe that a future energy system can function entirely without nuclear and coal. To make that work, we need renewable energies, good energy efficiency and enough storage, plus a revamped network, proper energy systems integration and smart energy management. We want to spearhead the development in Schleswig-Holstein, to demonstrate that it really can be done. Unfortunately, some federal regulations do little to help, but we are working on solving that problem. For example, we need to reform the system of taxes and charges in the energy sector, and do so quickly, to allow for an integrated network and the right environment for investing.

I know of no one at the federal level who has been pushing for hydrogen and fuel cells or has been advocating for hydrogen-based energy storage. Will that be changing soon?

Habeck: The focus is not on a specific technology but on the overall aim, that is, to produce carbon-free energy and create rules that facilitate its production. After that is done, it is up to the market to crown a winner.

Last question, again about state-level politics. Do you think it is possible for a manufacturer of fuel cell trains to be awarded the contract for supplying railroad operators in Schleswig-Holstein? What would you prefer?

Habeck: The bidding process is at least designed to allow for innovative engines to steam ahead. I am curious to see which kinds of bids the economy ministry will receive. At the very least, awarding the contract to makers of fuel cell trains would be another clear sign that Schleswig-Holstein is a pioneer in technologies transforming the market and will no longer rely on diesel to power trains running across the state.

Mr. Habeck, thank you for your time.

PUTTING A PRICE ON CARBON DIOXIDE

When asked about his idea for a carbon price, Habeck referred to a letter dated July 12, 2018, and signed by 11 German environment and energy ministers from the Green Party. Sent to the federal economy minister, Peter Altmaier, it read in part:

"The government's most recent climate change assessment indicates that Germany will fall 8 percentage points short of its emissions reduction target for 2020. [...] The ministers for the environment unanimously decided, at their 90th annual meeting, to implement carbon pricing. [...] Clear price indicators can support climate targets if they are designed as incentives to reduce carbon dioxide emissions. The environment ministers believe that the introduction of carbon pricing is needed to bring about a significant decrease in carbon dioxide emissions when producing heat and powering means of transportation. Likewise, it will prove that the ministers intend to honor their pledge to protect the climate. [...] Furthermore, it should be pointed out that French President Emmanuel Macron has been calling for a minimum charge of EUR 30 on each metric ton of carbon dioxide emitted. We ask that his proposal receive the backing of the European Union and be promoted throughout member states. [...] The main portion of additional revenues generated by carbon pricing should be used to reduce electricity prices by virtue of lower taxes or charges, such as those imposed via the Renewable Energy Sources Act."

Category: Energy Storage | **Authors:** Dr. Tom Smolinka, Franz Lehner, Steffen Kiemel, Dr. Geert Tjarks

WATER SPLITTING IS READY FOR THE MASS MARKET

Study shows road map to gigawatt-size industry

The splitting of water to produce hydrogen will become a requirement if renewable electricity is to be converted into other energy carriers and industrial base materials to transform the energy market and meet climate targets in Germany. Expectations are that by 2050, electrolyzer capacity will run into the tens of gigawatts countrywide. Nowadays, most devices are either customized or manufactured in small numbers. As part of a study conducted on behalf of the German transportation ministry, researchers have explored options for turning the electrolysis of water into a powerful and fundamental component of a future energy system and probed the challenges that Germany will encounter when establishing a new gigawatt-size industry.

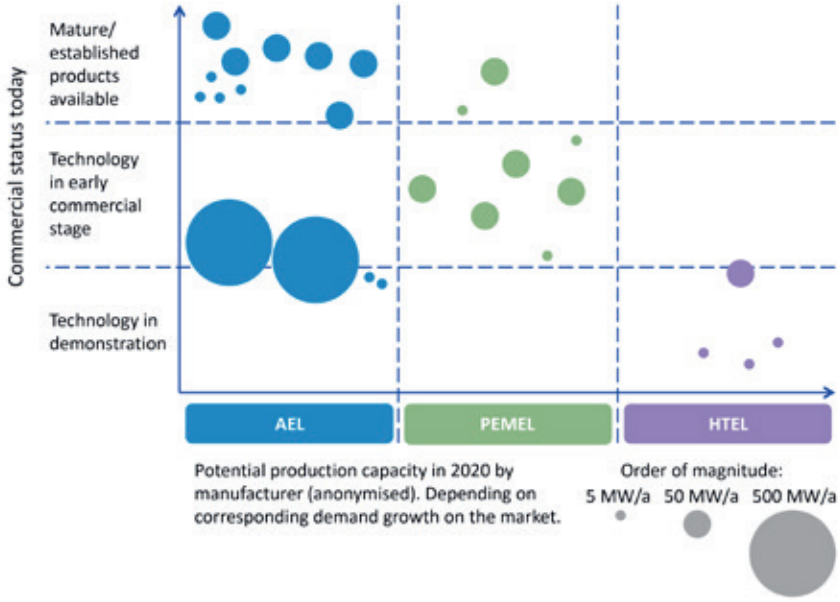


Fig. 1: State of the art of different electrolyzer technologies and data on key suppliers broken down by technology (and anonymized)

Even today, there are technologically advanced methods for splitting water, such as alkaline and, for the most part, PEM electrolysis. By contrast, high-temperature electrolysis has only recently entered the commercial stage. In the study period, researchers surveyed businesses in the industry to determine state-of-the-art production techniques and to ask what progress of a technical and economic nature could be expected regarding each type of technology.

The findings show that, for example, there is still considerable potential for increasing system lifetime, whereas all three technologies already run at high

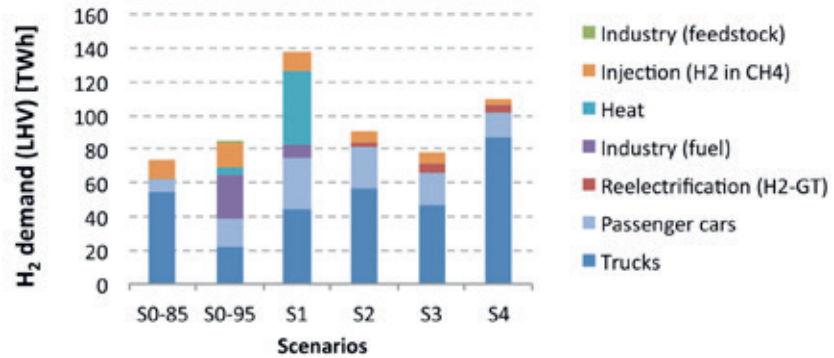


Fig. 2: Hydrogen demand in each scenario (S) until 2030
85: 85 percent reduction in carbon dioxide emissions by 2050 compared to 1990 baseline – 95: 95 percent reduction of the same

electrical efficiency. Likewise, the manufacture of systems and components continues to offer significant cost-saving opportunities. These could be exploited by either technological advances or, above all, economies of scale through a substantial increase in production output.

In addition, globally leading suppliers were asked about their manufacturing techniques and processes and the rate at which they could increase capacity. The response was that capacity could be revved up to an annual 2 gigawatts worldwide by 2020 (see fig. 1). European businesses would contribute approximately two-thirds to the total, which would be dominated by suppliers from the chloralkali industry. This industry has the proper supply chains available for a timely expansion of large-scale water electrolysis, although it has only recently begun to cater to the market.

Over the last two to three years in particular, the observation was that suppliers of electrolyzers were preparing for an eventual ramp-up of capacity and were only waiting for the right kind of support. Although the industry may still regard research, development and demonstration projects as needed for growth, sufficient market demand will be central to technological progress and cost cutting, as well as improvements to production processes.

At present, virtually all manufacturers of water-splitting systems produce on a make-to-order basis because of low demand for large systems in high numbers. Yet, they are familiar with methods for high-volume production in other fields and industries and their suppliers have implemented them to some degree. All in all, no general need for new manufacturing techniques could be identified. There is consensus that, without using much effort, businesses could scale existing methods and establish them throughout the industry.

ELECTROLYZER CAPACITY The study's authors used the REMod-D tool, which was developed by Fraunhofer ISE, to conduct simulations of the German >>

	Unit	2020	2030	2050
Installed electrolyzer capacity	[GW]	0.32 (0–1)	44 (7–71)	213 (137–275)
Average growth based on 2017	[GW p.a.]	0.1 (0.0–0.2)	3.4 (0.5–5.4)	6.4 (4.2–8.3)

Table 1: Electrolyzer capacity installed in Germany and average growth in the base scenario. Figures in parentheses show the range across all scenarios chosen for the study.

energy system and to estimate hydrogen and electrolysis requirements for transportation, heat and power until 2050. The computer models comprised six scenarios to allow for a more detailed overview and include the full spectrum of key indicators from the survey.

The main objective was to meet the climate targets that Germany set for 2020 and beyond. This would require that between 137 gigawatts and 275 gigawatts of electrolyzer capacity be installed by 2050 (see table 1). This capacity is in the upper range of estimates found in the literature. However, the percentages of hydrogen imports or synthetic fuel, or both, were higher in other studies, which would result in comparable increases abroad to meet demand for hydrogen in Germany. In each case, the global electrolyzer industry would grow substantially. Considering this, it seems that the scenarios were based on a reasonable set of parameters.

To validate the findings, multiple types of end users were asked about expected demand and requirements in each sector. Interestingly enough, they believe that transportation will only see a modest rise in demand until 2030. By contrast, the simulations – which are primarily influenced by the fulfilment of climate targets as early as the 2020s – indicate rapid growth in hydrogen-powered transportation across all scenarios up that point (see fig. 2). Since the drastic political and industrial measures required to achieve that level of expansion are nowhere in sight, however, it is unlikely that electrolyzer capacity will be installed at the projected rates during the first few years.

Rather, market players expect hydrogen to be used in refineries and as a base material for synthetic fuel first. Some also anticipate a partial increase in demand for industrially used hydrogen in general before there are considerable advances in the fuel cell vehicle market.

COMPONENTS AND PRODUCTION TECHNIQUES Discussions with electrolyzer manufacturers and suppliers resulted in estimates for electrolyzer components and an identification of potentially suitable manufacturing techniques. Existing supply chains may show some single-source component and material risks, but ramp-up will make it very likely that the market can offer enough competition.

Expectations are that capacity demand for each of the three technologies will grow at exponential rates until 2050. Since large-scale production techniques have already been available, however, comparatively little investment in manufacturing capacity will be required to meet component demand. Consequently, few factories will be needed to fulfil the estimates (see table 2). In addition, the industry seems to have developed close ties across Europe and the world, so that mass-producing electrolyzers will not be limited to Germany but occur globally.

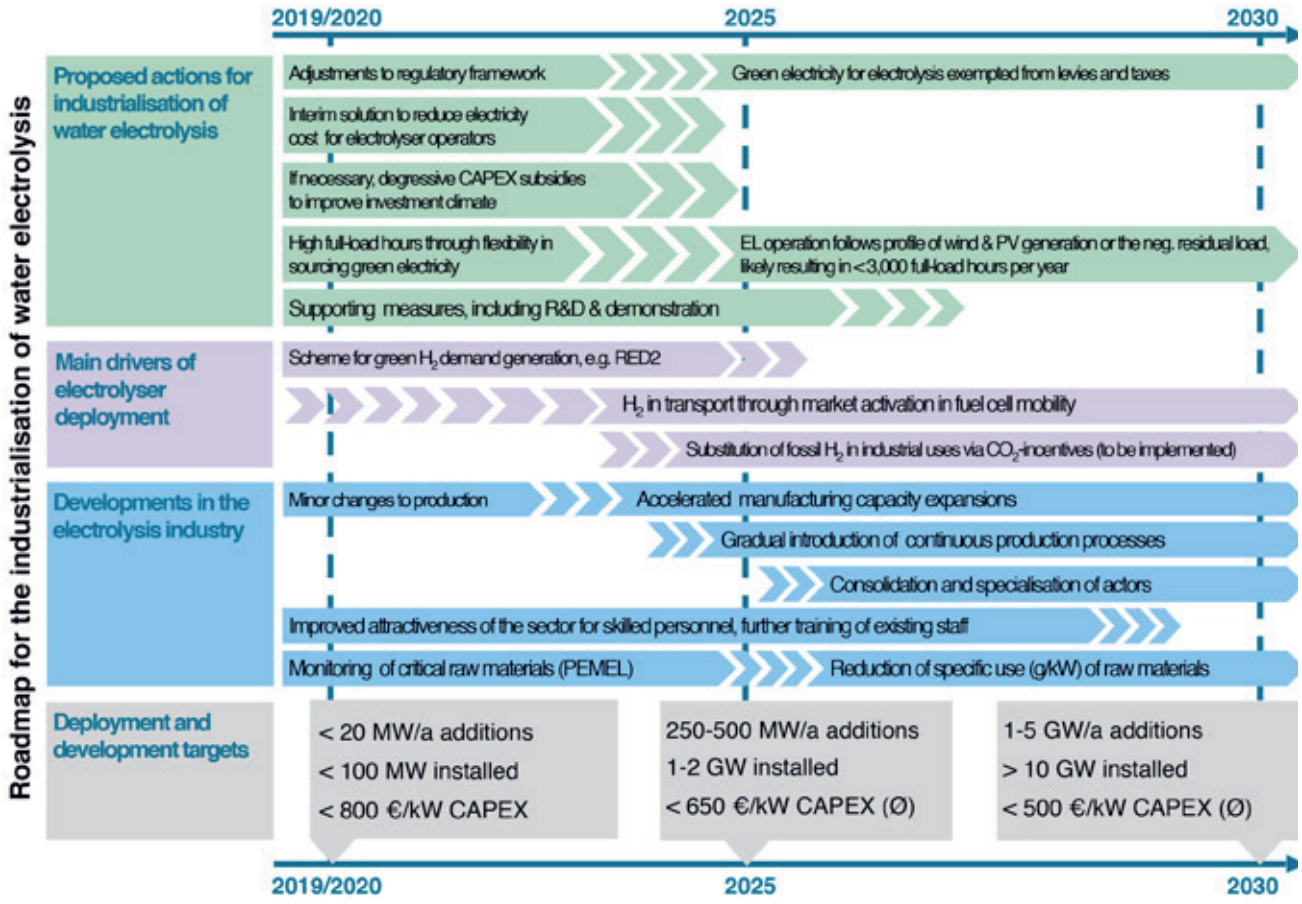


Fig. 3: Road map toward commercializing water electrolysis in Germany

	Component	Production method (commercial scale)	Factory capacity [m² p.a.]	Demand in 2050 [m² p.a.]	Required no. of production facilities
Alkaline	Membrane	Casting	~1.5*10⁶	~300,000	1
	Electrodes	Cutting and stamping / plasma spraying	~79,000	~520,000	7
PEM	MEA	Catalyst coating on decal	←3*10⁶	~91,000	1
	Bipolar plate	Hydroforming / PVD	~300,000	~91,000	1
	GDL (anode)	Cutting and stamping / resistance welding	~79,000 / ~3,300	~63,000	1/20
High-temperature	Interconnect	Hydroforming	~300,000	~235,000	1
	EEA	Casting / sintering	→10⁶	~235,000	1

Table 2: List of quantities and production methods required (capacity was estimated based on information supplied by the manufacturers)

CONCLUSIONS The German electrolyzer industry must now develop into one of gigawatts to meet federal climate targets. Support for the ramp-up of production will be essential to exploiting economies of scale to advance technologically and cut costs. Stable annual sales from 20 megawatts to 50 megawatts per manufacturer will be needed for bringing about a sizeable market, provided suitable manufacturing methods are available. A more diverse and competitive supply chain environment will be realistic only if demand rises and remains strong over time.

All in all, the study has shown that the components rated as being most at risk of supply shortages can be expected to have none, in neither the short nor the long term. Thus, mass production could progress as required. In addition to market support, certain research and development objectives will still need special attention in the future. One example is the decrease of catalyst loading with iridium in PEM electrolysis.

Regulation on a new market support program for water electrolysis would provide long-term planning security. The focus should be on the price structure of electricity. Charges, fees and taxes levied on electricity prices are the main cause of a lack of competitive environmental projects. A road map included in the study depicts the central political issues, steps to be taken by the industry, and growth in demand as well as advances in technology (see fig. 3). ||

Reference(s)

- Smolinka, T., et al. (2018). Industrialisierung der Wasserelektrolyse in Deutschland: Chancen und Herausforderungen für nachhaltigen Wasserstoff für Verkehr, Strom und Wärme.
- The final report, created on behalf of the Federal Ministry of Transportation, BMVI, was published Sept. 17, 2018.

Written by

Dr. Tom Smolinka
tom.smolinka@ise.fraunhofer.de
Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Germany

Franz Lehner
franz.lehner@e4tech.com
E4tech, Lausanne, Switzerland

Steffen Kiemel
steffen.kiemel@ipa.fraunhofer.de
FraunhoferÐInstitut für Produktionstechnik und Automatisierung IPA, Stuttgart, Germany

Dr. Geert Tjarks
geert.tjarks@now-gmbh.de
NOW GmbH Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie, Berlin, Germany

Category: Energy Storage | **Author:** Jörg Staude

GREEN GAS FROM ABROAD?

Guest article about dena's road map, carbon pricing and politics

Eco-gas such as hydrogen or methane produced from renewable electricity is widely regarded as central to effective climate change policy. But if the latest predictions are any indication, Germany will need to import most of it. This doesn't bode well for a shift in attitude, as much of the natural gas consumed in the country is shipped in from abroad as well. It is doubtful that continuing the practice with eco-friendlier imports will be a plus for sustainability or the image of renewable energies in general.

In mid-July, Gazprom began laying the first sections for the Nord Stream II pipeline project in the Baltic Sea. At around the same time, the president of the European Commission, Jean-Claude Juncker, assured U.S. President Donald Trump that to avoid an escalating trade war, the European Union would import additional quantities of natural gas extracted by fracking.

This is good news for the gas industry, which can play off one large supplier against another to cut prices. But cheap natural gas is a danger to the climate. This fossil fuel is seen as bridging the gap between available and future technologies to reduce carbon dioxide levels – temporarily. It does have half the GHG emissions of coal and one-third less than oil, though the substance from the depths of the earth is far from climate-neutral.

The medium-term objective is to decarburize the gas industry, too. And what systems could beat electrolyzers at producing mostly climate-neutral hydrogen, and later methane, from water and renewable electric power? Computer models that paint a picture of Germany in the greenest of all shades in 2040 and 2050 show scores of power-to-gas systems. They consume renewable gas for heating purposes, create base compounds in the chemical industry and store on-demand energy when neither the wind is blowing nor the sun is shining.

The gas industry is warming to the concept, since it will most likely be able to continue current business models without much interruption. Gas power plants would still be the ones to provide supply security, with the caveat that they would run on renewable instead of liquified natural gas, as advocacy group Zukunft Erdgas said in late June following its Triple G – Green Gas for Germany event in Berlin.

Hidden in the group's press release was this passage: At least since German energy agency dena had published its new study had it been clear that the country could produce only half the quantity of renewable gas required in 2050. "The remainder will be covered by imports," the chairman of Zukunft Erdgas, Timm Kehler, said.

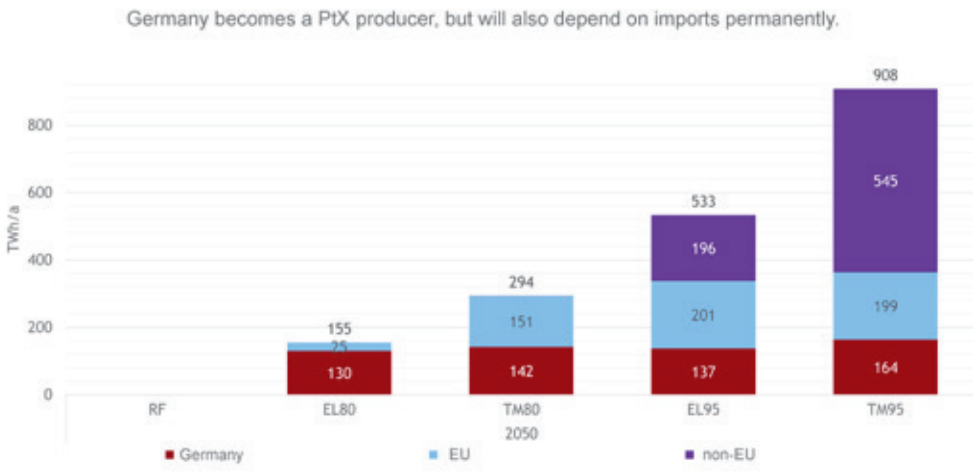


Fig. 1: Partial findings from the dena study

STUDY SEES IMPORTS CLIMB TO 900 TERAWATT-HOURS That half of the renewable gas will need to come from abroad was not an estimate made by businesses in the industry, representatives confirmed. The figure had been taken from a dena study that was published in late May and describes scenarios for reducing Germany's carbon dioxide emissions by 80 percent and 95 percent, either through a heavy reliance on electricity or a combination of energy technologies.

What the study's authors found seems pretty discouraging. Only if Germany were to rely, for the most part, on renewable electric power to create a climate-neutral energy system, something dena termed the Electrification Scenario, and only if the goal were a reduction of 80 percent could power-to-gas stations produce most eco-gas domestically. Then, little beyond a small amount would need to be imported from other European countries.

If, however, the energy mix were more diverse and included biogenic gases as well as resources for power-to-gas, imports would make up "no more than" half the quantity required for an 80 percent reduction in carbon dioxide levels. This is the option seemingly favored by Zukunft Erdgas.

A goal of 95 percent, for which there is no real alternative if the intention is to keep the 1.5-degree target set in the Paris climate accords, will have power-to-gas capacity and renewable gas imports shoot through the roof in both scenarios. The authors write that a 95 percent reduction will see between three-fourths and four-fifths of all gas required for climate-neutral development in Germany be imported from other countries in Europe or from even farther away. They put the total number at up to 908 terawatt-hours.

In this situation, relatively little renewable gas would be produced in the country, between 130 terawatt-hours and 164 terawatt-hours each year. Current annual imports of liquified natural

gas equal about 1,400 terawatt-hours. Subtracting the amount of renewable gas from the total will still see renewable imports at half the fossil fuel quantity imported today.

NON-EU MEMBERS TO STEP IN Is that really in line with the aims of the eco-conscious? If you recall, one of their promises is that transforming the energy markets and switching to renewable energies will help lower the number of conflicts and wars over fossil resources around the globe. Renewable energies generate a dividend on peace is what they say. Up until now, the implicit assumption seems to have been that the energy demand of a climate-neutral Germany would be met by sources within the country's borders, wind farms in the North Sea notwithstanding.

Which countries would want to produce gigantic quantities of green gas to export them to Germany? Zukunft Erdgas didn't name any but would only say that there were non-EU members which the group believed had a more favorable environment for solar and wind power stations. Considering this summer, I wonder what place could have conditions more suitable than those in Germany.

Joke aside, others, namely the authors of the dena road map, were a bit more specific about the regions that could step in to produce all this energy. They write that "according to current estimates, most of the demand for synthetic energy carriers in 2050 will come from regions such as North Africa, which can produce energy at lower costs, including transport, and across a wider area."

The agency believes such imports to be inevitable. The authors write that neither Germany nor Europe should strive for complete energy independence, which would put the economy and supply security at risk.

GREENPEACE ENERGY: 40 GIGAWATTS OF ELECTROLYZER CAPACITY Guaranteeing supply security is no small feat. Last summer, eco-energy company Greenpeace Energy published a study called "Cold, dark, and calm," created by Berlin-based consulting firm Energy Brainpool. It stated a need for more than 40,000 megawatts of electrolyzer capacity to make sure that a global energy system had enough renewable sources available to meet a minimum level of demand. "The amounts of renewable gas required for transportation, heating and cooling, and industrial processes were not part of the analysis," said Marcel Keiffenheim, of Greenpeace Energy. The topic was under study, but research had not yet concluded.

And there was still the issue of where all those electrolyzers should be installed, Keiffenheim conceded. "To guarantee supply security along a widely connected energy system, it makes no difference on what side of the border the power stations are," he said.

But according to him, the most likely outcome would indeed be the installation of substantial capacity on the German side of the border, since factors such as electricity costs played a prominent role in investor decisions.

EUR 100 FOR A TON OF CARBON DIOXIDE Another but shorter study that Energy Brainpool had created in March had shown that his company's windgas could be produced at very low cost, Keiffenheim said. This was true for as long as power-to-gas systems were operated when electricity prices were the lowest and renewable supply as high as possible. In one simulation, for which Energy Brainpool assumed that between 80 percent and 100 percent of all electricity traded on the market was produced from renewable energy, electric power prices had been an average EUR 0.3 cents per kilowatt-hour for 1,500 hours to 2,500 hours a year.

At best, these 2,500 hours of cheap electricity and the 40,000 megawatts of electrolyzer capacity will amount to 100 terawatt-hours and provide enough energy during precisely those periods when there is a lack of wind and sunshine. But that's a far cry from the 900 terawatt-hours of imports that may be needed.

If electricity cannot become less expensive, the next idea could be to raise the carbon price and, consequently, the competitiveness of renewable gas. Apparently, this is the path Zukunft Erdgas wants to take. It has said that investing in eco-gas would become profitable if there was a price on carbon dioxide emissions saved.

Still, the carbon price at which eco-gas becomes cheaper than natural gas is relatively high. According to Energy Brainpool, one ton of carbon dioxide would have to cost more than EUR 100 to push the fossil fuel beyond the threshold of EUR 0.4 cents per kilowatt-hour. In the long term, the company hastened to add, prices for green gas could fall to 3 cents or below, at least, regarding production.

However, someone has yet to estimate what it will cost Germany to import gas from regions like North Africa. It is also not clear what price tag will come attached to infrastructure buildup or the efforts to ship the gas in tankers hundreds of miles across the sea – tankers powered by the same renewable fuel.

THE ART OF POLITICS The above illustrates why the natural gas and renewable gas industries have been closely involved in politics for a relatively long time: They are hoping that new rules will kick the power-to-gas market into high gear, as it has so far offered little beyond barely working demonstration systems.

Kehler has more concrete plans for the sector. Besides climate and renewable targets, he said, the government needs to set a goal for renewable gas. If it did that, the industry would be willing to talk about regulatory issues and ideas for an integrated energy system.

It would certainly be a sweet deal: Make sure we get a market while we consider your suggestions on the rules.

Even today, the industry said, there were some market players that had launched comparatively large pilot projects. For instance, Open Grid Europe and Amprion were planning to build a power-to-gas system with a capacity of 50 to 100 megawatts. Will they build the system in another EU country or even in North Africa? Apparently not. Instead, they are reportedly considering sites in Lower Saxony and the upper part of North Rhine-Westphalia. It seems as if gas production in the country will continue – at least, for now. ||

Category: Energy Storage | **Author:** Sven Geitmann

CO_2 PROVES A VALUABLE RESOURCE

Carbon2Chem® pilot plant comes online

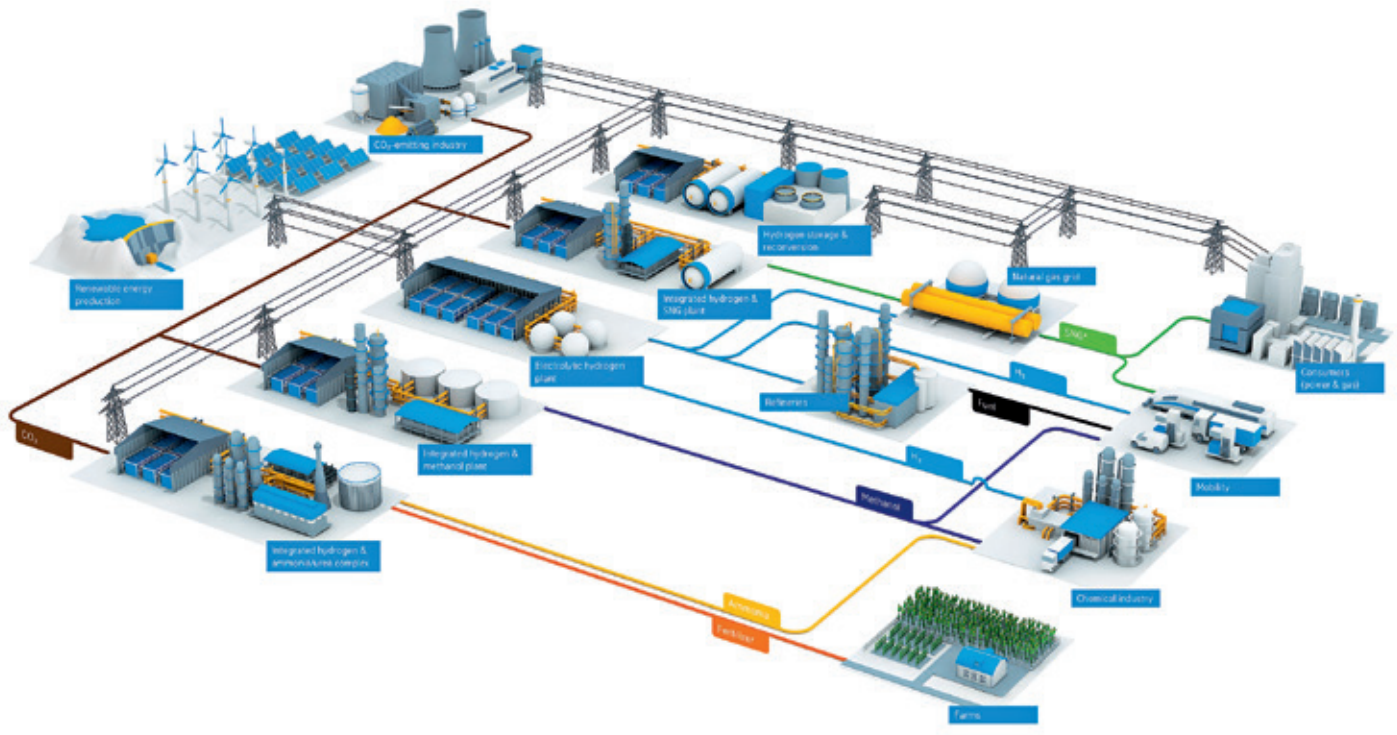


Fig. 1: Carbon dioxide (left) can be used in several ways. Source: thyssenkrupp

Here's an intriguing idea: Don't burn off most waste gases produced by steelmaking but turn them into basic chemicals and capture the carbon dioxide they contain instead of discharging it into the air. It is an idea with only one caveat, in that it will most likely take another 15 years before industrial-scale systems are available. Still, thyssenkrupp has taken the first step by starting its Carbon2Chem® project in Duisburg in mid-September.

As a steel and cement manufacturer, thyssenkrupp certainly is used to environmental regulation. But when the EU Commission and Council publicly pondered whether to lower the carbon dioxide limit for producing one ton of raw iron from 1,630 kilograms in early 2017 to 1,328, the corporation and many others in the industry began to push back. In the end, the EU scrapped its plan but tightened the rules on emissions trading.

When the European Union introduced its cap-and-trade program, companies had gotten carbon credits for free but currently need to pay if they cross a threshold on par with the most efficient gas-burning technology on the market. However, the EU has recently decided to reduce the number of free certificates by another 20 percent. It is this tightening of rules that is being met with opposition. Manufacturers in the steel industry say that there simply is no technologically and economically viable solution to meet the new requirements.

As Werner Diwald, the chairman of DWV, explained to H2-international, "The steel industry is in a dilemma. Its systems have been built to last up to 50 years and it cannot funnel money into projects just to satisfy the short-term targets of the EU. It must keep an eye on the 2050 targets, so introducing suitable technologies would be in the industry's best interest. But to do that, market rules need to allow fair competition. Otherwise, you'll risk punishing those companies that are trying to be responsible and sustainable." Clearly, the industry knows it will have to become more open about each company's carbon output and reduce emissions soon.

Reinhold Achatz, who heads the technology, innovation and sustainability department at thyssenkrupp, is not a big advocate of decarburization, as he thinks the word is nonsensical. He said that the point was not to envision a world without carbon, since "there is no such thing." Rather, the compound needed to become part of a cycle such as the one found in nature and should no longer be discharged into the air but captured. He likes to speak of fossil defuelization to describe the method for reducing fossil fuel consumption in the future.

His work is focused on gases produced by coking plants and other steelmaking facilities. Those gases contained not only hydrogen but a wide variety of raw materials, he said. Instead of burning them off, as had been done in the past, they could be incorporated into a carbon cycle to create useful chemical substances.

Fig. 2: Reinhold Achatz

"Carbon2Chem is not the solution but an important piece of the puzzle."
Reinhold Achatz, thyssenkrupp

CHEMICAL INDUSTRY TO MAKE USE OF STEEL PRODUCTION GAS Multiple steelmaking processes create waste gas as a byproduct. It is produced in the blast furnace, the oxygen converter and the coke plant. It contains hydrogen, nitrogen as well as carbon monoxide, dioxide and methane. For example, nitrogen and hydrogen can be combined as part of an industrial process known as Haber-Bosch to form ammonia and produce chemical fertilizer.

Likewise, carbon monoxide, carbon dioxide and hydrogen are the base components of methanol, which can be used to manufacture other kinds of chemical products, or even fuel. It is a very common organic compound. At present, however, much of the carbon needed for production is extracted from fossil fuels, such as natural gas.

The idea behind Carbon2Chem is that an increase in the range of applications will markedly reduce the amount of carbon dioxide that needs to be released into the atmosphere. Carbon is vital to steelmaking when removing oxygen from iron ore, or, in other words, turn iron oxide into pure iron. One – unavoidable – byproduct of this process is carbon dioxide. Instead of capturing and storing the compound, it could be immediately directed to other areas to reduce the consumption of fossil fuels.

The challenge will be to make efficient use of each waste gas component and, at the same time, meet demand for ammonia and methanol. Waste gases may contain enough hydrogen to synthesize ammonia, but additional sources will be required to produce methanol. Renewable electrolyzers will fill that gap, as thyssenkrupp will be testing them for multiple applications, from load to demand side management. They will run especially at times of surplus renewable electricity to keep the cost per kilowatt-hour as low as possible.

Intermittent operation is certainly not a hindrance for state-of-the-art electrolyzers. The same cannot be said about facilities producing ammonia and methanol. They have been mainly designed for continuous operation, and changes in pressure and temperature could damage or destroy core components such as catalysts. One of the main goals of Carbon2Chem will be to seek out catalysts that can cope with these operating conditions without becoming less effective.

CARBON DIOXIDE: A VALUABLE RESOURCE Carbon2Chem is an offshoot of PLANCK – Platform for Sustainable Chemical Conversion, a program established in partnership with the Max Planck Institute for Chemical Energy Conversion and 16 other research institutions and businesses, such as AkzoNobel, BASF, Siemens and ZBT, in December 2013. Bernd Overmaat, spokesperson for technology, innovation and sustainability at thyssenkrupp, said as early as 2014 that carbon dioxide was far from being just a climate killer but could become a valuable raw material in the chemical industry.

In the initial phase of Carbon2Chem, launched June 1, 2016, researchers investigated several types of systems, for example, by analyzing electrolyzer stacks in a dynamic laboratory environment. In late 2016, thyssenkrupp Steel Europe also began construction on a pilot plant in Duisburg, Germany, hoping to facilitate the transfer of findings from basic research to manufacturing. The system was started up Sept. 20, at a ceremony attended by Germany's education minister, Anja Karliczek. Her ministry had spent more than EUR 60 million on the project. The installation is the first to use waste gases for methanol production.

600 MEGAWATTS OF CAPACITY PER YEAR A benefit to thyssenkrupp is the corporate group's wealth of knowledge about electrolysis. A subsidiary named thyssenkrupp Industrial Solutions is offering industrial water-splitting equipment, which the company said had been "successfully brought to market." An alkaline electrolyzer is likewise part of Carbon2Chem, with Zero Gap technology being its most distinctive feature. Nearly closing the gap between the membrane and electrode has made it possible to raise round-trip efficiency to 82 percent. The system comes with a special cell design and an active cell membrane surface area as large as 2.7 m^2.

The company said several units combined could bring capacity up to several hundred megawatts. The patented design is based on other industry-leading electrolyzer technologies invented by thyssenkrupp. Roland Käppner, head of energy storage and hydrogen at thyssenkrupp Uhde Chlorine Engineers, said decades of experience in developing and building electrolyzers had allowed for the creation of a product that met the key requirements of the company's customer base. The system was not only highly efficient and economical but easy to ship and install. Annual production capacity totaled as much as 600 megawatts. ||

GERMAN-ITALIAN JOINT VENTURE
Dortmund-based thyssenkrupp Uhde Chlorine Engineers is a joint venture of thyssenkrupp Industrial Solutions and De Nora, a privately owned Italian supplier of electrochemical solutions. In April 2015, both merged their electrolysis business, now overseen by German management.

15-MEGAWATT SYSTEM IN SOUTH AUSTRALIA
Early this year, thyssenkrupp announced that it had received a USD 117.5 million order by Hydrogen Utility™ to build an electrolyzer at Port Lincoln, Australia. Supported with USD 12 million from the Renewable Technology Fund set up by the state of South Australia, the project will see the construction of a 15-megawatt electrolyzer and a facility to produce fertilizer from ammonia. Additionally, it will lead to the installation of a 10-megawatt hydrogen gas turbine and a 5-megawatt fuel cell, both of which are thought to deliver electricity to the state's grid.
"Hydrogen also offers an opportunity to create a new industry in South Australia where we can export our sun and wind resources to the world," explained Tom Koutsantonis, the state's finance minister. Attilio Pigneri, the chief executive of H2U, added that the Port Lincoln endeavor would "provide the perfect training ground for a new wave of green hydrogen professionals."

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

FUEL CELL COMMERCIAL VEHICLES MADE BY DAIMLER

Buses to arrive in 2022 at the earliest

At first, Daimler announced that it wanted to use fuel cells in light commercial vehicles. However, a few days later, news broke that the automaker planned to offer buses equipped with the technology as well, provided tests in a reasonable amount of time between 2020 and 2022 are successful. The decision is exemplary of the latest trend in the hydrogen and fuel cell industry to refocus efforts on commercial transportation.

Daimler showed its new vehicle base, a Sprinter powered by an electric motor and a fuel cell, on July 2. The fuel cell installed in this electric van is intended to function as a range extender during long-distance drives, opening up new opportunities for commercial and recreational uses. Three tanks were integrated into the underbody of the vehicle called Concept Sprinter F-Cell. Reportedly, they can store 4.5 kilograms of hydrogen to offer a range of 186 miles (300 kilometers), with a battery adding another 19 miles (30 kilometers) to the total. Like the GLC F-Cell, the 147-kilowatt van has a rear-wheel drive and was designed as a plug-in hybrid.

Daimler said that the benefits of the concept vehicle were a high range, a low overall weight, fast refueling and great versatility. Nevertheless, it seems the company is not gearing up for mass production: The relevant press release read that Mercedes-Benz Vans was putting a strong focus on custom solutions.

Fig. 1: A semi-integrated motor home based on the Concept Sprinter F-Cell, Source: Daimler

Volker Mornhinweg, who manages the Mercedes-Benz Vans division, stated that "an electric motor option will be part of all our commercial vehicle offerings at some point down the road. We will begin by selling the eVito this year and the eSprinter in 2019." He said that fuel cells had been incorporated into Daimler's eDrive@VANs strategy for their great medium-term advantages, particularly long distance, regardless of whether people took trips for business or pleasure. "There is no doubt that the technology has considerable potential and even more so when it is installed in relatively large vans used for long drives, where fast refueling is a must. After assessing the situation, we believe fuel cells can be a sensible addition to a product lineup such as ours, which consists of solutions for both private and business purposes."

FUEL CELL BUS WITH A RANGE OF NEARLY 250 MILES Daimler likewise revealed plans to re-enter the market for fuel cell buses. In late July, the mayor of the German city of Stuttgart, Fritz Kuhn, signed a letter of intent to have transit company SSB test four articulated buses by the automaker between 2020 and 2022. These buses, called eCitaro, would be either all-electric or hybrid ones, with fuel cells increasing the range of the latter. Till Oberwörder, who heads Daimler Buses, said that the letter "by a large transit company proves we recently made the right choice in offering eCitaro buses with a variety of battery technologies, as well as fuel cell range extenders."

Daimler unveiled its all-electric eCitaro bus on July 10, during a preview event for the IAA Commercial Vehicles. It has up to 243 kilowatt-hours of battery capacity, which is thought to be enough for around a third of all city runs in Germany. In 2020, a larger battery will reportedly raise that share to half of all scheduled routes. A fuel cell added at a later time would make for a range of 249 miles (400 kilometers). ||

Category: Electric Transportation | **Authors:** Stefan Keller M.S., Kläre Christmann M.S., Adrian Heuer M.S.

ZERO-EMISSION COMMUNITY VEHICLES

LADOG – fuel cells and batteries to replace diesel

To improve quality of life, a growing number of local councils have set up zones for environmental protection and noise reduction and have discussed driving bans to clean up the air in cities and metropolitan areas. One consequence of their efforts has been a tightening of emission regulations regarding community vehicles and public equipment. In response, researchers conceived a project named ELAAN to build an electric engine that is powered by fuel cells and batteries. The aim was to identify output requirements, map out a drive system, design fuel cell and battery modules, and integrate all components into a prototype. Computer models were employed to help draw up specifications and simulate operational modes.

Internal combustion engine vehicles must comply with ever-lower emission limits nowadays. Additionally, high noise levels, such as those caused by street sweepers and garbage trucks in the early morning hours, are often a serious impediment to quality of life, especially in metropolitan areas. One solution to these problems is the combined battery and fuel cell drive system that has been developed as part of ELAAN.

The system is nearly inaudible, while its only emission is water vapor. The use of hydrogen means that a high amount of energy can be stored in the tank of a vehicle and yet fueling takes little time. Batteries provide supplemental power and increase round-trip efficiency by harnessing kinetic energy.

However, it needs economies of scale to create a competitive engine. To lower costs, the system was designed with multiple applications in mind. One target market is industrial trucks, to which fuel cells are far more suited than batteries. This is particularly true if vehicles are required across three shifts, since their tanks can be filled up in a matter of minutes. Fast fueling is indeed the primary reason for the enormous popularity of hydrogen-powered industrial trucks in the United States, where the number of units ordered or shipped to customers has grown to more than 16,000 since 2009 [1].

Fig. 1: ELAAN LADOG

ANALYZING REQUIREMENTS To size the electric motor and the fuel supply unit, initial analysis involved driving a conventional LADOG T-1250 vehicle along a predetermined route. The objective was to identify the maximum and continuous power output of the standard model, which is equipped with a 74-kilowatt four-cylinder diesel engine, along with the amount of energy required for day-to-day operation. To determine the mechanical power that is transferred through a hydrostatic drive to all four wheels of the car, the instant fuel consumption and engine torque values recorded during the test drive were multiplied with brake-specific fuel consumption and hydrostatic efficiency:

The variable in the above equation represents instant fuel consumption and is measured in liters per hour, while is diesel density in grams per liter. Data on the other two variables came from the manufacturer. describes brake-specific fuel consumption, based on torque and measured in grams per kilowatt-hour, and denotes the efficiency of the hydrostatic transmission.

The analysis indicated requirements of 20 kilowatts and 60 kilowatts of respectively continuous and maximum power. The initial plan was that the fuel cells would provide those 20 kilowatts and the batteries the remaining 40. However, battery capacity was subsequently increased to 60 kilowatts to supply full power even when the fuel cells cannot yet deliver their maximum.

DESIGNING THE SYSTEM AND COMPONENTS The next step was to create a modular system. It supplies continuous power from two fuel cell units, each with a capacity of 10 kilowatts. The nominal voltage of both combined is 80 volts. The battery pack is directly linked with the variable frequency drives of the motor and, via buck-boost converters, with the fuel cells. This kind of arrangement allows for much control over energy distribution. Likewise, low voltage and high modularity result in a superior level of safety and a motor topology that can be easily adapted to fit a variety of applications. For example, half a LADOG system produces 10 kW_{el} and 30 kW_{el} of respectively continuous and peak power, which meets the requirements for a typical Class 1 forklift truck that is operated indoors. Key components of the vehicle tank can also be integrated into other 350-bar systems.

Then, the drive system was redesigned in its entirety. It is now a liquid-cooled, permanent-magnet synchronous motor with 60 kilowatts of nominal mechanical power at 80 volts of nominal voltage. One distinctive feature is the division of the stator windings into three same-size sections. They make it possible to use three standard motor controllers, so that each controller carries only one-third of the total current. The motor itself is mounted onto the back axle, along with a two-speed transmission. A drive shaft moves the front axle.

One battery module houses seven prismatic NMC cells, type PHEV2, a cooling system, temperature sensors and single-cell voltmeters. The cells, which are joined in series through laser-welded electrical contacts, provide 945 watt-hours of rated capacity. The rechargeable battery pack that was installed >>

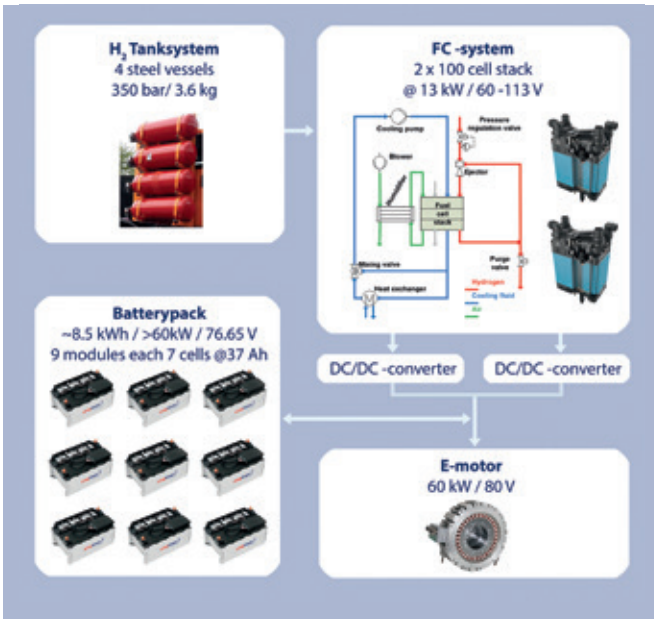


Fig. 2: LADOG topology developed during ELAAN

for ELAAN consists of nine units, which offer approximately 8.5 kilowatt-hours in total. Throughout three sections connected in series as well as three modules each in parallel, it generates approximately 80 volts, at a maximum discharge power capacity of more than 60 kilowatts. The design stage was accompanied by the characterization of cells and complete units in relation to multiple environmental factors and load points.

The base power demand of the vehicle is met by two fuel cell modules joined in parallel. The main component of each is an NM5 fuel cell stack consisting of 100 individual cells. It measures 243 mm by 161 mm by 152 mm and provides approximately 13 kilowatts of electric power at atmospheric pressure. Freeze-starts from minus 20 °C were conducted successfully without help from an additional source of heat. Durability was validated by the manufacturer, which reported that it had been running a 20-cell device under variable load conditions for more than 8,000 hours.

CREATING COMPUTER MODELS To test several operational modes at once, the fuel cell system was also modelled on a computer. Components were represented by data obtained from measurements or specification sheets.

The fuel cell was rendered as a single liquid-cooled unit. It depicted electrochemical properties as well as mass and energy balances. To ensure that dynamic processes were sufficiently represented in the system, it included differential equations to model heat transfer mechanisms, as they have by far the largest time constants. Initial values were specified for the electric current, the operating temperature and flow rate of the inlet coolant, the relative humidity, the pressure and temperature of inlet gases, i.e., hydrogen and air at the anode and cathode, and the ambient temperature. The cell voltage and the starting values of mass flows were calculated based on these parameters.

The battery, on the other hand, was created from equivalent circuits. It comprised a voltage source, which had multiple dependent parameters to model open circuit voltage, and an internal resistor. In addition, it included two resistor-capacitor circuits to depict dynamic processes inside the unit.

Capturing each and every part of the fuel cell and battery enabled project participants to improve methods for sizing, explore the full operating range, and assess predictions of efficiency. Two examples are found in figure 3.

LADOG T-1250
The vehicle has been exhibited at several trade shows and has sparked much interest. We would like to express our deepest gratitude for the assistance given to us by all project partners and funding institutions. ELAAN was financially supported by Germany's Federal Ministry of Education and Research under grant ID 03ET6026C. Our partner Fronius International GmbH received funding from the Austrian Research Promotion Agency FFG under project no. 840427.
Within the consortium, tasks were assigned according to expertise. Heinzmann GmbH & Co. KG developed the electric motor, along with the controllers. ElringKlinger AG designed the battery and fuel cell modules. LADOG-Fahrzeugbau und Vertriebs-GmbH incorporated the components into the vehicle. Fronius International GmbH, an affiliated organization based in Austria, combined the fuel cells and fuel cell components, battery modules, hydrogen fuel unit and power electronics into an integrated energy system. The Fraunhofer Institute for Solar Energy Systems – ISE supported ELAAN by characterizing components and conducting computer simulations.

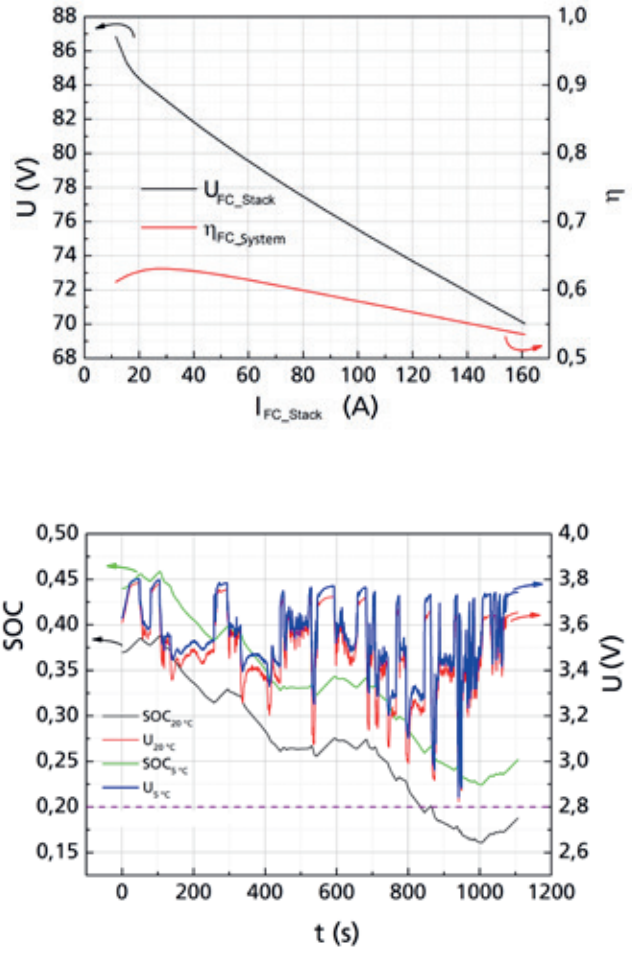


Fig. 3: The results of simulating the stack voltage and system efficiency were plotted on the left graph in relation to the load. The graph on the right shows, in two temperature settings, the battery cell voltage and charge level under a typical driving profile.

It ranges from 0.53 to 0.63 and approaches its maximum at approximately 20 percent of nominal capacity. It is thus recommended not to have cell output drop below that point. It would be recommended not to lower these values further. The one on the right depicts charge levels and the average cell voltage under a typical driving profile in either a 5 °C or a 20 °C environment. It makes clear that to avoid shut-off conditions during a freeze-start of the vehicle, the state of charge must be higher at low temperatures – in this case, 0.44 at 5 °C and 0.37 at 20 °C.

INTEGRATING COMPONENTS AT PROJECT END All components of the drive system were integrated into a working prototype of a LADOG T-1250 vehicle at the end of the project (see fig. 1). Although a road permit could not be obtained until that point, the car is available for test drives on enclosed premises. This option is a major step forward in the development of a commercially viable product. ||

[1] Devlin, P., Moreland, G. (2017). *Industry Deployed Fuel Cell Powered Lift Trucks*. DOE Hydrogen and Fuel Cells Program Record 17003. Washington D.C.: U.S. Department of Energy.

Written by

Stefan Keller M.S.
stefan.keller@ise.fraunhofer.de

Kläre Christmann M.S.
klaere.christmann@ise.fraunhofer.de

Adrian Heuer M.S.
adrian.heuer@ise.fraunhofer.de

All for Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Germany

50TH HYDROGEN STATION GOES TO POTSDAM

Nearly every week in August, a new hydrogen station came online somewhere in Germany. The H2.Live map by H2 Mobility showed fueling pumps being added in Weiterstadt, Ratingen, Munich (on Verdistrasse) and Stuhr-Großmackenstedt at the Stuhr autobahn interchange near Bremen. There are five commercial hydrogen fueling stations up and running in the state of Hesse alone. The most recent addition was a pump at the SVG truck stop Lohfeldener Rüssel near Kassel, close to the autobahn-to-autobahn interchanges between the A7, A44 and A49. Thomas Zengerly, the chairman of the board at Deutsche Shell, said at the opening ceremony on Aug. 9, "We at Shell believe in the technology and want to set an early example." However, he thinks countrywide deployment in transportation will not happen before the next decade.

In July, the first fueling site was started up in the region around Osnabrück, at the Hasbergen truck stop next to the A30. It began operation later than planned, but Total's district manager, Marco Rohlmann, said that he was glad that "we're finally kicking it off."

On Sept. 7, the country's transportation minister, Andreas Scheuer, attended the opening of a fueling station in Potsdam – the 50th in Germany according to H2 Mobility. On Sept. 18, at the same time as the f-cell show, the state of Saxony's first hydrogen station was started up during the Energy Saxony Summit, which was held in the state's capital, Dresden.

Meanwhile, two other stations are being built in the Rhineland region to supply power to the 40 fuel cell buses that Regionalverkehr Köln, Cologne's mass transit company, is planning to operate starting in 2019. The aim of the Zero Emissions project is to build one station each at company offices in Meckenheim and Wermelskirchen. Eugen Puderbach, the chief executive of the public transportation business, said that "both fueling stations are important elements of our strategy to offer zero-emission public transportation in the Rheinisch-Bergische and Rhein-Sieg districts." ||

MOVR FOR THE LAST PART OF THE ROUTE

After exhibiting a prototype at Hannover Messe this year, the German Aerospace Center, also known as DLR, has announced plans to make its hydrogen-driven cargo bike available on the market. Reportedly, a startup named Rytle, which sells all-electric bicycles called MovR, will be testing fuel cell versions this fall. Alexander Preuschoff, of Rytle, told H2-international, "We'll present a more advanced vehicle at the IAA."

Uses such as the one described above were exactly what DLR researchers had in mind when they developed a new type of fuel cell module. The organization said that it was superior to comparable batteries and offered a higher range and twice the lifetime at a competitive price. The plan now is to integrate the module into cargo bikes to offer a faster, easier and quieter zero-emission solution for transporting heavy items.

Called Fuel Cell Power Pack, or FCPP, the unit consists of a fuel cell that produces between 300 watts and 500 watts in continuous operation and a rechargeable lithium-ion battery to meet peak loads. Cold-start capability and fast refueling made it suitable for multi-shift work, said Mathias Schulze, who works at the DLR. It could be refueled by either filling up or exchanging the metal-hydride tank on the bike. His colleague, Christian Rudolph, added that the system had been designed for "last-mile delivery, which denotes the route between distribution centers and customers. More and more small shipments need to reach the final destination of the supply chain at an ever-faster pace."

In July, the FCPP project, which had been spun off by DLR, and five other innovative business ideas were chosen by the Helmholtz Association of German Research Centers for implementation under the Helmholtz Enterprise support program. ||

Fig. 1: Novel transportation concept

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

FUEL CELLS: THE MOST SOUGHT-AFTER ELECTRIC VEHICLE OPTION

Low-volume production of Hyundai-powered Audi cars in 2020

The Hyundai Motor Group, based in South Korea, is one of few automakers that offer fuel cell vehicles on the market. In mid-June, it announced that it would support Audi's work in the field and both corporations have since signed an agreement about cross-licensing patents. The contract expressly mentions the group companies that are part of the endeavor.

Besides Hyundai, the agreement also names Kia Motors, which belongs to the Hyundai-Kia Automotive Group, and Audi's parent company Volkswagen, which now has access to fuel cell components from the ix35 Fuel Cell and Nexo models. The main goal of all involved is an increase in the sales of fuel cell electric vehicles, or FCEVs for short.

The capacity of Hyundai's factory in Chungju, South Korea, currently stands at 3,000 fuel cell powertrains a year but can be increased to produce tens of thousands of units if the market demands it.

AUDI EXTENDS COOPERATION WITH BALLARD Shortly before news about the deal between Audi and Hyundai broke, Ballard announced that it had extended its partnership with the German automaker for three-and-a-half years. As part of the HyMotion demonstration program, Audi can now benefit from the fuel cell know-how of the Canadian business until August 2022. The contract, worth an estimated USD 53 million to USD 83 million, was signed in early June. It may mean that Audi will receive help from Ballard when introducing a small batch of fuel cell cars in the foreseeable future.

Randall MacEwen, the president and chief executive of Ballard, said that the long-term HyMotion program was a testimony to Volkswagen's as well as Audi's commitment to fuel cell electrification and their partnership with Ballard. He said that the auto industry was "undergoing extraordinary transformation, driven by electrification, shared mobility and autonomy." He added that shared transportation and autonomy would result in profound changes to the way cars were being used and trigger considerable increases in mileage and hours of operation.

In March 2013, Ballard and Volkswagen signed an initial four-year agreement, followed by a two-year extension in February 2015, with the contract ending next March. Audi took over the reins of the corporate group's fuel cell program in 2016. ||

Fig. 1: Some components installed under the hood of the Hyundai Nexo will soon find their way into a VW vehicle.
hyundai_nexo_details_feb2018 (5).jpg
Source: Hyundai

"The fuel cell has the best cost-benefit ratio to power electric vehicles [...]. Partnerships are a sensible option to make breakthroughs and lead the pack at attractive costs – and bring this sustainable technology to market."
Peter Mertens, head of technical development at Audi

"Part of our engine design strategy is an initial low-volume production of fuel cell cars, which will be up for sale in 2020. Hydrogen is a superb energy carrier to implement tomorrow's ideas for electric transportation."
Rupert Stadler, chairman of Audi

"If, after 2025, we get to around 100,000 units a year – which is entirely possible for a large corporation such as Volkswagen – expect the price for fuel cells to drop to about a third or fourth."
Nikolai Ardey, head of powertrain development at Audi

"We believe that the partnership between Audi and the Hyundai Motor Group gives us a chance to successfully demonstrate the benefits of fuel cell vehicles on a global scale."
Euisun Chung, vice chairman of Hyundai Motor Co.

"We take our role as pioneers of fuel cell vehicle development very seriously. Our intent is to provide as many as people as possible with access to this clean and efficient means of transportation."
Markus Schrick, formerly chief executive of Hyundai Motor Deutschland

Category: Electric Transportation | **Author:** Ralf Wascheck

FUEL CELL TEST STATION

Powerful and highly adaptable

Fuel cells are regarded as easy-to-handle, high-performance devices. When used in electric vehicles, they are a viable alternative to the battery-only option. They can be refueled in just a few minutes, offer a high range, and remain operational even in low-temperature settings. Plus, they are closely linked to renewable sources of energy. As hydrogen is en route to becoming the main method for storing renewable electricity, it will be available in large quantities. IAV recently added a fuel cell test station at its R&D center in Gifhorn, Germany, to increase the company's capabilities for designing fuel cell vehicle components.

Fig. 1: New testing environment, Source: IAV

Automakers have succeeded in driving fuel cells into the limelight, as evidenced by the rapid growth of IAV's development services and expanding test cycles. Fuel cell cars make it possible for manufacturers to cut the amount of carbon dioxide emitted by their vehicles without having to tell customers to expect a bumpier ride. In short, the fuel cell engine is certain to beat the competition.

A FULL RANGE OF APPLICATIONS In Gifhorn, IAV has the latest test equipment to investigate PEM fuel cell stacks and systems, as well as assess peripheral components, such as humidifiers, compressors and recycle blowers. The station has been designed for testing stacks at up to 180 kilowatts and systems at up to 150 kilowatts of electric power.

The equipment is a means to evaluate the effectiveness of hydrogen-driven PEM fuel cells installed in vehicles. It allows the researchers in Gifhorn to observe fuel cell behavior in dynamic settings that resemble real-world application. An extensive list of tools is available for analyzing mass-market products, but the station can also be used to answer questions at an early stage of development and research.

Fuel input can be regulated based on a wide range of parameters, for example, to study the impact of pressure, temperature and humidity on performance. It is also possible to vary hydrogen quantities to model increases in nitrogen concentrations inside fuel cells. In addition, the equipment includes tools to analyze stack properties. One example is a voltmeter for measuring the voltage of single cells under highly variable operating conditions.

A COMPLETE RANGE OF TEST CYCLES The station can run 24 hours a day, every day of the week, in a continuous cycle, for example, to study fuel cell degradation, test system functions and evaluate the characterization and design based on multiple operational modes and management strategies. It is part of a complex testing and simulation environment at IAV, allowing the researchers to determine how effective different methods of operation are and what impact they have on key figures, such as hydrogen consumption and vehicle range. In addition, it can be customized to conform to manufacturer-specific test cycles.

IAV has already begun to fulfil customer orders and the great number of requests illustrates how much interest there is in the new test station. Fuel cell engines play a key role at the business: Its employees have a wealth of expertise in the design of fuel cells. Early on, they started accumulating the know-how required to develop fuel cell vehicles and individual components. The new station to test fuel cells in high-capacity and dynamic settings is a perfect fit for its product portfolio. ||

Written by
Ralf Wascheck, Ingenieurgesellschaft Auto und Verkehr (IAV), Gifhorn, Germany
ralf.wascheck@iav.de

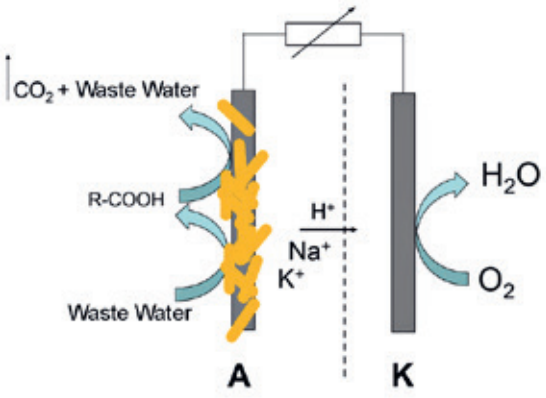
TECHNICAL SPECIFICATIONS
- Power output (fuel cell): 150 kW
- Power output (stack): 180 kW
- Voltage: 1,000 V
- Current: 1,000 A
- Cooling capacity: 250 kW
- Air flow rate: 10,000 NLPM
- Hydrogen flow rate: 4,100 NLPM
- Input fuel control accuracy: ≤ 1 % of full scale
- Fuel inlet dew point: up to 80 °C

Category: Research & Development | **Authors:** Liesa Pötschke, M.S., Georg Stegschuster, M.S.

TEXTILE ELECTRODES FOR MICROBIAL FUEL CELLS

Bioanodes no longer just a vision

Microbial fuel cells are one of the most well-known devices in a steadily expanding research field called bio-electrochemistry. As diverse and promising as technologies bridging the gap between electrochemistry and bio-economy may be, bringing them to market is fraught with challenges. Two recent collaborative efforts, TexKoMBZ and TextESys, thoroughly investigated how to develop components for these complex systems.



Microbial fuel cells work on the same thermodynamic principles as conventional fuel cells, although their core component is a microbial instead of a (precious) metal catalyst. Biocatalysts oxidize organic matter and transfer electrons released during the process to a solid electrode surface area. From a microbiological perspective, you might say that bacterial species use the fuel cell anode instead of dissolved oxygen or sulfate to "breathe."

It is this special ability that provides an entire range of opportunities for new fuels. Virtually all substances that, from a microbiological point of view, can be consumed will be. The most popular fuel is wastewater (see fig. 1).

Fig. 1: Working principle of a microbial fuel cell for wastewater: When electrochemically active microorganisms, such as Geobacter sulfurreducens, ingest short-chain fatty acids, or, more specifically, acetic acids, they oxidize these compounds to run cellular processes. Electrons emitted during processing are transferred directly to the anode (A), with the counterreaction often involving oxygen reduction at an air-exposed cathode (C). Cations such as Na^+ and K^+ play a more important role than protons in achieving equilibrium in the wastewater.

The goal, however, was not to design a powerful biobattery but to combine energy generation or recovery and wastewater treatment to lower demand for conventional yet expensive activated sludge processes. Laboratory experiments had already resulted in microbial fuel cells with high enough power densities to make wastewater treatment more economical. However, it often proved impossible to maintain those densities when scaling up entire systems. The lesson learned was that it would require a more profound understanding of the fuel cell's individual components to guarantee success. It was the reason for TexKoMBZ's focus on methods to develop and scale anodes.

WHAT A BIOANODE LOOKS LIKE

The combination of microbial catalyst and electrode is called a bioanode. Microorganisms cover the electrode material with a conductive biofilm, which is between 100 micrometers and 200 micrometers thin. One well-known species of electrochemically active bacteria is of type Geobacter sulfurreducens. When they grow into mature biofilms, these microbes convert acetic acid into carbon dioxide and electric power at nearly 100 percent efficiency. At this stage, they ingest most of the fuel to produce energy and little of it to grow. In actual wastewater, acetic acid is part of the food chain developing naturally within the microbial community of the biofilm. Every organism that is required for conversion will come directly from the wastewater and accumulate on the electrode surface.

WHAT IS REQUIRED OF ELECTRODES

Favorable environmental conditions will attract a greater number of desired microorganisms. This colony is key to ensuring the long-term efficiency and operational stability of a bioanode. Several difficulties arise in respect to electrode materials. While it is possible to use those commonly available for designing conventional fuel cell equipment, bioanodes generate electricity under entirely different operating conditions. For example, bacteria take about 10 times as long as precious metal catalysts to complete the task. In addition, an electrolyte such as wastewater is rarely buffered, if at all, which means that ionic conductivity is extremely low.

Thus, current density is by several orders of magnitude lower than in hydrogen fuel cells. Efficient bioanodes generate between 1 ampere and 10 amperes per square meter. Consequently, electrode materials must have an exceptionally wide surface area by means of which the biofilm can cover as much reactor space as possible.

HOW TO USE TECHNICAL TEXTILES

Typically, a microbial fuel cell is manufactured from carbon-based electrode material. The material is a sensible compromise between electrical conductivity, biocompatibility, corrosion resistance and cost. The electrode has a three-dimensional design, so that mechanical properties, i.e., flexibility, drapeability and porosity, need to be maintained as well. The challenge is to attain the largest possible surface area without reducing other electrode properties in the process. Prior attempts at solving the problem involved the creation of graphite brushes, thick and multi-layered graphite felts, graphite pellets and metal-based sponges. The use of any of these in microbial fuel cells has at least one drawback.

By contrast, technical textiles made of carbon fibers can be tailored to the exact needs of applications. Woven fabrics especially are highly versatile materials and the most suitable for creating entire 3D electrode solutions. It is why they became the investigative focus of the projects.

A woven fabric is a textile structure created by interlacing two or more threads at right angles to one another. A decisive factor is the weave, the smallest unit that is repeated to form a crisscross pattern (see fig. 2). Well-known types of weaves

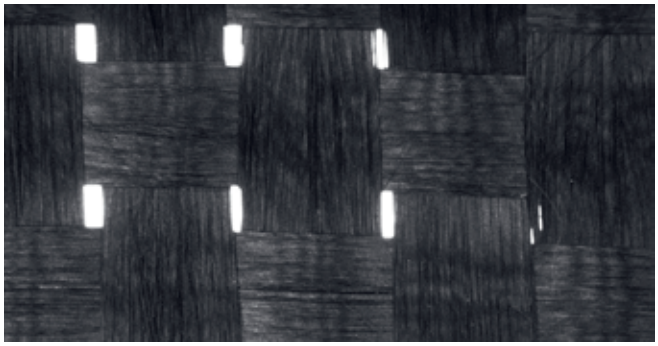


Fig. 2: Carbon fiber cloth in a plain weave

are plain, twill and satin, with varying degrees of drape and saturation. The choice of fiber and weave are only two of many ways to influence the manufacturing process.

EXPERIMENTS AND FINDINGS The overarching goal was to increase current density and, consequently, the efficiency of the woven electrode by 25 percent compared to commonly available materials. This required changes to the fibers and fabric as well as the 3D anode structure.

Initial efforts focused on improvements in the two-dimensional plane. Electrochemically active model bacteria and specified biofuels were used to establish stable operating conditions. The choice of inexpensive fibers with high current density was as much part of the enhancement process as a computer simulation of the impact of weave types and pore size on density. All enhancements are not limited to one group of applications, i.e., they can be implemented regardless of whether an electrolyte contains solids, as in the case of wastewater.

In addition, the investigation concentrated on surface treatment methods to increase carbon fiber conductivity and accelerate biofilm growth. The woven fabrics were manufactured by Carbo-Tex GmbH, Güth & Wolf GmbH and SGL Carbon SE. A comparison of their current density (see fig. 3) showed three types of cloth that exceeded the benchmark value of 1.4 amperes produced by Shewanella oneidensis MR-1 per square meter. Their output was between 57 percent and 78 percent, or between 2.2 amperes and 2.5 amperes, above baseline. Geobacter sulfurreducens, by contrast, can achieve up to 10 times as much.

Heimbach GmbH & Co. KG turned the woven fabrics into streamlined three-dimensional anodes placed into 2-liter laboratory-size and 30-liter demonstration reactors. These reactors were filled by UPM Hürth Rhein Papier GmbH with actual wastewater. One marked difference was the use of potentiostats for monitoring the smaller devices to remove most limitations imposed by their cathodes. In a laboratory setting, the bioanodes made up of mixed-species biofilms maintained output at a satisfactory 1 ampere per square meter, with peaks of up to 5 amperes. By contrast, weak air cathodes in the demonstrators resulted in a maximum of 0.08 ampere for every square meter. Nevertheless, the efficiency of wastewater treatment was between 40 percent and 50 percent, as expected. The reason for the low output is a multi-stage process that has the bioanode convert acetic acid to carbon dioxide and electricity in a last step. Cathodes specifically designed for this task could have prompted a notable increase in the output of the microbial fuel cell and, consequently, demonstrator efficiency.

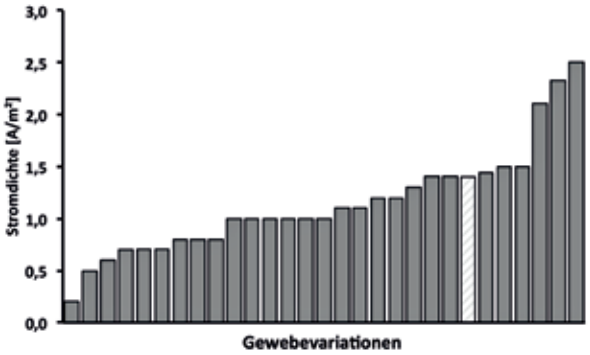


Fig. 3: Current density of various planar electrodes (in relation to a two-dimensional surface); pure culture of electrochemically active Shewanella oneidensis MR-1 bacteria

MARKET OPPORTUNITIES AND RESEARCH OUTLOOK Tailor-made bioanodes have become more than just a vision for the future. Designing fabrics over the course of two projects has produced know-how that will improve electrode manufacture. The materials and technologies are already available for other applications, such as lightweight aviation, aerospace and automotive design, and this technological maturity provides a low barrier to market entry.

In the long run, the bioanode can be deployed for a wide variety of innovative microbial fuel cell concepts. The conventional pairing of bioanode and air cathode for wastewater treatment, as described above, is basically no longer a topic for further study. Cathodes that can withstand the harsh conditions present in wastewater have yet to be identified, despite all efforts to find a solution. Likewise, most users will not see enough justification for a switch if the only advantage is the product's ability to generate electric power from the water.

The solution will be to combine energy generation based on organic matter with other value chains. Above all, this includes the production of higher-grade chemicals at the cathode, which could even be used as a microbial catalyst. Additionally, biosensors running on microbial fuel cells could be employed for medical, (waste)water quality and marine applications. Furthermore, electricity generation could be coupled with biosorption to bind contaminants such as heavy metals in polluted groundwater. There is an endless pool of ideas floating around, and all of them could come to fruition if manufacturers and researchers continue their interdisciplinary work. ||

TexKoMBZ was a research project funded by the German Federal Ministry of Education and Research under ID no. 031B0087A. TextESys was financially supported by the German Federation of Industrial Research Facilities, also known as AiF, under IGF project no. 19047 N.

Written by
Liesa Pötschke, M.S.
Institut für Angewandte Mikrobiologie, RWTH Aachen, Germany
liesa.poetschke@rwth-aachen.de

Georg Stegschuster, M.S. (right in the picture; left: Baden-Württemberg's state environment minister Franz Untersteller), Institut für Textiltechnik Augsburg gGmbH, An-Institut der Universität Augsburg, Germany
georg.stegschuster@ita-augsburg.de

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

MICROBIAL FUEL CELLS HAVE POTENTIAL

Slow but steady progress

The difference between microbial fuel cells and devices converting energy by purely chemical means is that bacteria and not artificial materials, such as polymer electrolyte membranes and ceramic oxide parts, control the reaction. Instead of a catalyst, microbes will feed on organic matter, for example, wastewater and lactic acid, to generate a voltage through metabolic activity.

Simply put, the microbial metabolism produces a constant stream of electrons. A fuel cell anode that has been colonized by the bacteria can then be used to transfer these electrons to a cathode to generate a current. Liesa Pötschke, of RWTH Aachen University, said the microorganisms were "the size of one micrometer. Often, they merge to form a biofilm. Any environment in which the bacteria feel comfortable can be used as an electrolyte. In contrast to electrochemical applications, these are primarily environments with neutral pH values between 6 and 8, low salt content, atmospheric pressure and temperatures between 4 °C and 37 °C, depending on the organism. In short, conditions are not nearly as harsh as in a conventional fuel cell. But the bacteria themselves never function as electrolytes."

Research on microbial fuel cell concepts was published as early as 1911. As Susanne Päch wrote on the SciLogs blogs at spektrum.de, it was the year when Michael C. Potter reported his observations about electricity being generated by microorganisms within biofilms. However, it took until 1962 for researchers to present a modern concept of a microbial fuel cell. At that time, methylene blue was still employed as a mediator to test bacteria for their ability to convert hydrocarbons into measurable current. Meanwhile, the means to transfer electrons from bacteria to electrodes have become known and can be grouped into two categories: Either the transfer is mediated, that is, indirect, or unmediated through redox proteins or electrically conductive extensions of the outer cell membrane. Some bacteria grow as a biofilm on the electrode and can transfer electrons directly to it. In 2000, researchers began conducting experiments into creating biofilms in a laboratory instead of letting nature determine the pace.

SYNTHETIC BIOFILM MADE IN BAYREUTH Researchers from the University of Bayreuth have succeeded in, essentially, customizing the slimy matrix that is home to the bacteria. A team led by professors Ruth Freitag and Andreas Greiner has created a biocomposite, a synthetic hydrogel, composed of a network of tiny polymer fibers to accommodate the microorganisms. In laboratory experiments, they used electrospinning, a common technology nowadays, to turn those fibers into a fleece material. Patrick Kaiser, a researcher who works at the university and reported on the work in an article published by Macromolecular Bioscience in early 2017 [1], said the biofilm included only one kind of bacterium called Shewanella oneidensis. It doubled the power output of a fuel cell compared to a same-type biofilm produced by natural means, he wrote. Additionally, it made for reliable and predictable generating capacity, as bacterial density was predetermined.

PAPER IN PLACE OF METAL AND FELT Researchers have been trying for years to find more suitable anode material for microbial fuel cells, since it has a strong impact on cell efficiency. Typically, electrodes are made of metal or carbon felt, on which bacteria live, reproduce and form natural biofilms. Felt is an inexpensive option but is porous and prone to clogging. Metals, on the other hand, corrode in some environments. Georg Stegschuster, of RWTH Aachen University, explained that the porosity could be an advantage, since it provided the biofilm with a larger surface area for interaction. However, clogging and low mechanical stability made fleece materials somewhat difficult to clean.

Professor Kara Bren and her team of researchers at the University of Rochester substituted paper for it, coating the base material with a carbon paste, a mixture of graphite and mineral oil (see fig. 1), which attracted a good number of electrons. Bren said that the new electrode had more than twice the current density of the felt one. The researchers put

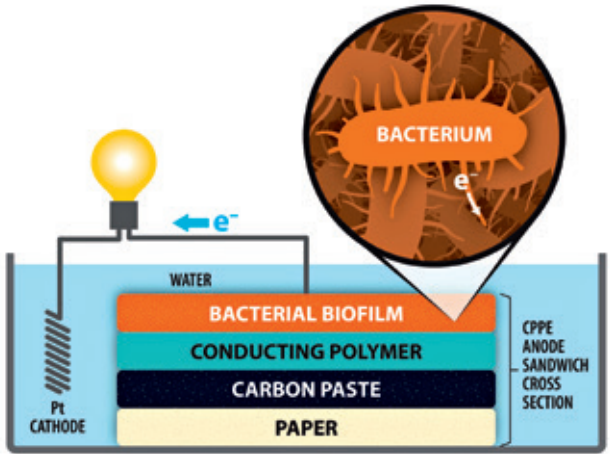


Fig. 1: Sandwich structure of a microbial fuel cell
Source: University of Rochester

CATHODE INNOVATIONS

Regarding the future, Pötschke said that cathode research was at a much earlier stage of development, though "all anode improvements could, in principle, be applied to cathodes as well and open up an even greater range of applications for bioelectrochemical systems. In that case, biocatalysts will again have to interact as efficiently as possible with an electrode surface area. Bacteria at the cathode could either absorb electrons directly or use the produced hydrogen as an energy source. Typical reactions include carbon fixation to convert carbon dioxide into acetate or similar compounds, methanation, and chemical manufacturing. Electrons are transferred to the cathode either from a bioanode or an external power source, such as a solar cell."

together a layered sandwich structure of paper, carbon paste, a conducting polymer and a film of bacteria called Shewanella oneidensis MR-1, which processes toxic heavy metal ions in wastewater (see article on p. 35).

Still, modified graphite felt could be just as promising. Kristina Kantmnienğ a chemical engineer working at the Kaunas University of Technology in Lithuania, said that she had modified an anode of a microbial fuel cell in a way that allowed for an increase in cell voltage. According to her, the voltage was "20 percent higher than in a control sample containing a conventional anode." ||

Reference(s)
[1] Kaiser, P. et al. (2017). Electrogenic single-species biocomposites as anodes for microbial fuel cells. *Macromolecular Bioscience, 17*(7). doi: 10.1002/mabi.201600442.

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

METHANATION BY PRIMORDIAL MEANS

Biocatalysts produce methane from CO_2 and H_2

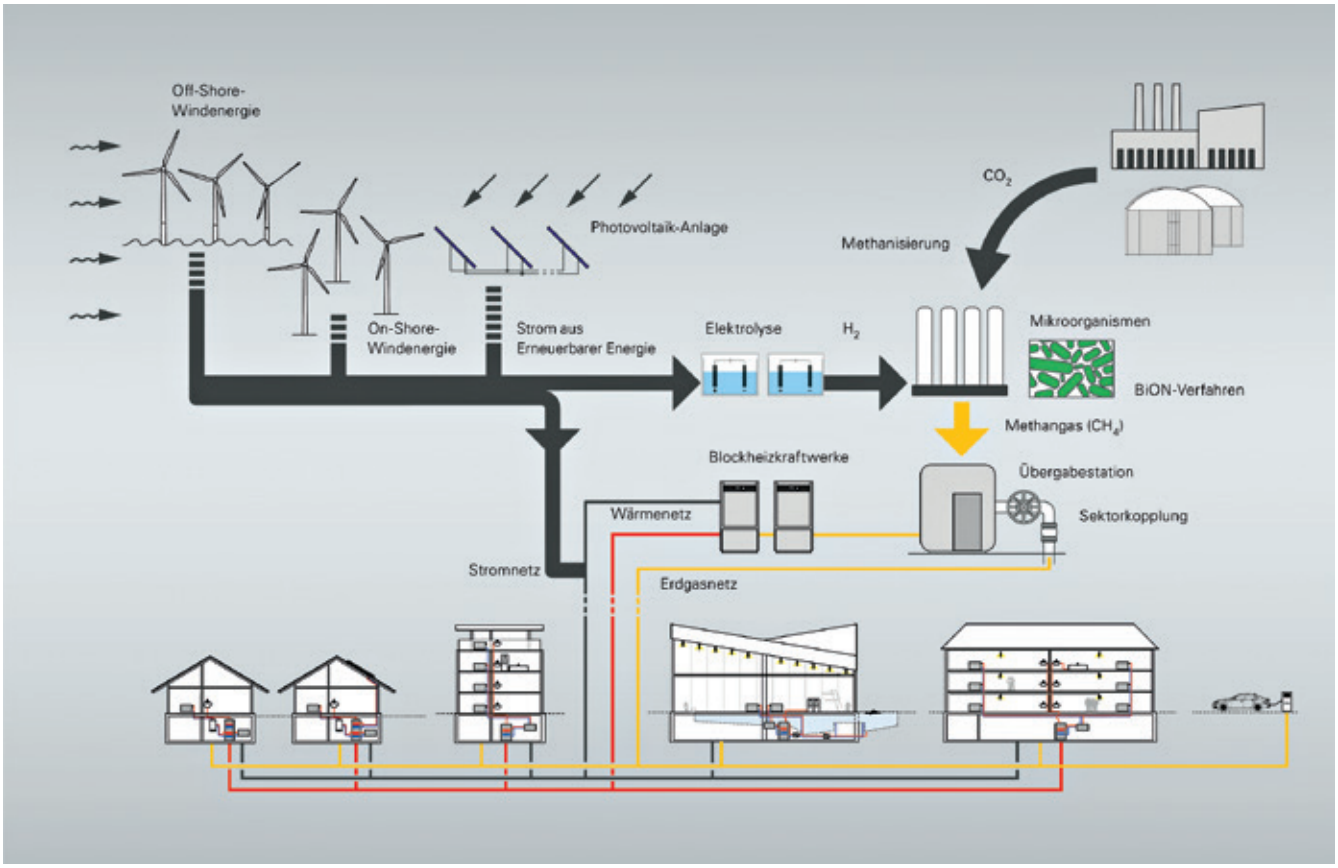


Fig. 1: Energy flow chart on methanation, Source: MicrobEnergy

Producing hydrogen in a completely natural way is something of a Rosetta Stone in science. Many have tried over the past decades, but rarely have they been able to announce a breakthrough in this field. Electrochaea, a startup based in a town west of Munich, could now have taken a big leap toward economic feasibility. This spring, the 20-staff company declared its intention to build power-to-gas bioreactors with a capacity of up to 50 megawatts. By 2025, output could theoretically hit the gigawatt mark if others are willing to join in.

The use of renewable energy, especially bioenergy, to create hydrogen could become an entirely clean method for ensuring supply security. At least, that is the vision of Electrochaea, headquartered in Planegg.

FRUGAL MICROBES More specifically, the company is planning to use electrolyzers powered by solar and wind energy to create the gas. The hydrogen, though, will not be consumed immediately but undergo a biocatalytic process. Microscopic organisms called methanogenic archaea will convert it into biomethane through the addition of carbon dioxide. Mich Hein, Electrochaea's chief executive, said that the company's bioreactors were "turnkey systems to store a renewable energy surplus and carbon dioxide in the form of synthetic gas." Its customers and partners would be able to put carbon dioxide to good use, either on-site or by injection into natural gas pipelines. As examples, he named garbage disposal, wastewater treatment, biogas and geothermal facilities. Industrial companies, too, produced large amounts of carbon dioxide, he said.

Fig. 2: Demonstration system in Copenhagen, Source: Electrochaea

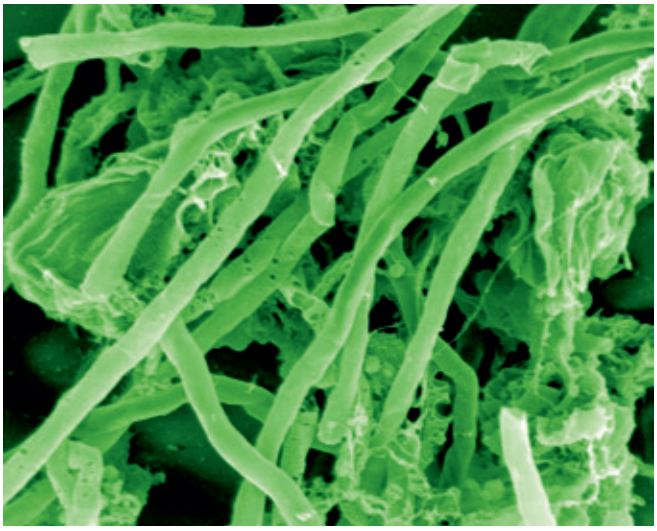


Fig. 3: Archaea – single-cell biocatalysts, Source: Electrochaea

Electrochaea has claimed that it possessed the world's most efficient archaeon strain and extensive expertise in biocatalysts in the form of exclusive licenses on patents by the University of Chicago. The microbe, one of the oldest organisms on earth, is found in oxygen-free habitats, such as moors, swamps and the digestive tracts of humans and cows.

The company started up its first industrial-scale demonstration system with 1 megawatt of capacity in summer 2016 at a site near Denmark's capital Copenhagen. In the same year in fall, it inked a deal for building a power-to-gas system with a capacity of 10 megawatts in Hungary. In partnership with energy supplier Magyar Villamos Művek, it formed a joint venture called Power-to-Gas Hungary. Zsolt Bertalan, the chief executive of the energy supplier's subsidiary Smart Future Labs, said at the time that the German startup had come up with an idea to store renewable energy but ensure a "permanent reduction of climate-damaging carbon dioxide. The potential of this disruptive technology is enormous." More recent information about the system could not be obtained from any of the organizations involved.

In late 2017, it was said that a pilot and demonstration system would be constructed in Solothurn, Switzerland, as part of Store&Go, a project funded by the EU's Horizon 2020 program.

SIMPLER THAN SABATIER REACTION One advantage of the single-cell organisms is that they require little to do their work. Not only can they convert less-than-pure carbon dioxide produced by biogas plants, but they flourish at a temperature of as little as 65 °C and ambient pressure. The company said that the microbes would have no difficulty coping with variable intake rates either. By contrast, standard methanation processes are much more demanding. Higher purity grades are just one issue. Operating conditions are more difficult to maintain as well: temperatures range between 300 °C and 550 °C, pressure needs to be above 10 bars and catalysts have to be made of nickel. On top of that, continuous operation is a must.

ALL-IN-ONE PROCESS In mid-July, Electrochaea said that it was on its way to simplifying what had so far been a two-stage conversion process and complete electrosynthesis in one single step. In partnership with organizations participating in the Central SME Innovation Program, also known as ZIM, it had been developing a microbial electrochemical cell to convert carbon dioxide directly into methane by means of electric power.

Doris Hafenbradl, the chief technology officer of Electrochaea, said that the company's prior work on microbial electrochemical cells had "shown great promise. We are pleased about the support we will receive for our new project, which we consider to be an investment in a clean energy future." Professor Haralabos Zorbas, the chief executive of Industrielle Biotechnologie Bayern Netzwerk and the coordinator of business network UseCO_2, has called the design of a microbial cell for electrosynthesis "a groundbreaking and important step forward." Direct conversion would lead to an additional, large increase in efficiency and reduction in costs, it was said. ||

MICROBENERGY

Another business exploring ways to make use of biotechnology is MicrobEnergy, a Viessmann subsidiary, which owns a 300-kilowatt testing facility in Allendorf (see H2-international, January 2016). In July 2017, the company joined ORBIT, a three-year project that aims to optimize a trickle-bed bioreactor. This reactor employs archaea to produce, via microbial synthesis, variable amounts of methane in a power-to-gas system. Funded with EUR 1 million from Germany's economy ministry and coordinated by the Regensburg-based East-Bavarian Institute of Technology, also known as OTH, the endeavor has brought together eight organizations that plan to redesign and reinforce the links between biological methods, process techniques and plant control.

Additionally, the company has a project in the works for Limeco, one of Switzerland's regional energy suppliers. In Dietikon, a hybrid power system is to be added to Limeco's wastewater treatment plant. Eva Sonnleitner, of MicrobEnergy, told H2-international that the system would be built by Carbotech. MicrobEnergy would oversee startup and support biological methanation through a process called BiON®. The aim, she added, was to convert all the sewage gas produced by wastewater treatment into methane, so that it can be injected into the gas grid. Thomas Di Lorenzo, head of biological wastewater treatment at Limeco, said, "With electricity from a waste-to-energy plant and sewage gas from a wastewater treatment facility, we are delivering the two key ingredients of the power-to-gas process – from the same site, no less." The system will reportedly come online next summer.

Category: Research & Development | **Authors:** Alejandra Lenis, Dr. Kristoffer Ooms, Dr. Henry Rieße, Christoph Wöllgens, M.S.

METHANOL FROM BIOGAS

Storing energy during wastewater treatment

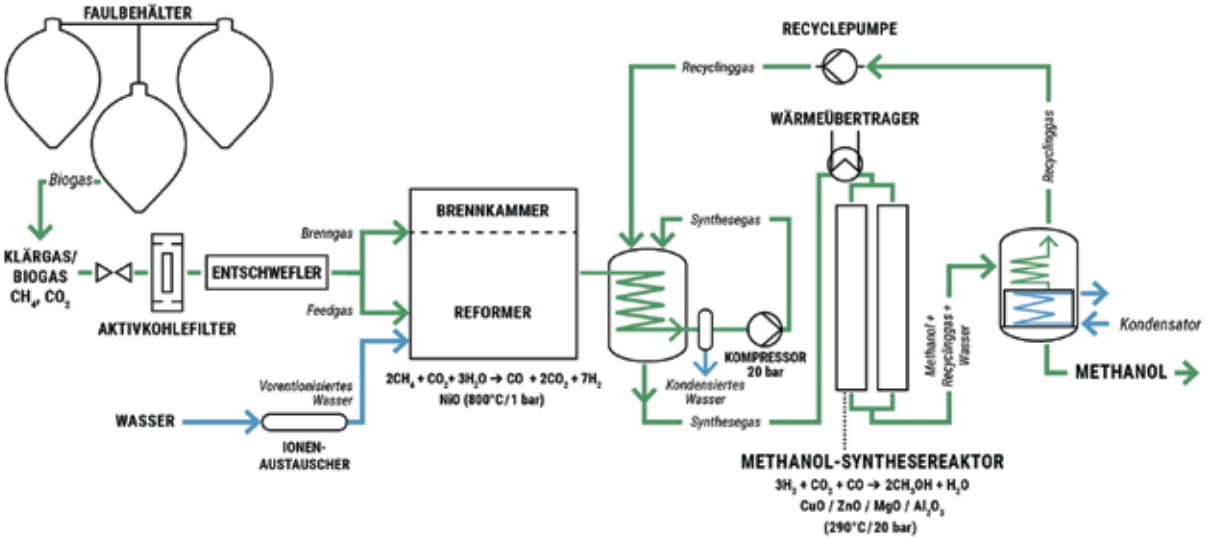


Fig. 1: This illustration depicts the core processes of the methanol synthesis under study. Source: FiW

Biogas has, for a long time, been known as a renewable energy source. It powers not just stationary systems, that is, CHP plants, but also means of transportation, albeit in purified form. Another versatile energy carrier is hydrogen, especially considering its deployment as zero-emission storage. It can be stored and transported without major technical issues. However, low energy density in the gaseous state and low energy conversion efficiency from liquid to gas are impediments that cannot be easily overcome. One alternative solution is the storing of hydrogen in methanol. This technique can create sustainable pathways for synthesis, most of all in combination with carbon dioxide. Methanol has the distinct advantage of being simple to store but having a relatively high energy density. It can likewise be used for almost any application. In a project called WaStraK NRW – Use of Hydrogen Technology in Wastewater Treatment, a pilot system was constructed to synthesize the compound.

The principal aim of WaStraK, established under the auspices of the state environment ministry of North Rhine-Westphalia, was to design and build a small-scale pilot system to demonstrate that biogas can be incorporated successfully into chemical synthesis.

HOW THE SYSTEM WORKS By using water vapor, pre-purified organic feed gas is converted inside a reformer into synthesis gas composed of hydrogen, carbon dioxide and carbon monoxide. It is then directed to a reactor, which synthesizes methanol with help from a catalyst. To provide the heat for reforming, part of the feed gas flow is mixed with ambient air and burned off.

The system was designed to be operated at a pressure of between 20 bars and 22 bars, which is notably below the industrial benchmark ranging from 50 bars to 100 bars. This reduction in pressure, however, facilitates the use of the device and its integration, for example, into biogas facilities.

The distinctive features of the method are a highly efficient heat transfer inside the system and the recovery of energy from wastewater treatment to maximize production output. A programmable logic controller makes it possible to change parameters during experiments.

WHAT OBSERVATION REVEALED The project showed the successful technical implementation of methanol synthesis, including the recovery of non-combusted parts of the gas. The combination of heating and cooling especially allowed for exploiting the potential energy of educts, products and byproducts.

First, the investigation focused on biogas reforming. Considering the gas contains around 60 percent methane and 40 percent carbon dioxide, the key criterion to observe was reformer operation, as the unit had originally been designed for use with methane only. Experiments were conducted with a constant flow rate of 0.5 cubic meters of biogas and 1.2 liters of water per hour. The reactor temperature was kept at 850 °C and pressure at 1.4 bars.

Then, attention shifted to methanol synthesis. Pressure, temperature and gas flow rate were analyzed for their impact on methanol production output before the methanol-water blend was condensed. The objectives were to maximize output and allow the system to run without interference as much as possible.

HOW REFORMING HOLDS UP Efficiency was central to studying the reforming process, for which hydrogen production output was calculated based on how much hydrogen can be produced from the methane contained in the biogas [1]:

$$\eta_{H_2} = \frac{\acute{n}_{H_2,SG}}{\acute{n}_{CH_4,FG}} \cdot 0{,}25$$

Variable represents the hydrogen mass flow contained in the syngas at the reformer outlet and the methane mass flow at the inlet. The multiplication factor of 0.25 on the right is the result of stoichiometric relationships that describe the reforming reaction. The output figures obtained in experiments were compared with those found in the literature [1] to rate the effectiveness of the reformer. The comparison indicated well-matching figures, proving that the device is an efficient means to reform biogas.

The average efficiency of hydrogen production has been 86.4 percent, above the 78 percent cited by Kolbitsch, Pfeifer, & Hofbauer (2008). However, the difference can be explained by a change in temperature. The method selected by Kolbitsch et al. reforms biogas at 750 °C, whereas reforming in this study occurred at 850 °C.

The reason for the increase in hydrogen output at 850 °C is that the reaction is endothermic, which means that the equilibrium will, according to Le Chatelier's principle, shift to the side of the products [2]. Nevertheless, the previously created synthesis gas requires additional hydrogen to attain stoichiometric amounts for synthesizing methanol. They would be about 72 percent by volume of hydrogen, 14 percent by volume of carbon monoxide and the same percentage of carbon dioxide [3]. The synthesis gas produced for this project has 64 percent by volume of hydrogen, 15 percent by volume of carbon monoxide and 18 percent by volume of carbon dioxide.

HOW BEST TO SYNTHESIZE Multiple parameters were changed during the investigative process to determine the operating conditions that were most likely to guarantee the highest-possible methanol production output. These conditions ranged from operating temperatures of 190 °C, 220 °C, 250 °C and 310 °C, as well as 20 bars and 22 bars of pressure, to flow rates of 8 and 10 cubic meters an hour inside the methanol reactors, which contained a commercially available copper-based catalyst made by Alfa Aeser. The experiments showed that 22 bars of pressure, a temperature of 190 °C and a flow rate of 10 cubic meters an hour are ideal parameters for operating the demonstration system and creating as much methanol possible. When using 8 kilograms of catalyst material, the production rate each hour is 63 grams of methanol per kilogram of catalyst material.

Like reforming, methanol synthesis showed values similar to those found in the literature (see table 1).

In table 1, the findings of this project were compared with those by Kung, Liu, & Willcox (1984) [4], as the two studies were conducted based on similar conditions. Of note is that there are minimal differences in methanol production. In the study undertaken by Kung et al., output was 3 percent higher, which can be explained by an increase in hydrogen content: The synthesis gas contained nearly 70 percent by volume of hydrogen compared to 64 percent in this study.

Table 1 also shows a comparison of the findings with those from industry. Industrial-scale systems [5] produce much higher amounts of methanol than the pilot installation because of higher operating pressure. Increasing the pressure would shift the equilibrium to the side of the products, which is one of the new objectives of the Research Institute for Water and Waste Management – FiW at RWTH Aachen University.

Overall, the findings indicate that units for sale on the market are capable of reforming biogas and synthesizing methanol via the method described in this article. They also point to larger potential for implementation.

Having gained much expertise in how to improve the process chain and increase system efficiency, FiW intends to upscale the technique and prompt further technological advances as well as economic viability in a relatively short amount of time. Future investigations are to focus on how renewable hydrogen can be integrated as well as injected, for example, by means of electrolysis, into energy systems. Other aims are to increase synthesis gas production and raise the proportion of renewables in thermal and electrical energy supply. ||

PROJECT PARTNERS
Forschungsinstitut für Wasser- und Abfallwirtschaft (FiW) e.V., Tuttahs & Meyer Ingenieurgesellschaft für Wasser-, Abwasser- und Energiewirtschaft mbH, Emschergenossenschaft and Ingenieurbüro Redlich und Partner GmbH – Beratende Ingenieure für Elektrotechnik.

Reference(s)

[1] Kolbitsch, P., Pfeifer, C., Hofbauer, H. (2008). Catalytic steam reforming of model biogas. *Fuel 87*(6), 701-706. doi: 10.1016/j.fuel.2007.06.002

[2] Mortimer, C. E., Müller, U. (2010). *Chemie.* Stuttgart: Georg Thieme Verlag KG.

[3] Bolle, F.-W. (2012). *WaStraK NRW. Einsatz der Wasserstofftechnologie in der Abwasserbeseitigung – Phase I. Band I: Kompendium Wasserstoff.*

[4] Kung, H. H., Liu, G., Willcox, D. (1984). Effect of CO_2 and H_2O in the Methanol Synthesis Reaction on Cu-Zn-O. *ACS Division of Fuel Chemistry, Preprints* 29(5), 194-195.

[5] Asinger, F. (1986). *Methanol – Chemie- und Energierohstoff.* Heidelberg: Springer Verlag.

Written by

Alejandra Lenis, Forschungsinstitut für Wasser- und Abfallwirtschaft an der RWTH Aachen (FiW) e.V., Aachen, Germany
lenis@fiw.rwth-aachen.de

Dr. Kristoffer Ooms
Dr. Henry Rißе
Christoph Wöllgens, M.S.

	Reactor [°C]	Pressure [bar]	Methanol Yield [g/(kg_{kat}·h)]	H_2 in Synthesis Gas [Vol.-%]
Test Facility	250	20	37,25	64,00
Kung et al.	228	17	38,5	69,3
Industrie [5]	250	50	958,3	75

Table 1: Comparing methanol production rates with output figures found in the literature. Temperatures ranged from 228 °C to 250 °C and pressure from 17 bars to 50 bars.

Category: Research & Development | **Authors:** Dr. Matthias Breitwieser, Dr. Severin Vierrath

THE HEART THAT BEATS IN EVERY PEMFC

MEA development at Hahn-Schickard in Freiburg

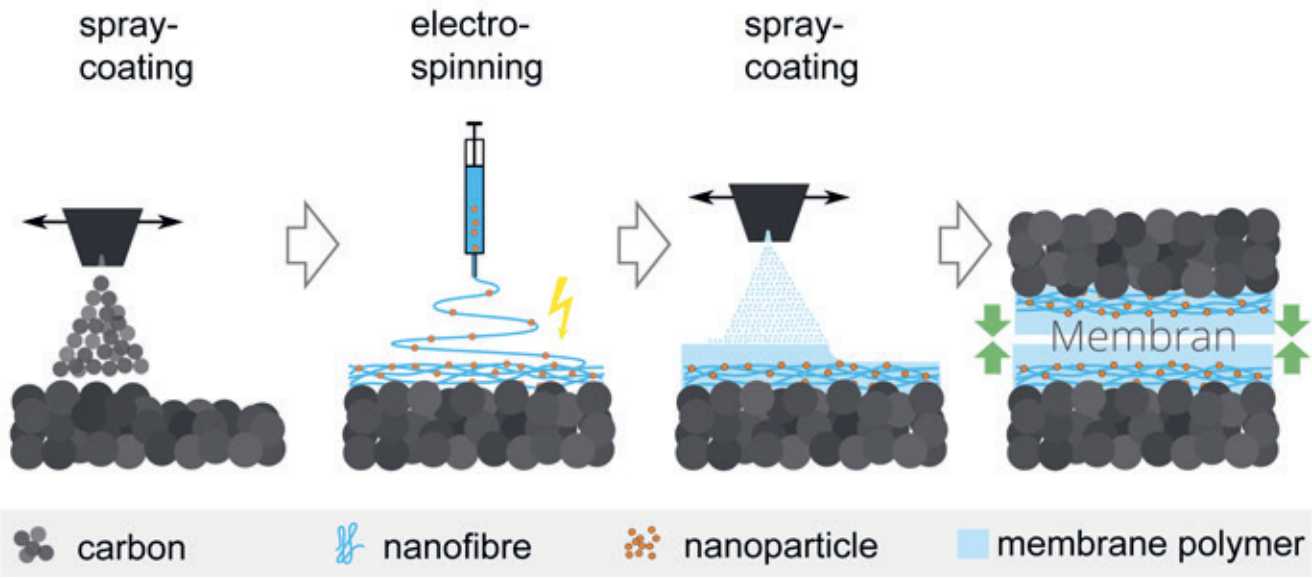


Fig. 1: In this image, the technique of producing thin film has been replaced by applying a composite membrane over an electrode through electrospinning and spray coating. It makes for simplified and flexible manufacturing and facilitates the creation of an interlocking boundary between a membrane and an electrode.

At the heart of every PEM fuel cell, there is a membrane electrode assembly. It has a considerable impact on the output and lifetime, as well as the cost, of a stack. It is of such import that it has sparked multiple efforts to research and develop new kinds of materials and manufacturing techniques. A working group made up of scientists from the University of Freiburg, Germany, and the local Hahn-Schickard Institute has been looking into options for the production and microstructural characterization of membrane electrode assemblies, or MEAs for short. The aim is to improve their interfacial properties.

The interfaces between membranes and electrodes are essential to the power output of fuel cells. Yet, most of the time, MEA components are designed individually. It is usually only at a later stage that the hubs of chemical reaction, the electrodes, are added to a thin-film polymer separator during a roll-to-roll process. However, both layers are closely interconnected owing to water management and proton transfer.

As for the water that is produced at an electrode when running a fuel cell, it helps humidify the membrane and has a major influence over the proton conductivity inside the separator. The membrane itself acts as the source of protons to set off chemical reactions at the electrode, so that the highest reaction rate is found in the region between both. Every electrode also contains an ionomer that provides an internal pathway to transfer protons throughout.

The above illustrates how important it is to consider the boundaries between membranes and electrodes when developing PEM fuel cells. It is why the two components must always be treated as an inextricably intertwined unit.

DIRECT MEMBRANE DEPOSITION This year, researchers at the Hahn-Schickard Institute published a study for which they reviewed the findings of about 100 science papers that explore improvements to the interfaces between membranes and electrodes or proton-conducting phases and catalytic centers[1]. The authors concluded that progress had indeed been made. Examples are an increase in ionomer or platinum content toward a membrane and ionomer impregnation on that side of an interface. As reported elsewhere, micropatterned membranes could also allow for substantially larger boundaries[2].

The working group developed an alternative method called direct membrane deposition to apply a membrane to an electrode through dispersion. The technique enabled the researchers to raise power output significantly. They were successful in increasing cell performance by about 30 percent, while platinum loading and thickness remained constant[3]. The combination of electrospinning and spray coating has created new opportunities for designing and manufacturing a nearly unlimited variety of composite membranes. Some of them are as thin as approximately 10 micrometers but showed excellent durability after being reinforced with polymer nanofibers decorated with cerium oxides[4].

All newer approaches involve very distinct manufacturing methods but have one thing in common, namely that they enlarge and improve the interfaces between membranes and electrodes. The result is a power density rise of up to 50 percent due to a higher ionic and a notably lower mass transfer resistance. In many cases, the latter correlates with a notable degree of oxygen diffusion into active catalytic centers. >>

These findings indicate a fundamental yet positive shift in fuel cell water management. Water that is produced at the cathode can move more easily to the anode thanks to a larger boundary. This dehydrates the cathode to facilitate oxygen diffusion. Likewise, the water permeability of the membrane is known not to be dependent on membrane thickness but mainly the size of the interface. Thus, a larger boundary leads to a greater quantity of water being transported in relation to the cell surface area[5].

3D STRUCTURE AND MATERIAL DATA To succeed in designing and improving fuel cell MEAs, it is essential to study the microstructures of membranes and electrodes. Desired improvements can only be made by correlating electrochemical with structural factors. Examples of the former are ionic resistances, mass transfer characteristics and effects of degradation, while the latter include tortuosity, porosity and ionomer properties. The challenge will be to size assemblies, considering that catalyst particles measure few nanometers only. Furthermore, all assembly materials, that is, the polymer, the carbon and the metal catalysts, differ in their imaging requirements. Whereas the electrodes can withstand high acceleration voltages when put under a scanning electron microscope, or SEM for short, the same is hardly true for electrically insulating ionomer membranes.

Nevertheless, the last years have seen remarkable progress in the microanalysis of fuel cells. For example, with a focused ion beam SEM, the shape and structure of electrodes can be studied in all three dimensions to create images that can be incorporated into computer simulations and be used to optimize properties within a virtual environment. The microstructure of the electrode is captured by the microscope at the nanometer level while an ion beam removes the thinnest possible layers from it to create a 3D image.

This imaging technique enabled the researchers to explore the boundary between the catalyst and neighboring microporous layer, or MPL for short (see image on the left in fig. 2). It helps find the correct porosity of MEAs in manufacture and reveal undesired morphological changes caused by aging processes, such as carbon corrosion.

Additionally, Raman spectroscopy can be employed to study the chemical structure of components and identify materials according to an energy shift in backscattered laser light. This shift is unique to not only every material but also each molecular structure, even among polymers. The confocal microscopy technique that is being used during the project lets laser light travel through a specimen to generate a 3D computer model, such as that of a membrane, without damaging the component. For example, it allowed the first-ever imaging of the composite structure that makes up a commercially available Nafion™ XL membrane (see image on the right in fig. 2).

The membrane is composed of Nafion and has been reinforced with porous expanded PTFE. As confocal Raman spectroscopy can provide both chemical and structural information, it allows for tasks such as determining the equivalent weight of proton-conducting sulfone groups within the Nafion. Through the signal intensity of these groups, researchers can investigate conductivity at a specific point on the separator without causing damage. A concrete example of highly practical value is the localized imaging of degradation mechanisms, for which it may help to determine the side, that is, the anode or the cathode, that has experienced more ionomer degradation. ||

Reference(s)

[1] Breitwieser, M., Klingele, M., Vierrath, S., et al. (2018). Advanced Energy Materials, 8(4), 1701257. doi: 10.1002/aenm.201701257

[2] Koh, J. K., Jeon, Y., et al. (2014). *Journal of Materials Chemistry A*, 2(23), 8652-8659. doi: 10.1039/C4TA00674G

[3] Breitwieser, M., Klingele, M., Vierrath, S., et al. (2016). *Electrochemistry Communications*, 70, 65-68. doi: 10.1016/j.elecom.2016.06.017

[4] Breitwieser, M., Klose, C., Vierrath, S., et al. (2017). *Advanced Energy Materials*, 7(6), 1602100. doi: 10.1002/aenm.201602100

[5] Adachi, M., Navessin, T., et al. (2010). *Journal of Membrane Science*, 364(1-2), 183-193. doi: 10.1016/j.memsci.2010.08.011

[6] Vierrath, S., Zielke, L., et al. (2016). *RSC Advances*, 6(84), 80700-80705. doi: 10.1039/c6ra16560e

TWO INSTITUTIONS – ONE RESEARCH GROUP

At the University of Freiburg, the department of microsystems engineering, also known as IMTEK, established a research group on Electrochemical Energy Systems under the chair of MEMS applications, over which Professor Roland Zengerle resides. Headed by Severin Vierrath und Matthias Breitwieser, it was created to improve upon the knowledge base built from initial research into the microstructural and electrochemical characterization of fuel cells. The group has won multiple industry awards over the past years, from the f-cell Award 2015 and first place in EnergieCampus 2015 to the DWV Innovation Award 2018. Besides PEM fuel cells, the scientists have begun focusing on MEAs and membranes used in electrolyzer cells and vanadium redox flow batteries.

In parallel to basic research at IMTEK, the Hahn-Schickard Institute in Freiburg is putting ideas into practice, for example, by continuing the design of fuel cell membranes and MEAs and employing FIB or SEM tomography to study microstructures. Hahn-Schickard is a service provider whose object is to turn scientific advances into real-world applications. It has entered into partnership mainly with midsize companies based in the German state of Baden-Württemberg. FIB and SEM microstructural analyses and multiple MEA manufacturing solutions are also marketed by the company as separate services.

Written by

Dr. Matthias Breitwieser
Matthias.Breitwieser@Hahn-Schickard.de

Dr. Severin Vierrath
Severin.Vierrath@Hahn-Schickard.de

Both for Hahn-Schickard-Institut, Freiburg, Germany

Category: Research & Development | **Author:** Thomas Jungmann, Dr. Alexander Dyck

APPROVED – CERTIFIED – STANDARDIZED

Shared rules in the fuel cell and hydrogen industry

Businesses need clearly defined rules to popularize new technologies among a wide variety of users. Because those in the rapidly growing market for fuel cell devices have seen limited success in standardization, several companies and institutions are now trying to create a shared set of recommendations.

A standard developed by a committee represents the global consensus in a market. Although standards are not legally binding, they can become mandatory by implementing legal or administrative regulations at the national or global level or by entering into a special agreement. In essence, they are suggestions made by private-sector associations, such as DIN, DKE, IEC and ISO, to help synchronize manufacturing with workflow. They are general in nature and intended to engender trust in new products, technologies or services, ensure quality and spread innovation. In addition, they provide solutions for safety issues raised by multiple companies aiming for more marketable products.

Without exception, committees devise these rules independent of any one manufacturer. This strengthens the position of users in relation to suppliers, as the standards state the most recent level of technological progress, which may prove relevant in a court case. Therefore, they describe the minimum requirements for competition and the market in general.

A standard is created by technical experts in partnership with stakeholders to ensure that it will be in continued use. Draft versions are published early on, so that everyone can familiarize themselves with the topic and voice their opinions. Mirror committees have been set up in each country to coordinate the effort and present a joint nationwide approach when dealing with international associations. Every standard is also updated and revised regularly to take scientific and technological advances into account.

HOW STANDARDIZED DOES IT NEED TO BE? Fuel cells have a vast array of uses and these uses involve several issues related to standardization. As a result, the IEC created an entire family of standards to cover multiple technologies. For example, the IEC 62282 series contains recommendations for areas such as safety tests of fuel cell modules as part of IEC 62282-2 and, in the third subpart IEC 62282-3, rules on the installation, safety and performance of stationary systems. More recent additions include IEC 62282-8, which describes procedures for testing the single-cell and stack performance of PEM fuel cell modules, and IEC 62282-6, which deals with micro-size fuel cell devices.

Figure 1 shows the family and current individual standards. For example, ISO 6469-1 specifies requirements for rechargeable energy storage in road vehicles, including fuel cell cars. Other sets of rules that are being created define hydrogen quality. One of those is ISO 14687-3, which specifies the quality to be used for PEM fuel cell systems, such as hydrogen fueling stations.

The above shows that rapidly increasing demand for fuel cell and hydrogen applications has prompted multiple efforts to establish new standards. Nevertheless, many areas have yet to be covered. For example, the testing of components that come in contact with hydrogen shows few recommendations, regardless of whether they are part of fuel cells, electrolyzers or systems in general. This concerns issues such as the durability of polymers that are used to make valve assemblies.

Likewise, there are few standards for automotive fuel cell systems or components that are operated below 30 bars of pressure. The only relevant European Union directive is EC No. 79/2009, which places no requirements on the fuel cell modules and systems described in IEC 62282. Regarding bipolar plates, a federally funded project called BePPel has brought together organizations aiming to improve analytical methods with the help of some companies in the industry.

Based on these examples, it can be said that the supplier industry, the size of which is a distinctive feature of the manufacturing landscape in Germany, is currently struggling to certify new hydrogen products and bring them to market. It is therefore recommended that all stakeholders in the fuel cell and hydrogen sector work together to increase standardization. >>

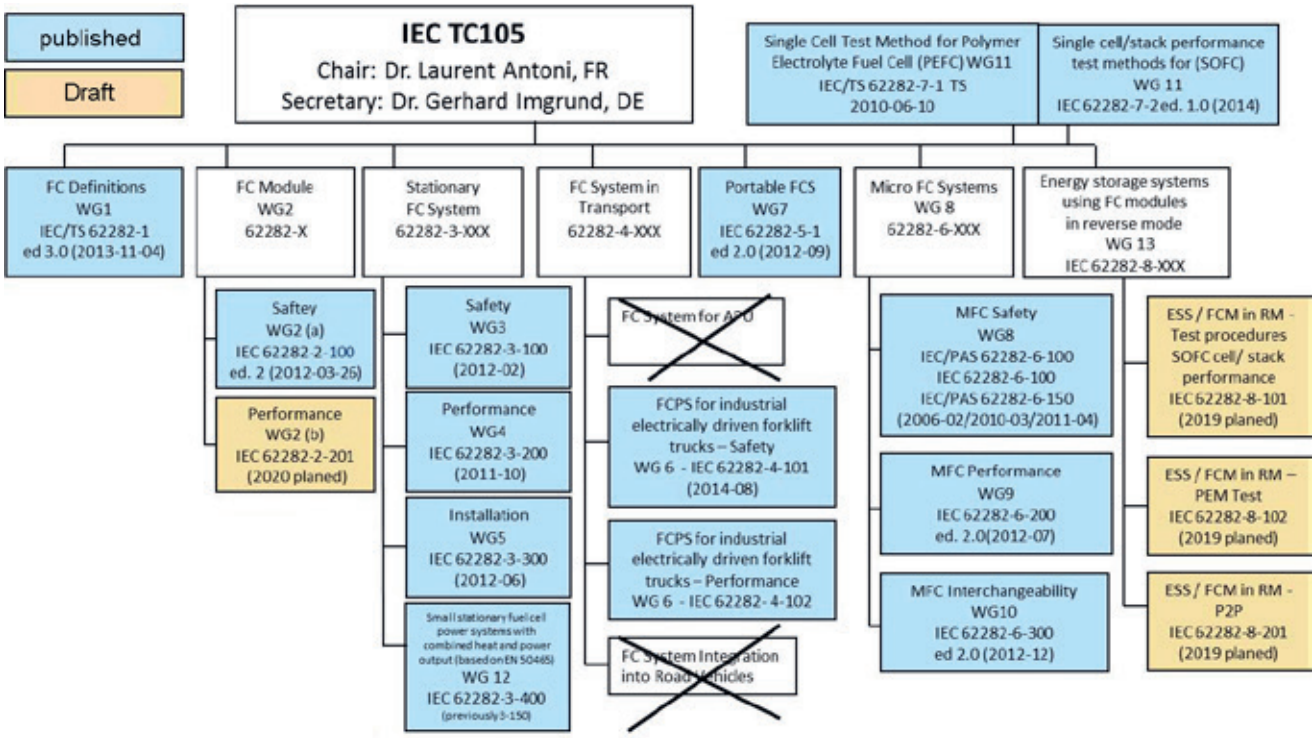


Fig. 1: IEC TC 105 fuel cell standards and working groups, Source: Alexander Dyck

GLOBAL REACH Worldwide, two organizations are responsible for creating standards. One is the International Electrotechnical Commission, or IEC for short, and the other is the International Organization for Standardization, or ISO. As for the IEC, Technical Committee 105 is in charge of establishing standards for fuel cells, except for those installed in vehicles. The latter are the subject of ISO Technical Committee 22 Road Vehicles. Likewise, the standards for hydrogen storage are created by Technical Committee 197 Hydrogen Technologies. The German equivalent of TC 105 is part of the DKE, the Commission on Electrical, Electronic and Information Technologies, set up under the aegis of DIN and the VDE.

TC 22 and TC 197 have mirror committees at the national level. They are being coordinated by DIN, the German Institute for Standardization. There are also multiple European bodies, which mainly translate global standards and facilitate the exchange of information between international organizations and those on the continent. An example is the European Committee for Standardization, or CEN for short; another is the European Committee for Electrotechnical Standardization, or CENELEC.

The principal committee on IEC TC 105 standards in Germany is Working Group 384 Fuel Cells, which is headed by Alexander Dyck from the Oldenburg-based Institute of Networked Energy Systems at the DLR, also known as the German Aerospace Center. The national organization coordinating much of the work with respect to ISO TC 197 is the DIN association's Gas Technology Standards Committee, or NAGas. The committee on fuel cell use in vehicles is called the DIN Road Vehicle Standards Committee, or NAAutomobil.

WORKSHOP IN GERMANY NOW, the National Organization Hydrogen and Fuel Cell Technology, is supporting this push for standardization and approval in the German industry. Besides contacting national committees, stakeholders can participate in events such as "Approved – Certified – Standardized," a popular annual workshop. The next one will take place Feb. 26 and Feb. 27, 2019, in Duisburg and will again be organized by the ZBT Fuel Cell Technology Center, the Fraunhofer Institute for Solar Energy Systems ISE, and the DLR Institute of Networked Energy Systems.

Globally, it is the International Conference on Hydrogen Safety, ICHS, organized by the International Society for Hydrogen Safety – HySafe, that attracts the most attendees. This conference takes place every other year.

In short, there already are multiple options to ask experts and share knowledge in order to determine whether there are enough standards available to allow product approval in multiple countries. This exchange of ideas is also crucial when trying to develop a sense of which standards require revision and where new ones need to be established. ||

Written by

Thomas Jungmann, Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, Germany
thomas.jungmann@ise.fraunhofer.de

Dr. Alexander Dyck, DLR-Institut für Vernetzte Energiesysteme e. V., Oldenburg, Germany
alexander.dyck@dlr.de

Category: Stock Market | **Author:** Sven Jösting

IS THAT THE TURNAROUND ON THE HORIZON?

Sven Jösting's stock market analysis

The second half of the year is said to right the wrongs of the first, when fuel cell stocks did not have a chance to shine in the spotlight. Recent oil price hikes, typically a surefire recipe for larger investments in renewable energy, have had no discernable impact either. The interest shown by institutional investors in Tesla is much higher than that in the companies described below, most likely because their market caps are nowhere near USD 50 billion. Though, to paraphrase what someone once said in a galaxy far, far away: The important thing is the journey, not the destination. There are more and more news reports that illustrate how vital fuel cells and fuel cell applications, as well as renewable hydrogen, are becoming to renewable energy systems around the world.

What it needs now is a signal to get the stock market's attention. The IPO of Bloom Energy could be that signal – interestingly enough, despite key performance indicators that are lower than those of Ballard. All businesses described in the following have a secure footing and are expected to outperform the market average.

Fig. 1: Historical prices of the five companies mentioned below. Source: © wallstreet-online.de, Retrieved Aug. 30, 2018

BALLARD ANTICIPATES STRONG GROWTH IN SECOND HALF OF 2018

Even Ballard's chief executive, Randall MacEwen, has been heard using the word "megatrend" to describe the future of the fuel cell market. The industry is benefitting from the technological readiness of multiple fuel cell products and bringing them to market will only be a matter of time. The driver of growth at Ballard is a broad portfolio of prototypes and partnerships. A recent example is the collaboration with Scotland-based Ferguson Marine for building a car and passenger ferry powered by fuel cells and hydrogen.

Seen in this context, quarterly figures are hardly meaningful indicators. Ballard is constantly pumping funds into research and development projects. It is not only holding but expanding its lead in the market. The reduction in cash reserves, from more than USD 68 million to USD 35 million, is the result of a rise in inventory to meet fast-growing demand. This seems like a prudent strategy, considering backlog topped USD 283 million.

As it stands, Ballard is on track to assume the leading position in several fuel cell markets. Worldwide, a rising number of buses are being equipped with the company's stacks. Daimler, too, regards the fuel cell as an ideal complement to the batteries that are to drive its soon-to-be-available electric buses, above all to extend their range.

Smaller orders are gradually turning into large ones, since a series of tests has been wildly successful. In El Paso, Texas, buses powered by Ballard fuel cells ran for 16 hours on 5 days a week, and 30,000 hours in total. You can hardly wish for more. In California, the state government pays a grant of USD 300,000 per vehicle. Even without incentives, fuel cell buses have become less expensive due to advances in technology and improved electrolysis has made renewable hydrogen production as efficient as never before. Three years ago, a fuel cell bus cost between USD 850,000 and USD 1 million. Meanwhile, prices have tumbled to about USD 650,000 and could soon approach USD 450,000.

The very limited hydrogen infrastructure is being expanded at a steady pace. It could, if the number of fuel cell vehicles reaches a tipping point, experience a rapid buildup and solve the chicken-and-egg dilemma, which fuel cell opponents, specifically battery fans, are never getting tired of mentioning. As said, it will only be a matter of time.

AFCC, a research partnership of Daimler and Ford, has been wound up. Ballard sold its stake to Ford years ago but stayed on as a strategic partner. AFCC basically sub-rented about 11,000 square feet (1,000 square meters) at Ballard's headquarters in Vancouver, Canada. Ballard has gained a great deal from Daimler and Ford parting ways in fuel cell research. When the collaboration came to a close, it paid as little as CAD 6 million, or USD 4.6 million, for vital test and production equipment, so it can make twice as >>

many membrane electrode assemblies. The exit by Daimler is also putting some distance between the two businesses. As a large bus manufacturer, the automaker is essentially a competitor, since Ballard has teamed up with Broad Ocean in China to mass-produce low-cost fuel cell bus and truck stacks for Dongfeng. I think Daimler has yet to come far enough technologically, which is why it is taking the path of least resistance by producing battery-electric buses and trucks – the wrong decision, if you ask me. In the meantime, Broad Ocean has reportedly agreed to invest another USD 20 million to retain its 9.9 percent ownership position in Ballard after it was announced that Weichai Power would soon purchase 19.9 percent of the Canadian company to become its largest shareholder.

On to second-quarter results: Ballard (Nasdaq: BLDP) generated revenues of USD 26.4 million. The gross margin improved to 36 percent. Cash reserves for component purchases and vital research dropped by more than USD 16 million to USD 35 million. The company said that the second half of 2018 would be different. In other words, liquidity would not reduce any further. The net loss per share reduced to USD 0.02.

The second half of the year should indeed provide much more cause for optimism. And by that, I mean not only Van Hool's booking for 40 bus systems but also USD 11 million in outstanding payments from partners in China and a new Audi order worth between USD 62 million and USD 100 million up to August 2022.

Fig. 2: Ballard's current liquid-cooled FCvelocity® 9SSL fuel cell stacks, Source: Ballard

NEW STACKS PROMISE POTENTIAL FOR GROWTH Likewise, Ballard's new stack generation called a liquid-cooled fuel cell stack, or LCS for short (see box), offers attractive prospects. MEAs will also come in a new design. Fittingly, the positive news cycle isn't breaking up. Siemens has partnered with the business to design stacks for trains and ABB has done the same for ships. And subsidiary Protonex has received a U.S. Navy booking for 13 fuel cell systems to power drones.

KEY DATA ON NEXT FUEL CELL STACK GENERATION LCS
- 33 percent higher power density
- 40 percent lower costs
- 30 percent less weight
- More than twice the operating lifetime
- Improved low-humidity tolerance and enhanced high-temperature resistance
- Improved freeze-start capability
- Available for sale in 2019

The joint effort of Ballard and China's CRRC, the world's biggest rolling stock corporation, to integrate fuel cells into trains and streetcars has faced some delays in implementation but will reportedly get back on track, quite literally, when the companies test hydrogen-powered streetcars in 2019. The third and fourth quarter of 2018 would mark the arrival of multiple bookings and partnership agreements, according to MacEwen's statements during the second-quarter conference call. This means that the recent downward trend of Ballard stock would grind to a halt before going into reverse. Or, more to the point, it already has.

FUELCELL ENERGY STOCK STILL IN THE VALLEY OF TEARS

FuelCell Energy (Nasdaq: FCEL) disclosed in June that South Korean Posco Energy would end its agreement with the company to provide certain market access rights in Asia. By contrast, other Korean suppliers have begun to invest in fuel cells on a large scale. Posco's decision could have been made for strategic reasons, maybe to limit its product range. The fuel cell division seems to be the logical choice: The two businesses have built relatively large fuel cell parks together, but the total investment has been comparatively small. The real question is which organization bought Posco's 15 million shares. Also, did the corporation accept a discount on the price, which would explain the steep drop on the stock market?

The name of the new shareholder will certainly become public at one point, though it could likewise be a group of investors that managed to split up the parcel to circumvent reporting requirements. In my view, there is only one positive interpretation, considering Posco's shares were again offered for sale later. A high-ranking Ballard employee may have used the opportunity to purchase stock in the amount of USD 200,000.

Around the same time, the company was able to add some bookings, for example, by the U.S. Navy. Moreover, it announced intriguing advances on the technology front. My gut feeling is that FuelCell Energy is trying to get into a more favorable market position, as it expects large orders to arrive soon. The company stated that it had bid on projects worth more than USD 1.6 billion. This is in line with its announcement to increase capacity from 25 megawatts to 55 in a year and hire another 100 employees.

Not long ago, it won two contract bids for delivering 22.2 megawatts of capacity in Connecticut. Additionally, the U.S. Department of Energy awarded FuelCell Energy USD 10 million in research funding.

As for the results from the second quarter ended April 30, 2018: The company was able to increase backlog to USD 682 million and has an eye on USD 1.6 billion in biddings. Cash amounted to a healthy USD 105.2 million of restricted and freely available funds. If you add NRG Energy's credit facility of USD 40 million, FuelCell Energy has cash reserves totaling USD 145.2 million.

Shares convertible into Series C preferred stock at USD 1.84 cost the company USD 4.2 million in dividends, but the payment was – in my estimation, albeit no guarantee it's true – in the form of shares. My interpretation of this financing method is that capital is made available on demand, so to speak, and taking full advantage of that method could rake

in about USD 50 million. These funds will become important when FuelCell Energy needs to deliver large orders that require equity or securities.

I think the price took a dive because of Posco's exit and not fundamental change, so that we may soon see the stock recover, provided business develops as expected.

Fig. 3: Pere Margalef, Source: FuelCell Energy

FuelCell Energy Solutions has again needed to reassign responsibilities for sales in Europe, or, more specifically, Germany. After Klaus Ullrich left the company, his tasks were taken up by Pere Margalef, who "has been put in charge of all sales operations in Europe," Chip Bottone, FuelCell Energy's chief executive, told H2-international. Ullrich had been elevated to vice president of business development in May 2017 (see H2-international, August 2017) after Andreas Frömmel had gone to work for sunfire, where Ullrich is now employed as well.

HYDROGENICS SEES PRICE RESET

From USD 6 to USD 12 and right back where it all started, you might say. Low revenues in quarters one and two prompted the price to dwindle. But Hydrogenics continues to offer a great outlook given all the bookings made throughout the year. Likewise, it is working on a variety of projects, particularly in China. Recently, it started up one of the world's biggest power-to-gas systems in Ontario, Canada. All things considered, the stock price is at a truly attractive level.

Not unlike Ballard, Hydrogenics (Nasdaq: HYGS) expects that strong growth will prevail in the second half of the year. Some large projects may unexpectedly carry over from one period to the next, which means that financial results may fluctuate every three months. Increases in inventory reduced cash levels from USD 22 million at the end of 2017 to USD 15 million. Revenue totaled USD 7.6 million, at a loss of USD 2.4 million. Backlog amounted to USD 132 million. Alstom is said to place initial orders very soon. Hydrogenics has been extremely successful in upgrading trains as well as ships. The bright outlook means that current stock quotes only reflect the latest financial results, not the company's prospects.

PLUG POWER ACQUIRES MORE FUEL CELL EXPERTISE

Plug Power (Nasdaq: PLUG) was in the news in the second quarter for buying American Fuel Cell to improve its technological standing. However, a loss of USD 25.9 million, or USD 0.12 per share, is the reason for dampened enthusiasm, despite revenues of USD 39.9 million, that is, 75 percent year-on-year. Plug will find a way to make it big in material handling. It will need to have a word with partner Ballard Power, though, as its business model requires some tweaking. The stock has potential, but others have more. And the company's statements about financing are simply too vague. Plug may be hyped for one news cycle (see also Tesla), but it will hardly change the overall picture. The third-quarter objective is positive cash flow. I'll wait and see – and will put this one on hold. >>

Fig. 4: System startup in Ontario, Source: Hydrogenics

Fig. 5: Supercharger pictured next to a Model S (middle) and two Model X, Source: Tesla

44 TESLA OR THE PATH TO AND FROM PRIVATIZATION

There came the bombshell: On Aug. 7, Tesla chief Elon Musk tweeted he was considering taking the company off the stock market, a process known as delisting. And he put a price on it – USD 420 per share, which would mean a market value of more than USD 80 billion, including debt. He said funding had been secured. Had it really been?

It was said that the suggestion to privatize came from Saudi Arabia's sovereign wealth fund, which intended to purchase a stake in Tesla too. Since even Tesla's board of directors looked taken aback by the announcement, I am not so certain about all of it. Musk then had to act, as this kind of statement has – legal – consequences. His decision to do an about-face in less than three weeks means short sellers now hold all the cards. Costly lawsuits are sure to follow. One organization has already sued Musk: the U.S. Securities and Exchange Commission. The subsequent agreement between him, Tesla and the SEC two days later will force Musk out of the chairman role and make him and the company pay USD 20 million each. Of course, had it been one of his other projects, such as SpaceX, which are not listed, he wouldn't have had to ask in the first place. Stay tuned.

Big funds such as Fidelity have large unrealized gains. Do these institutional investors wait until the last minute to see a few percentage points added and get to USD 420? Obviously, they would need to sell shares no longer traded on the market. Considering this, it is entirely understandable that major shareholders favored delisting, as they would have received USD 420 per share in cash. At that point, though, they would no longer have been shareholders, as the stock would have needed to be available for revaluation.

SAUDI FUND UPS THE GAME The Financial Times has reported that the Public Investment Fund of Saudi Arabia had spent USD 1.7 billion to USD 2.9 billion on buying a 3 to 5 percent stake in Tesla (Nasdaq: TSLA). I was left wondering, though, why this hadn't been done through a capital raise, which could have put up to USD 2.9 billion into the company's bank accounts. The only reason I could come up with was that Musk had ruled out raising capital another time and was intent on following through with his pledge. However, a raise would have provided much needed liquidity. Plus, let's be honest, Musk has had to walk back some of his statements before.

As said, Saudi Arabia was allegedly the driver behind the privatization attempt. I seriously doubt it: I have yet to see proof in writing and words alone won't do it. The next question is whether Musk purchased his two parcels of shares in the amount of USD 9 million and USD 20 million at around the same time as he negotiated with the Saudi Arabian fund. If so, it would be a clear case of insider trading that could have legal repercussions.

PUT ON A HAPPY FACE Previously, on Aug. 2, Musk had announced that Tesla would be cash flow positive starting in the third quarter and would remain that way, even though this doesn't mean it will generate a profit each time. The corporation would not require fresh capital – so no capital raise – as cash flow would take care of everything and would be able to cover 7,000 weekly orders, that is, 5,000 for Model 3 cars and 2,000 for Model S and Model X, by then. The news sparked a wave of euphoria, catapulting the stock from about USD 300 to USD 350 in just one day of trading. The market cap grew by more than USD 8 billion. Then came the tweet about privatizing the company.

"Everything's all right" is how you could have summed up the state of business and Musk's comments after the company published results for the second-quarter ended June 30, 2018. Production would increase to 750,000 units in 2020,

it was said. Quite frankly, I will remain skeptical, since the company's financials paint a different picture. Net loss in the second quarter was USD 718 million. Tesla kept the cash level at USD 2.2 billion, down from USD 2.7 billion on a year-over-year basis but better than the capital drain of up to USD 1 billion that some analysts had expected. Deposits earned the company more than USD 900 million. It's worth taking a closer look at that liquidity figure. The company's USD 4 billion in liabilities and outstanding invoices could have risen more than expected, while accounting changes may have also had an impact. Obviously, if you don't pay the bills, your cash reserves remain untouched or grow. In any case, Musk has again managed to push the stock price to new heights and caused some analysts to change their views to a more positive outlook. Let's see what's next.

ADDICTED TO TWITTER, JUST LIKE TRUMP In the meantime, even major investors have become annoyed by Musk's sheer endless stream of tweets, some of which have absolutely nothing to do with company operations and look more like a strategy to distract from the issues at hand. One tweet, which sounded almost like an ultimatum, was supposed to put short sellers in a bind within three weeks. The one about privatization did that after five. Its style and tone could remind one of tweets put out by U.S. President Donald Trump. Plus, they contain statements I believe chief executives aren't allowed to make due to stock market regulations, most of all during trading hours when they can have an effect on stock prices.

Messages to tout the 5,000-per-week milestone in Model 3 production capacity seem harmless in comparison. But plans to establish new battery and vehicle factories in China and Europe, or, more specifically, in Shanghai and Germany, don't engender trust. Those would need loads of cash, which Tesla couldn't provide at present, even though Panasonic has indicated that it would stay on as a partner.

Many Model 3 buyers are faced with a cut in the USD 7,500 tax incentive for Tesla vehicles, as the company has surpassed the 200,000-unit mark. The incentive is currently half the amount but will be gone in several months. The USD 35,000 base model is unavailable anyway. Tesla is offering premium versions only, as they have higher price tags and thus greater margins. What is more disconcerting is the situation surrounding former employee Martin Tripp, whom Musk has accused of sabotage. Tripp has claimed that Tesla had been using both defective parts and defective batteries in some Model 3 cars to meet the ambitious production targets set by Musk. Even marketing and consumer protection agencies have begun to recommend not being among the first to receive a Model 3.

The aggressive pricing strategies of competitors could have a negative impact as well, some analysts have said. Investment banking firm Needham recently downgraded the corporation's stock to Underperform, saying that USD 1,000 deposits were being cancelled at a faster rate than new ones were made. Likewise, Tesla is now asking for another but non-refundable USD 2,500 deposit for Model 3 cars. I share the opinion of the sell-side analysts and will remain a skeptic. My cautious stance has little to do with those handsome electric cars that the company is putting on the market. Rather, a worrying financial situation, growing competition and the attempt to privatize business could have serious legal and financial consequences for Musk himself and for Tesla. Additionally, other automakers may soon put on the pressure by presenting new electric and, in time, hydrogen-powered vehicles and fuel cell hybrids.

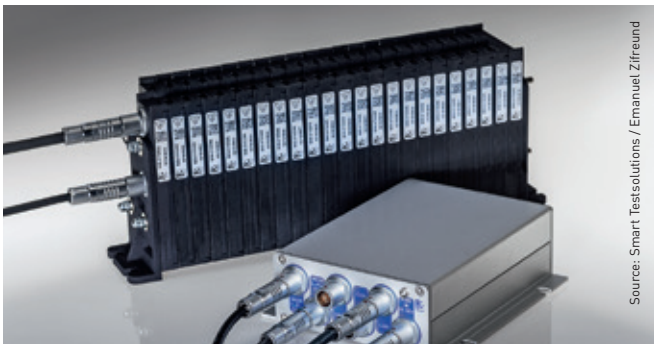
RISK WARNING
Share trading can result in a total loss of your investment. Consider spreading the risk as a sensible precaution. The fuel cell companies mentioned in this article are small and mid-cap ones, i.e., they may experience high stock volatility. This article is not to be taken as a recommendation 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.

My prediction is that the reduced cash reserves of USD 2.2 billion and the loss of USD 718 million will inevitably lead to a request for a larger amount of capital. Though Tesla has repeatedly denied that possibility, it wouldn't be the first time the company has said one thing but done another. Musk could take advantage of current stock price highs and a bright outlook to justify a capital raise. The company will certainly need cash to implement all those plans for new production facilities. But a raise would mean it will need to be very upfront about the aims, reasons, the price and terms of it. The renewed hype over Tesla could quickly grind to a halt. There were analysts that recommended gradually selling shares when prices exceed a certain limit and realizing profits. It is time to act, since a market capitalization of USD 50 billion will, at some point, require matching revenues. The company could soon find itself in a tight spot, considering several manufacturers of long-distance fuel cell cars could be on their way to disrupt the market by then.

The grandiose claims by Musk clearly illustrate to what lengths the company will go to bring about positive cash flow at the end of the third quarter. For example, the second quarter didn't feature any tax incentives for zero-emission vehicles. Since Tesla can decide when to include them in accounting, I am certain they will show up in the third. Some estimates put the figure between USD 200 million and USD 300 million, so this can be noted down as an option to improve financial results. However, this tactic is not sustainable or related to day-to-day business. In my view, the stock price could go even higher until reversing later this year and especially in 2019. ||

FUEL CELL INNARDS

CELL VOLTAGE MONITORING DEVICE AND CONTROLLER WITH BUILT-IN COMPUTER



Source: Smart Testsolutions / Emanuel Zifreund

Smart Testsolutions, based in Stuttgart, Germany, has developed a new software application to provide deeper insights into fuel cell systems. To improve cell voltage monitoring, or CVM for short, it has equipped its various products with a state-of-the-art program capable of visualizing measurements almost instantaneously.

The company offers solutions for keeping a close watch on fuel cells, batteries and electrolyzers. It designed a web-based platform that can be used for the rapid, uninterrupted monitoring of several hundred cells at once. Wolfgang Neu, the business's chief executive, said that the new "web-based interface of our CVM systems lets users display and record data on 420 channels simultaneously to monitor fuel cell stacks in real time. It makes them aware of issues that conventional but slow-rendering testing applications could not visualize."

Neu added that the CVM software did not need a workstation but could run on any device that had a browser installed because the entire program was stored on the master unit. Data could be transferred over a wireless network. ||

ALL FROM ONE

PRESSURE GOVERNOR

Source: PTEC

Recently, PTEC – Pressure Technology based in Burscheid, Germany, started to offer customers an entire range of hydrogen components. In June, it had six additional parts, including fuel, purge, solenoid and pressure relief valves, and a filter, certified for 350-bar applications. Four components, including a check valve and a pressure governor, had been certified previously. The chief executive of PTEC, Klaus Perthel, said that his company was the "only business globally to offer 10 products that are compliant with EC79 and suitable for a pressure level of 350 bars." He added that PTEC was developing versions for 700-bar use and that prototypes were available.

The 10-staff business has sold more than 0.5 million units worldwide. One of its customers is Van Hool, a Dutch manufacturer that has signed a contract to provide the public transportation company in Cologne with 40 fuel cell buses. In 2019, those buses will reportedly run through Burscheid as part of their schedule. ||

Category: Global | **Author:** Sven Jösting

THINGS MOVE FORWARD IN CHINA

Third CHFCE in Beijing

Fig. 1: Sven Jösting (left) and Chen Wei of the China International Hydrogen and Fuel Cell Conference Committee (middle)

Enthusiasm was on display at the International Hydrogen and Fuel Cell Conference and Exhibition, which was held July 26 through 28 in Beijing. It showed the incredible speed at which China as well as Japan have grown in importance in the global hydrogen and fuel cell market. The People's Republic knows how to benefit from the potential offered by both technologies.

The country is acutely aware that much needs to be done in little time to resolve its massive pollution problem. But China's aim to increase renewable capacity from about 149 gigawatts today to more than 250 gigawatts by 2020 will prove a solid foundation for the use of a variety of fuel cell applications powered by green hydrogen.

Likewise, the government has plans to up the number of electric vehicles carrying goods and passengers across the country's huge landmass from about 1.2 million to 10 million by 2030. Fuel cells, on the other hand, are still limited to a niche market, even though bus manufacturers seem to be making some inroads. An example is the partnership between Broad Ocean, Guangdong Energy and Canadian manufacturer Ballard Power. Additionally, some expect that the People's Republic will map out a comprehensive fuel cell strategy and increase funding. If that happens, the nationwide 2030 goal of 3,000 hydrogen fueling stations could be too low. China can be fast.

Great Wall Motors' Hydrogen Technology Center stated that those stations would have to not only be built at a greater speed but become less expensive in the process. Several speakers at the conference seemed to expect the price for green hydrogen to drop, too, with USD 5 thought to be an attainable goal. This would increase the number of fuel cell uses and products in the foreseeable future. An estimated 500,000 fuel cell trucks could be on the roads by 2030, the year when the first fuel cell cruise ship is to be put into service.

Several of those giving presentations said that fuel cell trucks had clear-cut advantages over all-electric ones. Likewise, they added that fuel cell taxicabs and forklifts provided a better return on investment during multi-shift operations due to their faster fill-up with hydrogen. PEM stacks, and not high-temperature alternatives, are believed to be the fuel cell's future, as they are easier to assemble, more reliable and last longer – up to 20,000 hours. Also, they are efficient and start up in just a few seconds each time.

National and international corporations, as well as research institutions, have begun to allocate a great deal of resources to the design of PEM stacks, specifically membrane electrode assemblies, with the goal to substitute carbon compounds for platinum throughout those units. Many speakers put production techniques front and center during their presentations.

After talking to many of the participants, I got the impression that although the number of attendees was down from last year, the presentations were of higher quality and the exhibits more intriguing. Much of what people asked or presented bore some relation to safety or the range of applications, from hydrogen use in cars, trucks and buses to power-to-gas. Companies based in Canada, such as Ballard and Hydrogenics, and those based in Germany, like ElringKlinger, have become fully aware of the potential fuel cells have in the People's Republic and are well-connected through joint ventures with Chinese corporations. Now, they can reap economies of scale and cater to not just one market but the world. ||

www.chfce.com

This article was written by independent stock market analyst Sven Jösting, who spent several days in China to report about hydrogen and fuel cell innovations at CHFCE. His trip was partly funded by Peter Sauber Agentur Messen und Kongresse GmbH, a company organizing events in Japan and Canada, in addition to the German f-cell show and WHEC in Brazil.

Category: Global | **Author:** Sven Jösting

MILITARY AS DRIVING FORCE BEHIND FUEL CELL DEPLOYMENT

U.S. Army could accelerate market readiness


Source: GM/Jeffrey Sauger

There has been a long tradition of hydrogen and fuel cell use in spaceflight programs. But it is a little-known fact that the U.S. Army, too, has been developing fuel cell devices for multiple applications. Could its efforts translate into a first-mover advantage and give the market the boost it needs? Here's a look at how "America First" could be a blessing for fuel cells.

One might say that, all in all, it is U.S. President Donald Trump himself who shares some of the blame for the oil price hikes in past months as well as their growing frequency. You could also say it's about cause and effect. His threating Teheran has done little to calm the waters. On Nov. 4, another round of sanctions will hit Iran: Expect global oil production to drop by 3 million to 4 million barrels a day. Typically, that's good news for renewables, but the Environmental Protection Agency has been grappling with massive budget cuts imposed by the Trump administration. Unexpected allies in the fight for renewable energy could be the Department of Energy and the armed forces.

U.S. MILITARY IS WORLD'S BIGGEST OIL CONSUMER The U.S. military is not just the biggest oil consumer in America but the entire world. Together, its departments need more than 350,000 barrels each day. The amount is understandable given that there are about 1.2 million active duty members who operate a huge fleet of air, land and water vehicles and vessels. Thus, it shouldn't be too difficult to find uses for fuel cells and green hydrogen to raise energy efficiency and cut back on oil supplies. For example, fuel cells have long been an integral component of submarines made in Germany.

In 2010, the U.S. Army equipped an Abrams M1 main battle tank with the technology. Five years later, General Motors started using fuel cells in military vehicles. In 2017, the carmaker showcased a Chevrolet Colorado ZH2 concept study of a military jeep. Northrop Grumman, on the other hand, has been buying fuel cell equipment from Kellstrom Defense for its transport helicopter UH-1, nicknamed Huey.

Fig. 1: This picture from 2017 shows Paul Rogers, director of the U.S. Army Tank Automotive Research, Development and Engineering Center, as he is being handed the keys to a Chevrolet Colorado ZH2 Fuel Cell.

The benefits have now trickled down to the common soldier, who will have a much easier time carrying around a fuel cell system than a heavy pack of batteries, with a hydrogen cartridge being the only part that needs to be changed. The technology can reduce the weight of electrical equipment, including radio, night vision goggles, IT and weapon systems, by more than 80 percent. The era of rechargeable batteries is slowly coming to an end. A painstakingly long recharge time isn't their only disadvantage. They also weigh too much and must be disposed of at the end of their lifetime.

Protonex, a subsidiary of Canadian fuel cell manufacturer Ballard Power and a Boeing partner, supplies fuel cell units for military gear, UPS systems and drones. Drones especially are much lighter if they are powered by fuel cells instead of rechargeable batteries, which will result in a higher range. The difference in flight time will also have an impact on civilian use, where large corporations such as Amazon, Google and DHL see potential for logistics operations.

In this context, it should be noted that the U.S. Navy intends to keep its Ion Tiger drone in the air for three days straight. Currently, 48 hours are possible. The collaboration between Protonex and the Navy began in 2006 and could lead to U.S. military orders worth more than USD 150 million over the coming years, according to Ballard. Key advantages of fuel cell vehicles are low noise and pollution levels, which make them much harder to track.

In the end, Trump's "America First" could prompt a run on fuel cells among military leaders. The departments' gigantic budget of more than USD 650 billion a year could help move market deployment forward and provide a boost for civilian use down the road. Environmental factors should not be downplayed when the biggest oil consumer in the world rethinks and redrafts its supply strategy. The U.S. military may see this as the perfect opportunity to frame "America First" in a positive light, though all ideas are no more than wargames right now. ||

Category: Global | **Author:** Sven Geitmann

FRANCE INVESTS IN A HYDROGEN FUTURE

Decarburizing energy supply, the French way

Fig. 1: Nicolas Hulot, Source: Ministère de la Transition écologique et solidaire

Compared to other countries in Europe, France has launched a sizeable number of projects on hydrogen and fuel cells. Reportedly, the latest plan of the government is to move far beyond current figures: In early June, former environment minister Nicolas Hulot, a member of EELV, France's Green Party, said that France would provide EUR 100 million to support the technologies over the coming years. He also presented a road map in the hopes that hydrogen can be integrated into several industries. The overarching goal is to decarburize the country's energy supply bit by bit.

Hulot, whose nature series Ushuaïa made him a popular TV personality, wanted to turn hydrogen into a central pillar of his country's energy system and intended for France to become a leader in hydrogen technology. In an unexpected twist, he resigned during a live radio show on Aug. 28, saying that he was dissatisfied with progress on the environmental front. This month, French President Emmanuel Macron named François de Rugy the new environment minister. At the very least, de Rugy has been skeptical of putting up more nuclear power plants.

The 2023 aim was to build 100 fueling stations, plus 5,000 light and 200 heavy-duty commercial vehicles as well as vessels for air, water and land transportation. By 2028, four times that number was to be in service. By 2023, 10 percent of the hydrogen consumed in industry was to be sourced from renewables, and between 20 percent and 40 percent in 2028 at the latest. Hopes were that a broader range of hydrogen applications would result in 10 to 12 megatons lower carbon dioxide emissions by 2030. If the road map is left unchanged, the organization in charge of coordinating the effort will be French environment agency Ademe.

A study by consulting firm McKinsey has shown that the country's objectives could generate revenues of about EUR 8.5 billion per year in 2030 and create more than 40,000 jobs. Hulot had also planned to draw up technical requirements for injecting hydrogen into the pipeline system. There has been no word yet on what a post-2019 budget for the technology would look like.

As little as four weeks after Hulot's road map presentation, Paris-based gas supplier Air Liquide announced that it would support STNE, a Chinese startup, financially and in terms of expertise. It paid around EUR 10 million for a minority stake and said it would help the business get around 7,500 hydrogen-powered trucks and 25 fueling stations on the road by 2020. In an unrelated piece of news, Air Liquide stated that it had increased the number of hydrogen taxicabs in its Hype vehicle fleet, which it operates in partnership with Société du Taxi Electrique Parisien in Paris, to 100 in July. The goal by the end of 2020 was 600.

Meanwhile, McPhy and Engie reported about the startup of three electrolyzers and two storage systems on the premises of Minatec in Grenoble. McPhy said that the new installation "fits perfectly with the French ministry's strategic plan to support the roll-out of carbon-free hydrogen and make France the world leader in the field." ||

Category: Global | **Author:** Alexandra Huss

INDIA'S ENERGY HUNGER

Looking beyond the oil market

Due to a population that continues to grow and a booming economy, India will be the country to experience the largest increase in energy demand by 2040, according to the IEA's latest World Energy Outlook published in 2017. The immense hunger for energy is being driven mainly by additions of generation capacity as well as electric vehicles. The government knows that fossil fuels will be able to meet only part of that huge demand. Even today, India is forced to import large quantities of oil. Not least because of the ratification of the Paris climate accords has it set a 40 percent renewable production target by 2030.

The rise in consumption has already moved India to third place, after the United States and China, on the list of countries emitting the most carbon dioxide. To follow through with the goals it established as part of the Paris climate accords, it will need to implement drastic cuts in fossil fuel use. Expanding the application of renewable energy is just one objective of the government, which has also established reforestation programs and ordered the planting of new trees to provide more opportunities for capturing carbon dioxide.

Decarburizing transportation is near the top of the agenda, as the high number of oil imports are costing India a fortune. Ever-increasing traffic, particularly on the road, is likewise beginning to have detrimental effects, both on the people and the environment throughout metropolitan areas and large cities such as Bengaluru, Chennai, Delhi, Kolkata and Mumbai. The government created regulations to replace petroleum-based fuels with natural gas in public transportation and effect drastic reductions in air pollution levels as early as 2008.

A very popular means of transportation in the world's second most-populous country, and one that is virtually unknown in Europe, is an auto rickshaw, colloquially called a tuk-tuk, with a two-stroke engine. Most of these rickshaws have three wheels and are used to transport goods or, as taxicabs, people around a city. Not only do they play an important role in India's mass transit system but they also represent a sizeable market. There is an entire loan program for the sole purpose of people purchasing a rickshaw – which costs about EUR 2,000 – and becoming self-employed. It is a very attractive option, for example, to pay for one's university studies. In 2015, the number of auto rickshaws sold and registered in India exceeded half a million.

PROMOTING HYDROGEN AND FUEL CELL TECHNOLOGY Clean and sustainable – and, above all, inexpensive – fuel is one of the decisive factors in any rickshaw buy. In partnership with the oil industry, most of which is under government control, politicians have made attempts to introduce new fueling solutions, such as hydrogen and fuel cells. But despite efforts to promote the use of both technologies, the government has yet to manage something beyond the stage of development, research and demonstration.

After India established incentive programs for hydrogen and fuel cells, the technologies have become a topic of intensive study at universities and research institutes. The oil industry, energy suppliers and, most of all, India's automakers, such as Tata Motors and Mahindra & Mahindra, have since been part of numerous demonstration projects. Portable and stationary products, however, are in the same early stage as in other countries in Europe and North America, with the exception of Canada.

Support programs for fuel cell and hydrogen research, development and demonstration are the domain of the Ministry for New and Renewable Energy, or MNRE for short. It pro-

Fig. 1: Three-wheeled electric rickshaw HyAlfa by Mahindra

vides comprehensive R&DD project funding at universities and research organizations and half the funds for the same kinds of projects in industry. In 2017, its hydrogen and fuel cell budget amounted to INR 220 million, or about EUR 2.8 million, for research into new materials, processes, parts, subsystems and entire installations. It also offers support for developing hydrogen infrastructure components.

The RD&D projects supported over the past decade have brought forth many prototype vehicles using fuel cells to convert hydrogen into electricity or Hythane, a mix of hydrogen and natural gas for combustion engines. The government considers the blend a compromise until there are cost-effective hydrogen and fuel cell systems on the market. The mixture will increase the efficiency in LNG engines, like those installed in many LNG buses, and cut emissions in cities by about one-fourth in the foreseeable future.

Post-2020, however, India intends to rely to an increasing degree on pure hydrogen to power fuel cell vehicles. The main reason that is preventing the country from showcasing units driven by hydrogen alone is the lack of infrastructure. So far, most of the gas has been produced at refineries and factories that manufacture fertilizer or chlorine-alkali solutions and is being consumed on-site. Likewise, there are no regulations in place to govern the transportation and storage of hydrogen in pressure vessels at more than 200 bars.

HYDROGEN-DRIVEN AUTO RICKSHAWS In partnership with the Delhi-based Indian Institute of Technology, vehicle manufacturer Mahindra & Mahindra has developed over the past years a hydrogen rickshaw named HyAlfa and two minibuses powered by a blend of hydrogen and natural gas. The blend, stored in six Type III 74-liter tanks, provides energy for a 66-kilowatt, four-cylinder turbocharged combustion engine. The minibuses run at the Indian Oil Corporation R&D Center in Faridabad, south of Delhi. Earlier this year, two Tata Motor buses with 120-kilowatt PEM modules were added to its fleet. Their Type III tanks store 40 kilograms of hydrogen at 350 bars for a range of about 186 miles (300 kilometers). As early as 2012, the Gurgaon-based National Institute of Solar Energy had started field-testing 15 rickshaws and five SUVs, the latter equipped by Mahindra & Mahindra with bivalent hydrogen-diesel engines, in Delhi and will continue to do so for the time being. In addition, the campus of Banaras Hindu University in Varanasi, in the northern state of Uttar Pradesh, has been turned into a demonstration site for 15 hydrogen-powered motorcycles.

As far back as 2008, Indian Oil had added a hydrogen pump to one of its gas stations in Dwarka, a Delhi subcity. The pump is linked to an electrolyzer, which gives off five normal cubic meters of hydrogen per hour. Hydrogen from the pump is used as fuel or blended with natural gas. Another station of this type has been installed at the research site of Indian Oil in Faridabad.

Last but no less important RD&D support is available for systems producing hydrogen from biomass. This is an important step forward in a country such as India, which generates 500 million tons of biomass each year and could use between 120 tons and 150 tons of it to create hydrogen. Current pilot systems for development and demonstration are at the Indian Institute of Technology in Kharagpur, in the northeastern state of West Bengal, the Indian Institute of Chemical Technology in Hyderabad, in the southern state of Telangana, and the Indian Institute of Science in Bengaluru, in Karnataka, also in the south of the country.

In past years, India has reduced import tariffs to raise the number of renewably powered fuel cell systems. The government's Make in India initiative, which is extolling the benefits of local manufacture, has also been crucial to establishing partnerships with foreign companies. ||

Fig. 2: Tata's fuel cell-driven Starbus, Source: Tata Motors

EVENTS 2018

November 6 to 7, 2018
International EV Batteries
Cost-Effective Engineering for Hybrid and Electric Vehicles
in Twickenham Stadium, London, United Kingdom
www.imeche.org/evbatteries

November 13 to 14, 2018
16th Ulm Electrochemical Talks (UECT) Batterie and Fuel Cells – from Cradle to Cradle
in Ulm, Germany *www.uect.de*

November 27 to 28 2018
Zero Emission Bus Conference (ZEB)
in Cologne, Germany
www.zebconference.com/eu

EVENTS 2019

January 30 to 31, 2019
El-motion – 8. Austrian Electric Mobility Congress
in Vienna, Austria
www.elmotion.at

February 13 to 15, 2019
H2 meetings by HyVolution
Side event of BePOSITIVE
in Lyon, France
www.bepositive-event.com

February 27 to March 1, 2019
FC Expo – International Hydrogen & Fuel Cell Expo
Tokyo Big Sight, in Tokyo, Japan
www.fcexpo.jp

March 12 to 14, 2019
IRES – International Conference and Exhibition for the Storage of Renewable Energies
in Düsseldorf, Germany
www.eurosolar.de

March 12 to 14, 2019
Energy Storage Europe
in Düsseldorf, Germany
www.energy-storage-online.com

April 1 to 5, 2019
Hannover Messe
Group Exhibit "Hydrogen, Fuel Cells, Batteries" and MobiliTec
Hannover, Germany
Hannover Messe, *www.h2fc-fair.com*

April 24 to 26, 2019
Hypothesis XIV
HYdrogen POwer THeoretical & Engineering Solution International Symposium
in Itaipu, Brazil
www.hypothesis.ws

May 7 to 9, 2019
The Battery Show Europe
in Stuttgart, Germany
www.thebatteryshow.eu

May 7 to 9, 2019
Electric & Hybrid Vehicle Technology Expo Europe
in Stuttgart, Germany
www.evtechexpo.eu

Conference: May 14 to 15, 2019
Fair: May 15 to 17, 2019
ees Europe & Power2Drive Europe
Europe's largest exhibition for batteries and energy storage systems
The exhibition for charging infrastructure and e-mobility, in Munich
together with Intersolar Europe
www.ees-europe.com
www.powertodrive.de

May 22 to 23, 2019
Hydrogen + Fuel Cells HFC
in Vancouver, Canada
www.hfc2019.com

July 2 to 7, 2019
European Low-Temperature Fuel Cells / Electrolysers & H2 Processing FORUM
EFCF-Conference with Exhibition
in Lucerne, Switzerland
www.efcf.com

DISCOUNTS + TICKETS

January 30 to 31, 2019
El-motion
in Vienna, Austria
100 Euro Discount
Code: HZwei Abo
www.elmotion.at

BUSINESS DIRECTORY

EDUCATION & TRAINING

H-Tec Education GmbH, Demonstration & Education for Schools, Universities, Maria-Goeppert-Str. 9a, 23562 Luebeck, Germany, Phone +49-(0)451-39941-0, Fax -799, info@h-tec-education.com, *www.h-tec.com*

ELECTROLYZERS

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

Diamond Lite S.A., Rheineckerstr. 12, PO Box 9, 9425 Thal, Switzerland, Phone +41-(0)71-880020-0, Fax -1, diamondlite@diamondlite.com, *www.diamondlite.com*

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

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

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

H-Tec Systems GmbH, PEM electrolyzers for industry application, Maria-Goeppert-Str. 9a, 23562 Luebeck, Germany, Phone +49-(0)451-39941-0, Fax -799, info@h-tec-systems.com, *www.h-tec.com*

Hydrogenics GmbH, Am Wiesenbusch 2, 45966 Gladbeck, Germany, Phone +49-(0)2043-944 141, Fax -6, hydrogen-sales@hydrogenics.com, *www.hydrogenics.com*

iGas energy GmbH, Cockerillstr. 100, 52222 Stolberg, Germany, Phone +49-(0)2402-9791600, Fax -7094864, *www.iGas-energy.de*

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

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

ELECTRONICS

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

ENERGY STORAGE

GKN Powder Metallurgy, GKN Sinter Metals, PO Box 55, Ipsley House, Redditch B98 0TL, Worcestershire, United Kingdom, *www.gkn.com/sintermetals*

Hexagon xperion GmbH, Otto-Hahn-Str. 5, 34123 Kassel, Germany, Phone +49-561-58549-0, Fax -29, *www.hexagonx-perion.com*

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

Hydrogen + Fuel Cells NORTH AMERICA, Solarpower 2019, September 23–26, **Group Exhibit Hydrogen + Fuel Cells + Batteries,** Hannover Messe 2019, April 01–05 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*

FITTINGS, REGULATORS, VALVES

Bürkert Werke GmbH, Mass Flow Controllers, Christian-Bürkert-Str. 13–17, 74653 Ingelfingen, Germany, Phone +49-(0)7940-10-0, Fax -91204, *www.burkert.com*

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

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

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

FUEL-RECIRCULATION AND AIR-SUPPLY

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

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

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

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

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

GAS DIFFUSION LAYERS (GDL)

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

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

HYDROGEN DISTRIBUTION

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

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

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

MEMBRANES AND SEPARATORS

FUMATECH BWT GmbH, Carl-Benz-Str. 4, 74321 Bietigheim-Bissingen, Germany, Phone +49-(0)7142-3737-900, Fax -999, *www.fumatech.com*

Plansee SE, Bipolar Plates, Interconnects and Metal Supported Cells, 6600 Reutte, Austria, Phone +43-(0)5672-600-2422, *www.plansee.com*

ORGANIZATIONS

German Hydrogen and Fuel Cell Association, Deutscher Wasserstoff- und Brennstoffzellen-Verband e.V. (DWV), Moltkestr. 42, 12203 Berlin, Germany, Phone +49-(0)30-398209946-0, Fax -9, *www.dwv-info.de*

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

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

REFORMERS

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

RESEARCH & DEVELOPMENT

Fraunhofer Institute for Microengineering and Microsystems IMM, Reformer and Heat Exchanger, Carl-Zeiss-Str. 18–20, 55129 Mainz, Germany, Phone +49-(0)6131-9900, info@imm.fraunhofer.de, *www.imm.fraunhofer.de*

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

SUPPLIERS

Anleg GmbH, Advanced Technology, Am Schornacker 59, 46485 Wesel, Germany, Phone +49-(0)281-206526-0, Fax -29, *www.anleg-gmbh.de*

Borit NV, Bipolar plates and interconnects, Lammerdries 18e, 2440 Geel, Belgium, Phone +32-(0)14-25090-0, Fax -9, contact@borit.be, *www.borit.be*

ElringKlinger AG, Max-Eyth-Str. 2, 72581 Dettingen/Erms, Germany, Phone +49-(0)7123-724-0, Fax -9006, info@elringklinger.com, *www.elringklinger.com*

ElectroChem Inc., 400 W Cummings Park, Woburn, MA 01801, USA, Phone +1-781-9385300, *www.fuelcell.com*

HIAT gGmbH, Schwerin, Germany, CCMs / MEAs / GDEs for PEFC, DMFC & PEM-Electrolysis, *www.hiat.de*

Kerafol Keramische Folien GmbH, Koppe-Platz 1, 92676 Eschenbach, Germany, Phone +49-(0)9645-884-30, Fax -90, *www.kerafol.com/sofc*

Pajarito Powder, LLC, 3600 Osuna Road NE, Suite 309, Albuquerque, NM 87109-4427, USA, Phone +1-505-2-935367, Fax -448040, *www.pajaritopowder.com*

WEKA AG, Schuerlistr. 8, 8344 Baeretswil, Switzerland, Phone +41-(0)43-833434-3, Fax -9, info@weka-ag.ch, *www.weka-ag.ch*

SYSTEM INTEGRATION

Deutsche Zentrum für Luft- und Raumfahrt (DLR) / German Aerospace Center Institute of Engineering Thermodynamics Energy System Integration, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany, Phone +49-(0)711-6862-672, Fax -747, *www.dlr.de/tt*

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

TESTING

JA-Gastechnology GmbH, Albrecht-Thaer-Ring 9, 30938 Burgwedel, Germany, Phone +49-(0)5139-9855-011, Fax -33, *www.ja-gastechnology.com*

Maximator GmbH, High Pressure Hydrogen Technology, Testing Equipment, Customer Testing Services, Lange Strasse 6, 99734 Nordhausen, Germany, Phone +49-(0)3631-9533-5107, H2Team@maximator.de, *www.maximator.de*

Resato International B.V., H_2-Pressure Testing, H_2 gas booster for refueling stations, high pressure technology, Duitslandlaan 1, 9400 AZ Assen, Netherlands, Phone +31-501-6877, h2sales@resato.com, *www.resato.com*

SMART Testsolutions GmbH, Rötestrasse 17, 70197 Stuttgart, Germeny, Phone +49-(0)711-25521-10, Fax -12, *sales@smart-ts.de*, *www.smart-testsolutions.de*

TesTneT Engineering GmbH, Schleissheimer Str. 95, 85748 Garching / Munich, Germany, Phone +49-(0)89-237109-39, *info@h2-test.net*, *www.h2-test.net*

TEST STANDS

AVL List GmbH, Hans-List-Platz 1, 8020 Graz, Austria, Phone +43-316-787-0, Fax -400, info@avl.com, *www.avl.com*

AVL REVOLUTIONIZES FUEL CELL DEVELOPMENT

AVL opens R&D center for fuel cells in Vancouver

Thanks to the unique synergies between development, simulation and testing, AVL offers highly innovative, market-ready and application-specific solutions for fuel cell-powered vehicles. The proven and reliable toolchain for validating internal combustion engines is now available for fuel cell technology, revolutionizing FCEV development.

AVL has now opened a new development center, AVL Fuel Cell Canada in Vancouver. Vancouver has one of the world's largest fuel cell tech clusters and a solid base from which to break new ground in these technologies.

YOUR BENEFITS:

- Development, simulation and testing of fuel cells for the automotive industry
- Time-saving and cost-effective fuel cell development thanks to the integrated and proven AVL toolchain for vehicle development
- Established series development environment for fuel cell technology – from cell to vehicle

www.avl.com/fuel-cell