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H2 international

THE E-JOURNAL ON HYDROGEN AND FUEL CELLS

→ HIGH-PRECISION, COST-OPTIMIZED SERIES PRODUCTION OF BIPOLAR PLATES

→ PROJECT AND MARKET OVERVIEW FOR BUILDING ENERGY SUPPLY SYSTEMS

Hydrogen Regions, Part X:
HyPerformer – HyWays for Future

Aktualisierte
und erweiterte
Auflage
Sven Geitmann und Eva Augsten
WASSERSTOFF UND BRENNSTOFFZELLEN
DIE TECHNIK VON GESTERN, HEUTE UND MORGEN
HYDROGEIT
Mit einem Vorwort von Prof. Volker Quaschning
BESTELLUNG ÜBER WWW.HYDROGEIT-VERLAG.DE,
BUCHHANDLUNGEN ODER PER EMAIL: KONTAKT@HYDROGEIT.DE

AVOID REBOUND EFFECTS

Dear Readers!

Today, we're feeling the effects of what we did or allowed in the past. Not just with the energy and climate crisis but also in daily life. Whoever earlier installed a private PV system or heat pump may be enjoying the present, since they do not have to worry about staggering increases to their electric/gas bills.

This could also have been the case for the German energy supply, but both the impedance of the expansion of renewable energies and the apodictic trust in the gas industry have now maneuvered Germany into a rather disagreeable position.

Kurt-Christoph von Knobelsdorff, managing director of the German administrative agency for hydrogen and fuel cell technology (Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie GmbH, NOW) found clear words on the matter during the FC industry networking event Marktplatz Zulieferer in Berlin. He said that the proponents of the energy transition had placed too much emphasis on natural gas and electrification while neglecting the alternatives as well as a timely expansion and reconstruction of the corresponding infrastructure.

The NOW director outlined the vision of a climate-neutral society and confirmed that there is a great deal happening in all areas right now, but at the same time outright stated that the Federal Republic of Germany has long ceased to be a leader in renewable energies. Most recently with the Inflation Reduction Act that US President Joe Biden presented in August 2022 (see also pgs. 50 to 57) has the US "moved into the fast lane."

In China, incidentally, electrification has been ramping up for a while, so the number of hydrogen fueling stations, for example, is now increased fivefold. On the other hand, here there is "really too little," according to von Knobelsdorff: "We needed to accelerate the path to a hydrogen economy, but there hasn't been much to see." Instead, he dejectedly noted, "The Energiewende people squandered away the time."

Indeed, many millions of euros and dollars are now being invested in H_2 technology, both on the part of the government, in research and development as well as in support measures, and on the part of companies, in company acquisitions and in technology purchasing (see p. 8). But as a result of the old constraints of the fossil fuel age, it is currently difficult for Germany to fulfill the envisaged role as a lead market anytime soon.

The persisting forces that continue to urge that we should not place too great a burden on conventional industries, because they stand in global competition, are still influential. The hesitators, who would prefer to reactivate nuclear or coal power instead of fully committing to renewables, still occupy central decision-making positions.

Progressive sections of the government and the business community, on the other hand, have long since recognized the hour. The will to streamline and shorten approval procedures is there. Also the willingness to invest sufficient available money in not only new technologies and production capacities, but always also in order to take sustainability aspects into account, is there. Nevertheless, too little is still being done.

From an unideological point of view, it is not comprehensible why at the opportune time of the end of the German fuel supply tax reduction as well as the 9-euro train ticket, a temporary speed limit for the autobahn would not be introduced, in order to provide more freedom this way. Even if savings in the oil sector only indirectly affect other energy sectors, this would have been a clear sign of how simple energy saving can be. Even speed lovers would in the current situation have the understanding to drive a little slower for a few months so that no one has to freeze at home.

Starting on new paths would immediately offer a chance at new degrees of freedom for all of us. In doing so, however, it is crucial to not repeat the mistakes of the past. Up to now, it has been the case that technological leaps have usually not produced the hoped for savings. For example, the introduction of LED lamps did not lead to the hoped-for energy saving effects in all places, because the lights were sometimes switched off less often.

We can no longer afford such rebound effects. If the massive production of electrolyzers just leads to other resources being exploited and us becoming dependent on other nations, then it would help us very little.

It is already apparent today that there will be fierce global competition for certain resources. For example, cobalt, which is needed for electric cars, is found almost exclusively in the Congo. However, catalyst materials like platinum, ruthenium and iridium are also only minable at a few locations around the world. And lithium, which is also needed for the battery inside fuel cell vehicles, is still not recyclable to a sufficient quality.

Against this background, it is essential to recognize that less is more. Less use of all these resources is better for the environment and also reduces the risk of new dependencies. The same applies of course to energy consumption.

So that the vision of a climate-neutral energy supply does not remain an illusion, a more attentive approach is required overall – with resources, with energy, with the environment and with fellow human beings. If this is successful, we will indeed emerge from these crises much stronger. Climate-neutral energy is not a dream but a huge opportunity for us all. ||

Sincerely,

Sven Geitmann
Publisher of H2-international

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Source: RUB

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Source: Gascade Gastransport

Source: Schaeffler

SEIFERT IS NEW decarbXpo DIRECTOR

Fig.: Malte Seifert
[Source: Messe Düsseldorf]

The restructuring of Messe Düsseldorf continues. After Energy Storage Europe was combined with the IRES Conference, the #P2X Conference and ecoMetals Day, and renamed decarbXpo (long form Expo for Decarbonised Industries), this band of events received a new leadership on August 1st, 2022. Malte Seifert has since been the new project director of this decarbonization fair, which will take place under the new focus parallel to partner trade fair Glasstec on September 20th to 22nd, 2022. The 37-year-old additionally directs the trade fair quartet that together make up the event The Bright World of Metals, namely GIFA, METEC, THERMPROCESS and NEWCAST, as well as the seven internationally oriented offshoots. ||

PONIKWAR CEO OF THYSSENKRUPP NUCERA

Fig.: Dr. Werner Ponikwar
[Source: ThyssenKrupp]

In the highly competitive electrolyzer market, Essen-based company Thyssenkrupp AG has gotten Dr. Werner Ponikwar to lead the recently created subsidiary Nucera. On July 1st, 2022, the chemist assumed his new role as managing director (CEO), following in the footsteps of Denis Krude, who now fills the newly created function of chief operating officer (COO), as planned.

About this, Dr. Volkmar Dinstuhl, CEO of Thyssenkrupp division Multi Tracks, stated, "Werner Ponikwar has a broad range of experience from various management positions in plant construction and chemistry as well as the rapidly growing hydrogen market." Ponikwar had been working at the gas company Linde for many years. Initially, he headed the business unit Polyolefins at Linde Engineering as well as Key Account Management at Linde AG, before he became managing director of Linde Hydrogen FuelTech GmbH, a subsidiary of Linde plc.

Thyssenkrupp nucera had been introduced in January 2022 as a new brand and had immediately, in the first quarter, received two large orders regarding H_2 projects in the Netherlands and in Saudi Arabia. According to information by the company, they are still considering whether an IPO should be the preferred option for further development. ||

BRITISH GIGAFACTORY

With the help of the British government, a large-scale factory to produce components for the hydrogen and fuel cell market is to be built in England. Johnson Matthey (JM) intends to erect this gigafactory, a cost of 80 million pounds, at its location in Royston.

Earlier this year, the British technology company had set the goal of becoming "market leader in power components for fuel cells and electrolyzers" and achieving an over 200 million pounds turnover with H_2 technologies by the end of 2024. As part of this, numerous highly qualified manufacturing jobs are to be created by the first half of 2024.

The British government has pledged support out of the Automotive Transformation Fund (ATF) so that 3 GW in PEM fuel cell stacks for hydrogen vehicles can be produced annually. The United Kingdom is forecast to require 14 GW in fuel cell stacks and 400,000 high pressure carbon fiber tanks annually by 2035.

Liam Condon, Chief Executive of Johnson Matthey, stated, "Decarbonising freight transportation is critical to help societies and industries meet their ambitious net zero emission targets. Fuel cells will be a crucial part of the energy transition." The British economic minister, Kwasi Kwarteng, said, "We are working hard to ensure the UK reaps the benefits of the green industrial revolution, and today's announcement reaffirms UK's reputation as one of the best locations in the world for high quality auto manufacturing." ||

SWIFT ESTABLISHMENT OF AN H_2 GRID

For green hydrogen, coming from Canada and Australia and being unloaded at the planned LNG terminals for example, to be able to be distributed throughout Germany, an H_2 grid is needed. To encourage a swift realization of this need, the German energy agency dena presented a green paper at the end of August 2022. In it, Andreas Kuhlmann, manager director of dena, stated, "The rapid and reliable development of a hydrogen network is an uncircumventable prerequisite for the urgently needed ramp-up of the hydrogen economy in Germany."

The proposal is based on guaranteeing "a fair division of risk" between grid operators and future grid users. "Core of the proposal is a safeguard for investments in the initial phase through an 'amortization account' as well as a government-set level for network charges such that they are not prohibitive for the first users of the networks." Further, Kuhlmann said that the first users should "not bear the full cost of the hydrogen network," because this could result in such high network charges that the economic viability of these initial projects would hardly be feasible.

The grid operators would be commissioned to construct this H_2 starter network by both building new pipelines and converting existing natural gas pipelines. The grid operators would use their own funds to pay for the construction ahead of time, while the state would secure the investment by guaranteeing the network operators a return on their investment in the long term. ||

→ www.dena.de

POOLING OF H_2 KNOWHOW

In April 2022, the German association for gas and water standards DVGW founded the "H_2-Kompetenzverbund der deutschen Energiewirtschaft" to promote the use of hydrogen and the market ramp-up of H_2 technology in Germany by pooling expertise. In this uniting of various institutes of the DVGW research network, the Engler-Bunte-Institut of the Karlsruhe Institute of Technology (DVGW-EBI), DBI Gas- und Umwelttechnik GmbH of the German fuel technology institute in Leipzig (DBI-GUT), the German fuel technology institute in Freiberg (DBI-GTI) and the fuel and heating research institute Gas- und Wärme-Institut in Essen (gwi) working in cooperation.

DVGW chairman Gerald Linke explained, "Without effective sharing and broad communication of research results, the mammoth task of converting our energy supply to climate-neutral sources cannot be accomplished." Spokespersons of the new association are Gert Müller-Syring and Dr. Jörg Nitzsche, both from DBI. ||

LNG TERMINAL WILL BE H_2-READY

The planning and design of floating liquid natural gas terminals in Brunsbüttel and Wilhelmshaven continues to progress. On September 1st, 2022, German economic minister Robert Habeck announced that in addition to the so far four planned government-chartered specialized ships, a fifth floating storage and regasification unit (FSRU) is being rented. This fifth FSRU is scheduled to go into operation the fourth quarter of 2023 and will also be conceived for the onshoring of green hydrogen.

Habeck stated: "All these projects we are building are hydrogen-ready and so are suitable for the future, the pipelines and the terminals that are to be built. For the future where we bring hydrogen to Germany so that we're thinking about a new infrastructure at the same time as a detachment from the fossil age."

The H_2 company Tree Energy Solutions GmbH (TES), founded in October 2021 and based in Wilhelmshaven, expects that the FSRU will be able to import green hydrogen already during the first twelve months of operation. The stated goal of the German ministry for economics and climate protection is to operate the LNG-FSRU "at the Wilhelmshaven location only for the time until the H_2 terminal for green fuel gas is put into operation"– presumably by 2025. ||

HYDROGEN ATLAS INTRODUCED

Fig.: Dr. Michael Sterner and German education minister Bettina Stark-Watzinger [Source: BMBF/Hans-Joachim Rickel]

It should serve as a signpost, as a "helpful tool" for decision makers. The federal minister of education and research, Bettina Stark-Watzinger, presented the Wasserstoffatlas (hydrogen atlas) at the end of July 2022 in Berlin as a tool to facilitate estimation of the "potential, consumption, costs and effectiveness in emissions reduction of different hydrogen applications."

According to the minister, the atlas should give a clear picture of "where we stand" as well as "what there is still to do." Stark-Watzinger stated, "We have a vision: Make Germany into a hydrogen republic, in order to widen our energy supply – clean and secure. And we will now put these plans into action."

She further said, "The German government has set itself the goal of being climate-neutral by 2045, and this will only succeed with energy of the future hydrogen. Green hydrogen is our big chance."

The new compendium, which manifested with the help of the technical university Ostbayerische Technische Hochschule Regensburg (OTH Regensburg), should show which H_2 potentials and capacities are already available and what possibilities will arise in the future. Which plants are there already? Where are new ones planned? Where could the use of H_2 technologies be worthwhile – where is it rather not? What CO_2 saving options are there, and how expensive are they? And where is there potential to create employment opportunities?

Dr. Michael Sterner, professor at OTH Regensburg, stated: "We need renewable electricity and hydrogen and its derivatives for our energy supply security and climate neutrality. And in great quantities. Hydrogen is not at all the champagne of the clean energy transition, but rather, in addition to renewable electricity, the main fuel to make Germany climate-neutral. We have great potential to do it in this country, which we want to activate with the hydrogen atlas."

The hydrogen atlas, funded with 700,000 euros, lists inventory data from 2012 to the present and additionally should allow a comparison of hydrogen with fossil fuels in all sectors and applications (electricity, buildings, transport, industry). It is therefore suitable as a tool for project planners, municipalities, public utilities, investors and other decision makers. It does not limit itself to Germany, but includes cooperations with foreign technology partners as well. ||

→ www.wasserstoffatlas.de

MILLIONS BEING INVESTED IN H_2

Gold fever has broken out. Numerous corporations are taking over medium-sized companies or establishing joint ventures (see p. 6) – many large companies are investing millions to secure themselves a piece of the H_2 pie. The world market for hydrogen is now being divided up, at least the portion that was not already snapped up in the past few months.

One example of this global competition can be found in Jänschwalde, a coal mining town in the state of Brandenburg. Mid-July, Wiesbaden-based company Hy2gen announced that is going to invest 500 million euros in production of green hydrogen and sustainable aviation fuel there. The plant is to be built by 2027 on the planned industrial park Green Areal Lausitz.

Investments are similarly being made within the state of Mecklenburg-Vorpommern. HH2E AG and the Switzerland-based MET Group jointly founded a project partnership for the development of one of the largest green hydrogen production plants in Europe. In Lubmin, 100 MW of capacity for the production of 6,000 tonnes of H_2 per year is to be installed by 2025, which could be scaled up to 1 GW

Fig.: Founding crew of Blue World Technologies [Source: Blue World Technologies]

by 2030. Around 200 million euros is to be made available for this.

Likewise, in June, Ceres Power and Shell let it be known that together they intend to build a demonstration plant in the megawatt range in Bangalore, India based on a solid oxide electrolyzer (SOEC). The aim is to provide low-cost green hydrogen for decarbonization of the industrial sector. Fuel cell manufacturer Ceres has set aside 100 million pounds for development of its SOEC technology – with the goal of achieving a market-leading levelized cost of hydrogen of 1.5 USD per kg by 2025.

At the beginning of the year, Voss Fluid acquired the Austrian company HypTec GmbH. Through this acquisition, the manufacturer of pipe connection systems has secured its access to high-pressure components for H_2 applications. HypTec, founded in 2010, has valve technology that is small and lightweight though resilient to high pressures – important prerequisites for the upscaling of H_2 components.

Already in January 2022, Fortescue Future Industries and Covestro had concluded a long-term supply agreement for green hydrogen. It involves up to 100,000 tonnes in green hydrogen equivalents per year, which could, for example, be transported as ammonia from Australia to Europe starting 2024. FFI wants the green hydrogen production to rise to 15 million tonnes annually by 2030. ||

DÉJÀ VU IN STUTTGART

f-cell moves – again – to fairgrounds

For all those who have been active a little longer in the hydrogen and fuel cell industry, it was like déjà vu when they arrived at f-cell on October 4th, 2022. They were walking from the S-Bahn station or airport to the Stuttgart fairgrounds, and not, as in previous years, to the Haus der Wirtschaft. And this very move – from the Stuttgart city center to the airport – has already been made once before, in 2008. At that time, however, still under the direction of Peter Sauber.

This time, for the 22nd hosting of f-cell, Peter Sauber Messen und Kongresse GmbH was only involved in an advisory capacity. Organization of the event was now, for the first time, the responsibility of Landesmesse Stuttgart GmbH. Although they had also already been involved in the running of f-cell in 2008, it was limited to the Battery & Storage segment.

What was not achievable within four or five years from that time was this time: selling a lot of exhibition spaces to presenters of technologies for energies of the future. The trade fair company will constantly be faced with this challenge in the coming years. The starting conditions are promising, as the takeover from Peter Sauber Agentur took place harmoniously and without complications. Numerous former employees moved over to Landesmesse and continue to contribute the whole of their expertise there.

Additionally, hydrogen and fuel cells are no longer niche areas. At the same time, however, the number of events focused on them in Germany and Europe has significantly increased. Messe Stuttgart beard therefore not only the comparison with the first move of locale, but also against other – sometimes new – trade fair organizers. ||

PRE EVENT

Source: Landesmesse Stuttgart

With the so-called f-cell Pre Event under the motto "Innovationen im Fokus" (innovations in focus) on June 30th, 2022, Messe Stuttgart promoted its trade fair f-cell as well as the corresponding English-language conference. During the pre-event that was held during "Woche des Wasserstoffs Süd" (hydrogen week Southern Germany), there was, among other activities, the Pre Pitch Challenge, which was a competition where different start-ups could present their solutions and technologies in short succession. HEE Technologies GmbH was awarded the winner. The Cologne-based company designs fuel cell systems for stationary applications and is getting sponsored a stand space at the f-cell in October in Stuttgart.

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

BLAZING A TRAIL WITH 350 HEATING APPLIANCES

DVGW and Avacon trial a 20 percent hydrogen blend

The project partners had been working toward this moment for years, and on April 28, 2022, the time had finally come. At Saxony-Anhalt's representation in Berlin, the German gas and water industries association DVGW, together with E.ON subsidiary Avacon, presented the results of their long-term trial in which 20 percent hydrogen was blended into the natural gas grid. As project leader Angela Brandes explained, the project has shown that it "is technically feasible to inject a much higher percentage of hydrogen into the existing gas network than has so far been provided for in the technical rules of the DVGW."

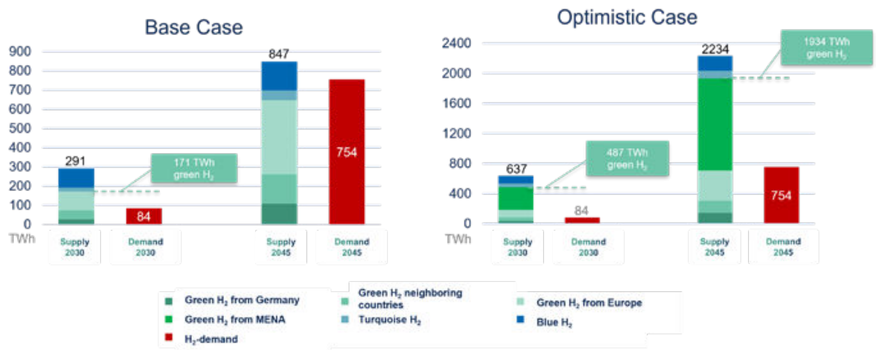

Fig. 1: Results from the DVGW sustainable heating sector research project [Source: DVGW]

"In 2045 we can meet Germany's entire energy requirement with hydrogen." These were the ambitious words of Gerald Linke, chairman of the DVGW, who was speaking at the results presentation. He continued: "Contrary to widespread assumptions, hydrogen will be available in sufficient quantities. We have been able to prove this recently in our study which was commissioned by Frontier Economics."

Here, Linke was making reference to the sustainable heating sector analysis published by Frontier Economics in April 2022 (see fig. 1). The report states that in the year 2030 roughly 290 terawatt-hours of low-carbon or carbon-neutral hydrogen will be available. Around 60 percent of this could be green hydrogen from domestic electrolysis and other European countries – a much larger figure than has been quoted previously by most other forecasts.

Based on these figures, the DVGW outlines a scenario in which enough sustainably produced hydrogen is available, which would mean that there would also be sufficient hydrogen gas left for the heating sector. Up until now, green hydrogen has been frequently hailed the "Champagne of the future" and much too good to waste on heating. Should the association be right, existing gas suppliers and DVGW members will be able to continue using the best part of their assets and retain their current market-leading position as the world enters an era of net-zero.

Linke clearly sets out his aims: "Things mustn't just stop at political declarations on diversifying the energy supply. It's a case of unburdening the system at all levels while taking into account continuing electrification." This statement doubtless refers to the move away from the concept of an all-electric world and toward an energy supply system in which molecules are still expected to play a decisive role. In the DVGW's eyes, eschewing hydrogen in the heating market would be unthinkable.

SECTION READY FOR UP TO 20 PERCENT HYDROGEN Evidence that hydrogen heating actually works comes from Avacon. In its H2-20 project, the network operator investigated the use of gas equipment already installed in existing buildings. Appliances of varying ages and designs typical to Germany were operated on gas containing up to 20 percent hydrogen without having to carry out an extensive replacement program. Angela Brandes from Avacon Netz explained: "Over the past few months, we have been progressively raising the proportion of hydrogen in our gas grid in Jerichower Land and have already successfully blended 20 percent hydrogen by volume. This worked perfectly." The amended DVGW standard G 260 currently allows for 10 percent hydrogen by volume to be supplied to large parts of the existing housing stock if a separate individual assessment is carried out.

> "The project has shown that it is technically feasible to inject a much higher percentage of hydrogen into the existing gas network than has so far been provided for in the technical rules of the DVGW."
> *Angela Brandes, project leader for H2-20 at Avacon Netz*

In all, around 340 households in Fläming have been taking part since December 2021. The central feed-in point for hydrogen in the 22-mile (35-kilometer) section of the network was located in Schopsdorf where over 350 gas appliances are in service, most of which are used for heating. Firstly, all equipment was recorded and checked by the gas and heat institute GWI in Essen and by the appliance manufacturers. Four appliances deemed unsuitable were changed for new and advanced hydrogen-compliant models.

The proportion of hydrogen injected was raised incrementally from 10 percent to 15 percent and then finally to 20 percent. Testing is being carried out over two heating periods – 2021/22 and 2022/23 – with the 20 percent mark already reached in spring 2022. A further 20 percent injection phase is planned to take place over several weeks this winter.

Public meetings were held to keep domestic and commercial customers up to date and involved in the project. This social engagement is said to have been extremely worthwhile. Berthold Vogel from the sociological research institute SOFI in Göttingen, who provided scientific support to the project, confirmed there had been "high social acceptance in Schopsdorf" which is a necessity when introducing this type of new technology.

Environment minister for the state of Saxony-Anhalt Armin Willingmann, who visited Schopsdorf in March 2022, stated: "Valuable pioneering work is being carried out in Jerichower Land that

"I would say the installation of new gas heating systems in this situation is politically wrong and irresponsible. Germany has a higher dependence on gas, oil and coal than other European nations." We therefore have a duty to quickly release ourselves from this.
German economy minister Robert Habeck

will enable carbon-neutral hydrogen to flow through existing pipes instead of fossil-based natural gas. […] I was able to witness firsthand the kinds of experiences had by the residents, and those experiences were consistently good." Angela Brandes is in full agreement, saying that all the appliances used in the trial have been "run through."

DVGW HYDROGEN DATABASE Meanwhile, the DVGW continues to shift its focus away from fossil-based natural gas and toward hydrogen. In Linke's words: "It is incumbent upon us to draw up guidelines for hydrogen." For years the association has been an important certification body, a role it wishes to pursue within the hydrogen sector in future. For this reason an enormous amount of information has been compiled over recent months in order to create a database that provides a complete list of all hydrogen-compatible components. This database is set to go live shortly.

POLICY FRAMEWORK The building sector has a key part to play in the energy transition. One considerable challenge is the target stipulating that every newly installed heating system must run on at least 65 percent renewable energy from 2024. At present, around a half of all apartments in Germany, approximately 20 million households, are still heated by gas.

Zukunft Gas, an initiative started by companies from the German gas industry, had this to say on the matter: "This target imposes an impossible task on hundreds of thousands of households." That's why it's all the more important, said the organization, that hydrogen readiness is officially recognized and a hydrogen-ready standard is introduced for new gas applications. While heat pump production will indeed be increased, it explained, it would take an additional 60,000 installers to be able to fit them.

Additionally, a municipal heating plan has been called for that will give residents an idea of when, for example, their region will be connected to a hydrogen pipeline. This advance notice is necessary, it has been suggested, since consumers will ultimately be the ones who will need to take action by changing to low-carbon forms of heating.

In July 2022, however, the German government announced an emergency program of climate action measures aimed at the building sector. Klara Geywitz, German housing minister, explained that municipal heating plans are due to be addressed after the summer recess so that climate protection measures can be approved in the fall. Patrick Graichen, state secretary at the German economy ministry, said: "Municipal heat planning is important. Local authorities, municipal energy suppliers, will assume responsibility."

As it turns out, the raft of measures in the German government's Summer Package was heralded a great political success. Yet both the emergency program for the building sector and a further emergency program for the transport sector drew disappointment. The DVGW critically remarked: "The assumption that pure gas heating systems can no longer be installed because they are not able to meet the required 65-percent-renewables rule for new heating systems from 2024 is simply wrong. Gas heating systems fulfill this

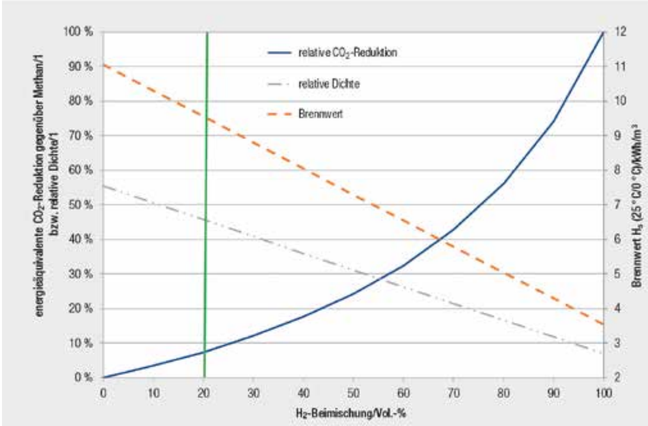

Fig. 2: Carbon dioxide reduction, relative density and calorific value when blending hydrogen with methane [Source: DVGW-EBI]

requirement if they operate on biomethane or, in the future, on carbon-neutral hydrogen or when combined with other technologies such as solar thermal."

It has since been announced, however, that other appliances can also be used besides heat pumps and that there are to be transitional periods of up to three years. These periods could apply for instance in the event that heat pumps or installers were unavailable for a short time. Hybrid appliances are also to be ranked more favorably. Even if their output equates to just 30 percent, this could still satisfy the 65-percent-renewables requirement. Green gas heating systems that run on biomethane or green hydrogen are also permitted.

REFIT KIT FOR GAS BOILERS Nevertheless, the impression given by heating system manufacturers appears increasingly to be that hydrogen will be used in converted gas boilers within domestic settings in the future. Fuel cell heating appliances such as those sold by Viessmann or SOLIDpower, by comparison, work on a cogeneration principle in that they produce both power and heat from natural gas. Pure heating modules, like today's natural gas-fired condensing boilers, will be designed "hydrogen ready" which will allow them to run on 100 percent hydrogen once the burner has been changed.

Rainer Ortmann from Robert Bosch told H2-international: "We, together with three/four other manufacturers, have given assurances to policymakers that from 2025 it will be possible to convert appliances within an hour using a refit kit." This refit kit is expected to be on sale for a few hundred euros. ||

HYDROGEN COMPETENCE GROUP

In April 2022 the DVGW set up a "hydrogen competence group of the German energy industry" in order to drive forward the use of hydrogen and encourage the ramping up of the market for hydrogen technology. The collaborative group is made up of various institutions that form part of DVGW's research network, namely the Engler-Bunte-Institut at the Karlsruhe Institute of Technology, the DBI alongside the DBI-GUT in Leipzig and the DBI-GTI in Freiberg, and the gas and heat institute GWI in Essen. The DVGW chairman Gerald Linke explained: "The mammoth task of converting our supply to carbon-neutral energy carriers cannot be accomplished without the effective transfer and widespread communication of research results." Spokespersons for the new group are Gert Müller-Syring and Jörg Nitzsche, both from DBI.

Category: Building energy | Authors: Marius Holschbach, Peter Stenzel

ENERGY SELF-SUFFICIENCY WITH HYDROGEN

An overview of projects and markets

Decarbonizing the energy supply is essential if climate targets are to be met. The issue of gas and heating supplies has again become a focus of public concern, not least because of the ongoing gas supply crisis triggered by the conflict in Ukraine. In the near term, measures are being discussed that will save energy at all levels and particularly for domestic and commercial customers. But that's not all. The structural changes that are needed to transform the heating sector and decarbonize the energy supply to buildings are also taking center stage in the current debate.

It's within this context that heat pumps have been singled out as a key technology for achieving net-zero space heating. However, there has also been repeated talk of green hydrogen offering a possible solution.

While up until now energy has traditionally been supplied from a centralized grid, as has long been the case for natural gas, in recent years a number of pilot projects have got underway in which hydrogen is produced and used to generate power and heat through a decentralized model. One of the key motivating factors for these projects is an ambition to achieve a year-round autonomous energy supply from local renewable energy sources. The explosion in price for electricity, natural gas and heat which we are now experiencing means that the issue has added poignancy.

The aim of this article is therefore to provide an overview of example projects that have been completed so far and to shed light on the current supplier situation for self-sufficient building energy systems that are based on hydrogen. As these two areas are subject to dynamic changes, this summary does not claim to be exhaustive.

OVERVIEW OF PROJECTS Table 1 shows a selection of German projects in which locally generated hydrogen is used for storing energy and supplying energy to buildings. As well as achieving different levels of self-sufficiency, the projects diverge in how they implement and integrate hydrogen technologies. In some instances the projects integrated turnkey system solutions that offer hydrogen production, storage and utilization within a standard product. These systems will be considered in greater depth later on (see table 3). Meanwhile other projects had individually tailored designs in which electrolyzers, fuel cells, storage systems and other components were sourced from various manufacturers and suppliers and then combined by a system integrator to create an overall solution. Another distinction was made in terms of the scope or the size of each project. This allowed the projects to be divided into residential buildings, commercial premises and neighborhoods.

From 2018 onward, over 100 hydrogen energy supply projects were completed within buildings using Picea systems, thus enabling the manufacturer Home Power Solutions, known as HPS, to become established in the German market. Because of the similarity between hydrogen houses that have a Picea system, table 1 only shows two such projects in single-family homes and one such project in a commercial property. The single-family home in Zusmarshausen deserves particular attention. As well as using the standard commercial HPS product, other components were added to the system which resulted in an entirely off-grid energy supply. In addition to the gel battery included in the Picea system, a further 25-kilowatt lithium-ion battery was installed as a backup and to give the option for bidirectional charging of a battery electric car. What's more, a relatively large hydrogen tank was fitted in comparison with other projects involving single-family homes.

By contrast, the project in Lahn-Dill-Kreis is a typical example of a Picea house. Here, for instance, heat pumps were installed to support heat generation as well as a photovoltaic system. It is also possible for the Picea systems to supply a building with energy on a larger scale. In 2021, the company Josef Küpper Söhne installed a self-sufficient building energy supply for one of its commercial operations in the form of a multi-Picea system consisting of five units.

One project in Augsburg has a unique feature that is worthy of note. Whereas all the other projects store and use hydrogen, in this case the supplier Exytron created a partially self-sufficient multifamily home with a methanation plant that converts locally produced hydrogen directly into synthetic natural gas, i.e., SNG. The carbon dioxide that is needed for the conversion is obtained from the combustion of SNG in a combined heat and power unit and a condensing boiler, meaning that the process is carbon free overall. A fuel cell is not used.

Compared with the projects described thus far which have all concerned single buildings, the two neighborhoods in Bochum and Esslingen presented in table 1 incorporate custom designs. The Open District Hub achieved partial self-sufficiency for its 81 apartments through the use of electrolyzer equipment, a fuel cell, a PV system, a battery and a heat pump.

The eco-friendly neighborhood in Esslingen am Neckar (see H2-international, May 2021) is based on a combination of several energy conversion systems that provide electricity and heating to residential buildings, university buildings, offices and commercial spaces. A fuel cell, however, is not used. In order to heat the neighborhood, particular use is to be made of the waste heat from the electrolyzer. The resulting hydrogen is to be used in a multi-fuel CHP unit and also marketed externally, in other words sold outside the neigh-

DEFINITION: ENERGY SELF-SUFFICIENCY
The term "energy self-sufficiency" is understood to mean a total independence from external, often grid-based energy supply infrastructure, for example for power, gas and heating. All the energy required is produced, stored and consumed locally within a certain boundary, such as a building. Any excess power and heat can be fed into external supply infrastructure. If the system is "power self-sufficient," that signifies that only electricity needs are met through local generation. In this case it's possible to feed into the grid. "Partially self-sufficient" supply systems often achieve a high level of autonomy without being fully independent of external supply infrastructure.

borhood through a supply arrangement with a hydrogen refueling station as well as fed into the natural gas grid.

Besides the above neighborhood schemes, a fully self-sufficient events center is also in operation in Ursprung in which energy is supplied by means of PV power, electrolysis, a fuel cell and a compost heater. Plus, there is a project planned for Gütersloh in which an entirely off-grid district will make and use its own hydrogen. The two projects are not listed in table 1 since it has not yet been possible to obtain precise information about the systems used or their size in either case.

Looking beyond the German projects outlined, the first hydrogen systems designed to supply energy to multifamily homes were completed in Sweden and Thailand as early as 2015. In these examples hydrogen was used for both energy provision and storage (see table 2).

SYSTEM PROVIDER Since HPS was founded in 2014, several suppliers have emerged in recent years, particularly in Germany but also internationally, which offer energy supply systems with hydrogen technology to the building sector (see table 3). Their products can be divided into complete systems and modular systems. Complete systems in the form of standardized products, such as those supplied by HPS, Solenco Power and Lavo, make use of conventional electrolyzer and fuel cell capabilities. Systems can be scaled up by linking several systems together. In principle it is possible to increase the storage capacity, as exemplified by the hydrogen house in Zusmarshausen, through a variable number of gas cylinder racks, regardless of the number of individual systems.

In modular systems, electrolyzers and fuel cells are used in varying numbers and with varying output levels according to customer requirements. A further distinction can also be drawn here in terms of the system enclosure. H2 Core-Systems and H2 Powercell integrate system components either in a cabinet (HydroCab PowerCore) or a shipping container (H2 Multi Purpose Container, H2PowerCube 3.0) in standardized sizes. Modularity is thereby constrained by the limited installation space and further scaling is enabled by combining multiple cabinets or containers.

Ostermeier H2ydrogen Solutions prefers to house electrolyzers and fuel cells in 19-inch cabinets. If the number of system components exceeds the capacity of the cabinets, the company develops a custom design. Umstro engineers the systems and the component enclosures in line with customer requirements which means that the design can be highly specific to the individual project.

Each of the two foreign manufacturers have a unique selling point in comparison with their German competitors. Solenco Power uses a reversible electrochemical cell that can be operated both in electrolyzer mode and in fuel cell mode. The Australian supplier Lavo uses metal hydride systems for storing hydrogen.

OUTLOOK Although several projects have already been implemented successfully and the number of system providers is increasing, it still remains to be seen how the market will develop in future. Due to the current energy supply crisis, self-sufficient hydrogen-based energy supply systems for buildings are receiving a great deal of attention. This interest is driven by the desire for independence and for a sustainable, local supply solution. Despite the financial support that is on offer, the costs for hydrogen-based supply solutions are still too high at the moment for widespread adoption. For customers seeking entirely off-grid supply solutions, they will undoubtedly need to consider producing, storing and using hydrogen locally, and the projects and system suppliers presented here illustrate the feasibility of doing so at different levels, from individual buildings and multifamily homes to commercial premises and neighborhoods. ||

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Tab. 1: Brief overview of international projects (selection)

PROJECT NAME	Nilsson Hydrogen House	Phi Suea Haus	Umwelt Arena Spreitenbach	Knappenhaus	Backgårdsgatan
LOCATION	Surrounding area of Gothenburg (Sweden)	Chiang Mai (Thailand)	Brütten (Switzerland)	Kasern, Ahrntal (South Tyrol, Italy)	Vårgårda (Sweden)
YEAR OF COMPLETION	2015	2015	2016	2019	2019
LEVEL OF SELF-SUFFICIENCY	Fully self-sufficient	Fully self-sufficient	Fully self-sufficient	Fully self-sufficient	Fully self-sufficient
SOURCE/ ADDITIONAL INFORMATION	https://www.h2-international.com/wp-content/uploads/2019/05/H2-international-April-2019.pdf	https://www.phisueahouse.com/technology.php	https://www.umweltarena.ch/ueber-uns/architektur-und-bauprojekte/#toggle-id-3-closed	https://baubiologie-magazin.de/wasserstoff-wohnhaus/	https://www.hzwei.info/wp-content/uploads/2020/04/HZwei_April_2020.pdf

Tab. 2: A selection of projects from Germany (own research)

ALLGEMEINE INFORMATIONEN	**PROJECT NAME**	**Hydrogen House – Zusmarshausen**	**Hydrogen House – Lahn-Dill-District**
	LOCATION	Zusmarshausen	Lahn-Dill-District
	YEAR OF COMPLETION	2018	2018
	LEVEL OF SELF-SUFFICIENCY	Fully self-sufficient (off-grid)	Partially self-sufficient
	INTEGRATED SYSTEM OR INDIVIDUAL DESIGN	Integrated system (Picea) + individual design	Integrated system (Picea)
	SCOPE	Residential house	Residential house
	POWER OF PV-SYSTEM kW_p	30	10
ELECTROLYSIS	**MANUFACTURER**	Enapter	Enapter
	TECHNOLOGY	AEM	AEM
	H_2-PRODUCTION Nm^3/h	0.5	0.5
	ELEC. POWER kW_{el}	3	3
	THERM. POWER kW_{th}	1	1
FUEL CELL	**MANUFACTURER**	N/A	N/A
	TECHNOLOGY	PEM	PEM
	ELEC. POWER kW_{el}	1.5	1.5
	THERM. POWER kW_{th}	N/A	N/A
H_2-STORAGE	**TECHNOLOGY**	Gas cylinder bundle	Gas cylinder bundle
	CAPACITY* kWh_{H2}	2,400	1,350
	PRESSURE bar	300	300
ADDITIONAL INFORMATION	**ADDITIONAL STORAGES**	Lead-gel battery (Picea), lithium-ion battery, hot water tank, bidirectional charging of a BEV	Lead-gel battery (Picea)
	ADDITIONAL TECHNICAL COMPONENTS	Facade PV	Heat pump

* Related to the lower heating value
** System provider Exytron undertakes a project-dependent, individual design

Commercial business · Residence · District

Climate-friendly living in Augsburg	Energy self-sufficient commercial company	Open District Hub (ODH)	Neue Weststadt – Klimaquartier
Augsburg	Meckenheim	Bochum	Esslingen am Neckar
2019	2021	2021	2021 / 2022
Partially self-sufficient	N/A	Partially self-sufficient	Partially self-sufficient
Integrated system (Exytron)**	Integrated system (Picea)	Individual design	Individual design
Residential house	Commercial company	District	District
105	98	800	1.483
N/A	Enapter	N/A	Hydrogenics
Alkaline	AEM	N/A	Alkaline
10	2.5	N/A	185
52	15	N/A	1.000
N/A	5	N/A	250
Not used	N/A	Proton Motor Fuel Cell GmbH	Not used
Not used	PEM	PEM	Not used
Not used	7,5	36	Not used
Not used	N/A	N/A	Not used
Not used	Gas cylinder bundle	N/A	Gas tank
Not used	30,000	N/A	1,000
Not used	300	N/A	10
SNG-tank, CO_2-tank, O_2-tank, hot water tank	Lead-gel battery (Picea)	Lithium-ion battery	Batteries and thermal storages
SNG-reactor, heat pump, CHP and condensing boiler for usage of SNG	heat pump and facade PV	Heat pump	Heat Pump, bivalent CHP (natural gas und H_2), gas-fired boiler, bottling of H_2, H_2 filling station, charging stations for BEVs, gas grid feed-in

Tab. 3: System suppliers for energy supply systems with hydrogen (own research, in some cases supplemented with manufacturer data)

	COMPANY	HPS Home Power Solutions AG	Solenco Power NV	Lavo
GENERAL INFORMATION	COUNTRY	Germany	Belgium	Australia
	HOMEPAGE	https://www.homepower-solutions.de/	https://www.solenco-power.com/	https://lavo.com.au/
	MODEL	Picea	Solenco Powerbox	Lavo Hydrogen Battery System
	SYSTEM TYPE	Integrated system	Integrated system	Integrated system
ELECTROLYSIS	MANUFACTURER	Enapter	N/A	N/A
	TECHNOLOGY	AEM	Reversible electro-chemical cell	N/A
	H_2-PRODUCTION Nm^3/h	0.5	1	N/A
	ELEC. POWER kW_{el}	2.4	N/A	2.2
	THERM. POWER kW_{th}	1	N/A	N/A
FUEL CELL	MANUFACTURER	N/A	N/A	Nedstack
	TECHNOLOGY	PEM	Reversible electro-chemical cell	PEM
	H_2-PRODUCTION Nm^3/h	0.83 – 1	N/A	N/A
	ELEC. POWER kW_{el}	1.5	5	5 (max. 6.8)
	THERM. POWER kW_{th}	N/A	N/A	N/A
H_2-STORAGE	TECHNOLOGY	Gas cylinder bundle	Gas cylinder bundle	Metal hydride storage (4 containers)
	CAPACITY* kWh_{H2}	600**	N/A	40
	PRESSURE bar	300	N/A	35
BATTERY STORAGE	TECHNOLOGY	Lead-gel	Not used	Lithium ion
	CAPACITY kWh_{el}	Grid backup mode: 25 Grid parallel mode: 20	Not used	5
ADDITIONAL INFORMATION	SCALABILITY	Combination of several systems	Combination of several systems	Combination of several systems
	ADDITIONAL COMPONENTS	Optional hot water tank including a heating rod, ventilation system for room ventilation and humidity regulation, enthalpy heat exchanger for waste heat utilization	N/A	N/A

* Related to the lower heating value

** Per cylinder bundle with 16 cylinders; also available with 12 cylinders; cylinder bundles can be combined as desired

H2 CoreSystems GmbH		**H2 Powercell GmbH**	**Ostermeier H2ydrogen Solutions GmbH**	**Umstro GmbH**
Germany		Germany	Germany	Germany
https://www.h2coresystems.com/		https://www.h2power-cell.de/	https://ohs.energy/	http://umstro.com/
HydroCab PowerCore	H2 Multi Purpose Container	H2PowerCube 3.0	H2-Battery	N/A
Modular	Modular	Modular	Modular	Modular
Enapter	Enapter	Enapter and in-house system	H-TEC SYSTEMS GmbH	Enapter
AEM	AEM	AEM | PEM	PEM	AEM
0.5 – 2	up to 26	0.5 | 7.6	0.22 – 100	According to customer request
2.4 – 4.8	up to 125	2.4 | 50****	1 – 500	According to customer request
0.49 – 0.98	N/A	1 | 8	0.1 – 50	N/A
Intelligent Energy	Intelligent Energy	Own system	Proton Motor Fuel Cell GmbH	Proton Motor Fuel Cell GmbH
PEM	PEM	PEM	PEM	PEM
0.8 – 6.23	N/A	3.7	3.8 – 6.1	According to customer request
1.2 – 8.0	up to 40 kW	5 (modular)	1.2 – 8.4	According to customer request
N/A	N/A	5 (modular)	0.36 – 2.52	N/A
Gas tank or gas cylinder bundle	Gas tank or gas cylinder bundle	Gas tank or gas cylinder bundle	Gas cylinder bundle	Mainly gas cylinder bundle
90 – 3,150***	up to 1,666.5	467 – 16,665	According to customer request	>600 (according to customer request)
35 – 1,000***	35 – 1,000	35 or 450	According to customer request	If possible: 300
N/A	N/A	Lithium ion	N/A	(hybrid system, 4 vessels)
N/A	N/A	4,8	According to customer request	According to customer request
Variable power and number of components as well as combination of several systems	Variable power and number of components as well as combination of several systems	Variable power and number of components as well as combination of several systems	Variable power and number of components	Variable power and number of components as well as combination of several cabinets or container
Supercapacitor for short-term storage. Waste heat utilization of water-cooled electrolyzers	Waste heat utilization of water-cooled electrolyzer	Hot water storage, waste heat utilization of electrolyzer and fuel cell	Wankel engine as an alternative for the fuel cell, waste heat utilization of electrolyzer and fuel cell	If possible: Waste heat utilization of the electrolyzer and fuel cell

*** Other sizes and capacities possible on request
**** can each be installed modularly; maximum of 1,000 kW_{el}

Category: Policy | Author: Sven Geitmann

IPCEI TECHNOLOGY WAVE INITIATED

Europe begins ramp-up of hydrogen economy

Fig. 1: Locations of the 62 IPCEI projects from Germany [Source: BMWi]

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After a long wait, the European Commission has approved the first projects of IPCEI Hydrogen. With these Important Projects of Common European Interest, significant progress towards the establishment of a hydrogen economy is to be made. The associated special approval under EU state aid law means that much more funding can be allocated than would otherwise be permitted within Europe. Among the initial are four projects from Germany. More are to follow in the course of the year.

On July 15th, 2022, Margrethe Vestager, vice president of the European Commission, announced the names of the approved projects for which the funding decisions are now being drawn up. This first wave of approvals, referred to as IPCEI Hy2Tech, involves technologies for the production, transport and use of hydrogen, particularly in the mobility sector. What they all have in common is that they go beyond the previous level of development and will generate significant momentum in the development of an integrated hydrogen economy in Germany and Europe.

Following this technology wave is to be, still this autumn, an industrial wave with its additional projects, before the third wave for infrastructure and fourth for mobility come in. Altogether, 24 Member States of the European Union along with Norway are participating in IPCEI Hydrogen.

Among the four just approved German technology projects are two that will furthermore receive funding from the German economic or, alternatively, transport ministry Sunfire1500, a project to create a production landscape to bring electrolyzers of alkaline (AEL) and high-temperature (SOEC) technology into series production, will receive such support. For this, Sunfire GmbH plans to build up production capacities in the state of Sachsen as well as some in Nordrhein-Westfalen, which are to serve as a blueprint for series production in Europe.

As to the second project, namely BoschPowerUnits, Bosch intends to take the final R&D steps on the path to series production of its stationary solid oxide fuel cell systems.

The German ministry for transport and digital infrastructure (BMDV) is funding the project NextGen HD Stack, in which EKPO Fuel Cell Technologies intends to develop a new generation of stacks and drive their commercialization forward. At the same time, the carbon footprint during the production of these stacks conceived for commercial vehicles, ships and trains as well as for stationary power generation is to be reduced.

Also getting support is Daimler Truck AG, which aims to decarbonize cross-border freight transport through its fuel cell-based drive trains for tractor-trailers. As part of this project named Pegasus, the practicability, reliability and technical maturity of these new H_2 drive systems are to be tested along several major shipping routes in the central area of the EU.

Federal transport minister Dr. Volker Wissing additionally proclaimed, “With the IPCEI subsidies, we are offering German companies for the first time the opportunity to implement cross-border projects with European partners in the field of hydrogen and fuel cell technology.” For accuracy, it

> "Today, we have taken a big step forward on the way to the ramp-up of the hydrogen economy in Germany. The four projects from Germany are making an important contribution to the development of hydrogen technologies."
>
> *German economic minister Robert Habeck*

should be noted that there have already been large European hydrogen projects supported with a large amount of funding. Moreover, neither the FDP (Wissing's political party affiliation) nor the federal transport ministry made this possible, but Brussels.

NO ADDITIONAL FUNDING Efforts to develop IPCEI hydrogen had already begun under the previous German administration. In May 2021, the federal transport minister at the time, Peter Altmaier, reaffirmed the ambitions of the federal government, namely that Germany would be "number one in the world in hydrogen technology" and stated, "We're making available for the 62 German projects selected today over 8 billion euros of federal and state funds and are representing the entire value chain with the selected projects – from hydrogen production to transport, to use in industry."

The funds already committed at that time are coming from the federal ministry for economy and climate protection (Bundesministerium für Wirtschaft und Klimaschutz, BMWK; 4.4 billion EUR), from the BMDV (1.4 billion EUR) and from the German states, and should spark investments amounting to 33 billion euros. However, these financial resources are not additional funding. In answer to H2-international's inquiry, the BMWK reported, "The planned IPCEI Hydrogen is therefore financed with money from the economic stimulus package plus state funds. So out of the 7 billion euros of stimulus money set aside for national projects."

In Germany, a total of over 200 project outlines were submitted. These were first discussed with the partner EU countries in a matchmaking process where it was determined whether they could be linked together in such a way that all countries can benefit from each other and jointly build a European hydrogen economy. Involved are companies such as Airbus, ArcelorMittal, BASF, BMW, BP, Faun, Gasunie, Linde, OGE, Ontras, RWE, Salzgitter Stahl, Shell, Siemens, Tennet, Thyssenkrupp, Vattenfall, Volvo and Wacker.

Lastly, criticism of the handling of the IPCEI approval process had been raised. During the plenary session of NOW in Berlin, July 2022, it was criticized that the IPCEI project participants had to agree in advance to act in compliance with the EU energy directive RED II, without knowing exactly what the revised RED II would look like and specifically call for. ||

Category: Policy | **Interview Partner:** Werner Tillmetz

MARKET IS DEVELOPING REALLY WELL

Interview with Dr. Werner Tillmetz

Dr. Werner Tillmetz has not only promoted the advancement of hydrogen and fuel cell technology for many years, he has also at various points played a decisive role in shaping it – be it as a board member of the PV and fuel cell research institute of the state of Baden-Württemberg (Zentrum für Solar- und Wasserstoffforschung, ZSW) or in the formulation of the national support program for hydrogen and fuel cell innovation (Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie, NIP). Sven Jösting, on behalf of H2-interntional, spoke with Tillmetz, who after retiring founded an H_2 business network for the Lake Constance Region called h2connect.eco, and asked him for an assessment of the current developments.

Fig. 1: Prof. Werner Tillmetz [Source: h2connect.eco]

H2-international: Dr. Tillmetz, you have dedicated your life to fuel cells, as people can tell from reading your wonderfully written book "Wasserstoff auf dem Weg zur Elektromobilität" (hydrogen on the way to e-mobility). Where are we today regarding fuel cells in mobility?

Interestingly, I've dealt with all these topics – electrolysis, fuel cells, batteries – somewhat equally, having worked in a wide variety of companies as well as in research. Quite an exciting wealth of experience. In the case of the fuel cell in mobility, it is fascinating to follow the now very broad and worldwide industrialization. Asian companies have started series production, but also German and European companies are now very successful in this. Technologically, fuel cells are ready for the market.

You are closely connected to development at Canadian company Ballard Power – including via cooperations with Ford, Daimler, and so on. Can you briefly describe for our readers how you'd valuate Ballard today?

In the 1990s, I was one of the pioneers in actively shaping the activities at these companies. Since 2003, I've been following the activities very intently from the outside and still have good contacts in the scene that I stay in touch with. When judging companies such as Ballard, on the one hand there is the technological point of view. In this respect, Ballard belongs, like previously, to the leading players. However, crucial is always economic developments. Here, the quarterly reports of the various publicly listed hydrogen startups give me pause, since with very few exceptions, losses have been similar to sales in value for the last twenty years. However, the market has only really recently started to develop well, primarily driven by legislation around the world towards climate protection. The number of acquisitions and the associated valuations are also impressive.

How would you appraise battery development? Why is especially the automotive industry set on battery-electric mobility and attempting to copy Tesla?

This is quite an exciting phenomenon. In recent years, the vehicle industry has failed to continue curbing global emissions legislation. At the same time, Tesla, an initially ridiculed competitor, came to the market and increasingly took sales away from the established companies in the high-margin segments. Quick action was called for, and the strategists reflexively said to themselves, "What Tesla can do, we can do too." In this, they overestimated themselves and underestimated Tesla.

With e-vehicles, energy consumption and charging infrastructure are decisive. Tesla has excellently mastered both, while the big car companies, for example, are trying to delegate the issue of charging infrastructure to the state and to energy suppliers. With their billions in annual profit, they could make it themselves too – but profit takes precedence.

Two other major hurdles for the battery are becoming increasingly visible: where all the raw materials are going to come from and how enough green electricity for (fast) charging can be provided to meet demand.

There are various models of how hydrogen will be brought to use in motor vehicles. For example, there are models put forth in which ammonia, methanol or hydrogen (liquid or gaseous) are directly used in the engine – without the detour via a fuel cell. How do you assess this development? Is there a winner?

In general, we should be open to technology and let the engineers develop the best solutions. The legislators should only define the guard rails such as emissions. In my view, there are two crucial issues: the efficiency of the drive system and the availability of green fuel at the "gas station."

For the dynamic operation of vehicles, electric motors with a battery have enormous advantages – a mechanical drive cannot achieve this efficiency. The (small) battery, however, can be charged by an engine or a fuel cell during the trip (serial hybrid) and then be run at the best time.

With regard to the supplying of the fuel: Hydrogen can, ideally, be directly generated in the region or transported by pipeline from sun- and wind-rich regions to filling stations throughout Europe. For the cost-effective overseas transport of energy from the world's many sun belts, ideal is a fuel that is liquid at ambient temperature and easy to produce: methanol. At electricity prices of less than one euro cent per kilowatt-hour, the costs for generation play a very minor role. We are still at the very beginning of a marathon run – only at the finish will the wheat be separated from the chaff.

Competition has flared worldwide. What countries do you think have the better approaches?

German and EU policy is not very well thought-out strategically and is influenced by ideology in many places. On top of that is the very discussion-happy society and grassroots democratic structures that make much very slow. On the other hand, there are excellent, creative engineers and skilled workers and a solid industrial infrastructure, especially with the many family businesses that think long-term.

Asian countries often have a better thought-out strategy and are much faster to implement. Last but not least comes California, with its extreme capital and readiness to take risks – the latter seems to be lost in Germany.

Now we come to charging infrastructure: electric charging stations versus hydrogen refueling stations. What should it be, do you think? Are there any critical views or visions about this that you have?

Battery-electric vehicles are best charged when and where there is direct green electricity and the fully charged battery is sufficient for a few days of driving – even when the sun is not shining or the wind is not blowing. This can also be the case at the employer's, for example, if they equip the parking spaces with photovoltaics or install small windmills on the roof. For all frequent drivers, city buses and transport companies, fast, flexible refueling is critical: you can fill up with green hydrogen or green methanol anytime, anywhere.

Where do you see the fuel cell going in the passenger car market? In the commercial vehicle, they're indeed convinced that a fuel cell is advantageous over a battery for long journeys. What is the situation with passenger cars? Note there are rumors Apple could be entering the market with an iCar in 2024 that would make use of a small battery for short hauls and a fuel cell (H_2) for long hauls. Do you think that's realistic?

Modern fuel cell drives, including the tanks, are significantly lighter and smaller than a battery, for the ranges often required. The difference to the classic combustion engine is barely there. Whereas installing a battery of over 600 kilograms in a car or of up to five tonnes in a truck really makes no sense. Apple's concept is good and is already commercially offered for the delivery vans and trucks of Renault and the Stellantis brands.

Which countries are ahead regarding fuel cells, and why?

It's more about the companies than the countries. Both Toyota and Hyundai are taking their respective products (fuel cell system) into many applications and markets. That achieves quantity and thus reduces costs. Bosch has a powerful strategy and will supply its partners around the world very quickly. The French car companies have positioned themselves well with strategic partners. And of course so have the many Chinese companies, who will reach really large quantities the fastest.

Could you please develop a future scenario for the fuel cell and hydrogen? Where, in your opinion, do we stand today, in five years, in ten years and in 2040 in terms of hydrogen and fuel cells, but also batteries?

We are standing at the very start of a marathon. The changes will be as dramatic as they were more than a hundred years ago, when Henry Ford's gasoline-powered carriage replaced horse-drawn carriages and the internal combustion engine completely changed the world for the next hundred years. With disruptive innovations, the changes are extremely rapid and hardly predictable, as the example of Kodak and digital photography has also shown us. The battery alone will not be the magical solution for everything, as Bosch chairman Stefan Hartung recently made very clear. To be able to get a handle on climate change at all, we need all options and, above all, more action than discussion.

What would policymakers (Germany, EU) have to do to give fuel cells and hydrogen in mobility a boost?

Be open to technology and have a holistically thought-out strategy. For this, it helps to look out of the window from time to time to see whether there is enough sun or wind to ensure the energy supply for all consumers. ||

Interviewer: Sven Jösting

CONTRIBUTION TO THE EFFICIENCY DEBATE

With reference to the guest opinions on e-fuels from the May 2022 issue of H2-international

"Efficiency first" or "Efficiency is key" – is what countless headlines read. This is then backed up with graphs that all suggest that battery-electric e-vehicles are dramatically better than fuel cell and hydrogen e-vehicles. And e-fuels rank far behind in last place. Often the efficiency (fuel or energy consumption) of the vehicle is then lumped together with that of the upstream chain (fuel production). A comparison with reality almost always leaves something to be desired.

Comparing the energy consumption between vehicles should actually be quite easy, if you also compare vehicles that are similar to each other. The consumption (or fuel economy) is stated in the sales prospectuses and is determined in accordance with criteria prescribed by law – unfortunately in varying units: electricity in kilowatt-hours, hydrogen in kilograms and liquid fuels in liters (or gallons), without taking calorific value into account.

The real world of consumption can be found in a thorough examination of the test reviews. There, one quickly discovers that the 20 to 30 percent advantage of battery-powered vehicles practically disappears in winter, when both the passenger compartment and the battery (for fast charging) have to be heated.

Now to the upstream chain of electricity or fuel production. Here, it is almost always assumed that the electricity to charge the battery comes directly from the photovoltaic or wind power plant. The fact that no sun shines at night, nor through rain, snow or fog, is interestingly omitted. The wind also does not always blow, especially in the South of Germany. If the electricity for charging the battery is generated via a gas turbine (efficiency: 40%) powered by natural gas, or in the future hydrogen, then hopes of first place in efficiency are quickly deflated. The direct use of hydrogen in a fuel cell vehicle makes more sense here.

This is true even if the electricity is 100 percent green. On many days in Germany, there is much more electricity from wind or sun than we need. Yet especially in the winter months, there may be no wind or sun for days. So the electricity needs to come from the wind- and sun-rich times of the year. The storage of such large amounts of energy, however, is only economically feasible with hydrogen.

Today, two-thirds of our energy supply is imported (oil, gas and coal). Although 100 percent self-sufficiency is theoretically possible in Germany, in reality it's rather unlikely. Importing green energy from very sunny and windy regions makes a lot of sense economically. Transport via power lines will, however, be limited to certain regions such as the North Sea. Using the existing European gas grid for the transport of green energy in the form of hydrogen is more than logical. For overseas transport, liquid energy sources such as methanol or kerosene (e-fuels) are becoming unbeatably attractive. It is furthermore much more efficient to use this in the drive system than to remake electricity from it.

The green energy supply of the future, thought through to the end, is very different from what most headlines today suggest: electricity, hydrogen and e-fuels are all sensible green energy sources.

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Category: Policy | **Authors:** Jan Michalski, Ulrich Bünger

H_2 MERIT ORDER – FUTURE PRIORITIES FOR SUPPLYING H_2 ENERGY

About the growing relevance of a more decentral global energy supply

A full decarbonization of the European energy supply to achieve the 1.5 °C target from the Paris agreement is not a question of "if" but of "how". In particular, the European Green Deal envisages climate neutrality by 2050 based on renewable energy sources (RES) as top priority of its political agenda for the coming decades [1]. What is more, the International Energy Agency (IEA) promotes a radical paradigm change of the global energy supply in favour of RES [2]. In Germany, a foregoing climate policy has been fortified by the federal German Constitutional Court's groundbreaking verdict to introduce more stringent climate policies as a reaction to several constitutional complaints against failing climate policy. In the Netherlands, the local Den Haag Court of Justice has ruled that Shell shall amplify its CO_2-emission reduction measures in its global operations [3] [4] [5].

Both the European Commission and the IEA underpin that hydrogen should gain a key role in the power sector as well as in all other energy sectors on the way towards zero CO_2 emissions [1] [2]. Hydrogen can be easily stored in large quantities for long periods of time and used for re-electrification in corresponding power plants. In this way, it can contribute to integrate intermittent renewable power into the energy system [2].

In this context, an important question referring to the optimal mix for hydrogen production has yet not been answered: from which energy sources and in which world regions shall (green) hydrogen be produced and what are relevant corresponding international strategies? From the German and European perspective, multiple hydrogen supply options could be chosen from as hydrogen is a universal energy carrier which can be produced by different and in the future more decentralised technologies around the globe [6] [7].

MULTIPLE HYDROGEN PRODUCTION OPTIONS Following the official terminology of the European Commission concerning different production pathways [8], hydrogen is classified as "fossil-based H_2" and "electricity-based H_2", distinguished by primary energy input (e.g. natural gas, mineral oil or electricity) and the respective key production technology. These two classes are subdivided into "low-carbon H_2" (incl. "fossil-based H_2" with carbon capture as well as "H_2 from electrolysis with electricity from grid or nuclear electricity") on the one side and "renewable or clean H_2" through electrolysis with renewable electricity (REN-E) on the other side. In addition, the following terms are being used:

- Green hydrogen (electrolysis based on renewable electricity or gasification of biomass),
- Blue hydrogen (traditional process from fossil energy with carbon capture and storage – CCS),
- Turquoise hydrogen (methane pyrolysis),
- Yellow or red hydrogen (electrolysis based on nuclear electricity) and
- Grey hydrogen (traditional processes without CCS or electrolysis based on grid electricity).
- The structure of terms and the colour coding are depicted in Figure 1.

TRADITIONAL PRODUCTION TECHNOLOGIES The traditional hydrogen production technologies belong to the group of fossil-based processes, today typically dominating global bulk hydrogen production. Steam reforming of natural gas or methane (SMR) is the principal process technology (catalytic, endothermal) in (chemical) industry which requires steam as single additional feedstock and with highest efficiencies in large plants. Worldwide, about 2% of global coal and 6% of global natural gas consumption is used for hydrogen production, out of which 73 Mt_{H2}/yr are converted to pure hydrogen and a further 42 Mt_{H2}/yr blended with synthesis gases [6].

Tab. 1: Key data of the most relevant hydrogen production technologies

H_2-class	Technology	TRL[1] [1-9]	Costs (2030) [€/kg_{H2}]	Efficiency (LHV[2]) [%]	CO_2-emissions [g_{CO2}/kWh_{H2}]	Operating temperature [°C]
Fossil-based H_2	SMR	9	1.5 – 6[2]	65 – 80[3]	310 – 400[3]	700 – 800
	POX	9	1,5	69		1,300
	ATR	9	1,5	65		850 – 1,300
	Pyrolysis[4]	3 – 7	2.5 – 7	30 – 60	190 – 230	600 – 1,600
Renewable or clean H_2	Gasification of biomass	7	3 – 5.5[3]	45 – 70[3]	40 – 90[3,5]	T-Band[6]
	PEMEL	8 – 9	3 – 6.5[7]	59 ... 71	0[7]	50 – 100
	AEL	9	3 – 6.5[7]	58 ... 67	0[7]	70 – 90
	SOEL	5 – 7		>80	0[7]	700 – 900

[1] TRL – Technology Readiness Level; [2] LHV – Lower heating value; [3] Depending on plant scale; [4] Bandwidth depending on technology; [5] For larger plants also depending on transport distances for biomass; [6] The reaction zone comprises a temperature bandwidth [10]; [7] Strongly dependent on electricity supply costs; [8] Only for full renewable electricity utilization

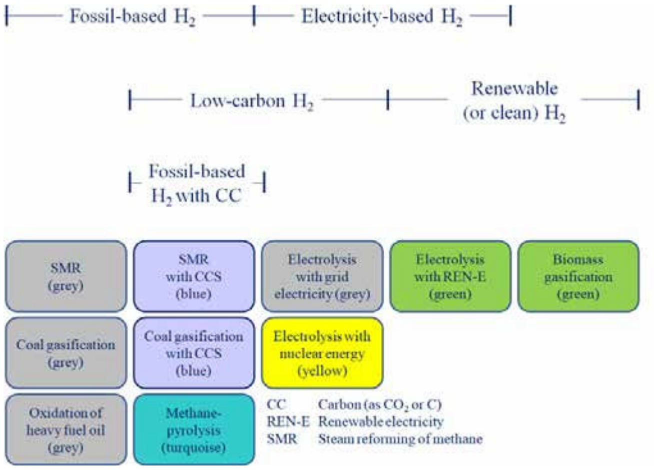

Fig. 1: Terminology and colour coding for the most relevant hydrogen production options [9] [Source: LBST]

Another similar and widely applied industry process technology is dubbed partial oxidation of heavy fuel oil (POX), which requires oxygen as feedstock (non-catalytic for sulphur-containing fuels, exothermal). It is applied in locations where cheap heavy fuel oil (HFO) is available such as in oil refineries. By combining both processes through adjusting a stochiometric equilibrium of steam and oxygen feeds, the highly dynamic autothermal reformation process (ATR) has been developed for e.g. natural gas as feed at a somewhat reduced overall efficiency (65% instead of the up to 80% of SMR). Another advantage of this technology is that the resulting synthesis gas has high hydrogen contents.

Furthermore, the reaction is energy neutral, i.e. neither auxiliary thermal energy is required nor waste- or off-heat need to be considered, allowing a robust process design (Table 1). With the goal to substitute fossil by renewable energy according to emission reduction targets, SMR, POX and ATR will only contribute temporarily. Both regional and logistic aspects have to be considered in assessing an economic competitiveness of fossil hydrogen over time, and the degree to which CO_2 can be taken out of the atmosphere at the given and measurable scale.

All fossil processes are characterised by highest efficiencies at large plant scales even though there is a small market for decentral yet less efficient methane steam reformers today. Nevertheless, the current hydrogen supply is dominated by the delivery (merchant hydrogen) or production of large hydrogen quantities onsite.

PYROLYSIS, ELECTROLYSIS AND BIOMASS-GASIFICATION

Another fossil energy based hydrogen production technology – undergoing commercialization since only recently – is the so called methane pyrolysis. It comprises a class of process technologies of its own, all having a high specific energy input in common. Possible concepts are the electric arc or microwave plasma processes (using direct electricity as energy input) or the energy contained in part of the methane feed to heat a (catalytic) moving reaction bed reactor at very high temperatures crushing the remaining methane share into its constituents hydrogen and carbon. On the one hand, an advantage of all pyrolysis based processes is solid carbon as final product instead of gaseous – and hence difficult to handle – CO_2. If applied well, solid carbon can be re-utilized in a way that no CO_2 is released to the atmosphere in any of the consecutive processes. On the other hand, the pyrolysis process is highly dynamic and difficult to control, i.e. it is not as robust as SMR. Finally, also the solid carbon markets are rather limited seen from an energy market scale perspective.

The key technology for green hydrogen production is electrolysis. It comprises a group of technologies, splitting water into its constituents hydrogen and oxygen using electricity as energy input. The proton exchange or membrane technology (PEMEL) applies solid proton conducting membranes whereas alkaline electrolysers (AEL) use caustic soda in an internal electrolyte circulation loop and as gas carrier. Both technologies are operated at low temperature in opposite to the high temperature or solid oxide electrolysis (SOEL) using a steam feed at up to 850°C. SOEL apply solid anode and cathode layers, plated on a gastight ceramic carrier substrate. The Anion-Exchange-Membrane Electrolysis (AEMEL) has begun to be offered in the market only recently and currently in small numbers. It promises however to be comparatively cost efficient as the use of Pt-group catalysts is avoided and at the same operational dynamics as PEM electrolysis.

Another relevant green hydrogen production pathway is the gasification of biomass or biogenic residues applying steam in an allothermic process (Güssing principle) [10]. As compared to low temperature AEL and PEMEL this technology has not been widely commercialized yet. Furthermore, its wide application is hampered by the limitation of available biomasses or (non-)organic residues in Europe.

Beyond hydrogen from electrolysis, it may also be produced through further green hydrogen production pathways (see Fig. 2). A thorough assessment of 10 process technologies found, however, that most of the alternative options are limited by either region specific advantages or are at a very early research or development stage [11]. Processes applying solar thermal energy, direct sunlight and biomass have been considered. Some of the processes are interlinked, such as applying SMR of raw biogas from fermentation or combining direct sunlight with REN-E in photoelectrochemical cells (PEC). The conclusion was that none of the assessed technologies would reach technical or economic competitiveness of the selected green (electrolysis) or CO_2-lean (SMR with CCS) reference technologies within the critical timeframe of 2030. Also, some of the technologies will be further hampered by either the available primary energy potential (biomass gasification) or their regional focus (solar high temperature thermal processes).

Other term widely used today is "by-product H_2." The term is applied to (chemical) processes (e.g.in refineries) in which hydrogen is produced "inadvertently" and can be made readily available at low cost in large quantities. As today's by-product hydrogen is generated through fossil based processes it is in principle also denoted as grey hydrogen, i.e. characterized by similar specific CO_2 emission levels.

Depending either on production technology or customer specific quality requirements, the hydrogen delivered has to be purified by a set of gas cleaners designed to meet the relevant end-user needs by impurities, process layout and plant scale. Typically and according to recent agreements by European gas industry, this will comprise industry grade hydrogen in dedicated hydrogen transmission grids or fuel cell grade hydrogen with a very low level of hydrogen impurities [9]. Gas purification may usually be sited close to the hydrogen production site or onsite the end-user location.

Natural hydrogen has been dubbed as "white" and is not industrially applied today. As its exploitable potentials are limited in view of the energy markets, white hydrogen from indigenous sources such as from Africa or Brazil is believed to have little impact on the development of future hydrogen energy markets, even though further analysis is being undertaken [11] [12] [13].

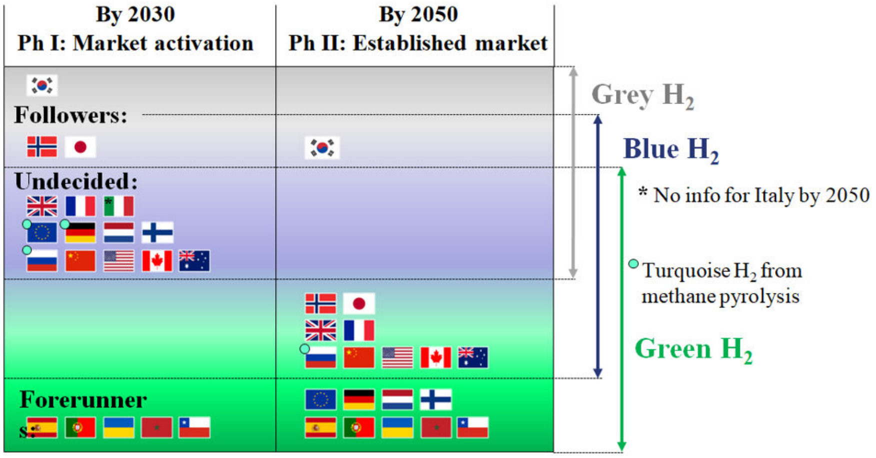

Fig. 2: Scheme with ten selected other green hydrogen pathways beyond electrolysis of water [11] [Source: LBST]

POWER-TO-X AS MAJOR INGREDIENT FOR RENEWABLE HYDROGEN PRODUCTION Water electrolysis is the key process technology of all Power-to-X concepts which are the basis of green hydrogen supply. Power-to-X can be principally subdivided in different main pathway routes. The major concept is the one of Power-to-Gas (PtG) with its two options Power-to-Hydrogen (PtH_2) and Power-to-Methane ($PtCH_4$). Further Power-to-X concepts, extending the gas-focused energy world by other alternatives are: e.g. Power-to-Heat (PtH), Power-to-Liquids (PtL) as well as Power-to-Chemicals (PtCh). With the exemption of PtH, all concepts are unified by the common and central hydrogen molecule.

A major consequence is that electrolysis is seen as key technology for the future sustainable energy supply, with high electrical efficiency at all scales, large and small. This is the consequence of electrolysis being a surface-driven process for which only the balance-of-plant equipment's efficiency does not scale linearly, and in contrast to volume-driven processes which are characterised by significantly increasing efficiencies towards larger process scales. The underlying argument is that today's fossil or nuclear primary energies will be substituted by electrons as major primary energy source. Electrolytic hydrogen can thus contribute to seasonal energy storage at large scale and supplement the short-period local energy storage of electrons in mechanic-kinetic (e.g. flywheel) or mechanic-potential (pumped hydro storage) or electrochemical storage (e.g. batteries) systems. A side-effect is the substitution of a large number of aboveground electricity transmission lines with large specific footprint by cost efficient and publicly acceptable underground gas pipelines with a low specific footprint.

The CAPEX-dominated costs and resource-intense application of large-scale electricity transport and storage will thus be pushed towards OPEX-dominated costs, combined with the high energy-density gas transport/storage. With a view to water intensity, electrolysis consumes about 9 kg of water per kg of hydrogen, a factor asking for monitoring in the future. This poses no substantial challenge for central Europe (e.g. a long-term production of 100-400 TWh_{H2}/yr of hydrogen for the case of Germany would require the provision of ca. 27-108 Mt/yr of water, equivalent to about 0.7-3.0% of all German drinking water needs today). In addition, it should be borne in mind that water after thermal use in fuel cells becomes part of a natural water recirculation, even though locally uncoupled in case of large scale hydrogen imports.

INTERNATIONAL HYDROGEN PRODUCTION STRATEGIES Several strategic considerations accompany the techno-economic aspects of introducing hydrogen into the energy system at large scale. In general, they strongly depend on regional framework conditions in different countries and specifically the individual strategic energy and industry policy targets, climate policy ambitions or availability of natural energy or material resources as well as societal development ambitions. Typically, these aspects are reflected in the national hydrogen strategies, being developed by different countries worldwide.

In view of the international context, the strategies to introduce hydrogen as energy carrier foresee two phases (Fig. 3). The first phase until 2030 typically comprises an activation of potential H_2 markets. Being a transitional phase, all hydrogen colours will typically be allowed by policy makers for cost and capacity arguments. Just a few countries with specifically large renewable energy potentials such as Spain, Portugal, Ukraine, Chile or Morocco put their focus explicitly only on green hydrogen from the very beginning. In contrast, in e.g. Japan and South Korea also grey hydrogen will contribute to the H_2 production mix due to cost reduction considerations (Japan) or yet less ambitious climate policy goals (e.g. South Korea), even if it is "only" imported as grey hydrogen in short term.

In other countries with a relevant natural gas production level or well-implemented gas infrastructure such as the Netherlands, the United Kingdom (UK), Norway or Russia blue hydrogen is believed to contribute in short- and medium-term. Some countries such as Germany, the European Union (EU) and Russia have developed a technology-neutral approach open for a large variety of different options. Nevertheless, Germany plans to install an electrolysis capacity of 10 GW by 2030, and the European Union of 40 GW, giving room for an early large share of green hydrogen [8].

LONG-TERM FOCUS ON GREEN HYDROGEN In the long-time perspective after 2030, the global focus visibly shifts to the production and use of green hydrogen. In particular, Germany and the European Union including most EU Member States stick out visibly in their ambition to focus on green hydrogen from renewable sources, reflecting the European zero CO_2 emission policy by 2050. In this way, an attempt is made to use the many advantages of green hydrogen and to achieve several energy policy goals at the same time. On the one hand, green hydrogen can be used effectively for climate protection in sectors that are difficult to decarbonize, such as heavy-duty transport or steel industry and on the other hand, to improve the flexibility of the energy system. It can also reduce dependence on fossil fuels, promote economic growth and create new jobs.

The production of blue hydrogen shall be eventually phased-out stepwise in long-term or otherwise be marginalized. By 2030, turquoise hydrogen from methane pyrolysis is seen as a bridging technology by 2030 in the national strategies specifically in Germany and the EU. The only longer-term perspective for turquoise hydrogen has been mentioned by Russia so far.

PERSPECTIVES OF A FUTURE HYDROGEN SUPPLY In addition to the domestic production of hydrogen, also (green) hydrogen imports (or exports from countries rich in renewable energy) have gained strategic importance. Specifically countries with large industry intensity such as Germany, Japan or South Korea will depend on hydrogen imports. In contrast Australia, Chile, Portugal, Spain, Morocco or Ukraine with high solar or wind potentials, understand hydrogen as an energy carrier for renewable energy with high economic potential.

It is obvious that new energy partnerships will develop, which can be observed already today. Both bilateral agreements between individual countries as well as superordinated regional cooperations will be needed in the future. An example for the first one is the cooperation between Australia and Japan for providing grey/blue hydrogen in the short-term and liquefying and shipping it to Japan at large scale or the declaration of cooperation between Germany and Ukraine to develop an energy partnership focusing on hydrogen among others.

The second option is reflected by the extensive EU programs currently in preparation to support innovative H_2-projects such as e.g. the "Important Projects of Common European Interest" (IPCEI), aiming at explicitly strengthening the cooperation of individual member states in super-regional projects. As this approach is technology neutral a harmonisation process is needed in respect to hydrogen quantities, type of hydrogen carrier (either gaseous or liquefied hydrogen versus hydrogen derivatives such as methane or liquid fuels versus ammonia or methanol), hydrogen colour (i.e. remaining CO_2 burden) as well as transport routes and relevant future infrastructures.

SUFFICIENT RENEWABLE ENERGY POTENTIALS IN EUROPE From the European perspective, a number of criteria and open issues will have to be respected and/or decided to clarify important aspects of a large-scale hydrogen energy infrastructure, specifically with a view to the hydrogen import/export relations. The availability of renewable electricity to produce hydrogen in the EU or in Europe, in other words the green hydrogen potential, is paramount to be assessed for a fully green hydrogen portfolio in the long-term.

According to the renewable electricity production potential within EU-27 and the UK amounts to a total of about 14,000 TWh_{el}/yr, the major share contributed by fluctuating

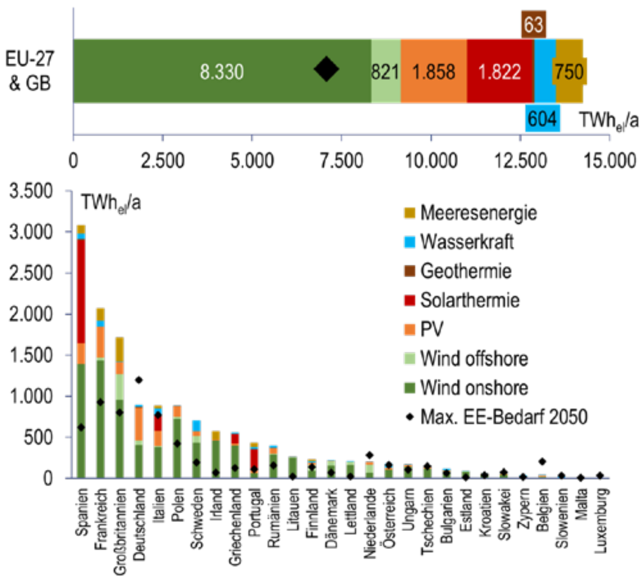

Fig. 3: Hydrogen colour preferences of selected national hydrogen strategies [Source: LBST]

wind (ca. 9,000 TWh_{el}/yr or 64%) and solar electricity (ca. 3,700 TWh_{el}/yr or 26%). In addition, this estimate is rather conservative as further potential might become available through the use of additional areas for PV plants and so-called floating technology for wind offshore.

Putting today's electricity demand of ca. 3.000 TWh/yr into perspective, it is found that close to 80 % of the total RES potential becomes available for further electrification of the energy system, e.g. for mobility (battery electric vehicles) or room heating (electrical heat pumps) as well as for the production of green hydrogen via electrolysis (Fig. 3). In view of the 2045 policy target of climate neutrality the electricity demand for direct electricity use and hydrogen production in Europe will sum up to 5,300-6,900 TWh/yr [22]. Depending on the individual scenario, this would then be less than half of the total REN-potential as explained before. Further hydrogen quantities could be added as potential imports from neighbouring countries and regions such as Norway, North Africa but also Ukraine.

The findings of the above analysis show that the renewable electricity potential in Europe is sufficient to satisfy all demand for green hydrogen. For future discussions on green hydrogen import/export, it will thus not be Europe's renewable electricity potential becoming the ceiling for domestic production. Instead, the focus should be directed at further criteria such as technical, economic, social and strategic hydrogen supply aspects such as hydrogen cost along full supply chains, energy supply independency, local value creation, political stability, established political relationships and public acceptance.

Of course, this relationship does not apply to every Member State, since both the renewable energy potential and the energy demand are unevenly distributed. Countries with high energy consumption such as Germany or the Netherlands will still be dependent on imports, which can, however, be served within the EU from countries with high RES potential such as Spain, Portugal or France.

ADVANTAGES OF A "MERIT ORDER" FOR HYDROGEN SUPPLY IN EUROPE In this context, the future hydrogen production mix will become an important, but currently not fully resolved aspect of future regional energy systems with hydrogen as one of major energy carriers. In contrast to natural gas, the advantage of hydrogen is that it can also be produced regionally in modular electrolysers with similar efficiency as in large electrolysers around the globe. Due to its physical properties, hydrogen is similarly well transportable and storable as methane and – depending on the electricity source – can be produced at low cost. Both aspects will become relevant for the "Merit Order" for hydrogen supply seen from a regional perspective and could virtually turn it upside down in comparison to today's fossil and centralised energy supply system.

Fig. 5 illustrates considerations for a "merit order" for green hydrogen supply given different supply options for a potential case of Central Germany (Mitteldeutschland) [25]. To benefit from an individual region's opportunities in a robust way, (green) hydrogen supply should have more than one pillar. Providing hydrogen from regional renewable electricity should have highest priority from a local value creation standpoint, supplemented by national hydrogen sources imported from renewable energy rich regions e.g. by existing or refurbished hydrogen pipeline infrastructure with the ambition to safeguarding existing assets. In the case of Mitteldeutschland this could be hydrogen from on- and offshore wind in Northern Germany (e.g. in the federal state Mecklenburg-Vorpommern) through a pipeline.

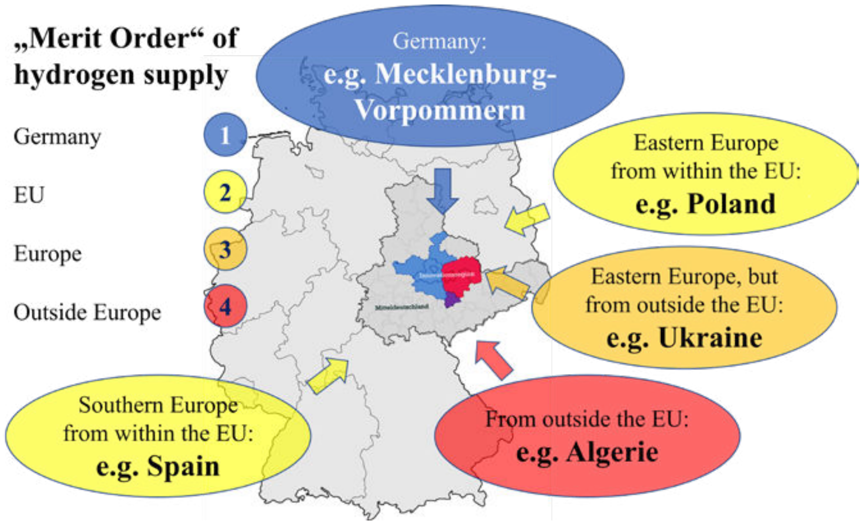

Fig. 4: Renewable electricity potential and electricity use in Europe [Source: LBST]

Any further hydrogen demand surpassing the available local, regional and national energy resources need to be imported from farther away locations, such as other parts of the EU (e.g. from solar or wind power in Spain) or geographical Europe (e.g. from wind in East or Northern Europe) or even outside of Europe (e.g. from solar power in North Africa) simultaneously strengthening the European wide hydrogen pipeline infrastructure.

Should even these sources not prove to be sufficient e.g. during the transition phase then green hydrogen could be imported from other international resources yet at lowest priority. The long-distance import options would contribute to establish global hydrogen partnerships and a global hydrogen market, possibly lowering the global hydrogen energy price not only for industrialized countries.

Furthermore, hydrogen production costs are not the only criterion for decisions on hydrogen supply options. Other criteria such as independence, political stability, flexibility of the energy system and local value creation will come into play. Telling from the recent national hydrogen strategies, this paradigm shift has not been well understood, such that rethinking a sustainable energy system for the future by industry and politics is overdue.

GREEN HYDROGEN AS LOCAL AND GLOBAL OPPORTUNITY Hydrogen has been identified as a central element of a future climate neutral energy system in Europe. It will facilitate the integration of renewable electricity and improve the security of energy supply. Moreover, hydrogen will generate economic welfare and entail new jobs. Even though fossil-based hydrogen is produced at large scale already today for industrial applications renewable hydrogen has been earmarked to replace the fossil-based processes by water electrolysis from renewable electricity.

Only Power-to-X concepts will fully exploit all advantages of a hydrogen-based energy system becoming the basis for a sustainable and lasting transition of the energy system. In the transition period until 2030, also low-carbon technologies using fossil energy such as e.g. natural gas through steam reforming enhanced by CCS (blue hydrogen) or methane pyrolysis (turquoise hydrogen) in some regions will activate the hydrogen market lowering the initial cost burden to develop large-scale gas infrastructures. However, in the long term, i.e. by 2050, Europe will push towards green hydrogen.

Analysis has proven that Europe's renewable electricity potential is sufficient for a self-sustaining renewable hydrogen supply, which will extend the considerations of import-export relations for green hydrogen. Further criteria addressing technical, social and strategic aspects will receive growing attention. For a region-specific evaluation the so-called "merit order" of hydrogen supply need to be developed as multi-criterion analysis. It will be focused on nearby renewable energies and fill up the gap between regionally exploitable renewable energy potential and energy demand by green hydrogen from farther away regions. This approach will help to exploit and combine the different regional strengths and opportunities of hydrogen from different world regions.

We interpret the results of a recent analysis by the International Renewable Energy Agency (IRENA) [26] as first international evidence for the expected paradigm change. In a central graph the following four aspects have been illustrated from the viewpoint of an emerging European hydrogen energy market:

- By 2050, hydrogen will be preferably provided from renewable energy sources within Europe (4,771 PJ/yr),
- All hydrogen imported to Europe will preferably be transported cost efficiently by pipeline from neighbouring North Africa (2,382 PJ/yr),
- Whereas only small quantities of ammonia are expected to be produced within Europe (136 PJ/yr), a significant percentage will again be imported from North Africa by ship (1,606 PJ/yr), further yet smaller quantities also from South America and the Near East.
- The ammonia vectors are believed not to be applied for hydrogen transport (H_2 derivative), but for later end-use as base chemical and here preferably for fertiliser production.

Yet, many aspects surrounding the production of (green) hydrogen have not been finally solved and require further analysis and instruments. Among others, an international hydrogen market will need to be established with an optimum balance between domestic hydrogen production and imports. In order to integrate Power-to-X concepts into international energy markets adequate regulations will have to be developed and agreed for safe and transparent hydrogen handling (e.g. certificates of origin as suggested by the European CertifHy project).

Even though CO_2 emissions will become the new currency in a future energy system lock-in effects (e.g. blocking investments and trained workforce, who would develop green technologies instead) from investing in durable but non-sustainable technologies (e.g. to produce blue hydrogen) need to be avoided. Green hydrogen based on renewable energy is one of the keys to achieve the 1.5 °C target from the Paris Agreement in a sustainable, socially acceptable and cost-effective manner. ||

Literature: To be acquired at Hydrogeit Verlag or from the authors

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Fig. 1: Laying of the natural gas pipeline Europäische Gas-Anbindungsleitung (EUGAL) in Brandenburg. The natural gas pipeline runs from the Baltic Sea coast of Germany to the Czech Republic [Source: Gascade Gastransport]

Category: Energy storage | **Author:** Niels Hendrik Petersen

TRANSPORT OF H_2 IS DETERMINING IN THE EAST OF GERMANY

Need to transport H_2 pushes infrastructure development

Eastern Germany could be short 54 terawatt-hours (TWh) of hydrogen in 2045, based on a year-by-year analysis. As usual with forecasts, this is still dependent on many factors, such as the exact H_2 demand in the individual sectors. But one thing is clear: H_2 infrastructure will be lacking if the future becomes a major energy diversification scenario. In such a case, 48 TWh would then still need to be further distributed via transmission lines to neighboring regions. Prerequisites for this would be conversion of numerous pipelines from natural gas to hydrogen, as well as installation of new pipelines.

This assumption is supported by the study "Wasserstoffmarkthochlauf in Ostdeutschland bis 2045 – Eine Infrastrukturanalyse anhand der regionalen Erzeugungspotenziale und Bedarfe" (hydrogen market ramp-up in eastern Germany up to 2045 – an infrastructure analysis based on the regional production potentials and demands). Scientists from the Energiewirtschaftliches Institut an der Universität zu Köln (EWI), the energy economy institute at the university in Cologne, compiled this on behalf of Gascade Gastransport, the system operator for the German transmission network. The EWI team analyzes in the study two scenarios for the development of demand and supply of hydrogen in eastern Germany. The scenario Diversification supposes that hydrogen will play a much greater role in the substitution of fossil fuels, whereas the scenario Electrification assumes that energy consumption will be strongly electrified and hydrogen is much less significant.

NORTH-SOUTH DICHOTOMY "In eastern Germany, a difference in hydrogen demand is likely to develop between the North and the South, with the South being higher," says Dr. Eren Çam. He heads the energy raw materials division of EWI and had put together the study along with three colleagues. This differentiation is especially visible from the blue and red regions in Figures 2 and 3 for the year 2045. "The regional differences and the increasing potential for H_2 transits through the East of Germany could become decisive drivers of the growing hydrogen infrastructure."

The calculated H_2 deficits, or surpluses, provided in the study, together with the possible import and export demand in eastern Germany, give a picture of the future transport requirement. According to this, a strong domination of electricity-based energy usage shows a deficit in hydrogen capacity of only 2 TWh in year 2045. Hydrogen transits would then hardly be necessary.

H_2 production has great potential in eastern Germany. In addition to green electricity-based H_2 production, natu-

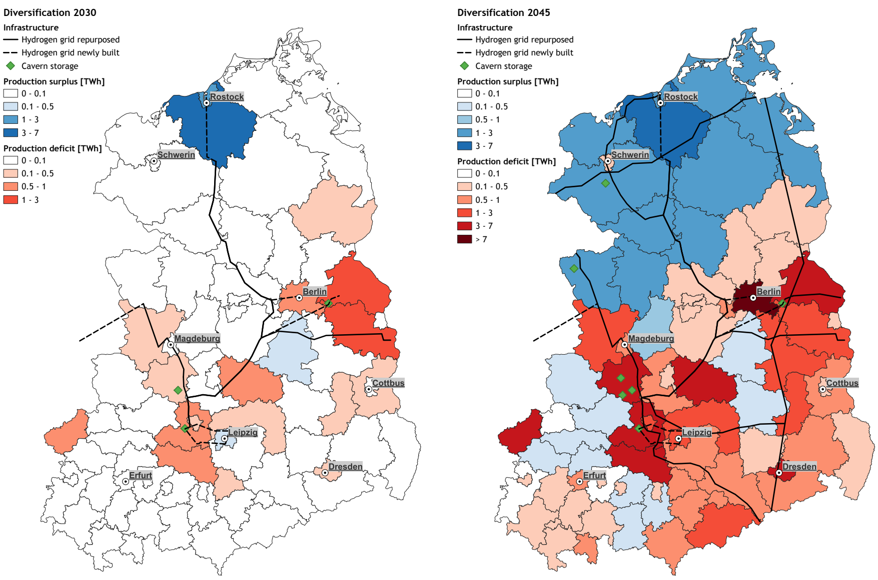

Fig. 2: The H_2 network in scenario Diversification

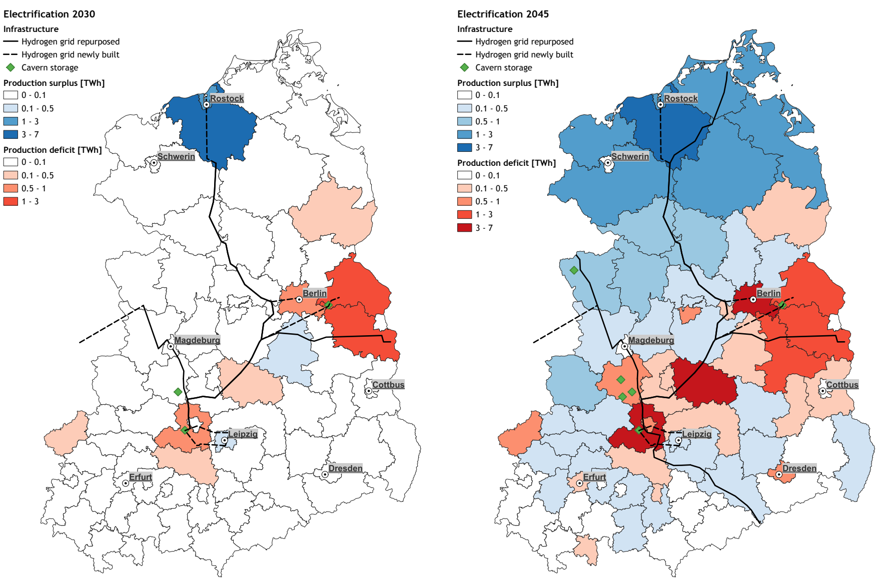

Fig. 3: The H_2 network in scenario Electrification

ral gas reforming or methane pyrolysis with capture of CO_2 emissions could also be climate-neutral alternatives. This would make the region a net exporter of hydrogen by 2030. The researchers from EWI estimate the production potential at up to 366 TWh annually for year 2045. So an even greater need for pipelines would result.

CREATE INCENTIVES FOR INVESTORS How the future hydrogen network should look is currently a matter of debate and depends decisively on how supply and demand develop. Among other things, this influences the technology and cost developments as well as possible funding and support mechanisms. These uncertainties make investments in hydrogen networks risky. On top of that, the production of green hydrogen via green power stations is, at this time, generally uneconomical.

Visions of the future network therefore range from individual islands to a comprehensive and highly meshed network. It is imaginable that it will be much like today's natural gas network. "With the recently confirmed Opt-in-Erklärung (voluntary agreement by operators of hydrogen networks to be regulated), lawmakers have taken a step to increase the safety for investments and to ensure an expansion of future hydrogen networks in line with demand," stated Çam. Accordingly, in a transitional phase, operators of hydrogen pipelines will be free to choose whether or not to be subject to network regulation.

USE OF NATURAL GAS PIPELINES In the study "Wasserstoffinfrastruktur – tragende Säule der Energiewende" (hydrogen infrastructure – backbone of the clean energy transition), Siemens Energy, Gascade and Nowega looked at the actual conversion of gas transmission networks to hydrogen in practice. "Contrary to a frequently held view, the transportable amount of energy with hydrogen is only slightly lower than that with natural gas," it is stated in the paper. In summary, "the conversion from natural gas to hydrogen would therefore have only a minor impact on the transmission capacity of a pipeline."

The upper heating value of natural gas is about three times that of hydrogen. However, when comparing the energy current or flux of two different gases sent through a pipeline, it is not only the volume that plays a role, but the three parameters density, flow velocity and pressure, according to the authors. They state, "Since hydrogen exhibits one-ninth the density and three times the flow velocity of natural gas, almost three times as much hydrogen as natural gas can be transported in the pipeline at the same pressure and in the same time." As a result, the energy density is hardly reduced. So modifying the natural gas pipelines for use with H_2 makes perfect sense.

THE CHICKEN-AND-EGG PROBLEM Who takes the first risk? At present, attempts are being made to resolve the chicken-and-egg problem via pilot and demonstration projects with the larger aim of achieving a greater scaling as well as a cost reduction of the technology. The findings of the EWI study indicate that H_2-Startnetz, the starter hydrogen transmission grid to be developed by 2030 as an IPCEI project (Important Projects of Common European Interest), will cover a majority of the transport demand in 2030 and will be needed for the two hydrogen demand scenarios.

Medium-term, the sole financing of pilot and demo projects will not, however, be sufficient to stimulate sustained supply and demand of hydrogen and to drive forward commercialization, the EWI researchers concluded. Additional support for supply and demand is therefore needed.

The costs for the green hydrogen that is to fill natural gas pipelines in the future depend mainly on two components: the electricity costs, including all related taxes and levies, and the investment costs for the electrolyzer. Investment costs could be lowered through targeted support measures such as grants or interest-free loans, the scientists explain. Innovative methods of electrolyzer production could also be promoted. Especially since the expansion of production capacities results in learning and scaling effects. And a higher degree of automation could reduce costs.

CONTRACTS FOR DIFFERENCE On the electricity cost side, legislators have also taken the first steps. H_2 producers are exempted from grid use charges under certain conditions. In addition, the levy imposed on electricity consumption by the renewable energy law (EEG-Umlage) is as of July 1, 2022 no longer in effect – the operators of electrolyzers benefit from this of course as well. More difficult are the actual costs to purchase power. With the recent sharp rise in electricity prices on the stock exchange, the economic viability of green hydrogen is also becoming more difficult.

What will help in the long term is therefore only the expansion of renewable energies. In the short term, targeted support measures, such as Contracts for Difference, can also help to secure a maximum electricity price or a hydrogen purchase price for producers. This is quite a common means of establishing a new technology in a market economy.

It therefore makes sense initially to establish smaller independent networks in industrial centers, such as the chemical production triangle Chemiedreieck Leuna-Buna-Bitterfeld, or in large urban areas, for example Berlin, to connect local demanders, producers and storers. In the next step, these island networks can be connected to each other and to possible import points on the coast or to neighboring regions. In the long span, a Germany-wide network arises that enables trans-regional cooperation and cross-border trade.

On the demand side, green hydrogen can have various potential uses, for example in fuel cell trucks, trains or buses, to reduce greenhouse gas emissions particularly in public transport, to name a few examples from the mobility sector.

Which regions benefit particularly? On the one hand, it is primarily the industrial centers, for example chemicals and steel, which are facing the need to transition to climate-friendly production. On the other hand, regions in which production capacities for electrolyzers are being built. Last but not least, new jobs will be created at these places and additional tax revenue will be generated.

WHICH PLAYERS CAN DRIVE DEVELOPMENT FORWARD?

In the case of pipeline-based H_2 transport, natural gas transmission system and distribution network operators might easily also become future operators of a hydrogen network. They have the capability to convert existing natural gas pipelines to hydrogen pipelines – even if this requires major investments. In addition, they are practiced in the transport of gaseous energy carriers as well as the operation of regulated supply lines.

Analyses of the EWI additionally suggested that energy suppliers could play a central role on the distribution side. Because they have a decisive competitive advantage. Through their core competencies of electricity generation and electricity trading as well as their often broadly diversified power generation portfolios – including green electricity production stations – they have the necessary expertise to couple electrolyzers to power networks. ||

Category: Energy storage | **Author:** Silke Timmer

GREEN HYDROGEN FROM THE NORTHWEST

Hydrogen Regions series: HyPerformer – HyWays for Future

The HyWays for Future project will boost efforts to ramp up renewable hydrogen production and use in northwestern Germany through a network of around 250 members. The aim of the initiative is to firmly embed sustainable hydrogen in the industry, energy supply and mobility sectors. Its initial focus will be on the deployment of hydrogen within transportation. As part of the project, investment will be channeled into various schemes, including the construction of hydrogen refueling stations, mobile storage, the procurement of hydrogen buses for local public transport, street sweepers and hydrogen-powered cars.

Hydrogen's role as an energy carrier makes it a vital building block in the energy transition and northwestern Germany lends itself as a location for establishing a strong, sustainable hydrogen economy, in other words a veritable hydrogen hub. The focal point for this flagship hydrogen region is the Northwest Metropolitan Region which is home to the towns and cities of Cuxhaven, Wilhelmshaven, Bremerhaven, Oldenburg and Bremen.

NATIONAL HYDROGEN HUB The HyWays area is well placed to become a leading region for hydrogen in the transport sector. Thanks to the high number of wind plants, situated both onshore and offshore, the electricity consumed here is already nearly 100 percent renewable. What's more, the region offers caverns that are suitable for hydrogen storage and there are a wide range of possible outlets here for hydrogen use. Consequently a hydrogen economy will have enormous potential to create new added value in the region. It's this favorable location and potential for development which the project is hoping to exploit.

HyWays for Future is founded upon two pillars: the implementation project and the innovation cluster.

HY.CITY.BREMERHAVEN BUILDS LOCAL GREEN HYDROGEN INFRASTRUCTURE

A scheme in Bremerhaven will create a regional green hydrogen ecosystem from the end of 2022. To enable this vision, the company HY.City.Bremerhaven will build and operate an electrolyzer plant with a 2-megawatt capacity and a hydrogen refueling station located immediately adjacent to the service yard of Bremerhaven Bus. HY.City.Bremerhaven was established especially for this project by Bremerhaven startup Green Fuels, Bremerhaven Bus, construction service provider Georg Grube and tank logistics company UTG together with energy transition experts GP Joule. The project will construct a 2-megawatt electrolyzer and a public hydrogen refueling station for buses, trucks and cars. Funding for HY.City.Bremerhaven will come from the German transportation ministry as part of the HyWays for Future scheme.

THE IMPLEMENTATION PROJECT The clearly communicated aim of the HyWays for Future initiative is to not only produce clean hydrogen locally with sustainable energy but to use it locally too. To make this happen, the implementation project plans to develop electrolyzer capacities and hydrogen refueling stations as well as invest in hydrogen vehicles.

Hydrogen production: HyWays for Future will rely on a variety of models for the manufacture of green hydrogen depending on local circumstances. Options include decentralized on-site production at refueling stations using small electrolyzers and large-scale centralized production, for example at industrial parks from which the hydrogen will then be transported to the filling stations.

HYFRI – HYDROGEN BUSES FOR THE FRIESLAND DISTRICT

The German district of Friesland is deploying hydrogen buses to enable zero-emission public transportation in some parts of its local network. The project, which will initially see five vehicles enter service, is designed to kick-start the expansion of the local hydrogen economy. The title HyFri, a contraction of Hydrogen and Friesland, underlines the project's local roots and the regional nature of the value chain. The hydrogen buses, operated by regional bus company Weser-Ems-Bus, will pioneer the use of green hydrogen in the area. This is because of the potential to save vast amounts of carbon dioxide within the transportation sector.

Bus refueling will take place at a new hydrogen filling station which is to be conveniently situated in the town of Schortens. Operation of the refueling station will fall under the remit of a new operating company founded by the partners Weser-Ems-Bus, EWE and the Gödens Group. HyFri will be funded by the German transportation ministry as part of the HyWays for Future scheme.

Hydrogen refueling stations: Filling stations are vital facilities that underpin the use of hydrogen within the transportation sector. Up to five such refueling stations could be created in the flagship region as part of HyWays for Future. These stations will then form a network that will ensure widespread availability of hydrogen for fuel cell vehicles.

Fuel cell vehicles: Finally there are the zero-emission vehicles powered by green energy that will consume the hydrogen. The project foresees the purchase of buses, municipal vehicles such as street sweepers, and cars.

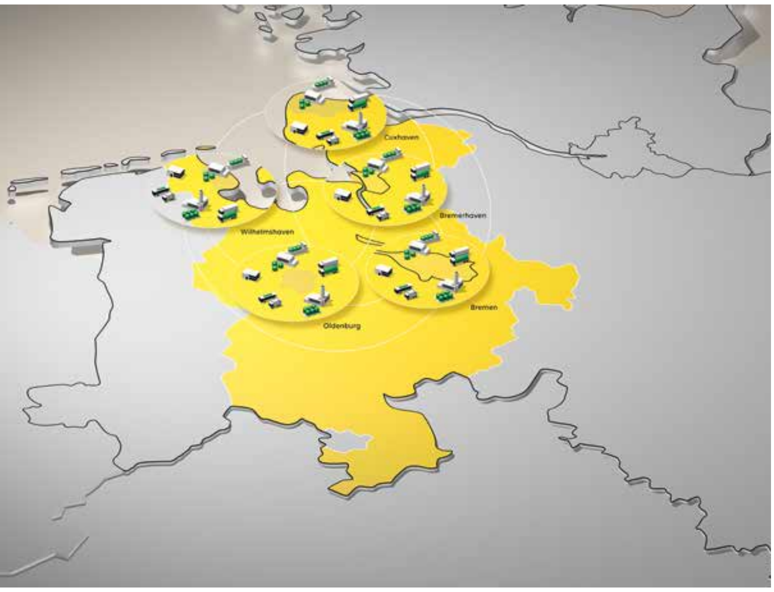

Fig. 2: Northwest Metropolitan Region [Source: HyWays]

THE NETWORK WITHIN THE INNOVATION CLUSTER Parties involved in the innovation cluster will work together as part of a strong network of partners with the aim of turning the northwest into a leading hydrogen region. The goal is to gain mutual benefit from experiences across the entire value chain. Participants will go on a shared learning journey as the project unfolds. Concepts and initiatives relating to regional value creation will be devised, new funding projects launched and infrastructure and outlet markets developed. In short, the plan is to bring hydrogen into everyday life.

An exchange of ideas will be facilitated through participation in regular working group meetings. Discussions will center on four topics: Working Group 1 will deal with hydrogen for municipal vehicles and local public transport, Working Group 2 is tasked with freight transport and logistics, Working Group 3 will handle maritime applications and port logistics and Working Group 4 will concentrate on infrastructure and hydrogen provision. These working groups are public and all interested parties are invited to become involved.

The knowledge level of individual participants in the network varies widely, with some members dipping into the subject of hydrogen for the first while others are engaged in the local rollout of hydrogen. This is what makes the network so diverse and dynamic, with participants having the opportunity to learn and benefit from each other. The working groups will be led by representatives of major companies and institutions from the region, namely energy engineering consultancy PLANET, the Ems-Jade transport association, the city of Oldenburg, the Oldenburg Chamber of Industry and Commerce, Bremerhaven University of Applied Sciences, MARIKO, EWE NETZ and swb. The working groups currently have around 250 active members.

OLDENBURG ENERGY CLUSTER
The energy cluster in Oldenburg known as OLEC is the largest cross-technology energy network in northwestern Germany. Its members have a comprehensive knowledge and a high level of expertise in the energy sector and are focused on renewable energies and how they can be integrated efficiently into future energy systems. OLEC brings together important regional stakeholders and acts as a discussion platform for the energy transition in Lower Saxony. It has also taken on the role of coordinating the energy cluster as part of the HyWays for Future project and is responsible for communication between working groups. OLEC organizes the working group meetings and workshops and helps to arrange network meetings.

The fifth working group, overseeing publicity and marketing, is not open to the public. It is directed by the Northwest Metropolitan Region and EWE and handles the project's website. The working group has also produced films in the region and last year ran a creative contest.

RESULTS In addition to the HyLand grant, other pots of funding are available for the purposes of stimulating the market. These sources will be used to finance further vehicles and additional infrastructure, with a hydrogen refueling station in Oldenburg being one such example. HyWays for Future has already resulted in specific action; investments have been made and projects have been developed. The purchase of hydrogen buses in the Friesland district and the setting up of hydrogen infrastructure in Bremerhaven provide two illustrations of this. The continuously growing network of local stakeholders also has links to the initiatives of neighboring regions, giving a wider perspective. Next year, the network will grow further and stimulate rollout, laying the foundation for the development of sustainable hydrogen infrastructure in the northwest. ||

→ www.hyways-for-future.de

Energy company EWE is the consortium leader for the project and hence has the knowledge, infrastructure and transport networks to use and transmit the power generated from renewables for the purposes of electrolytic green hydrogen production. The HyWays for Future project, with its numerous partnering organizations, is one of the winners of the German transportation ministry's ideas contest entitled "HyLand – Hydrogen regions in Germany." Around EUR 90 million, including government funding, is due to be invested in the region over the coming years.

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Category: Energy storage | **Author:** Eva Augsten

MICROBES FOR THE CLEAN ENERGY TRANSITION

H_2 and power generation with the aid of microorganisms

Microorganisms have many talents. Some of them produce hydrogen from sunlight or biomass, others produce electricity from hydrogen. With their help, metabolic processes from the earliest days of the planet could become an integral part of a modern energy economy.

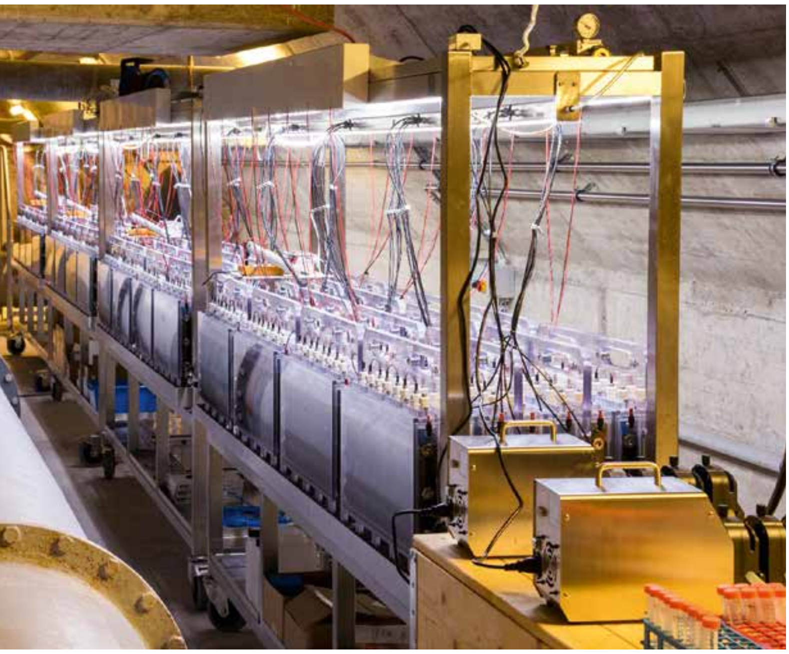

Fig. 1: In the sewage plant of Châteauneuf-Sitten, the longest microbial fuel cell in the world cleans wastewater and produces electricity at the same time [Source: Scom HES-SO Valais-Wallis]

Blue-green algae do not have a good reputation. When they emerge in lakes visited by bathers, their toxic metabolites can cause dizziness and breathing difficulty. But they are the basis for all life on earth. And these special microbes are not actually algae at all, but bluish bacteria – today, therefore, they are also known as cyanobacteria.

Billions of years ago, they developed the ability to convert sunlight into energy and to store it. It is only thanks to this process, photosynthesis, that more complex forms of life have been able to develop.

Today, researchers are trying to use photosynthesis to produce hydrogen in an environmentally friendly way. For this, they are focusing on certain enzymes, specifically hydrogenases, that can originate from blue-green algae or “real” algae.

HYDROGEN VIA PHOTOSYNTHESIS The process of photosynthesis occurs in several steps. In so-called photosystem I, sunlight sets energetic electrons free. Normally, the cell would use these to store energy in the form of sugars in further steps. The enzyme hydrogenase can capture these electrons and bind them to H^+ ions instead, which are available everywhere in the cell. This is how hydrogen is biologically produced from sunlight.

This process is a relic from times when completely different conditions prevailed on earth. “We can encourage this metabolic pathway by putting the algae on a type of sulfur diet in an airtight container. After they have consumed the oxygen, they begin to produce hydrogen, which rises in small bubbles,” illustrates Christina Marx of the photobiotechnology working group at Ruhr-Universität Bochum (RUB).

THE SEARCH FOR THE PERFECT ENZYME Also Kirstin Gutekunst, professor in molecular plant physiology at Universität Kassel, emphasizes, “No organism has an interest in primarily producing hydrogen for humans.” To promote hydrogen production, they therefore have to artificially join the hydrogenase to photosystem I. A major challenge in this is that the hydrogenase is sensitive to and reacts with oxygen, which also evolves from the water splitting during photosynthesis.

Marx, Gutekunst and other researchers are therefore in the laboratory searching for microorganisms, enzymes and other biological components that produce as much hydrogen as possible yet at the same time are not destroyed by oxygen.

In 2020, Gutekunst had led the research group at the Christian-Albrechts-Universität zu Kiel (CAU) that succeeded in inducing the process in a living cyanobacterium for the first time. The advantage of this is that the bacterium can repair itself, so the process is more stable. Also the H_2 yield ended up being significantly higher than in earlier projects. However, the cyanobacteria got the electrons not only from water splitting, but also from sugar. “Either the organism must produce the sugar itself beforehand or we must supply it externally. What we really want is to produce hydrogen exclusively with water and sunlight,” explains Gutekunst.

As part of her professorship in Kassel, she is continuing the research towards finding suitable hydrogenases. “Right now, we’re studying an enzyme from knallgas bacteria. It is fairly resistant to oxygen. Unfortunately, it takes up H_2 rather than producing it,” says Gutekunst. That’s why her team is working in parallel with different mutations – always in search of the all-rounder.

BIOINSPIRED CATALYSTS The Arbeitsgruppe Photobiotechnologie team around Prof. Thomas Happe at the RUB, to which Marx belongs, is also looking for the perfect enzyme for hydrogen production. Together with the University of Osaka, the researchers at the RUB want to understand the structures and mechanisms even better, by looking at cryogenic enzyme samples and other biological building blocks under the electron microscope. Their goal is not only to make the enzymes more active and stable, but also to develop simpler structures, which are easier to use technically.

“We are working on so-called mini-enzymes. These have the function of a hydrogenase, but are smaller and simpler in structure. They contain practically only the active center and the necessary structure to be able to catalytically produce hydrogen as well as split hydrogen. This way, they will also be easier to commercially manufacture and use later on,” says Happe.

A challenge is still the sensitivity to oxygen. Some enzymes, like the CbA5H being studied at the RUB, can shield themselves against oxygen. “This is an important step, because then the active center stays intact,” says Marx. “But as soon as oxygen is present in the environment, it’s kind of like the pause button is pressed and the enzyme doesn’t produce more hydrogen, although like practically all other enzymes is not destroyed by oxygen. Our goal is to develop an enzyme that does not allow oxygen to penetrate into the active center and at the same time still produces hydrogen.”

In order for these enzymes to be used technically, they must be applied to surfaces, and in such a way that they stay a long time and can work as efficiently as possible. The RUB team intend to approach this task in further projects.

FERMENTATION: BACTERIA GENERATE H_2 FROM BIOMASS

The advantage of a fermentation over a photosynthetic approach is that it is significantly closer to commercial use. While researchers are still tinkering with enzyme fundamentals, a small pilot reactor for the project HyPerFerment II is already going into operation. The downside: While water and sunlight are available in practically unlimited quantities, appropriate substrates are required for fermentation.

This involves essentially the same raw materials from which biogas is also produced. “Our goal is therefore to allow hydrogen production to take place before biogas production. In the pre-fermentation stage, the microorganisms break down the substrates only to a small extent. The biogas produced in the next step may even be higher as a result,” says Fabian Giebner, a research associate at the microbiology company MicroPro GmbH and the project leader of HyPerFerment II. In the laboratory tests with maize silage, sugar beet pulp and molasses, the methane production increased by about one third.

The consortium, to which also the plant builder Streicher Anlagenbau GmbH & Co. KG and the automation research institute Fraunhofer Institut für Fabrikbetrieb und -automatisierung (Fraunhofer IFF) belong, has just constructed a10-m^3 (350-ft^3) test fermenter near a biogas plant in Magdeburg (see Fig. 3). With this, they want to experiment with parameters to find out the optimal modes of operation. Giebner expects the bacteria in the pilot plant to produce at least 4 to 5 kg of hydrogen per day. On top of this is a somewhat smaller amount of CO_2. Methane will hardly be produced there, as the predominant organisms that do in biogas plants have no chance at the pH value significantly under 6 and the temperature of nearly 60 °C in the hydrogen fermenter.

For the operators of biogas plants, hydrogen production could be an added business with little additional cost. The substrate should only need to be in the H_2 fermenter about three to ten days. That’s one-tenth of the dwell time of the usual biogas plants – correspondingly, the size of the plant can be smaller.

From one kilogram of maize silage, the bacteria in the lab produced about 100 liters of hydrogen. With wheat bran, it was a little less. So if all of the biogas plants in Germany were to be combined with an H_2 fermenter, only a few percent of the expected hydrogen demand could be covered.

Therefore, even with a large degree of scaling, it is a question of rather small quantities of hydrogen. This could be used locally for agricultural machinery or trucks, for example. When a larger-scale pilot project is launched in two or three years, it may therefore be accompanied by a small hydrogen fueling station. Before then, however, the hydrogen is to be enriched in the current test plant and fed into the biogas plant so that the organisms there produce more methane.

Fig. 2: Kirstin Gutekunst, professor in molecular plant physiology at Universität Kassel, is looking for the perfect enzyme for H_2 production [Source: Universität Kassel]

MICROBIAL FC: ELECTRONS FROM WASTEWATER At the sewage treatment plant Kläranlage Châteauneuf-Sitten, researchers from the technical university Fachhochschule Westschweiz-Wallis (HES-SO Valais-Wallis) in Sion, Switzerland recently completed testing of a 1,000-liter microbial fuel cell. With 64 individual cells and 14 meters total length, it is, according to the group, the longest microbial fuel cell system in the world thus far (see Fig. 1).

On the carbon foam electrodes are settled about ten different microbial species that occur naturally in wastewater. There, they break down the digestible components, very similar to what happens in the activated sludge basin of a normal sewage treatment plant. The difference: In a conventional activated sludge tank, air is blown in with high energy expenditure, because the bacteria need oxygen. This penetrates into the cells and takes up electrons there.

Microbes in the biofuel cell instead pass electrons directly on to the anode. “It is a sort of external respiration. When there was no oxygen in Earth’s atmosphere, bacteria passed off electrons to, for example, oxidized volcanic rock,” says Fabian Fischer, professor in chemical biotechnology at HES-SO Valais-Wallis. The microbial fuel cell therefore not only generates electricity, but also saves energy by eliminating the need to aerate the basin.

Electrons from the anode flow to the cathode – an electric current is generated. The simultaneously occurring hydrogen ions diffuse through the proton exchange membrane to the cathode side. There, electrons and protons come into contact with atmospheric oxygen and react to form water.

The potential for the technology is great – in wastewater treatment as well as power generation. In the wastewater treatment plants of smaller cities of up to 10,000 inhabitants, a biofuel cell could completely replace the current way of treatment in the activation tank. The potential electricity yield lies at 0.2 kWh per inhabitant per day. For this, the bacteria would have to convert about 25 percent of the digestible mass in the wastewater into usable electricity. The pilot plant has so far achieved six to twelve percent. In the next phase of the project, not only the efficiency but also the performance of the cells are to be increased – within the same dimensions, throughput and electricity generation are to grow to twice the amount. Industrial partners should also be in on the project, but none have been named so far. ||

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

WITH A BIG BANG INTO A NEW ERA

Clean Logistics presents H_2 truck in Stade

Fig. 1: Fulminant performance of the fyuriant

EU TYPE APPROVAL
The German automotive office (Kraftfahrtbundesamt) gave the Eugenius brand of the Faun Group, which was introduced in the August 2022 issue of H2-international, EU type approval, which means their vehicles are allowed in road traffic throughout the EU without additional approvals from member states. Head of development Georg Sandkühler said, "As our type approval is the first granted worldwide for hydrogen-powered commercial vehicles, it means that this type of drive has taken a big step forward overall." However, their trucks are also not over-length, because the H_2 tanks are integrated in the chassis.

The presentations of new hydrogen trucks are becoming more and more spectacular. After first Faun in Bremen and then Paul Nutzfahrzeuge in Vilshofen each introduced their new H_2 trucks the June of 2022, Clean Logistics (CL) followed suit on June 23rd. Paul Nutzfahrzeuge, in a hybrid in-person/online event with much dramatic steam and music, ushered in the PH2P. Clean Logistics topped this and held races with its new fyuriant on the grounds of the local airport in front of 600 invited guests.

The interest was great – on the industry side with shipping and logistics specialists as well as on the investor side, along with the media. Everyone wanted to watch and see how the retrofitted H_2 truck (tractor unit) from Clean Logistics would fare against its diesel counterpart. Long story short: In the drag race – narrated by Formula 1 commentator Kai Ebel – Swedish technology influencer Angelica Larsson, in the fyuriant, gave opponent Janina Martig, in the diesel truck, no chance.

FROM HYBAT-TRUCK TO FYURIANT In the midsummer heat, the two Clean Logistics founders Dirk Lehmann and Dirk Graszt, affectionately referred to as H_2D^2, revealed a colorfully painted hydrogen-powered tractor unit. At their side was Dr. Klaus Bonhoff from the federal transport ministry (BMVD), formerly head of the national administrative organization for hydrogen and fuel cells (Nationale Organisation Wasserstoff- und Brennstoffzellen-Technologie, NOW). Both institutions, BMVD and NOW, have been giving support to the small business founded in the state of Niedersachsen since 2017 and thus had a large part in the bringing about of this spectacle.

Bonhoff frankly explained that we "have achieved relatively little so far in the vehicle sector." But then he pointed out that the now presented H_2 truck that came out of the NIP program HyBat-Truck was excellent and that its development had been supported with 3.3 million euros of government funding. The first talks about a truck were held with shipping specialist Dirk Graszt in 2017, and then Dirk Lehmann was brought in. Lehmann, who is actually a shipbuilder, was immediately enthusiastic about the idea of converting long-haul trucks to run on hydrogen. At the time, Lehmann was managing director of E-Cap Mobility GmbH, which electrifies, in addition to maritime vehicles, also road vehicles.

> "We are starting with a big bang into a new era… We already have the capability to make zero-emission vehicles available on the market today. Thanks to the converting of classic diesel vehicles into emissions-free hydrogen vehicles, this is also being done in a very resource-saving way. This is how we will rapidly drive the transformation of mobility into a sustainable future."
> *Dirk Graszt, CEO of Clean Logistics*

The two Dirks teamed up, and this resulted in CL. Since then, they have been working to convert conventional diesel vehicles to zero-emission H_2 vehicles. After buses, the formerly small company from Niedersachsen will immediately also be pushing out 40-tonne semi-trucks for the program.

"The demand is enormous," stated Graszt in Stade. It's no surprise, since according to the German climate protection law (Klimaschutzgesetz, KSG), greenhouse gas emissions in the transport sector must fall to 48 percent of 2019 levels by 2030. This means that of the 340,000 trucks currently registered nationwide, around 240,000 will need to be operated climate-neutrally by then.

NEW CI – NEW LOGO During the premiere at the airport in Stade, Clean Logistics SE presented itself in a completely new design – with a new corporate identity. With a new logo and a much more internationally oriented strategy. Additionally, Lehmann said, “We’re integrating Chinese technology.” The reason for this is obvious: “They're six or seven years ahead of us in China... Refire does fully automated series production.” These compliments were likewise returned by Audrey Ma, vice president of Refire, who said, “Clean Logistics has made history by making clean logistics accessible to the world.”

OVER-LENGTH IS AN ISSUE Clean Logistics sees itself purely as an integrator. The components are purchased and brought in – whether it’s the two 120 kW capacity fuel cells from Refire or the 43-kg hydrogen tanks stacked directly behind the driver’s cabin. Although these allow a range of over 400 km (250 mi), at the same time they make the vehicle around 60 centimeters (24 inches) longer.

The result of this “over-length” is that no series approval is possible under German law and only approvals on an individual basis have been granted up to now. Not only Clean Logistics is fighting this bureaucratic imposition. Because production capacities are meant to be massively expanded in Winsen an der Luhe. In the new production hall of 10,000 m^2 effective area (110,000 ft^2), up to 450 vehicles a year are to leave the yard starting end of 2023.

It was almost exactly one year ago that Clean Logistics gave the first pyuron, a hydrogen-converted bus, to the public transit company of the Uckermark in Brandenburg (Uckermärkische Verkehrsgesellschaft, UVG). The bus has been transporting tourists in the lower Oder River Valley ever since.

Dr. Klaus Bonhoff concluded, “No truck manufacturer can afford not to build H_2 trucks.” ||

Fig. 2: Great interest in the fyuriant H_2-Truck of Clean Logistics

PAUL NUTZFAHRZEUGE

Paul Nutzfahrzeuge GmbH is comparable yet quite different. Similarly to Clean Logistics, Paul is committed to H_2 trucks. “Hydrogen will prevail,” sales manager Thomas Kotowski is certain. Up to 200 km (124 mi) – no matter the tonnage – battery-electric is indeed more efficient. But for longer ranges, only retrofit or fuel cell solutions come into question for him. Larger providers like Faun (see H2-international Aug. 2022) won’t be an issue, as the Bremen-based company with its Enginius brand caters to municipal vehicles on short and medium routes, whereas Paul targets mid-weight, so 12- to 16-tonne, trucks on distribution routes. Particularly package delivery services such as Hermes and DHL are potential partners here.

“Everything that Mercedes does not build with the assembly line, we build,” Kotowski told H2-international. As a special vehicles builder, the Vilshofen-based company concerns itself with not only old-time car restorations, but also installation of alternative drive systems. Paul started in 2016 with a facility that could build 1,300 vehicles a year. In order to meet the growing demand for custom-made products, a second site is currently being prepared, which is to double the total production capacity to 2,700 vehicles per year. An initial 22 units of purely H_2-run trucks are foreseen for 2022, around 150 for 2023 and 500 per year for 2025. Each at an individual workstation, mind you. “We are crafters,” says Kotowski – not without pride.

Cooperation partner Shell is contributing the H_2 refueling stations. There will probably be eight in 2023. Maximator stands ready as a technology provider. Although Shell is financially strong, 3 million euros for one H_2 station with two pumps makes a big dent, even when the pressure is “only” 350 bar. And if several H_2 trucks are to be filled, it could quickly amount to 1 tonne of hydrogen per day that needs to flow.

Paul is also involved in the service realm. “Anything that breaks, we replace,” states the key account manager. At the same time, he points out that only trained personnel may touch alternatively powered vehicles – in view of the shortage of skilled workers, for certain a bottleneck. In addition, a workshop conversion, at around 200,000 euros, will be costly.

| **Category:** Electric transportation | **Author:** Michael Kriescher |

SLRV – LIGHT TWO-SEATER WITH FUEL CELL

Optimized for lowest energy consumption

Fig. 1: SLRV research prototype during a drive trial [Source: DLR]

The Safe Light Regional Vehicle (SLRV) was developed by the German aerospace center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) as part of the research project Next Generation Car (NGC). It addresses concerns about the safety of today's lightweight microcars with the novel metal sandwich construction. This together with an innovative entry concept, highly efficient H_2 fuel cell drive system and crash-optimized chassis were able to achieve the ambitious targets regarding weight (450 kg), safety, energy consumption and manufacturing cost.

The body of the two-seat SLRV is 3.8 meters long and low to the ground, for the lowest possible air resistance. The additionally low weight is crucial for low energy consumption. Even for electrified vehicles with recuperation, up to 93 percent of energy consumption, depending on which point in the drive cycle, is weight-dependent [FRI2010]. A low body mass also enables secondary mass reduction, so smaller and more cost-effective drive components, and its effects [ECK2011].

SANDWICH CONSTRUCTION: LIGHT, LOW-COST, SAFE To achieve the goal of a lightweight and safe construction that is nevertheless cost-effective, the so-called metal sandwich construction (metallische Sandwichbauweise) was developed (see 2). The materials are composed of metal cover layers and plastic foam as the core. The front and rear sections of the SLRV are composed of sandwich panels and serve as crumple zones [BRU2017]. A large part of the vehicle's machinery is also housed there.

The passenger compartment consists of a floor tray braced by a ring structure. This absorbs the forces that act on the car while it's driving and protects the occupants in the event of a crash. With the floor tray, assemblies that are individually found in the passenger compartment of a conventional car body, such as front wall, rear wall, rocker panels and floor, are combined into a single construction element, which significantly reduces the complexity as well as the number of joints.

Similar advantages are offered by the use of the upward-opening canopy in conjunction with a roll bar. With these, the doors, posts, A and C pillars, and roof have been replaced by a single piece. So far, structures made of sandwich materials have not yet been used in the series production of vehicles. The DLR has shown its potential and in the next step is working to optimize the relevant manufacturing technologies.

> According to initial simulation results, the SLRV is expected to consume only half as much hydrogen as a conventional fuel cell-powered passenger car.

CRASH BEHAVIOR IN THE EVENT OF A FRONTAL IMPACT The crash behavior of the SLRV body during a frontal impact was analyzed and documented in accordance with US NCAP guidelines. Such a crash corresponds to an impact of the vehicle against a rigid wall at 56 km per hour (35 mph). The crash box and front end of the SLRV are evenly deformed in the process and absorb the crash energy. The passenger compartment is not deformed, to not reduce the survival space for the occupants.

Important for the crash behavior is also the chassis design of the SLRV. The chassis is designed in such a way that the wheels detach in the event of a crash and are guided past the car body [KRI2019]. This way, the passenger compartment is not hit by the wheel and can be more simply designed.

ZERO-EMISSION: FUEL CELL-BATTERY HYBRID To be on the move in the least resource-demanding way possible, the SLRV possesses, in addition to the very light body, a highly efficient hybrid drivetrain. The SLRV's drivetrain contains a small fuel cell with 8.5 kilowatt continuous output and a battery that delivers an additional 25 kilowatts for acceleration and can also recuperate energy through regenerative breaking. This combination weighs less than conventional battery systems, provides a range of around 400 kilometers (250 miles) and allows a top speed of 120 kilometers (75 miles) per hour. Also on board between the two seats is a 39-liter pressure tank capable of storing 1.6 kilograms of hydrogen at 700 bar.

USE EXAMPLES AND FURTHER DEVELOPMENT The occupancy of passenger cars in German road traffic lies on average at 1.46 persons [BUN2018]. The SLRV was therefore purposefully designed to be a light two-seater that, due to its low energy consumption and fuel cell system, nevertheless offers a comparatively long range. Consequently, the SLRV is suitable, for example, as a commuter car, shuttle to local public transport, car-sharing

Fig. 2: Structure of the SLRV body

Fig. 3: Drivetrain of the SLRV

vehicle or company car – particularly in outer city or suburban areas. It could be a supplement to public transportation in the suburbs or the countryside, can be used as a second car and is well suited for car-sharing services due to the fast refueling with hydrogen.

Regarding the purchase price, the SLRV team at this time is assuming it will be about 15,000 euros. With an expected service life of ten years and a mileage of 300,000 kilometers (190,000 miles), that works out to about ten cents per kilometer.

Talks are currently being held with companies with the aim of further developing the SLRV into a vehicle for series production. In addition, a memorandum of understanding has already been signed with the hydrogen fueling company Blu Power. ||

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Fig. 1: Metal bipolar plate under inspection [Source: CellForm]

Category: Development | **Author:** Michael Nallinger

KEY COMPONENTS WITH OPTIMIZATION POTENTIAL

The scale-up in bipolar plate production continues

The bipolar plate is one of the most used components in a fuel cell stack, alongside the gaskets and the membrane electrode assembly. This is why it's important in the overall scheme of things to bring down their cost. Manufacturers, regardless of whether they produce metal or graphite solutions, are increasingly looking to automate and link up individual processes on the one hand and to optimize the products themselves on the other, for instance by further reducing sheet thicknesses. Already plans are afoot to scale up production and could result in several million bipolar plates being manufactured for use in over 100,000 stacks every year.

Fig. 2: Bipolar plate manufactured using passive hydroforming (see box) [Source: Fraunhofer IWU]

In a proton exchange membrane fuel cell, the bipolar plate is a key component. It accounts for up to 80 percent of stack weight and up to 65 percent of stack volume, hence its enormous importance in terms of the power density. It's equally significant for the functioning of the fuel cell: The bipolar plate or BPP separates and distributes process gases and removes product water. Not only that, this component is responsible for performing the essential tasks of conveying the generated current and evenly distributing all media.

BPPs are principally made from graphite carbon or metal. The various materials are associated with different properties and have different advantages for plate functionality. Because of low efficiency benefits and a lack of manufacturing processes for competitive metal BPPs, it is the graphite variant that has dominated in the past. However, graphite-based BPPs exhibit volumetric and gravimetric shortfalls compared with their metal counterparts, particularly when it comes to demanding applications. Plus, graphite is extremely brittle and can therefore break easily. Nevertheless, graphite plates are frequently deployed in stationary applications in which the volume of the structure is not a limiting factor.

On matters of cost, it's metal plates that take the lead. "With the right production process the sheet thicknesses can be reduced down to 0.05 mm. Here, metal is at a completely different price level to graphite," emphasizes German manufacturer CellForm. Given that several hundred plates are used in a single stack, the financial ramifications for the final application are huge. A further advantage of metal BPPs cited by CellForm is their positive impact on the cold-start capability of the fuel cell.

The company, based in Baienfurt in Baden-Württemberg, covers the entire manufacturing process for metal BPPs with a multistage forming process and subsequent laser welding. Commenting on working with metal, company representatives point out that the "extremely thin" sheet thicknesses are a particular challenge: Shaping such fine initial sheets and creating the highly precise and complex geometry of the channels can, due to physical constraints, quickly lead to fractures that would render the BPP unusable. On top of this come the stringent quality requirements with low margins for error which need to be met when producing in large volumes. "Only those who satisfy this requirement will be able to maintain their position in this growing and fiercely competitive market," says the company.

These challenges, according to CellForm, are putting a certain degree of selective pressure on the manufacturing processes which are still under development. "Physical restrictions – such as heat generation – will limit how much these processes can make in future mass production," states the manufacturer. This problem, it says, isn't noticeable when dealing with small volumes, but will become increasingly evident in the years ahead as demand grows.

Fig. 4: Joachim Scherer, Head of Product Engineering Components at EKPO Fuel Cell Technologies: "In the years ahead, further developments are expected with regard to lower material costs, higher material quality, improved supply security and efficient tool production." [Source: EKPO]

CellForm asserts that its custom technology, however, can be easily scaled and confidently claims that: "When combined with a thickness down to 0.05 mm, we are able to create flow fields for the most efficient fuel cell systems." Each part is produced using sophisticated machinery within a fully air-conditioned facility, it explains.

HIGH-PRECISION, STABLE, COST-OPTIMIZED PRODUCTION These challenges are also very familiar to the team at EKPO, a joint venture between ElringKlinger and the French company Plastic Omnium. "The BPP is one of the critical components that has a direct influence on stack performance and service life. The optimal distribution of media and cooling water uniformly across the stack and in the cells maximizes the performance of the membrane electrode assembly (MEA) and facilitates reliable control of the thermal load, even when operating at full power," says Joachim Scherer.

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PASSIVE HYDROFORMING

The passive hydroforming process now means that presses which weren't originally designed for high-pressure sheet metal forming can also be used for manufacturing bipolar plates (see fig. 2) – without the need for water hydraulic systems and pressure intensifiers. This method requires forming pressures of around 200 megapascals. The special feature of the process, which was developed by the Fraunhofer Institute for Machine Tools and Forming Technology IWU in Chemnitz, is its tool concept: The movement of the displacing piston as the press closes results in the compression of the active medium that is enclosed in the tool. This allows sufficient pressure to be created to form the BPP. A particularly challenging technical aspect is, according to IWU, the sealing of the active medium between the sheet being formed and the filling plate.

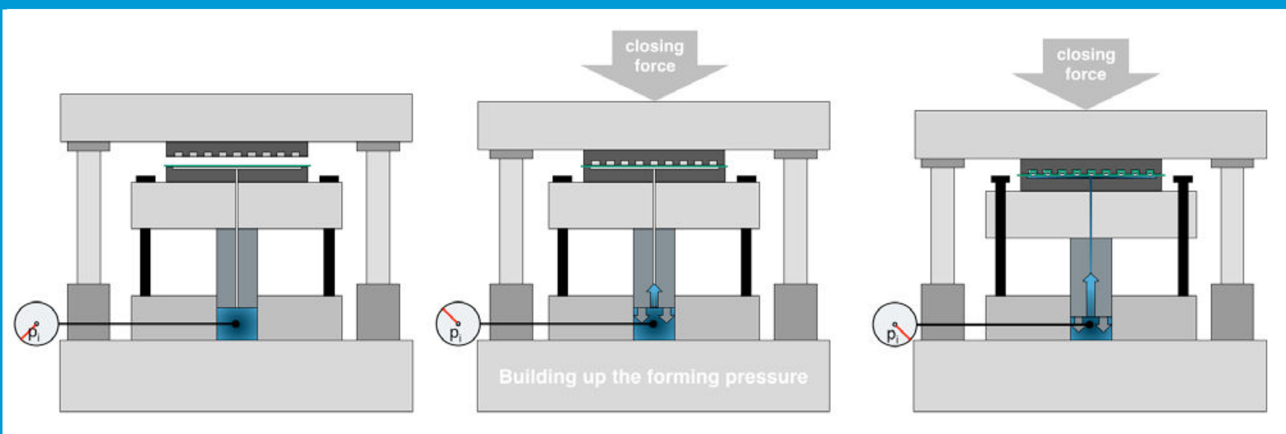

Fig. 3: Starting position with the loaded sheet (left); forming begins: the tool closes, simultaneously creating the forming pressure (center); tool completely closed, finished part has been formed (right) [Source: Fraunhofer IWU]

Fig. 5: Metal bipolar plates are a key element in a fuel cell stack [Source: Schaeffler]

According to the head of component product development at EKPO Fuel Cell Technologies, the high number of repeating units means that high-precision, stable and cost-optimized fabrication of BPPs is essential in order to achieve the necessary stack quality at a salable price. By integrating the sealing function as well as incorporating a robust design for metal BPPs, the time and effort needed for stack manufacture can be reduced which thereby lowers the inspection requirement and the costs.

EKPO refers to the flow simulation based on computational flow dynamics and a BPP design which is optimized with the help of finite element method. This, it says, makes for a dependable and error-free production process without affecting the properties of the product. In Scherer's view this is necessary to reduce or avoid control processes while at the same time minimizing the rejection rate for each step in an up to 10-stage manufacturing process in the parts per million range.

"Robust processes for forming, joining, coating and sealing BPPs will decrease deviations and chances for error in production and thereby prevent defects, which in some cases could only be identified previously by carrying out laborious tests on the final product," shares Scherer. This also particularly affects inspection costs, he continues, which can account for between 5 percent and 25 percent of the total cost depending on product readiness, in other words whether the product is a prototype or a mass-produced article.

At its site in Dettingen, Germany, EKPO has achieved an annual production capacity of 10,000 stack units in a setup which employs a number of different manufacturing stages. These include producing metal BPPs from coil with high-precision series tools in progressive die stamping operations and the joining of thin metal foils in a rapid laser process as well as testing interim products and ready-to-install BPPs through in-line process controls. In addition, spot checks are carried out to determine whether the dimensions and tightness comply with the usual principles and requirements for the automotive sector. In this case, the conductive coatings are either applied in advance to the coil or applied to the joined BPPs. There are also two different ways in which the company seals the cell, opting either for an integrated gasket on the BPP or a gasket that is integrally formed on the gas diffusion layer, otherwise known as the seal-on-GDL method.

FUTURE PRODUCTION WITH FULLY INTERLINKED SYSTEMS According to development chief Scherer, all processes and technologies are based on decades of experience gained at ElringKlinger/EKPO in large-scale production for the automotive industry. This brings with it benefits such as high-precision products, in-house tool production and the application of automotive quality and management techniques, he says. The company has already run through the appropriate Production Part Approval Process or PPAP for the NM5evo stack, a vehicle fuel cell module with a power output of up to 76 kilowatts. Scherer also highlights that suppliers are validated in line with automotive series processes. All manufacturing procedures at EKPO for metal BPPs are already highly automated.

Even so, Joachim Scherer believes that the high degree of production flexibility that is required to cover the wide range of BPP designs and variations means that it is does not make sense to further interlink individual processes at this stage. He does indicate, however, that dedicated BPP lines with fully interlinked production systems for individual stack platforms will be installed for the future manufacturing of very high part volumes.

What's more, the component production manager reports that for individual production steps work is already underway to create innovative processes for the next-plus-one generation that should make it possible to decrease cycle times even further. Such processes will be needed for volumes ranging up to tens of millions of BPPs a year.

EKPO is already envisaging the mass production of 100,000 stacks annually. The company points out that this will require procedures that enable components to be processed and checked in less than a second, an undertaking that will understandably come up against limiting factors, as Scherer underlines: "This up to 10-Hz production goes well beyond today's scale in terms of the critical requirements for processing speed, stability and control." It would also spark increased demands on the materials and tools used.

Scherer is well aware of what this signifies: "In the years ahead, further developments are expected with regard to lower material costs, higher material quality, improved supply security and efficient tool production." This calls for measures to optimize the component design, new methods of measurement and control that are integrated directly in the production systems and a further minimization of time-consuming component inspections.

SCHAEFFLER FOCUSES ON FUNCTIONAL COATINGS Automotive supplier Schaeffler has chosen to focus on a pressing method for forming BPPs combined with the application of functional coatings. "Here we can leverage our core competencies. For instance every year we coat over a billion parts for conventional powertrains," explains Benjamin Daniel who heads up the company's fuel cell division. The job of a BPP coating is to maintain a high level of electrical conductivity throughout the entire service life as well as to stop metal ion contamination of the MEA. Otherwise the ions would accumulate over time on both the active catalyst material and at the sites in the membrane through which the protons can pass.

Schaeffler has been developing several coating systems especially for BPP modules as part of its Enertect range. One is based on platinum group metals for very high service life requirements, and another is based on a low-cost carbon coating. According to Daniel, this is advantageous for customers: "Thanks to our expertise in surface technology, we are in a position to offer application-specific coating development and also to balance this against costs and performance according to requirements."

The coating systems are applied using the physical vapor deposition process which has already proved suitable for large-scale production – such as in the fabrication of heavily loaded valve train components, states Daniel.

Just as at EKPO, Schaeffler is also looking increasingly to scale up production. For example, at the beginning of the year a pilot plant at its headquarters in Herzogenaurach entered operation that will make more than 700,000 BPP modules for fuel cell applications on a yearly basis. The plant's design means that it also has the potential to manufacture even greater numbers of BPPs for electrolyzers. According to Daniel, the individual processing stages of the pilot plant, which was designed by Schaeffler's own specialized machinery department, are already highly automated. Furthermore, the pilot facility is embedded within a new hydrogen center of excellence at the Herzogenaurach site. The center includes a large area for testing electrolyzer technologies and fuel cells at the component, stack and total system levels.

THE DURABILITY ISSUE The automotive and industrial supplier is pressing ahead with further development at various levels. In addition to the joint venture agreed with Symbio, which will hopefully see the annual production of around 50 million BPPs by 2030 (see interview), a range of initiatives have been launched that will improve the efficiency and economy of manufacturing processes. Areas in which Daniel sees room for technical improvement include BPPs and the MEA. This is where the subject of component durability comes to the fore. It's a key issue for Schaeffler, according to the division head, and one where years of expertise acquired in surface coatings is reaping dividends.

There is also considerable potential, he says, when it comes to the selection of material for the substrate, coating and gasket as well as choices relating to the manufacturing processes and process management in general. Even the use of the material itself can be optimized, he explains, for in-

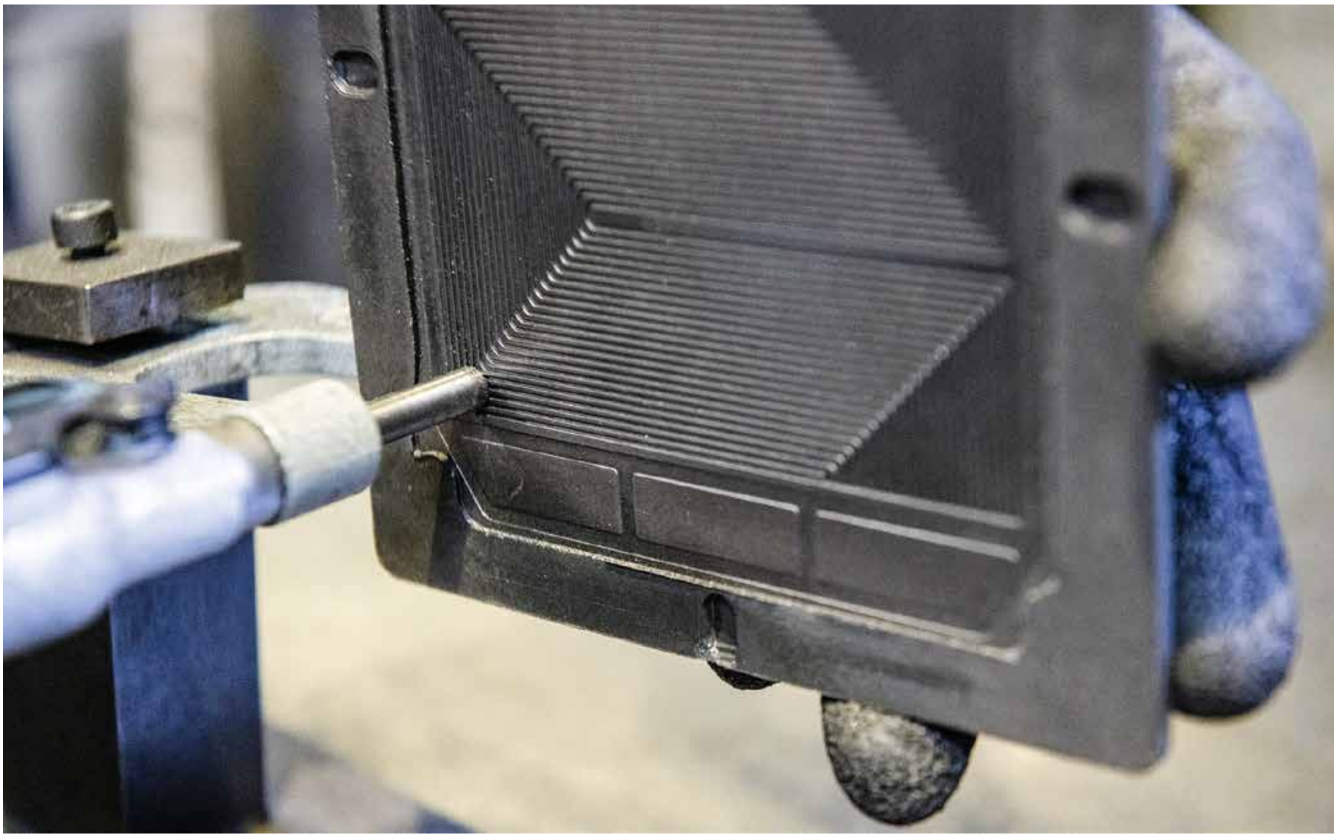

Fig. 6: The graphite bipolar plate is measured using a micrometer screw [Source: Eisenhuth]

stance by further reducing the sheet thickness to less than 100 micrometers for the substrate.

Daniel is convinced: "Our core competencies in forming technology, functional coatings, joining technology and high vertical integration using our own tools are the key to successful and optimized industrialization." In this regard, Schaeffler has specified other core competencies that are to be cultivated as part of pre-development activities in the lead-up to series production. One related example mentioned by Daniel is a passive hydrogen recirculation unit.

Additionally, engineers in Herzogenaurach are busy investigating how different fuel cell components interact – not just in the fuel cell system but also in the overall vehicle. This strategy also capitalizes on the development of a learning platform relating to the proprietary complete fuel cell system for motive applications. "That helps us to understand the requirements of higher integrated levels and their interaction with our components and subsystems and also assists us in supporting our customers in this area," elucidates Daniel.

INJECTION MOLDING MACHINES FOR GRAPHITE BPPS It was back in 2006 that German company Eisenhuth had its first dealings with graphite BPP production. Based in Osterode am Harz, the company has primarily concentrated on two main areas in the past couple of years, as its director Thorsten Hickmann reports: "On the one hand we have optimized our injection molding technology and can now produce graphite BPPs on relatively small injection molding machines in a similar way to how standard plastic components are produced. The second way is to systematically develop the continuous production of graphite compound plates with all material combinations: for high-temperature applications, applications in aggressive media or standard applications."

In the meantime Eisenhuth has a handful of series production projects, according to Hickmann. "We can use injection molding to produce plates in various sizes, be they components for relatively small-scale applications with a plate size of 60 mm x 320 mm or large plates with an area of over 1,000 cubic centimeters," explains the director. These advancements also have an effect on component costs. For example, the company recently offered an injection molding solution for graphite compound plates that has allowed the customer to suddenly decrease its costs by a factor of three, reports Hickmann. "So instead of having to pay 30 euros a plate for a stack with 102 cells, it now only has to pay 10 euros. That's a saving of over 2,000 euros for one stack."

Despite this progress, at the moment the degree of automation in plate production for graphite compound plates is fairly minimal. The reason for this lies in the volumes which entail a lower level of automated production. Nevertheless, Eisenhuth is already deploying smart automation solutions for the manufacturing of plastic parts, for instance by using articulated robotic arms to insert components. The next step is to automate injection molding applications. Also on the agenda is the rollout of continuous plate manufacturing for high-temperature applications.

RISK OF OFFSHORING? And how big a risk is it, in Hickmann's view, that BPP production will be transferred abroad sooner or later? "When we're in a position to further roll out injection molding so that plates can be produced fully automatically, then I see no difficulty in competing from Germany in the international marketplace," he explains in his analysis. He goes on to say that this only makes sense, however, if the entire "stacks for fuel cells" technology stays in Germany or indeed Europe.

EKPO, too, makes the case for a localized approach: "As things shift to several tens of millions of bipolar plates a year, it will make sense for their production to be located in the same place as the stack manufacturing. The global presence of manufacturing plants belonging to EKPO's parent companies means it will be possible to expand BPP production to wherever in future fuel cell stacks are being produced for global markets," says Joachim Scherer.

Likewise Schaeffler mentions its position in a global market. "Today there are already highly competent hydrogen technology players particularly in Asia. We're right at the start of global competition," sums up Benjamin Daniel. What's important is to extend our own technological expertise and continually expand competitive advantages, he says, stating that this is where Schaeffler is making the most of its many decades of experience in mass production. However, Daniel also makes clear: "We have a global setup and have sites around the world. We want to manufacture where our customers are – also for reasons of sustainability." ||

EFFICIENT COATING PROCESS FOR BPPS

Fig.: The in-line system i-L 4.3500 from PVT enables the PVD coating of 5 million BPPs for fuel cells per year [Source: PVT]

In PEMECs (proton-exchange membrane electrolyzers) as well as PEMFCs (PEM fuel cells), chemical processes are taking place during operation that attack the surface of the material used and lead to corrosion in the medium or long term. Various studies show that because of internal corrosion processes in BPPs (bipolar plates) made of pure stainless steel, the, for example, target fuel cell service life of at least 10,000 operating hours in passenger cars is difficult to reach. Fuel cells for heavy-duty applications or for electrolyzers in continuous operation demand much longer lifetimes.

PVD (physical vapor deposition) coating, a technology used for decades for a variety of applications, presents a solution to this problem. "Through suitable coating of the two outer sides of BPPs, their corrosion behavior under long-term operation and thus their service life can be significantly optimized," says Dr. Andreas Kraft, Director of Operations at PVT (Plasma und Vakuum Technik GmbH). According to him, this does not result in any loss of conductivity, but even rather an improvement towards a desired high conductance value. The company with headquarters in Bensheim, near Frankfurt am Main, has been operating in the field of ion- and plasma-assisted PVD coating of tools and components for more than 35 years.

The coatings that are applied to the BPP, although very thin, constitute a major cost factor in the manufacture of the plates. "For a plate with a size of about 750 cm², the cost of coating should end up well below 1 euro per plate," stressed Kraft. Simultaneous coating of both sides of a BPP therefore requires a highly productive coating process as well as technology that gives reliable, reproducible results. This is why, according to the materials expert, the batch coating systems typically used in tool and component coating are uneconomical in terms of productivity and do not lead to the desired results.

"For a mass production of this sort, only so-called in-line systems come into consideration, in which substrates are coated on both sides with high throughput and without rotation," stressed Kraft. In contrast to batch systems, these are multi-chamber setups in which the substrates are transported from chamber to chamber. The chambers are separated by large transfer valves, and the spatial and temporal separation allows various defined processing steps to occur. This design allows for a clean environment with consistent vacuum and processing conditions.

With the i-L 4.3500 in-line system developed by PVT, according to Kraft, 5 million BPPs of size 500 mm x 150 mm for fuel cells can be coated on both sides in the same consistent quality. The system is realized by the combination of four individual modules, with each forming a chamber, so that BPPs could simultaneously, at different positions, be fed in (into vacuum), coated under constant vacuum conditions, and finally discharged again (back into ambient conditions).

The PVT manager stressed that the coating costs per plate for a fuel cell BPP typically end up well below 1 euro. Depending on the process and coating materials used, the costs can even turn out significantly lower, according to Kraft. ||

Category: Development | **Interview Partner:** Benjamin Daniel |

QUICK MARKET ENTRY WITH PARTNER SYMBIO

Interview with Benjamin Daniel from Schaeffler Automotive Technologies


Fig.: Benjamin Daniel, head of the fuel cell business unit at Schaeffler Automotive Technologies [Source: Schaeffler]

In June 2022, automotive supplier Schaeffler together with Symbio – a Michelin and Faurecia company – established the joint venture Innoplate which plans to produce "the next generation" of bipolar plates. Benjamin Daniel, head of the fuel cell business unit at Schaeffler Automotive Technologies, explains the new options.

H2-international: Bipolar plates are considered a strategic component in a fuel cell system. At Schaeffler how do you tackle the challenges of their production? Which areas of expertise do you bring to this?

Daniel: The ability to mass-produce components such as bipolar plates efficiently and economically is essential for the large-scale deployment of fuel cell systems. This industrialization is at the heart of Schaeffler's strategy and is an important part of the 2025 road map. It allows an overall reduction in the cost of fuel cell stacks and systems. As a world-leading automotive and industrial supplier we have extensive expertise in precision forming and punching technology as well as a deep knowledge of the processes involved in the mass manufacturing of metal bipolar plates. We use this experience both for electrolysis and as a key element in fuel cell stacks. Schaeffler's high degree of vertical integration with regard to forming technology and its sophisticated coating processes form the basis for a sound understanding of mass production processes for bipolar plates.

What role does your joint venture with Symbio play here?

Together we see enormous potential in the developing hydrogen economy. The establishment of this Franco-German project will also strengthen the European value chain for hydrogen-based mobility. By the end of the year we will be starting joint venture operations under the Innoplate brand and pushing the production of next-generation bipolar plates for the entire market for proton exchange membrane fuel cells. As a result, customers will benefit in future from increased performance, larger capacities and a lower price. In addition, the joint venture allows us to quickly enter the market with a leading fuel cell provider as a partner.

What's the current situation and what will the next steps be?

At the moment we're developing the manufacturing processes in our center of excellence for hydrogen technology in Herzogenaurach and are establishing production at the joint venture site in Haguenau in France. At first we want to make 4 million bipolar plates a year at the production site in Haguenau, with the aim of producing around 50 million plates annually by 2030. By that time we expect there to be 120 members of staff working in this area. The joint venture's customers are Schaeffler and Symbio. Symbio has already received its first order as a major fuel cell system supplier from a leading vehicle manufacturer. It's envisaged that the joint venture will produce the bipolar plates for the order. ||

Category: Development | **Authors:** Nadine Hölzinger, Andy Fuchs

WITH A MOUSE CLICK INTO AN H_2 FUTURE

Simulation tool to promote regional participation

Participation in socio-political transformation processes by a wide range of actors is indispensable for success and acceptance of developed solutions. Depending on origin, qualifications and interests, however, many different views may exist as to how to formulate a problem and how to approach it with solutions. An incorporation of all perspectives at an early stage in the decision-making processes shaping the clean energy transition of a region requires the empowerment of regional actors that recognize and understand the technical and economic potential of hydrogen technologies in their respective regional context.

Not only since the current fuel gas crisis has it been clear that key assumptions and framework conditions of the energy transition can change rapidly and solutions that seem attractive today may turn out to be unreliable or economically unfeasible tomorrow. Decisions regarding investment in energy infrastructures with a planned operating period of 15 to 20 years must take into account these uncertainties – so it's even more important to be able to assess the effects of changing framework conditions.

From this line of thought came, during a cooperation between Spilett New Technologies and actors from the regional district Kreis Steinfurt in 2016, the idea of a scenario calculator tool for Hydrogen Regions. They formulated initial ideas of how regional decision-making processes under uncertain conditions could be better supported, and specified the content and concept requirements. It quickly became clear that a fully parameterizable optimization model would be required that reduces the complexity of the topic for the various target groups (energy industry experts, laypersons) and at the same time delivers sufficiently detailed and robust information for decision-making.

In 2019, the Toyota Mobility Foundation was able to be obtained as a sponsor for the development of the H_2 scenario calculator. Under the conceptual direction of Spilett new technologies GmbH, together with the modeling of BBH Consulting AG, software developers at ENDA GmbH & Co. KG and participants of energieland2050 in Kreis Steinfurt, the open-source online tool was developed and validated in the period from 2019 to 2022.

FUNCTION OF SCENARIO CALCULATOR The hydrogen scenario calculator enables regional decision-makers to, in the first step, identify a cost-optimized H_2 infrastructure system through individual configurations (regional energy demand, available resources and government objectives). The aim is to ensure on an hourly basis for a defined target year the hydrogen demand of different sectors under the given regional framework conditions with the goal of security of supply (see Fig. 1).

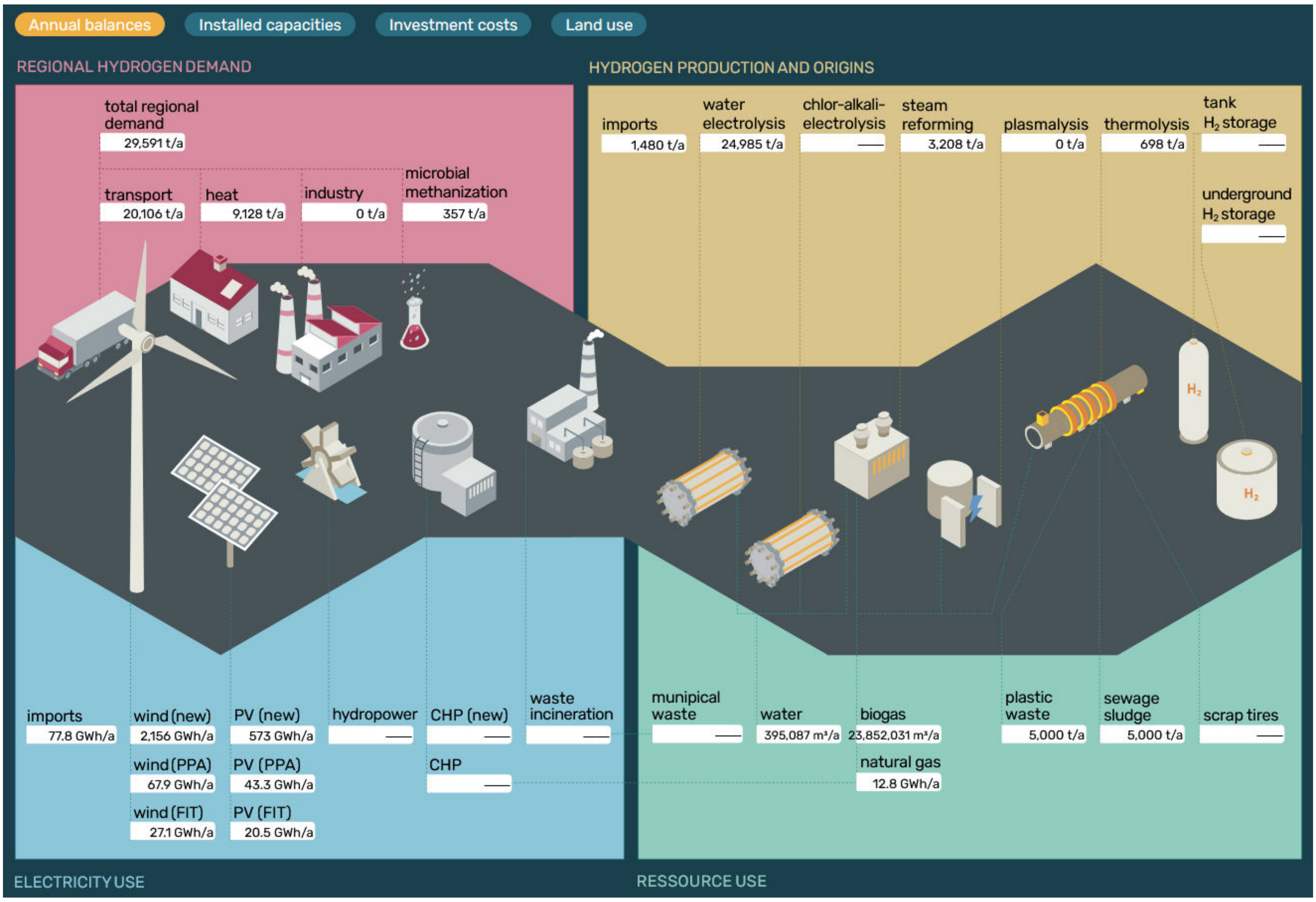

Fig. 1: Overview of results – cost-optimized infrastructure system

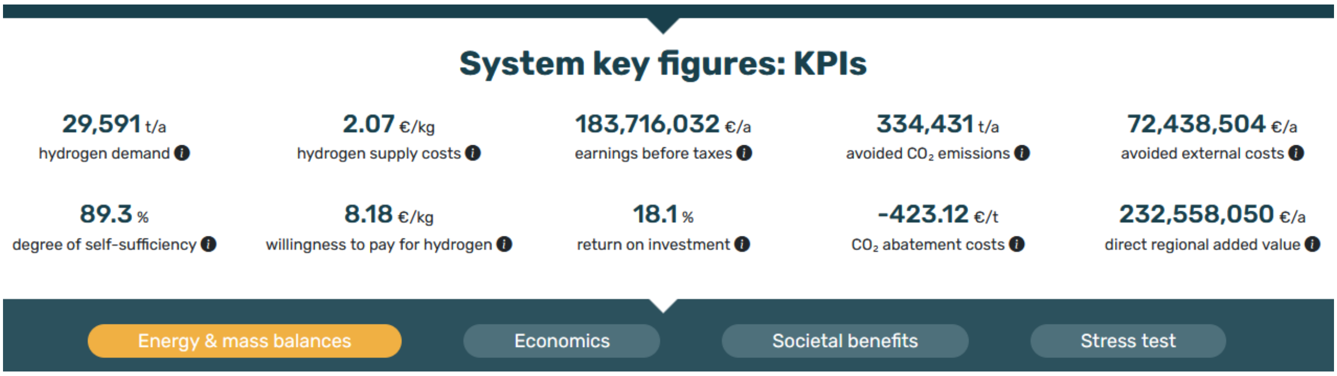

Fig. 2: The ten key performance indicators of the scenario calculator

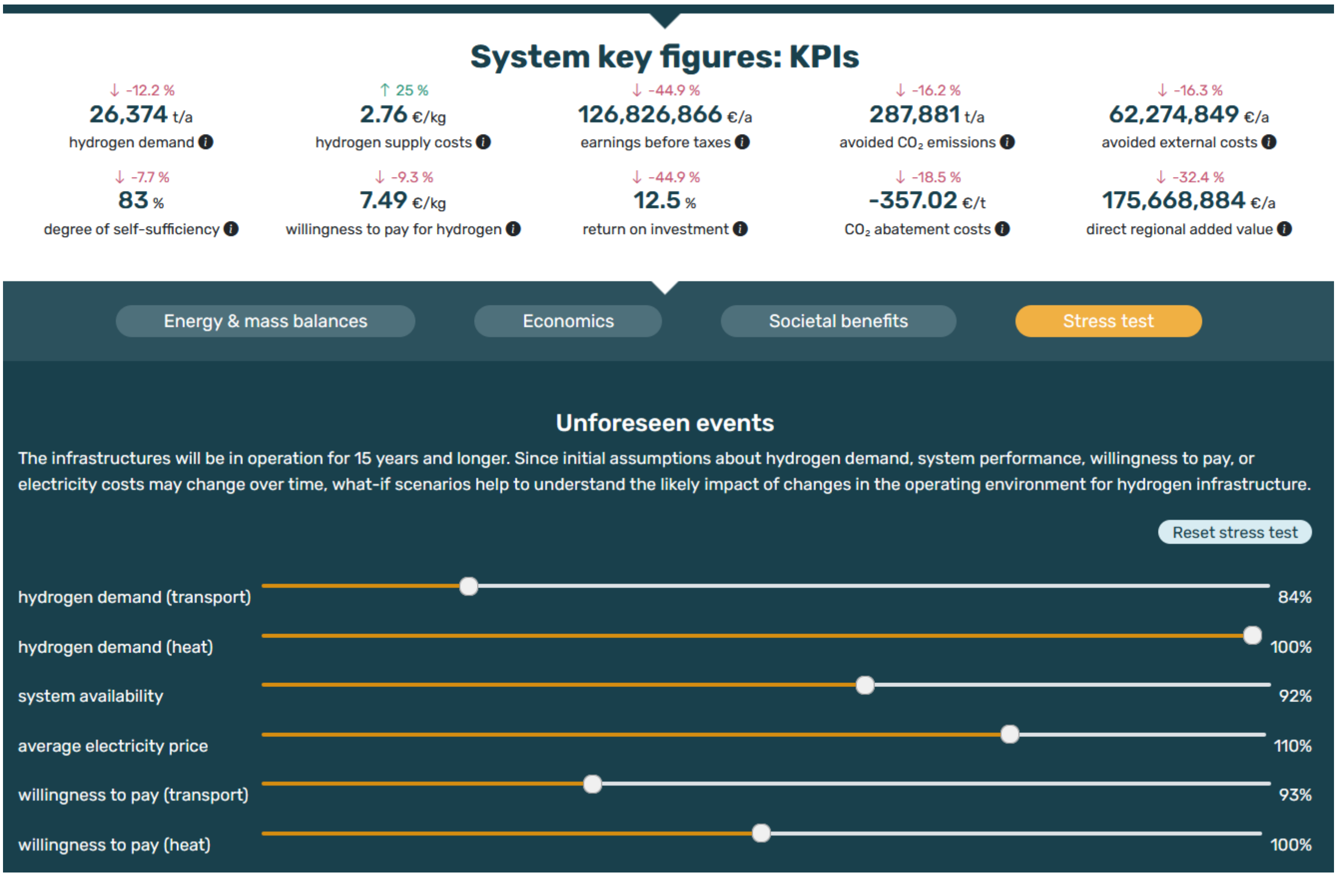

Fig. 3: Key performance indicators with adjustments in the stress test (external events)

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The economic, ecological and social costs, or alternatively benefits, associated with the construction as well as operation of the cost-optimized infrastructure system are broken down and presented in detail in a second step. A two-stage approach was chosen for this purpose:

- Ten key indicators give an overview of the most important economic and ecological performance parameters of the respective infrastructure system (key performance indicators, KPIs, see Fig. 2).
- Information and key indicators itemized by performance area (energy and material flow balances, economic efficiency, societal benefits) deepen the understanding

The results in the area of energy and material flow balances include annual and periodical overviews of hydrogen and electricity origination as well as their whereabouts at a given time. Here, the filling and withdrawal of hydrogen at regional storage facilities is displayed along with possible imports and exports of electrical power and hydrogen to cover temporary bottlenecks.

Furthermore, the quantities of water required for the production of hydrogen via electrolysis or steam gas reforming are shown, in order to avoid competing uses in times or regions where water resources are scarce. The waste heat generated during the H_2 production process is also broken down hourly and serves to support decisions on where to locate production facilities.

The results in the area of economic efficiency include information on key financial performance indicators (e.g. net present value, return on investment, amortization period and turnover), on the hydrogen production costs (broken down by investment costs, fixed and variable operating costs and CO_2 costs as well as taxes, fees and levies) and on the utilization rate of the installed plants (in full load hours for each plant).

The results in the area of societal benefits include information on the expected regional value added directly from

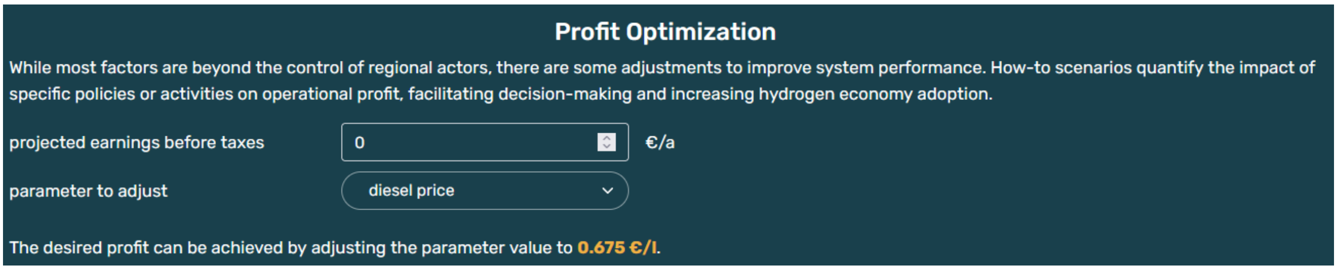

Fig. 4: Break-even conditions in the willingness to pay of the markets or the reference diesel price

operation of the infrastructure system (broken down into regional net income, regional profits and regional share of income tax and trade tax) and the amount of CO_2 emissions saved through the use of hydrogen as well as the avoided external costs as a result (CO_2 emissions, NO_x emissions of the transport sector).

ADDITIONAL FUNCTION: STRESS TEST Together with the actors from Steinfurt, a "stress test" function was defined, as a supplement to the main function, which allows quantification of the effects of changing framework conditions on the economic viability and societal benefits after the H_2 infrastructure has been put into operation. In a third step, the users of the scenario calculator can themselves identify which economic and ecological consequences there are as a result of changing the regional framework conditions during the up to twenty year operational phase of the H_2 infrastructure system. Additionally, this makes it possible to see how much room exists for improving the results of operation.

The changes to basic assumptions of the regional context can be chosen individually or in combination. Their respective impacts on the ten economic, environmental and social system indicators (KPIs) are indicated by the percentage changes to the ideal value, that is the initial value, for better comparability (see Fig. 3).

In order for the actors in politics as well as in society to develop an understanding of how the establishment of the regional hydrogen economy can also be actively supported, the stress test also includes the possibility of defining profit expectations and then of seeing based on selected adjusting screws where developments must be steered (target costs or willingness to pay). In Figure 4, as an example, the break-even case for two posed questions is shown.

SUMMARY AND OUTLOOK The hydrogen scenario calculator has been utilized in the fifteen HyStarter Regions of the HyLand federal support program since the beginning of 2022 and assists the regional actors in their decision-making and in formulation of their respective target systems for year 2030. By informative exchange with the participating regions, the suitability and topicality of the tool was able to be verified. The questions formulated by the Steinfurt actors with respect to the hydrogen economy were confirmed by participating actors in the other regions as being complete and effective for their needs.

The chosen approach of complete parameterization of the input values makes it possible to comprehensively map the current energy crisis by, for example, limiting the availability of natural gas for hydrogen production and flexibly adjusting the energy prices. Also the heat waves and water scarcity experienced in summer 2022 were able to be modelled by a limiting of the water resources and showed the actors alternative paths for electrolytic hydrogen production.

The H_2 scenario calculator is to be made available to all interested regions by the end of the year. In the meantime, interested Hydrogen Regions can contact the project team and get a trial access (szenarienrechner@spilett.com). ||

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ROLLING BEARINGS FOR CRYOGENIC HYDROGEN

Hydrogen cooled well below zero poses particular challenges to the components used, especially the moving ones. The ball bearings of submersible pumps for pumping cryogenic media are examples of such heavily burdened parts. That is why NSK, a company originated in Tokyo, has developed self-lubricating deep groove ball bearings that work without the need to apply a separate lubricant.

Source: NSK

Friction-reducing agents other than the pumped media are not used, which is normally tribologically unfavorable. Pumps designed for cryogenic applications have a double-row bearing arrangement of the pump shaft, where the inner and outer rings are made of special corrosion-resistant steel. The stainless steel NSK bearings have a wear-resistant cage made of self-lubricating fluoroplastic so that cryogenic gases such as GH_2 (gaseous hydrogen) or LNG (liquefied natural gas) can be pumped at down to -200 °C.

The European rolling bearing manufacturer NSK Europe Ltd. now offers a whole range of deep groove ball bearings specially designed for these unusual operating conditions – with shaft diameters from 30 to 100 mm. They tolerate very low temperatures as well as rotational speeds of up to 3,600 min^{-1} and are suitable for hydrogen refueling stations as well as for larger pumping stations. ||

H-TEC SYSTEMS INTRODUCES HYDROGEN CUBE SYSTEM

At Hannover Messe 2022, the company H-Tec Systems, from Augsburg, introduced the Hydrogen Cube System (HCS) to a wide audience. The HCS generates green hydrogen via PEM electrolysis. The modular system is suitable for use in large multi-MW electrolysis plants within the energy-intensive manufacturing and chemical industries or to store surplus wind power.

Source: H-Tec Systems

The Cubes are available as a closed container solution for outdoor installation as well as an open one for indoor installation. They are equipped with 18 S450 PEM stacks as well as integrated process water treatment and power supply. The system can optionally be expanded with a fresh water or hydrogen purification unit or a heat recovery unit, the manufacturer states.

Several 2-MW Cubes can be combined to form a multi-megawatt system. A plant to reach 50 MW in the long term can also be planned and designed in this way. The Cubes achieve, according to H-Tec Systems, a system efficiency of 74 percent. They have an integrated process water treatment and power supply system. An HCS with five units, so with 10 MW electrolysis capacity, can thus produce 4,500 kg of H_2 per day. That makes 40 to 50 truck or bus tanks full. Through the modular construction, several units can be joined together as described and the entire plant can be centrally controlled and monitored.

The HCS is suited, according to H-Tec Systems, for various applications in industrial production such as for chemical plants, for fleet refueling of trucks or buses, or in steel production. Additionally, operators of renewable power plants have the option of using it as a power buffer. A specific example: According to the company's own calculations, a 10-MW HCS could reduce the CO_2 emissions in the steel production industry by 117 tonnes per day and 42,000 tonnes annually.

Because of increasing demand, the Augsburg-based company intends to further expand its production capacity. Together with large-scale plant manufacturer MAN Energy Solutions, with its direct access to the large-series production knowhow of Volkswagen, an automated factory for the production of the electrolysis stacks is to be completed by the end of 2023, H-Tec Systems states. Through this, a production capacity of 1,000 MW is to be achieved, depending on demand, by 2025 – and continuously expanded in the following years, according to the current plans. ||

Fig. 1: MEBC 2022 – start of the Energy Class [Source: MEBC, Carlo Borlenghi]

Category: Education | **Author:** Sven Geitmann

SOLAR HYDROGEN BOAT ON COURSE FOR MONACO

Student-led project encourages sustainable boatbuilding

Thirty-two students from TU Berlin university have set themselves the ambitious task of building a renewables-powered boat by spring 2023 and racing it in the 10th edition of the Monaco Energy Boat Challenge. So far they only have a 4-inch (10-centimeter) model of its two hulls. By June next year they intend to have a seaworthy catamaran complete with electric power system.

It's the perfect setting for innovation: The young WannSea team meets in the cramped rooms of one of TU Berlin's ugliest buildings. Teaching was stopped here three years ago due to the building's state of poor repair, with plaster crumbling from the walls and some areas allegedly sealed off amid asbestos concerns.

And yet the fustier atmosphere, the fresher the thinking. Indeed the students, who hail from various academic departments, will need all the fresh ideas they can get if they are to achieve their lofty ambitions.

LOCKDOWN INSPIRATION The WannSea project, a name that meshes Wannsee (a lake in southwest Berlin) and the Mediterranean Sea, is headed up by Riccardo Petschke. His eyes light up with enthusiasm as he relates his plans and recounts how it all began. The story starts during the pandemic-struck winter of 2020 when all face-to-face lectures were canceled at German universities, forcing the budding industrial engineer to research alternative methods of study. As it turned out, TU Berlin has a scheme in place for "project laboratories" in which a number of students are able to work together on a practical project with a specific theme.

Making the most of his time during lockdown, Riccardo filled out an application and submitted his project idea as part of the selection process in May 2021. His aim was, as it still is, to join with other enthusiasts to compete in the Monaco Energy Boat Challenge or MEBC – and win. He told H2-international: "My aspiration is to create a startup-like atmosphere."

Despite an enormous amount of hard work, his initial application did not become one of the around 10 proposals selected each year by the university's management board. The reason being that his original concept did not give enough weight to sustainability, an aspect which TU Berlin judges to be highly important.

In December 2021, the then 20-year-old tried his luck again, making sure he was better prepared this time particularly on the sustainability front. On this occasion he was successful. The official seal of approval meant that in early 2022 Riccardo, working alongside academic Phillip Rüphmöller, was permitted to offer the project as an optional module to students who could choose it as part of their study program. Riccardo and Rüphmöller also managed to arrange it so that all participants could henceforth receive six academic credits for their involvement.

Then things really started to take off. After advertising his project around the university and on social media, Riccardo received four times the number of registrations from interested students than there were places available. As the project leader, he then had the difficult task of deciding who would be able to join the project. In the end he went for a mix of inquisitiveness and experience, with first-year students omitted. In some cases lots had to be drawn, such was the large demand.

CONSTRUCTIVE GROUP WORK The upshot is an interdisciplinary team made up of 10 nationalities. Formed in the summer semester of 2022, the group first got to know each informally. Since then the band of students has met every Wednesday in a lecture theater situated in the EMH building on the university's Einsteinufer site. The team is divided into five subgroups each of which has a specific focus, with some students, for example, concentrating on the energy unit while others work on the propeller or sponsorship and marketing ideas. Participants present their findings to the rest of the team as well as to one of two members of university staff – Sebastian Ritz and Phillip Rüphmöller.

Of TU Berlin's seven faculties, six are represented within the team, which comprises both undergraduate and postgraduate students. Interestingly, only one shipbuilder is among them. Other students include those pursuing humanities and communication courses and even one person from FU Berlin, another university in the German capital.

DESTINATION MONACO The team's aim is to only use alternative materials such as natural fibers, eco-friendly composite materials and recycled plastics for building the vessel and to only use renewable energy. The biggest logistical question is how to sustainably transport the entire crew and the boat from Berlin to Monaco once everything is ready. Ideas range from train travel to a publicity tour using hydrogen-powered trucks, but the partners needed to make this happen have so far not been forthcoming.

However, the team's efforts should receive a boost at the start of the 2022 winter semester, when the crew is expected to grow to 50 members. They will also be given their own lab which will allow them to finally get started on the practical preparations. In December they are intending to officially send off their race application. The plan is to finish building work by March so that tests can begin on Lake Wannsee in April.

The Monaco Energy Boat Challenge 2023 will then take place in July over the course of three days. The event will see vessels competing in three different categories. In the Open Sea Class, major boatbuilders will race commercial yachts over a distance of almost 19 miles (30 kilometers). Boats powered purely by solar energy will compete in the Solar Class. The Energy Class, in which the WannSea project hopes to sail, has only been in existence since 2018. In this class, all competitors use the same twin hull measuring approximately 16 feet (5 meters) in length and a total of 8 feet (2.5 meters) in width. The main challenge is therefore to design the most efficient and durable propulsion system within the sleekest cockpit.

SUPPORT FROM INDUSTRY Even though it is extremely unlikely that the students will gain a place on the podium or indeed win in their first year, they are intent on trying. "We are the only German team in this class," they state proudly, and express their hopes that they will receive more support from

Fig. 2: It's all about teamwork

local industry. Besides the WannSea team, there are a number of French crews in the lineup in addition to competitors from Dubai, Greece, India, Italy, Canada, Peru, Portugal and the Netherlands.

When WannSea members talk about FaSTTUBe their sense of awe is palpable. Otherwise known as the Formula Student Team TU Berlin, the group, with an annual intake of almost 80 students, has been taking part in race car design contests across Europe since 2005. The expectation is that the WannSea team could achieve something similar in the maritime sector. Hence the young academics hope to one day create a spinoff from TU Berlin that would enable further cohorts of students to gain as much practical experience as possible through similar project work.

Until that day comes, they need to be self-reliant. After winning EUR 500 in a video competition, they have now managed to print their first flyers and are eagerly distributing them at hydrogen network events. According to their own calculations, they would need around EUR 20,000 to take part in the regatta. To win would take an estimated EUR 50,000.

As if the financial hurdles weren't big enough, Riccardo, now a student and a tutor, also has the challenge of finding time to combine the management of the project with his regular studies. Nevertheless, he and his whole team are utterly convinced that they pick up far more from this kind of interactive learning than they do in traditional "chalk and talk" education, which is still the preferred teaching method at large German universities. All those involved in the WannSea project agree that, compared with learning in overcrowded lecture halls with 1,000 or more students, there's much more to be gained from sharing ideas in a student project with 32 like-minded enthusiasts. ||

ELEKTRA

Acting as the patron of the WannSea project is Gerd Holbach, head of the Design and Operation of Maritime Systems department at TU Berlin. In recent years Holbach has made his name as the brains behind Elektra – the first zero-emission pusher boat which was launched in the German capital on May 16, 2022. The academic has been working on the fuel cell craft since 2016 alongside his colleague Anna Loewe (see H2-international July 2016).

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

HYDROGEN AND FUEL CELLS ARE CREATING THEIR OWN TREND AT THE STOCK EXCHANGE – DESPITE INTEREST AND INFLATION FEARS

Sven Jösting's stock analysis

The interest rate hikes in the USA, necessary to combat inflation and already in prospect, is putting stock markets around the world to the test. Such a damper, since this economic development will affect the growth of companies, as consumers will be more inclined to reduce their expenditures. That's sure to the case in many instances, as rising costs for energy and food are placing a heavy burden on numerous households. In the US, consumers, which account for nonetheless two-thirds of the gross national product, are the basis for the economic growth that is therefore based on demand by them. But the US Inflation Reduction Act promises a lot of good things for the H_2 and FC sectors in particular.

The Inflation Reduction Act already in force stands for the topics of energy security, decarbonization and electromobility in the USA and of course provides massive support to companies that are active in the field of hydrogen and fuel cells there. And it is specifically these companies that we cover here in this stock analysis, as they – worldwide – are on the verge of tremendous, sustainable corporate growth. Which of course also has a positive effect on the associated share prices.

Thus, there will not only be losers on the stock market, but also winners with technologies and business models that are good for the climate. And that stand for falling energy prices, when hydrogen as an energy carrier becomes available in ever larger quantities at ever lower prices and competes with fossil energy carriers. At the end of the day, this is then even one of the many ways to counter inflation via falling energy prices, which should please Federal Reserve chairman Jerome Powell, even if inflation in the US is, at the moment, still being combated with rising interest rates.

The shares discussed here might even end up among the winners, since stock traders do not orient their actions only according to the general economic situation, but also assess an individual case or an entire industry according to its outlook. Institutional investors, such as BlackRock, even set this as an investment focus.

Investors with a medium-term investment horizon need not be alarmed by this if they hold shares in the hydrogen economy and should maybe even have bought again, bit by bit, since the trend of this market is very predictable – in a positive sense. On top of that, many of these – examples are Ballard Power and Nikola Motors – are at a low price level. Where – despite rising interest rates – medium-term, the share price is more likely to go sharply up than further down, if the companies would only implement what they themselves forecast. But that's just my personal view of things.

Of course no share can escape a general stock market trend (a bear market due to interest rate expectations), but there are at all times winners and losers. The former will be found on the stock market in the hydrogen sector, because all the arguments are in their favor. And many stocks in the US H_2 and FC sectors are trading at crash levels, when looking at the share prices from the turn of the year 2020/21 in comparison. Which are also in total contradiction to the milestones achieved in the meantime.

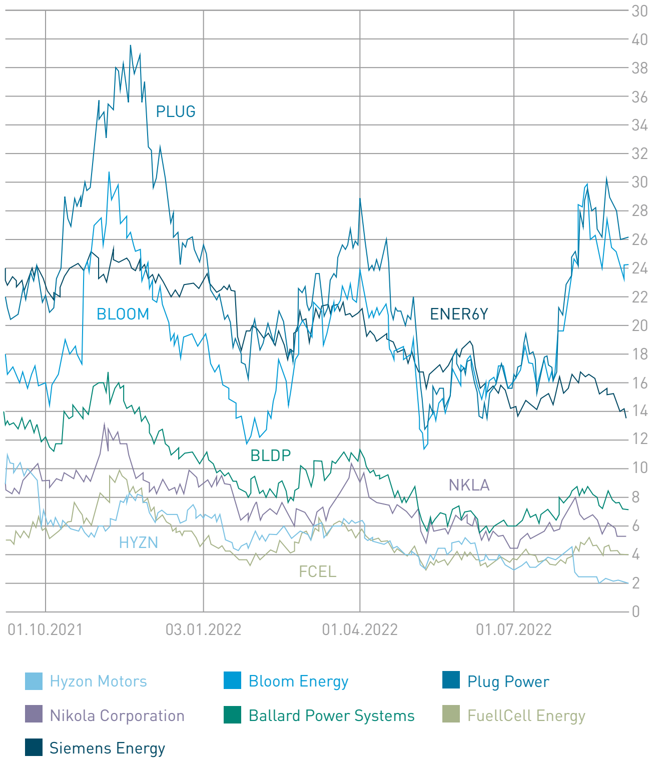

Fig. 1: Share price performance of the companies discussed [Source: www.wallstreet-online.de] Shares on August 7, 2022

AMERICAN CLIMATE BILL FINALLY PASSED The Inflation Reduction Act was the result of a very close vote. In the US Senate, the bill passed with 51 votes to 50 and with ex officio Senate president and US vice president Kamala Harris breaking the tie. On August 12, 2022, the bill passed in the House of Representatives with 220 votes to 207. After its signing by President Joe Biden, the law is now in effect and will lead to the implementation of many a climate-related funding program in the USA. A leg up for companies that are engaged in this topic, and above all for many, if not all, of the companies discussed here.

DRAWN-OUT PROCESS This was initially preceded by a no vote from Joe Manchin. And so he was the only Democratic senator to deny support for the Biden administration's comprehensive plans regarding climate change and thus blocked important decisions, since a stalemate was created between Republicans and Democrats in the Senate. It was like he was the finger on the scale. But now Manchin has agreed to the program upon certain conditions. In addition to the provisions for measures against climate change, there will also be a debt reduction (minimum tax for companies, closing of certain tax loopholes, price negotiations for medications, and more).

In total is a formidable 369 billion USD, which is to be invested in e-mobility, solar power and wind energy (production facilities/projects for solar panels and wind turbines, R&D) but also to promote energy efficiency measures as well as carbon capture. Hydrogen especially is a topic of importance. Here, the range extends from a tax credit of 0.60 USD per kg_{H2} (base rate) for the production of green hydrogen up to a 3 USD per kg_{H2} production tax credit if the facility for green hydrogen meets additional criteria. The aim is to promptly make green hydrogen competitive with hydrogen obtained from natural gas.

Additionally, the act includes funds for research and development of, among other things, electrolysis technologies to make the production of hydrogen more efficient. Forecasts see the H_2 price at 1 to 2 USD per kg_{H2} by year 2030. Instead of claiming tax incentives (tax credits), there is also the possibility for companies to opt directly for payments (grants). Which is good for their liquidity.

On the topic of decarbonization, there will be tax incentives for carbon capture measures (storage/deep well injection = CCS). Here, 85 USD per tonne of CO_2 will be granted. If CO_2 is stored in the earth under gas or oil fields or even experiences another use in industry, it's 60 USD per tonne of CO_2.

The whole program therefore covers perfectly a variety of different areas for decarbonization in the US and that address climate change through technology and market-based approaches. Comparing the program with similar ones in Europe, the US is really stepping on the gas, while Europe unfortunately still seems rather reserved with its programs. Even the 1 to 2 billion EUR set aside in Germany for subsidized purchase of hydrogen from around the world via the project H2-Global pale in comparison to the plans of the US. For the US companies discussed here, like Bloom Energy and Plug Power, the planned new programs are to be seen as a turbocharge for the individual business fields and will have a very positive impact on their share price performances – maybe not tomorrow, but in the future will there be positive effects.

BALLARD – BEFORE DECIDING, UNDERSTAND THE CORPORATE PHILOSOPHY

Ballard Power is going merrily – one could say "unperturbed" – on its way. The Canadian company already has production capacity at its central location in Vancouver in addition to a completed fuel cell production facility in China for, among other things, buses and trucks. Ballard is investing heavily in research and development and is building a network of strategic partnerships that will eventually lead to mass production for various markets.

Concurrently, Ballard is working on the permanent optimization of its FC products. Which will ultimately reflect in lower prices and will make these products particularly competitive as well as widen the profit margin in the course of scaling. All very normal.

After test projects, Ballard will enter mass production with various partners and OEMs. According to information by the company, this will begin in the second half of 2023 and experience a massive ramp-up in the following years, since the markets addressed (commercial vehicles, etc.) have a very high and very long-term growth potential, built on the decarbonization trend.

Fig. 2: Siemens Mobility sold seven Mireo Plus H units to the Heidekrautbahn project in Berlin/Brandenburg [Source: Siemens]

Ballard is doing everything right. Logical losses in this phase of transformation are normal. That must be understood by investors first. Ballard is increasingly making commitments with partners and customers that are not in competition with its own business model and is making a joint course of action in the interest of all virtually inevitable. With around 1 billion USD in the bank, Ballard can very well do all this on its own.

With regard to the Inflation Reduction Act (see above), Ballard is directly participating in several ways. The Canadians are going to build their own stack manufacturing facility in Oregon (4,500 stacks per year as target), in order to be eligible for government incentives (manufacturing tax credits). On top of that, Ballard is benefitting from the tax credit of 40,000 USD for any commercial vehicle with a battery-electric or fuel cell drive. This provision now applies to the entire USA. Accompanying that is a special program in which 1.1 billion USD annually in funding is to be directly invested on buses with battery or fuel cell systems. Ballard is a direct beneficiary here in various ways. Which sets it up for future growth.

MEANINGFUL ENGAGEMENT WITH FORSEE POWER Forsee Power, a French battery specialist that Ballard has a share in, is building another production facility in the US, in the state of Ohio. In a press release, it is explicitly pointed out how perfectly the battery solutions from Forsee synergistically fit the fuel cell applications from Ballard. The two companies are working on complete, pre-integrated powertrain solutions.

Forsee Power saw a very depressed price of around 2.50 EUR in July 2022, which rapidly increased to 4.50 EUR in the past few weeks. The company reports very good figures for the first half of the year: 49.7 million EUR turnover, which corresponds to an increase of 34 percent. Ballard Power is one of the largest shareholders and, at the same time, a strategic partner. Forsee's batteries are perfectly suited for use in the buses of Wrightbus, for which they've received an order for 420 battery systems. In addition, they will likely be put into use in buses by Iveco France as well as 20 trash collection vehicles from Ballard Motive, or even in ships or other applications.

The planning of a production facility in the US is, especially considering the support there from the Inflation Reduction Act, perfect in timing. For 2027, Forsee plans to achieve a turnover of 600 million EUR, according to the current press release. A thought: Would a full takeover by Ballard not also be an option, like Nikola did with Romeo Power, to be better- and more independently positioned?

Ballard partner Siemens Mobility meanwhile reports another order for seven hydrogen-powered trains – Ballard inside. As we heard directly from the company, there will be a new guidance for year 2023 and so on at the investor day in November. This is exciting – we expect a lot to come out of this.

In the meantime, a supplementary appointment was made to the executive board with David Mucciacciaro as Chief Commercial Officer. He worked top positions at Magna, TRW, Lear and ZF, and is expected to drive the commercialization of some of Ballard's FC products.

UNSPECTACULAR FIGURES IN THE SECOND QUARTER

Viewed objectively, the current figures are not very spectacular. They correspond to a time frame in which Ballard is positioned for high future growth. This will really gain momentum in the coming years. Specifically: 20.9 million USD turnover and a loss that, with minus 0.19 USD per share, will affect the books. The order backlog amounts to 91 million USD. Some expected orders have been pushed to the next quarter. For the next twelve months, however, the Canadian company expects "important platform wins." Like with companies such as Siemens in certain markets. From them, large orders are to come in, but also from other markets such as marine and stationary FC systems.

The stock market will allow the expected developments for 2023 onward to unfold in the anticipated price development, is my conviction, based on my own experience. People have to really understand how the company is positioning itself in the new megatrend market of fuel cells and hydrogen. Here, one year is nothing compared to the enormous price potential when production gets to ramping up in all the addressed markets, such as buses, trucks, ships and railways.

Ballard also cannot be compared with companies like Plug, Nel or Bloom, as they have completely different business models. The current turnover is due to pilot projects and small batches, so the number itself, as well as the reported loss, which are based on the large research expenditures (R&D), do not have the relevance that some investors, and also analysts, would like to read in.

Often argued is the disproportion between turnover and stock market valuation. Forget these comparisons. Via Ballard, you can bet on future markets that have a huge growth potential in terms of energy and sustainability (decarbonization). Demand for FC modules and stacks will drive the growth of the company. Special occurrences could also become a driver of the price, for example if Ballard is able to get itself investors like the Adani Group from India or start joint ventures with major companies (platform partners) in various FC markets.

In summation: Do not be unsettled by the low price quotations. Some clear advice: Buy and leave alone, and don't get rattled. Ballard is not making a splash, but will probably achieve its goals, even if it takes longer than expected. The journey is the destination.

BLOOM ENERGY – TURBOCHARGE FROM INFLATION REDUCTION ACT LEADS TO PRICE EXPLOSION

Fig. 3: Independent energy supply via Bloom Energy Server [Source: Bloom]

More is unimaginable, looking at the share price development of the past weeks for Bloom Energy: from 16 USD to over 31 USD, corresponding to a near doubling. The price decline that then occurred was the fault of a type of arbitrage, as Bloom had announced a capital increase at short notice and issued 14.95 million new shares at 26 USD, so traders were able to sell short at over 30 USD and stock up again at 26 USD – a common strategy that explains the recent fall in price.

But the outlook is favorable. The reason is the prospects given by the figures published for the second quarter: Bloom is maintaining a turnover of over 1.1 billion USD for the entire year as well as the targeted growth (30 to 35 percent over the next ten years) and profitability.

The climate plan within the framework of the already passed Inflation Reduction Act is highly instrumental in this. Bloom is benefitting, according to its own calculation, nine ways from the planned subsidy programs of the Biden administration. Specifically:

1. Tax credit and/or grant for H_2 production of 0.60 to 3 USD per kg
2. Sales potential of the Energy Server strongly rises
3. Waste-to-energy segment gets a push to promote biogas applications
4. E-mobility subsidy programs create potential for home/company on-site charging solutions
5. Micro-grid deployment receives boost from tax incentive programs (energy security)
6. Carbon capture tax credits make FC power plants more attractive
7. Tax credit for production facilities in the USA (Manufacturing Tax Credit)
8. Subsidy program for regenerative energies
9. Financing programs for many projects of Bloom's (direct pay and transferability)

Furthermore, news has reached us that a test program with the Idaho National Laboratory of the DOE (Department of Energy) was very successful and has given proof that the high-temperature fuel cells from Bloom yield 30 percent higher performance than PEM and alkaline electrolyzers. The project involved the use of surplus electricity from a nuclear power plant to produce CO_2-free hydrogen from this electricity. For this, Bloom also worked with Westinghouse. It can be assumed that results from these test series will be implemented commercially on a large scale. Westinghouse is technologically involved in over 50 percent of all nuclear power plants.

The increasing demand globally for energy generated CO_2-free is giving wings to all aspects of Bloom's business model. It's about energy security and issues like sustainability. For the pilot project of a dairy farm of CalBio, Bloom received the U.S. Dairy Sustainability Award. Manure and dung from cows serve as the basis for the production of biogas, which is then used in fuel cells and equally as an energy supply source for battery-electric vehicles – all in one. Follow-up projects can emerge from this pilot worldwide.

Bloom sees itself on its best path to offering alternatives in energy production. Also energy security through FC power plants as micro-grids that are not connected to the public grid belongs to the future that many companies, as well as customers such as hospitals and data centers, are counting on. Bloom offers technological solutions. The electrolysis capacity is to reach 2.5 GW by the end of 2023 – an enormous leap for hydrogen.

FIGURES FOR THE SECOND QUARTER Turnover in the second quarter amounted to 243 million USD, which was within the range of expectation. The non-GAAP loss lay at 118.8 million USD, which included, among other things, a depreciation of over 40 million USD. Per share, a minus of 0.20 USD non-GAAP and of 0.67 USD GAAP. And 1 GW of new annual energy output has been installed with the recent opening of the production facility in Fremont, California. There, 400 new employment positions will be created.

With the introduction of the new generation of Energy Servers, the operating profit margin will move, which currently lies at 20 percent (target: 24 percent non-GAAP gross margin). The turnover for the entire year is to rise to over 1.1 billion USD. Which means that the two quarters of the second half will see very high growth.

MOTLEY FOOL ABOUT BLOOM The US stock exchange service Motley Fool has named two companies that are expected to have above-average growth, in terms of stock price performance as well. Bloom Energy is one of them. Many arguments you're already sufficiently familiar with.

The meaning is: You indeed have to go through thick and thin and keep calm, but at the end of the day, the investment pays off. Just look at the trends of the future, and commit to companies that have a leading technological role there and have a growth plan for good positioning in this new market. Bloom has acknowledged the signs of the times with its SOFC fuel cell systems and electrolyzers. With these, clean energy can be gotten – whether via natural gas, biogas or hydrogen. In addition, Bloom also possesses electrolysis knowhow and will itself be producing green hydrogen.

By 2026, Bloom wants to already be making 2.5 to 3 billion USD from sales. And by 2030, it is to be already 8 to 10 billion USD from FC systems alone. A global market on the order of 1.4 trillion USD. Furthermore, 7 to 10 billion USD more is to come through electrolysis, carbon capture technology and maritime applications – with an annual growth of altogether 30 to 35 percent. The gross profit margin Bloom sees at 30 percent and net profit margin at 15 percent.

> "In all its businesses, Bloom Energy has a long growth runway. The company's focus on growth, while keeping costs in check, bodes well for its long-term success, as well as the price of its stock."
>
> *Motley Fool*

MSC meanwhile plans to commission two cruise ships with hydrogen fuel cells. Investment sum: 3.5 billion USD. Maybe Bloom's involved? Soon, Bloom is also building an FC power plant of 1 MW for luxury auto manufacturer Ferrari.

SUMMARY Bloom is well on the way to achieving the high targets it has set itself. Bloom has several big fantasies, which can be traced back to the technological successes of the company. It addresses the right markets and is receiving major support in many new markets from the Inflation Reduction Act. Major customer and shareholder SK ecoplant now needs to send the second tranche in the amount of 250 million USD out of the total investment of over 550 million USD.

Verdict: Any major dip as a result of profit-taking should be used for additional purchases, since the sustained goal of long-term high growth of 30 percent p. a. will also be reflected in the performance of the share price. Special developments might also come through big orders. My goal: 100 USD three years from now, 50 USD in 2023.

NIKOLA MOTORS – SUCCESSFUL VOTE SECURES FUNDING

Nikola Motors is on the right track. Various test trials of the Tre BEV battery-electric models are running successfully with customers like TTSI, Tiyaji Brothers (for Anheuser-Busch), Univar, Road One (for IKEA) and Covenant (for Walmart). So far, everything with 94 percent manufacturing capacity utilization. In the second quarter, 15 Trev BEVs were produced and 48 delivered. The preliminary quarterly turnover lay at 18.1 million USD.

The loss for the quarter lies at 173 million USD. So a minus of 0.41 USD (GAAP) or 0.25 USD (non-GAAP) per share. Included are the legal fees in association with company founder Trevor Milton in the amount of 13 million USD as well as stock-based compensation in the amount of 54.8 million USD. Also strongly increased freight charges of over 13 million USD were a factor in this. In cash and cash equivalents, Nikola had at the end of the second quarter 529.2 million USD at its disposal and additional equity lines (Tumim/3i) in the amount of 312.5 million USD – which together makes 841.8 million USD.

The acquisition of the battery manufacturer and supplier Romeo Power for 144 million USD in Nikola shares still lay within the existing authorized capital of up to 600 million shares. Issued were so far 433 million shares as well as 62 million option rights (employee shares and bonus programs) and 71 million shares set aside for convertible bonds. All these together are then 567 million shares with previously authorized capital in the amount of 600 million shares. Now, it could potentially become 800 million shares, since 66 percent of shareholders at the last annual general meeting voted in favor of this. The issuance of shares can now take place from time to time and bit by bit ATM (at-the-market), but that won't come until 2023 or later, and certainly not at these severely depressed stock prices.

Fig. 5: Modern workspace [Source: Nikola]

ROMEO POWER CREATES INDEPENDENCE Romeo Power was acquired in exchange for shares, so purely with Nikola's own equity. Romeo should have the potential to sink the annual costs for batteries by 350 million USD by 2026. Together with Romeo Power (former top talent from SpaceX and Tesla had founded the company), Nikola plans to go double-track with the batteries. Romeo, with its production site in the US, is to serve this market, while battery supplier Proterra is to be Nikola's partner for the European market.

The price to purchase Romeo Power, an equivalence of 144 million USD, corresponds to just nine percent of the stock market value achieved in the meantime. On top of that, Nikola is giving a liquidity grant in the low two-digit million-dollar range to Romeo. What does Elon Musk (Tesla) think of this? Isn't he himself planning to introduce a battery-electric truck?

ESTABLISHMENT OF AN H_2 INFRASTRUCTURE In the second quarter, six beta copies of the hydrogen-powered Tre FCEV were sent out for testing. Mass production of these will not start until the second half of 2023. Before that, the H_2 fueling stations must be in place. An installation, according to information by the company, takes more than a year, because of the approval process.

So far, the company has launched three H_2 fueling stations in California, which are to be in operation the fourth quarter of 2023. So perfect timing in solving the chicken-and-egg problem and freeing hydrogen production. Nikola will operate some H_2 fueling stations itself, but also many with partners. Partnerships for this with oil and gas companies are still to come in the current second half of the year.

The Biden administration's climate act is creating US-wide tax incentives that stretch up to 3 USD per kg of hydrogen. In California, there is an additional subsidy of 3 USD on top, so in total 6 USD per kg can be gotten there. Nikola is assuming that it can self-produce hydrogen for 3 USD per kg. That makes for a very high profit margin.

The factory in Coolidge, Arizona is to have a capacity of 20,000 trucks at the end of the first quarter of 2023 – of both types, the battery-electric and the hydrogen-powered. And it is to be 45,000 units altogether in 2024.

Meanwhile, it became known that out of the cooperation with Iveco in Ulm, Baden-Württemberg – a contract manufacturing agreement – is to now come a closer joint venture, with joint engineering and joint production. My take: Something is coalescing there. Is Iveco, or alternatively parent company CNH, increasing the share in Nikola, which has been 6.7 percent for some time now?

LOHSCHELLER JOINING THE PRESIDENTS Board chairman Mark Russell – he pulled Nikola out of rough water (holds about 9.6 percent in Nikola, a value of 260 million USD) – remains on the supervisory board, but will leave his post of CEO to Michael Lohscheller on January 1, 2023 (see also H2-international August 2022). Lohscheller had led the refurbishing of Opel, which today is part of Stellantis. Steve Girsky, former board chairman of GM Europe, is becoming chairman of the supervisory board at Nikola.

FOOD FOR SPECULATION Interesting in this context is that it was General Motors (GM), who was interested in a cooperation with Nikola at the time of CEO Trevor Milton, that was spoken ill of. As it goes, they wanted to build a hydrogen-powered SUV together, and GM was to receive a Nikola share package equivalent to the value of the activities (production/contract manufacturing). The deal fell through for a number of reasons, which are to be found in Milton's personage.

Could perhaps a cooperation offer itself again, though, with solid support from the top managers of Nikola? This already sounds propitious, since Nikola's strategy, to offer electricity and hydrogen itself as an energy solution (consumable) and to establish a unique infrastructure network for this, is gaining imitators. Getting involved could give it some speed.

What if Tumim/3i, a VC fund, has started or plans to look for another address for the investment in Nikola (maybe GM or CNH/Iveco?), passing the package on with a markup? Even Tesla could be interested in buying Nikola, after all arguments are weighed. While all vehicle manufacturers have their own strategies for commercial vehicles like trucks, they may find joy in strategic investments in infrastructure and alliances.

Nikola formally offers itself for all this, as the listed market value of 2.6 billion USD is far from the earlier, majorly overstated assessments and there is the opinion that the current stock market value now only reflects the battery area. Former GM managers Lohscheller and Girsky will ensure a new reputation for the company. Does Trevor Milton know something more? He very recently bought 3 million more shares at the price of 5.80 USD per share.

SUMMARY The stock market still needs convincing, as the share price went from under 5 USD to over 8 USD and then back down below 6 USD. Again were a whopping 78 million shares (mid-August) sold short. If something spectacular were to happen, then Nikola could again be valued completely differently and much higher. Overall, everything is on track. Highly speculative with high hopes.

PLUG POWER – MANY POSITIVE EFFECTS

Plug Power sees enormous potential for the company arising from the Inflation Reduction Act, as it benefits in a variety of ways from it. These are research grants, tax incentives, subsidies for hydrogen, or tax support for new production facilities in the US (manufacturing tax credits).

At the end of the second quarter, Plug remained at a minus of 173.3 million USD (previous year: minus 99.6 million USD), or a minus of 0.30 USD per share. Reported loss: 329 million USD in the first half of the year. This is certainly also due to the massive investments made by Plug in various projects and in the development of production capacities (gi-

Fig. 6: FC forklift truck with H_2 refueling station from Plug

gafactories). After all, electrolysis capacities to a volume of 1.5 GW are now in the books, as we have reported. Turnover is to reach 900 to 935 million USD this year, mainly stemming from large customers like Amazon. In the bank still lie funds in the amount of about 3 billion USD, which however corresponds to a high capital outflow. At the stock market, Plug is again valued at over 17 billion USD.

With Amazon, Plug recently concluded an offtake agreement for 11,000 tonnes of hydrogen per year. With this, 15,000 forklift trucks can be powered. There is to be a total of 20,000. And the so far 70 shipping centers in which forklifts are driven for Amazon is to grow to 100. For the end of 2022, Plug forecasts being able to itself produce 70 tonnes of green hydrogen per day.

The share will move with the news developments in the hydrogen segment, even if many expectations about the future have already made it into the stock market valuation.

SHOCK FROM HYZON MOTORS

The figures for the second quarter should be published August 15, 2022 at the latest, but Hyzon surprisingly reported that certain sales in China were not followed through in time to be able to be booked ("revenue recognition in China") and that there are "operational inefficiencies" at Hyzon Motors Europe B.V., the subsidiary in Holland. Earlier statements (balance sheet publications) are therefore invalid or obsolete for the time being. This is a real shock after all the news about orders, corporate partnerships, production ramp-up and the recent acquisition in Germany.

CRAIG KNIGHT HAS LEFT HYZON Hyzon has time from now to October 14, 2022 to file the necessary figures for the second quarter as well as the corrections for the previous quarters with the SEC (US Securities and Exchange Commission) and Nasdaq. After that, there is an optional extension of 180 days if the deadline cannot be met.

That the board chairman, Craig Knight, is immediately leaving the company, having been relieved from his post, suggests that something major must have gone wrong. The new chairman will be Parker Meeks, who was previously chief strategy officer – a McKinsey man with an impressive career. He will temporarily lead the company as interim CEO until a suitable new CEO is found.

ACQUISITION OF THE ORTEN GROUP The expansion of the company is proceeding according to plan despite the aforementioned problems, as the production facility in Rochester, NY and Chicago, IL demonstrate, as well as the start of MEA (membrane electrode assembly) production in the US and the current job ads for new personnel suggest. Hyzon has additionally received a funding decision and can now apply for state subsidies for trucks in the US (California and New York).

In order to better position itself in Europe, Hyzon has acquired the ORTEN Group (ORTEN Betriebs-GmbH and ORTEN Electric Trucks GmbH), one of the pioneers in the conversion of used and new diesel to battery-electric and hydrogen-powered trucks. With this, 80 employees have moved over to Hyzon, and it is also a good complement to the activities in Holland. Hyzon Europe ORTEN makes mainly trailers and truck conversions for the beverage industry of up to 26 tonnes load weight. Hyzon is thus also entering the battery-electric sector, like Nikola Motors has already. The aim is to be able to offer the shipper or truck buyer several options. The retrofitting of existing vehicles (chassis of diesel trucks) seems an important optional step. Thus Hyzon is addressing the right market and wants to be active not only in Asia but also in Germany and Europe.

COOPERATION WITH SCHLUMBERGER Major corporation Schlumberger is known mainly for oil drilling, where it is one of the heavyweights. Now the two have started a joint development program in which Hyzon's FC stacks are to be put into use in various heavy devices and vehicles as well as oil drilling platforms (rigs) for Schlumberger. These can be energy systems on drilling platforms as well as other heavy-duty equipment. The goal is to operate a drilling platform completely with hydrogen energy-wise (2.5 tonnes per day).

In the fourth quarter of this year, there will be a first joint showcase project, according to the press release. Typical 4-MW diesel generators are to be replaced by fuel cell systems. With such partnerships, new emphases are to be set. It's an accolade for Hyzon to be running a test series with a company like Schlumberger and perhaps then receiving larger orders. I would rather have seen a company like Cummins Engine in this position, only theoretically. But for Hyzon, this is a good and important step by which to bring its own FC technology to a wide audience.

In addition, there will be a memorandum of understanding that will be filled with content from a concrete project. In the coming twelve months, the Schlumberger subsidiary Ensign Energy Services Inc. will integrate a Hyzon FC system into an existing oil platform. Side note: Hyzon developed its own fuel cell technology throughout more than 20 years of research and is therefore not dependent on suppliers of such.

It is clear to us that the company, after all matters have been clarified, is executing its corporate strategy as planned, as already indicated by the presence of the interim CEO at

"The Company's Board of Directors (the "Board") appointed a committee of independent board members to investigate, with the assistance of independent outside counsel and other advisors, certain issues that were brought to the attention of the Board by Company management. These issues include revenue recognition timing, presentation, internal controls and procedures, primarily pertaining to its China operations."

Hyzon

Fig. 7: DB Schenker intends to rent out Hyzon trucks via hylane [Source: hylane]

specialist conferences. The share will certainly remain very volatile, owing to the existing uncertainty. Should after deduction of all possible losses and after balance sheet adjustments, among other things, the cash on hand still amount to over 300 million USD – it was over 400 million at the end of the first quarter – the stock exchange should take this into account in the valuation of the company.

I would say: Buy on bad news – but only for investors with a very speculative attitude and traders who know how to use daily fluctuations in the share price to their advantage. The course will have to be a bumpy ride – a roller-coaster ride. Perhaps a competitor is also using the situation to get on here and take advantage.

Investment banks like JP Morgan have of course revised their estimates downwards following the latest publications, though do not advocate selling now and completely breaking up with Hyzon. Is a 400 to 500 million USD loss in value at the stock market justified by the current situation of uncertain information? After all, Hyzon has many high-profile investors. In addition, blocks of shares held by insiders account for more than 60 percent of shares issued.

We're going crazy: On the one hand, the important trust in the company is lost until clarity (figures, financial statements) is achieved. There may be adjustments for certain financial transactions (stock purchase by Holthausen and transformation of Hyzon Motors Europe B.V.?), if therein lies the problem – and only if. What's clear: Class action lawyers may be able to take advantage of the situation. Rejoicing are the short sellers, who in the meantime had bet about 20 million shares on a price drop. On August 5, 2022 alone, the share price fell by over 38 percent. Now short sellers can profit massively from this, while some others might also think of tucking in until the time the company provides clarity.

FUELCELL ENERGY – BIG DREAMS WITH CARBON CAPTURE

FuelCell Energy sees itself as a leader in the CCS sector, where it is a frontrunner as a result of having its own carbon capture technology. With ExxonMobil, FCE has been active in such projects for years. Now the new climate protection program by the Biden administration may provide new potentials for orders, since the tax incentives, with amounts of 60 to 85 USD per tonne of CO_2, signify for many affected businesses an impetus, but also a pressure, to upgrade here technologically.

True, it would be logical for cooperation partner ExxonMobil to exert some positive pressure here, but follow-up orders have so far failed to materialize – they're only doing research together. But also clear: There is now another incentive to avoid CO_2 emissions, because you could be charged with penalties otherwise. For FuelCell Energy, this is surely a turbocharge for new orders, along with the incentives for the use and storage of emitted CO_2.

For now, we're waiting until there are concrete orders. The Inflation Reduction Act will have a positive effect either way. The company, however, must prove this with orders. Currently, it's valued at about 2 billion USD. With over 400 million USD in the bank, FCE takes sufficient account of current developments. For comparison, Bloom Energy has an order backlog of over 8.5 billion USD and already makes 1 billion USD turnover. According to statements by the company, FCE plans to generate a turnover of 300 million USD by 2025, and increase this to over 1 billion USD by year 2030, with a simultaneous sharp increase in profit margin.

SIEMENS ENERGY – SHARE PRICE DEVELOPMENT ANTICIPATES THE FUTURE

The integration of Siemens Gamesa will not be a quick job. The attributable losses will still burden the results of parent company Siemens Energy for several quarters. That is, until the results of the reorganization, the pooling of purchasing power (cost reduction potential) and other measures are reflected in better figures, according to our analysis. Because what ultimately counts is the stimulation of the growth of the corporate group as a whole, and this could not be better, at least in the area of hydrogen.

Interesting is that the share price has left its low and is gradually changing direction – because the stock market anticipates the future. The reported loss of 533 million EUR in the third quarter (fiscal year) is therefore still primarily attributable to the problem-making subsidiary (minus 446 million EUR), but also to the account of one-time effects like the termination of activities in Russia at a cost of 200 million EUR. Supply chain problems and increased costs for supplies and raw materials will continue to accompany the Group.

Nevertheless, the order books are full to bursting and, according to other calculation models, will lead to high-margin turnovers. The planned staff reduction (2,500 positions) will also have an impact. There are also many real synergies that can be leveraged if there is a combination of wind turbines and electrolyzers out at sea at the same time, enabling production of hydrogen at low cost and stationing Siemens Energy as a one-stop shopping partner for customers that are interested in total solutions. Managing director Christian Bruch accordingly described the order intake as "fantastic." Verdict: For us, a clear "buy on bad news."

COOPERATION WITH AIR LIQUIDE With the joint venture of Siemens Energy and Air Liquide, two heavyweights in the area of hydrogen and electrolysis are joining forces, with Air Liquide holding 25.1 percent and Siemens 74.9 percent in the JV. Together, the two companies want to get going a production facility for PEM electrolyzers at the site in Berlin. In addition, joint research activities in the field of electrolysis are being established. They are planning joint H_2 projects like a 200-MW electrolyzer in Normandy. They intend to jointly apply for funding support from the EU. Verdict: Such JVs, in which complementary players jointly develop projects, will now become more and more common in the hydrogen industry (see p. 6). There, Siemens Energy, and likewise Air Liquide, have the best of positionings.

Fig. 8: At a premiere celebration for Clean Logistics's fyuriant (see p. 34), André Steinau, managing director of GP Joule Hydrogen, announced to H2-international that its parent company had just reserved 40 assembly stations for 40 fyuriants: "We will solve, with the production of H_2, the building of H_2 refueling stations and the offering of vehicles, the well-known chicken-and-egg problem." Shortly afterwards, CL and GPJ signed a framework agreement for the supply of 5,000 H_2 trucks.

HYDROGEN STARTUPS

Startups in the hydrogen and fuel cell industry, such as Enapter, Lhyfe and Clean Logistics (see fig. 8), have received fresh equity via the stock exchange to implement their business plans and to evolve robust company stories from mere visions. The stock exchange is indeed also the right place to spread the investment risk over many shoulders (institutional and small shareholders). Investors willingly provide the necessary capital so that they can push along the company's growth with their own strength.

Further share issuances have a high probability of following, in order that the company can perfectly finance things itself. The company often has, through the IPO and the stock market listing, quite generous company valuations, calculated by the total number of shares multiplied by the stock market price. Here, it must be taken into account that the number of freely available shares – the free float – almost always comes out to be very low and the overall valuation of the company on the stock exchange therefore corresponds instead to a theoretical value, since the vast majority of shares are held by the company's founders and management.

An investor in these stocks will have to think about how long they plan to hold the investment. Because these companies will initially write losses, as a result of the use of capital obtained via the stock exchange. There must first be a building up of production capacity, which must be done from scratch. In addition, specialist personnel are needed to turn the plans into reality. Is it therefore possibly better to realize quick price gains after the IPO (initial public offering)? Can the companies constantly come up with (good) news, which is a prerequisite for higher, so raising of, share prices?

In a nutshell: The abovementioned shares are better acquired as a package via a fund, since with the spread of risk over many different stocks in the area hydrogen and fuel cells, the overall trend and a whole industry can be better assessed than in the case with individual stocks. In such funds are of course also heavyweights that are blue chips at the stock exchange and, with their lower volatility, provide a balance to the strong price fluctuations of the small stocks. Examples here are Siemens Energy, Linde, Air Liquide, Weichai and Cummins. Because clear is: Small companies in the startup range with the designation small- or micro-cap are much more volatile in their price performance than stocks with very high market capitalization. With a fund, this volatility is balanced out or minimized, since investors participate in the overall trend of this strongly growing segment by raising the prices.

Additionally, a sensible strategy may be to not make a one-time investment, but rather to build up an invest over a longer time period, for example monthly tranches. This would make use of the so-called cost-average effect (dollar-cost averaging). You gain a good average price course over time from the fact that the fund is always valued differently, so you receive more or fewer shares for the same monthly investment amount. With a horizon of ten years or longer, you are statistically always right, as this time period will see some bull markets and some bear markets and you can buy again at sometimes high and sometimes low prices along the course and obtain a very good average annual return.

Also to consider: For hydrogen and fuel cells, the megatrend on the stock market is just beginning. This means that such investments have above-average potential to increase in value and can be dubbed "sustainable." ||

DISCLAIMER
Each investor must always be aware of their own risk when investing in shares and should consider a sensible risk diversification. The FC companies and shares mentioned here are small and mid cap, i.e. they are not standard stocks and their volatility is also much higher. This report is not meant to be viewed as purchase recommendations, and the author holds no liability for your actions. All information is based on publicly available sources and, as far as assessment is concerned, represents exclusively the personal opinion of the author, who focuses on medium- and long-term valuation and not on short-term profit. The author may be in possession of the shares presented here.

Category: International | **Interview Partner:** Cornelius Matthes

HYDROGEN FROM THE DESERT

Interview with Cornelius Matthes, CEO of Dii Desert Energy

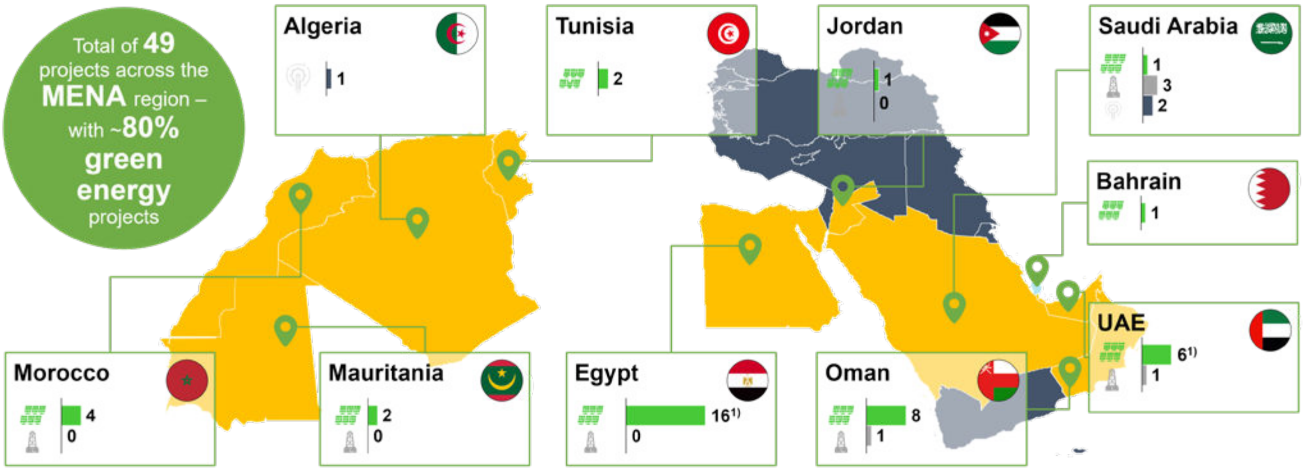

Fig. 1: Projects announced for H_2 production in the region Middle East/North Africa (MENA) – Countries with hydrogen projects are shown in yellow, countries without known hydrogen projects are gray. By "yellow hydrogen" is meant H_2 generated from waste.
[Source: Dii Desert Energy, business consultancy Roland Berger – no claim to completeness]

When the German companies exited the Desertec Industrial Initiative in 2014, many had considered the project a failure. But the network has developed further – and will now also be visible again in Europe, as Dii Desert Energy. Is now when energy will come out of the desert?

In 2009, the Desertec Industrial Initiative (Dii) started, with a lot of media hype. Especially German corporations wanted to build solar power plants in the southern Mediterranean countries. Concentrating Solar Power (CSP) was the technology of choice at the time. It was cheaper than photovoltaics and could, with thermal energy storage, produce electricity continuously. The power plants were to supply electricity not only to the region, but also for export to Europe.

But it went more haltingly than some had hoped. Most of the German companies, among them Deutsche Bank, MunichRE, Eon, Bosch and Siemens, left Desertec in 2014 – still during the construction phase of the solar plant Noor in Morocco. Innogy remained as the last German company, until its acquisition by Eon and incorporation into Dii.

Since then, hardly anything has been heard in Germany of Desertec. Many got the impression that the idea had been abandoned. But in fact, activities have since shifted increasingly to the Arabian Peninsula and the new office in Dubai – even if the official headquarters of today's Dii Desertec Energy GmbH is still in Munich. Also there meet the core members of the initiative for a conference year after year. Dii founder and president Paul Van Son as well as Cornelius Matthes, CEO of the organization since January 2021, courted the idea of desert energy with the oil states of the Persian Gulf.

Today, Dii Desert Energy is a political and economic network that stretches over several continents in which many major companies from the energy and hydrogen industries are engaged. For a long time, the shareholding partners were exclusively the Saudi Arabian state-backed energy corporation ACWA Power and the Chinese utility State Grid. To the "Lead Partners," the gold sponsors so to speak, today belong four holdings, of which two are from Saudi Arabia, one from Morocco and one from the Netherlands. The extended circle consists of a good 50 "Associate Partners." Among them are research institute Fraunhofer ISE, PV manufacturer Suntech, Shell and the Norwegian H_2 company Nel. Also Thyssenkrupp, as a market leader for electrolysis plants, had been one of these partners since 2017 – and became a shareholding partner at the beginning of 2022. That made the German press, after a long time, pay attention again.

The desert power grid has also changed technologically. Instead of plans for power lines, Dii Desert Energy presented at the beginning of 2020 the "MENA Hydrogen Alliance." It's for ammonia and methanol in addition to green hydrogen. Van Son, however, stressed that electricity generation is still a substantial part of the Desertec vision today – also and especially for local needs. Depending on the distribution of peaks in the load profile, he also sees a niche for solar thermal power plants in some regions.

The portents for energy coming out of the desert are better today than they were during the first attempt. The pressure for climate protection has grown strongly. Governments and businesses around the world have already included in their climate plans megatonnes of green hydrogen as replacement

> Jorgo Chatzimarkakis of Hydrogen Europe called years ago for hydrogen pipelines that would transport fuel gas from Africa to Central Europe and stated, "We (Germany) will be an importing country of renewable energies, but an exporting country of electrolyzers." On the other hand, Carsten Körnig, managing director of BSW Solar (German solar association) said that to import renewable energies in large quantities would not be possible, because other European countries would also stake demand for it. Because of this, according to Körnig, more emphasis should be placed on domestic green electricity generation. (S. Geitmann)

for oil and gas. And concrete projects are also popping up ever faster on the map. The best known of these is probably the futuristic conceptualized city Neom, which is to appear in the Northwest of Saudi Arabia on the Red Sea. Wind and solar power plants with a capacity of over four gigawatts are to supply not only the city. Also, around 650 tonnes of hydrogen daily is to be generated in Neom, mainly for further processing to green ammonia.

As to the participating businesses and persons, the same names can always be encountered. The electrolyzers are to come from Thyssenkrupp. Managing director of the project partnership is Peter Terium, formerly with Innogy and RWE. Project partnership Neom, the energy corporation ACWA Power and the technical gas producer Air Products announced in July 2020 that they would together invest 5 billion USD in the project. Construction has now begun – operations are to start mid-decade.

To learn a little more about the current status of this project, H2-international interviewed Cornelius Matthes, the CEO of Dii Desert Energy.

H2-international: Mr. Matthes, you say in lectures and publications that companies involved in Desertec will within this decade be able to supply the quantities of hydrogen that Europe requires. It sounds sincere. What is the basis for your confidence?

Matthes: We know the announcements and plans of our partners. These include projects such as Neom Green Hydrogen, which alone is to produce 650 tonnes of hydrogen daily, but also other projects from ACWA Power, Masdar, DEME, Linde or EDF. These are large companies whose track records show that they can handle such projects. If we include projects that are already between the stages of announcement and implementation planning, that comes to more than the 10 million tonnes per year that Europe wants to import by 2030. With the introduction of the Hydrogen Accelerator, as part of the REPowerEU plan, the production and import targets for Europe have been approximately quadrupled. That means, from the 2x40-GW initiative that we, together with our partner Hydrogen Europe, presented to Frans Timmermans in April 2020, is now a 2x160-GW initiative. So by the end of the decade, the MENA region will be able to supply the hydrogen that Europe needs.

Production capacity is one thing. But for green hydrogen to become an alternative to fossil hydrogen or other energy sources, it must also be affordable.

Our CTO Fadi Maalouf has developed models to calculate the costs of hydrogen, e-fuels and ammonia. Included are the announced H_2 production costs for the projects planned for the coming years. Neom wants to produce hydrogen starting 2026 for about 1.5 USD per kilogram. That's very ambitious. In Morocco, according to our model, costs under 2 USD per kilogram are possible. In Egypt, it could be a little more. Overall, however, we assume that there are many locations in the MENA region that will be able to generate hydrogen for 1.50 to 2.50 USD per kilogram by the middle of this decade, so the mid-2020s.

Then, however, the hydrogen is still in North Africa. By what means and at what cost does it come to Europe?

A transport by ship, including conversion, according to our estimate, would cost 1 to 2 USD per kilogram. With a pipeline, it would be significantly cheaper. If considering a new pipeline that would transport hydrogen from Egypt, Saudi Arabia and Jordan across the eastern Mediterranean, to be fed into the planned Hydrogen Backbone in Europe, the transport costs would lie at 50 US cents per kilogram, calculating over the entire lifetime of the pipeline, including capex and opex. With low production costs, as projected for Neom or even for later projects, it will therefore be possible to bring hydrogen all the way to Central Europe for 2 USD per kg.

The data on this comes from industry insiders in the oil and gas sector, like the King Abdullah Petroleum Studies and Research Center (KAPSARC) or ILF Beratende Ingenieure. ILF has already planned some pipelines in the region and can therefore make realistic assumptions on the costs. A possible specific route for the Africa-to-Europe line has also been quite well investigated.

Wouldn't it be easier to repurpose existing pipelines or to blend the hydrogen into them?

There are parallel initiatives to repurpose existing lines and, for example, to bring hydrogen from Morocco to Spain. But just the current supply relationships alone are politically very complicated. Normally, gas from Algeria flows through

Morocco and the Strait of Gibraltar to Spain. But Algeria has broken off diplomatic relations with Morocco and also stopped the supply of gas to it in November 2021, so Morocco was cut off from the direct means of supply. Now instead, Algerian gas comes first to Europe and then via Spain to Morocco. At the same time, Algeria is actually to be delivering more natural gas to Europe.

Also the blending of hydrogen in natural gas lines will presumably not play a large role. The natural gas would indeed be somewhat "greener" this way, but the real value of the flexible raw material that is hydrogen would be lost. That's why this form of transport is not very attractive.

Nothing further needed there. So can we do without the billions in subsidies for the hydrogen economy?

It will not work without political support. Above all, a secure supply of green hydrogen needs to be ensured in Europe for the projects to be economically attractive – aided by clear regulation as well as internationally well-coordinated certification. The current Delegated Acts on hydrogen of the EU is rather an example of how to delay the necessary development. Countries like India act much more pragmatically here. Also the countries along the route need to be on board, particularly Greece, where the pipeline would come ashore, and Italy. Guarantees and private-public partnerships would be necessary. Many discussions are already underway, and I think the COP27 climate conference in November will bring further progress. Clear is that the major infrastructure changes must be on the political agenda – they won't happen on their own.

This kind of thing can take time. How will hydrogen be coming to Europe in the next few years?

Pipelines, ammonia and e-fuels are all technologies for this decade. Besides pipelines, the most developed technology is definitely ammonia. There are over a hundred ships around the world that can carry it, many import and export terminals, and also a storage infrastructure. For the direct use in the chemical industry, for example at Covestro or BASF as well as the fertilizer industry, this is ideal. The technology reaches its limit when the ammonia is to be converted back into hydrogen. The cracking is energy intensive and not yet established on a large industrial scale.

LOHCs, that is Liquid Organic Hydrogen Carriers, also have a chance, but their success hinges on still many open questions. Liquid hydrogen, on the other hand, will not have a role in this decade. The technology is not yet mature enough for mass production. The test ship from Kawasaki has shown that intense development of many components is still necessary. But liquid hydrogen could have more significance in the 2030s. ||

Interviewer: Eva Augsten

Fig. 2: Cornelius Matthes [Source: Dii]

Cornelius Matthes studied business administration and has been on the management team of the Desertec Industrial Initiative (Dii) since 2010 and CEO of Dii Desert Energy since January 2021. He started his professional career at the Deutsche Bank Group. As Managing Director MENA for the Italian project developer Building Energy from 2013 on, he established a new location for them in Dubai. Starting in 2016, he has also been founding his own project development and investment companies for renewable energies with various partners. Matthes advises renewable energy companies and investment funds, is a guest lecturer at various universities and was named Solar Pioneer 2015.

| **Category:** International | **Author:** Aleksandra Fedorska |

HYDROGEN PRODUCTION IN ROMANIA

The role of the Three Seas Initiative and Dobrogea

While most countries in Western Europe laid out their strategies for hydrogen extraction some time ago, this southeastern member of the European Union has yet to take this step. Indeed the Romanian government isn't planning to announce its hydrogen strategy until 2023. Huge potential exists for Romania to excel in the production of carbon-free hydrogen, however, given the country's impressive sustainable energy mix.

In 2021, over 30 percent of Romania's electricity consumption was met by hydropower. Almost 20 percent of electricity generation is provided for by nuclear power plants. And wind power, at over 11 percent, accounts for a significant share which is also growing rapidly.

Despite the lack of a national strategy, hydrogen development is well underway in Romania. The infrastructure side is being supported by the Three Seas Initiative or 3SI. This project has been actively involved in all EU states located between the Baltic, Adriatic and Black seas since 2016. It aims to promote cooperation on the implementation of major infrastructure schemes which will connect the region economically and drive it forward.

One of the ways in which 3SI has provided assistance is by helping grid operator Hidroelectrica Romania establish a joint venture for the construction of hydrogen pipelines. What's more, Hidroelectrica has been taking part in the Green Hydrogen @ Blue Danube project alongside Austria (see fig. 1). Within the framework of the European Commission's Important Projects of Common European Interest or IPCEIs, the states in the Danube region and in southeastern Europe are to be supplied with green hydrogen along the Danube and in southeastern Europe. Other participants include Austrian power company VERBUND as well as Hydrogenious LOHC Technologies in Germany.

Fig. 1: IPCEI project: Green Hydrogen @ Blue Danube [Source: Verbund]

A MULTITUDE OF SEPARATE SCHEMES In 2009, Romania witnessed the founding of the National Research and Development Institute for Cryogenic and Isotopic Technologies ICSI and the National Center for Hydrogen and Fuel Cells CNHPC. Their remit is to encourage the introduction, development and spread of hydrogen-based energy technologies. However these initiatives have enjoyed only modest success. So far researchers from ICSI have developed two electric car prototypes that are powered by fuel cells and have a maximum range of around 200 miles (320 kilometers).

A pot of EUR 115 million is envisaged for the first 100 megawatts of green hydrogen production capacity. This funding is a key pillar in the country's recovery program entitled Național de Redresare și Reziliență or PNNR for short. In Romania, industry giants Hidroelectrica, Romgaz (SNG), OMV Petrom (SNP), Liberty Galați as well as several wind power producers are all currently investigating options to produce green hydrogen.

Liberty Galați recently announced its intention to manufacture green steel and also to develop hydrogen-powered vehicles. Romgaz is planning use photovoltaic power plants to generate electricity which it will use to make hydrogen. The hydrogen will then fuel the company's fleet of vehicles, 20 percent of which are to be converted to run on hydrogen. Also involved is Russian group Lukoil, which has a refinery in Ploiești. It too is expecting to take the first steps toward green hydrogen manufacturing. At the moment there are 13 industrial hydrogen producers in Romania and these principally use fossil fuels in their processes. Only Chimcomplex (CHOB) and Liberty Galați have projects to produce green hydrogen on their agenda.

Hence there is no shortage of initiatives from the hydrogen industry in Romania, but the lack of coordinated strategic planning has been viewed critically by local experts. Răzvan Nicolescu, Romania's former energy minister, sees insufficient investment particularly when it comes to the integrated production chains needed by the hydrogen sector. "We talk a lot about hydrogen (...), but we haven't yet actually asked ourselves how we can convince Cummins, one of the largest manufacturers of hydrogen plants, which is already based in Craiova, to produce electrolyzers in Romania," explained Nicolescu with disappointment.

INFRASTRUCTURE EXPANSION The operator of the national natural gas grid Transgaz (TGN) has been helped by the 3SI project in setting up a joint venture for the construction of hydrogen pipelines. Given the specifics of Romania's energy requirement, the need to expand pipeline infrastructure is of primary importance. Romania anticipates that hydrogen will be chiefly deployed in industrial applications. The country experiences particularly high demand for energy from its domestic refineries, chemical works and steelmaking plants.

The focal point for the development of the Romanian hydrogen sector is the region to the southeast of the country. This is because the Black Sea coast is home to major branches of industry and is also the location for the planned expansion in offshore wind. The port of Constanta is often cited in this connection.

The Black Sea area offers Romania enormous potential in terms of wind energy generation – estimated at over 70,000 megawatts. "This energy is also due to be used for hydrogen production," said former state secretary at the economy and energy ministry Niculae Havrilet.

The region that borders Ukraine in the north and Bulgaria in the south is known as Dobrogea. "Dobrogea ranks second after Scotland in terms of the size of potential for wind power generation in Europe. And this is where electrolyzer technology comes in, which allows the green energy generated by the wind turbines to be turned into green hydrogen," explained Alexandru Bădescu from Cluster South East Europe at Linde Gaz Romania, speaking to the Romanian media.

In Dobrogea the wind conditions are well-nigh ideal for electricity generation. The area is inspiring lively interest from national and international wind farm developers. Leading the way in the use of wind power for hydrogen production in Dobrogea are companies Romgaz and OMV Petrom which are already working in partnership to unlock natural gas resources from the Black Sea. ||

Category: International | **Author:** Moritz Haarstick

SOUTH KOREA ON A HYDROGEN MISSION

Turning crises into opportunities

The idea that a crisis can be seen as an opportunity ripe for exploitation is one that is extremely widespread in South Korea. The country is investing massively in both hydrogen technology and the hydrogen economy with the aim of minimizing the environmental impact of its industrial and energy sectors. Having previously built up a successful semiconductor industry from scratch, South Korea plans to leverage its experience of adapting and developing disruptive technologies. And it's a pragmatic route that the nation has chosen to get there, placing an emphasis on the creation of positive market dynamics over and above the ultimate goal of achieving net-zero.

This pragmatism is combined with the structural tendency (path dependence) to find the lowest common denominator that can achieve cross-party agreement when it comes to long-term strategy. Even though the fundamental elements of energy policy are known, it remains to be seen how the newly elected conservative government will fill out the policy framework.

Here, just as in Europe, the taxonomy of clean hydrogen is a weighty issue. Similar to the situation in other European countries, it's not just technical path dependences but also political ones that are dictating the future hydrogen color spectrum and the classification of clean hydrogen. Current political events, such as the recent election of the conservative government, are having a specific effect on how this is playing out.

"KOREA NEW DEAL" CREATES FRAMEWORK The COVID-19 outbreak put the brakes on global economic activities to such a degree that a significant decrease in pollution levels could be measured in some locations. However, the economic impact of the pandemic was felt much more severely by many people, especially in the United States. In order to quickly tackle the country's financial and social problems as well as ultimately address the environmental crisis, the US launched its "Green New Deal" in 2019 with the aim of bringing about the long-term decarbonization of its economy. There was no mistaking here that the financial and environmental crises were being viewed as an opportunity for more sustainable development.

The idea fell on fertile ground in South Korea which by comparison fared well through the pandemic, having avoided full lockdowns and high excess mortality figures and only experiencing a slight economic downturn. On July 14, 2020, President Moon, from the liberal government at the time, presented the "Korea New Deal" which outlined an overall volume of investment that equates to EUR 117 billion by 2025, of which EUR 84 billion was expected to come from state coffers and the rest from private enterprise.

From the total, more than EUR 53 billion are planned to be used for the environmental restructuring of industry, energy generation and housing infrastructure. The remaining funds are earmarked for digitalization and education in the widest possible sense. The Korea New Deal, which also explicitly mentions hydrogen as an energy carrier and hydrogen technology as an instrument on multiple occasions, is the policy framework in which the state-inspired project to establish a hydrogen industry is lodged.

ROAD MAP TO KOREAN HYDROGEN ECONOMY The liberal government, which was voted out of office in May this year, had previously presented its road map to stimulate the hydrogen economy in January 2019. A McKinsey study on the market potential of the hydrogen economy to 2050 described the establishment of a hydrogen economy with its own technology as a huge opportunity. In addition to the desired economic growth fueled by market participation, the report expected that jobs would be created in midsize companies, technology leadership might be established – thus creating chances for further direct investment from abroad – and enormously high dependence on fossil fuel imports would gradually decline.

What's more, the hope was also expressed that huge savings would be made in terms of greenhouse gas emissions and particle pollution. While South Korea doesn't have a long tradition in hydrogen technology to look back on, it is familiar with the rapid adaptation and development of disruptive technologies and has the necessary motivation to achieve this. Indeed it has announced the following specific targets announced for 2040:

HYDROGEN GIVEN LEGAL WEIGHT To Western observers, such targets will doubtless seem very ambitious or indeed unrealistic and only time will tell whether they can actually be achieved. Nevertheless, any assessment must take into consideration the fact that the Korean hydrogen industry is embedded in an entirely different legal and policy framework to the European model. For instance, the hydrogen law that was passed in February 2020, which currently comprises eight chapters and 62 articles and was the first law of its kind in the world, now governs key areas concerning the systematic development of the hydrogen economy. Furthermore, the then government, together with the national hydrogen council, set up an expert commission on the regulation and control of policy content and processes relating to hydrogen technology and the hydrogen economy.

The first major area of the hydrogen law can be said to be the legal framework surrounding state-supported "hydrogen-specialized enterprises." These are defined as small- and medium-sized companies which, depending on their overall turnover, generate between 10 and 50 percent of their income from hydrogen technology and dedicate 3 to 15 percent of their investment to hydrogen-related R&D activities (cf. chapter 1, article 2, paragraph 3). The law sets out various incentives to attract companies for the newly created certification scheme as well as for the overall national hydrogen industry project. These inducements may include more than EUR 100,000 of funding per company which can take the form of technical support (e.g., development, certification and patent registration) or commercial support (e.g., advertising, trade fair participation, market research, design development and brand development) (cf. chapter 3, article 9).

Additionally, certified companies are able to receive help and advice from H2KOREA, a consultancy financed by the

Fig. 1: Hyundai Motor Group Chairman Eui-sun Chung, SK Group Chairman Tae-won Chey, POSCO CEO Jeong-woo Choi and Hyosung Group Chairman Hyun-joon Cho take photos in front of Hyundai Motor's hydrogen fuel cell truck [Source: Hyundai Motor Co.]

state and the private sector that is tasked with promoting the hydrogen economy and which also receives a mention in the hydrogen law (chapter 5, article 33). The law further sets out that the legislator can urge energy suppliers, which are generally state owned, to expand hydrogen production and utilization capacity (cf. chapter 4, articles 19 – 21).

To boost the build-out and development of infrastructure, including facilities for development and testing, the legislator also focuses on the designation of "hydrogen-specialized complexes" (chapter 4, article 22). This primarily involves the creation of industrial clusters that can accommodate companies as well as research facilities and educational institutions in order to generate synergies and spillover effects between the organizations involved. In this regard the law creates a framework that allows decisions to be made about where the specialized complex designation is used and what proportion of funding will be allocated. These special-purpose hydrogen zones are being planned primarily in the northeastern Gangwon Province, the southeastern Gyeongsang Province, the southwestern Jeolla Province and the northwestern industrial city of Incheon.

The same law also provides for the expansion of hydrogen demonstration projects (chapter 4, article 24). So as to ensure price stability on the supply side, the legislator obliges gas suppliers to trade natural gas for reforming purposes at a capped price (chapter 4, paragraph 25). However, specific rates have not yet been set. Other key areas are, for example, the training of specialist personnel (chapter 5, paragraph 26), the creation of applicable industry standards (chapter 5, paragraph 27) and the encouragement of acceptance among the general public (chapter 5, paragraph 31). As revealed by the law's full title (the Hydrogen Economy Promotion and Hydrogen Safety Management Act), its main concern is to put in place rules that cover the safety management of this new technology.

KOREA H_2 BUSINESS SUMMIT Evidence that the country's hydrogen ambitions are also shared by industry, and are not just the subject of a government decree, can be found in the guise of the Korea H_2 Business Summit which was held for the first time in September 2021 in South Korea. Among the 17 founder members of this initiative are leading national groups and corporations that are keen to cooperate on hydrogen technology. Many of these groups have already pledged billions in financial support. According to media reports, total investment in the lead-up to 2030 runs to more than EUR 31 billion.

GROUPS INVEST BILLIONS One company that particularly stands out is the conglomerate SK Group, which wants to become one of the top hydrogen producers over the coming decades. More than EUR 13.5 billion are set to be channeled into creating production capacities of more than 250,000 tons per year up until 2030. As a result, Boryeong, a city situated on the west coast which also has its own lique-

Tab. 1: Goals 2040

Sector	To achieve by 2040		
		Global (export and domestic market)	Domestic market
Mobility	Ttl hydrogen vehicles	6.2 million	2.9 million
	of which cars	5.9 million	2.75 million
	of which taxis	1.2 million	0.8 million
	of which trucks	1.2 million	0.3 million
	of which buses	0.6 million	0.4 million
	Hydrogen refueling stations	not specified	more than 1,200
Energy production (fuel cell capacity)	Industrial production	15 GW	8 GW
	Private production	not specified	2.1 GW
Hydrogen supply	Ttl hydrogen production (requirement)	not specified	5.26 million tpa
	Partial oxidation (H_2 as byproduct)	not specified	together approx. 70% share
	Reduction from CH_4	not specified	
	Electrolysis	not specified	
	Import of CO_2-neutral hydrogen (Australia, Norway, Saudi Arabia)	ca. 30% Anteil	not specified
	H_2 target price (converted)	not specified	EUR 2.20/kg

fied natural gas terminal, is expected to become the world's largest hydrogen factory. At the moment SK is concentrating its efforts on manufacturing affordable blue hydrogen which should accelerate the build-out of the entire value chain from transportation through energy extraction. As a logical extension of this, SK is also investing in increasing the number of refueling stations and expanding fuel cell capacities. That said, the company has already signaled that it intends to invest in production capacity for green hydrogen as well.

Also automotive manufacturer Hyundai has restated its commitment to hydrogen mobility, claiming it will make a total investment of more than EUR 8 billion by 2030. Despite the continuing commercial success of its hydrogen-powered Nexo model, the corporation recently announced that it would be pausing the development of its successor, Genesis, in a surprise admission that affected the stock prices of many suppliers. However Hyundai has clarified that the deferment is only due to internal restructuring of development and that the company is still maintaining its hydrogen course.

The automaker is currently working on a compact 100-kilowatt fuel cell which it says will save a good 30 percent in space and around 50 percent in price compared with the 200-kilowatt fuel cell that was incorporated in the Nexo model. This, it explains, will not only greatly broaden its scope of application in the mobility sector but will also potentially widen its customer base. Besides further developing its hydrogen mobility portfolio, Hyundai is also involved in the serious task of expanding fuel station infrastructure.

Another important member of the Korea H_2 Business Summit is the steel giant POSCO which is planning to invest more than EUR 7 billion in hydrogen by 2030. On the one hand, POSCO is building industrial plants for extracting gray and blue hydrogen but it is also eager to create capacity for green hydrogen in the longer term. What's more, the group intends to decarbonize its core steelmaking business and, to this end, is increasing its use of hydrogen direct reduction, a process which has been promoted since 2003 under the Finex brand. The company's goal is to switch its manufacturing operations completely to hydrogen direct reduction by 2050.

One major corporation that is placing much greater emphasis on green hydrogen is the Hanwha Group. Its takeover of German photovoltaics company Q Cells back in 2012 enabled it to position itself within the renewables sector and subsequently become the market leader. As a means of complementing its PV portfolio, Hanwha now also plans to invest in electrolyzer technology, preferring to focus on innovative anion exchange membrane or AEM electrolyzers.

In a move that will take the company a step further in the value chain, the group's chemicals division is busy developing a gas turbine that will use a blend of LNG and liquefied hydrogen to generate power. To drive forward this development, last year Hanwha took over the US turbine manufacturer Systems Mfg as well as Dutch energy technology company Thomassen Energy. By 2023 Hanwha hopes to start supplying the first turbines to Korean grid operators. As hydrogen is due to make up more than 50 percent of the gas mixture, the turbines will bring about a significant re-

Tab. 2: Goals of different players

Company	Sector	Investment total (EUR billions by 2030)	Investment area	Target
SK Group	Conglomerate (energy, chemicals, IT, etc.)	13.5	· Hydrogen factory (first "blue," later "green") · Hydrogen liquefaction plant · Increase in fuel cell capacities · Increase in fuel station infra-structure	· H_2 production of 250,000 tpa (by 2025) · To become the largest H_2 producer · Construction of 100+ H_2 fuel stations (by 2025) · Creation of 400+ MW fuel cell capacity
Hyundai Motor Company	Vehicle manufacturer	8.2	· H_2 vehicles · H_2 mobility infrastructure	· Switch to H_2 mobility by 2040 · Global number 1 in H_2 mobility sector
POSCO (Pohang Iron and Steel Company)	Steelmaker	7.3	· CH_4 reforming (blue hydrogen) · Manufacture of green hydrogen abroad · Steelmaking through H_2 direct reduction (FINEX product)	· Switch to H_2 direct reduction by 2050 · Gray H_2 production of 700,000 tpa (by 2025) · Blue H_2 production of 5,000,000 tpa (by 2030) · Green H_2 production of 50,000,000 tpa (by 2050)
Hanwha Group	Conglomerate (chemicals, equipment, IT, heavy industry, etc.)	0.96	· Innovative electrolyzers · Power-generating gas turbines running on blended gas	· Setup of complete H2 value chain (solar cells, electrolyzers, H_2 tanks, fuel stations, fuel cells)
Hyosung Group	Conglomerate (chemicals, machine building, IT, etc.)	0.88	· LH_2 hydrogen factory · Cryogenic pump technology for H_2 · Carbon-fiber mesh for fiber composite tanks	· H_2 production of 130,000 tpa (by 2023)

duction in greenhouse gas emissions. With plans to invest almost EUR 1 billion by 2030, Hanwha is setting its sights on becoming one of the major players in the hydrogen economy. There are already signs that the company is well on its way: According to media reports, Hanwha has just recently been awarded a contract from German supplier Uniper.

Also the Hyosung Group, which made headlines through its cooperation with Linde, is continuing to pursue hydrogen. The company plans to invest EUR 800 million in the lead-up to 2030. Hyosung built its first hydrogen filling station in South Korea in 2008. Now, with over 20 refueling stations to its name, the company is the country's market leader. Yet Hyosung wants to go even further. Through its partnership with Linde, the company is intending to make a large-scale move into the production of liquefied hydrogen, otherwise known as LH_2. By mid-2023, the factory is expected to have reached a production capacity of 13,000 tons a year. The collaboration also covers the development of cryopump technology which is needed for refueling when hydrogen is in its liquid state.

Since the group manufactures carbon-fiber mesh, it is also looking to participate indirectly in the market for hydrogen tanks, which are generally made from fiber composite material. Saving greenhouse gas emissions, for instance by producing green hydrogen through electrolysis or by storing and processing carbon dioxide, are Hyosung's longer-term aims.

ACHIEVEMENTS SO FAR Despite the voting out of the liberal government that was initially responsible for the national drive toward hydrogen, the subject of hydrogen seems to have gained cross-party support in South Korea, even if there is no consensus on the color of clean hydrogen. That there is unity at all on the matter of hydrogen technology is still a major coup.

The area in which this success is most apparent is transportation. More than 30 percent of hydrogen vehicles sold globally are now driving on Korean roads, and most of these are emblazoned with the Hyundai logo. Not only that, South Korea is also the place where infrastructure expansion is advancing most rapidly, with over 130 hydrogen refueling stations already in place.

Progress in the hydrogen technology sector is plain to see. By May this year, H2Korea was able to certify a total of 44 companies as hydrogen-specialized enterprises. It's reasonable to assume that more than 90 percent of all key components for the hydrogen sector can now be supplied by domestic industry.

What South Korea is still lacking, however, is clean energy. At the moment more than 60 percent of energy is obtained from coal and gas, around 30 percent comes from nuclear power and only about 5 percent is generated from renewable sources such as wind, solar and hydropower. Consequently, South Korea's annual hydrogen production of 200,000 tons is limited almost exclusively to the reforming and separation of hydrocarbons. As such, most hydrogen is either blue or gray.

It is therefore fair to say that South Korea, by taking a long-term policy decision and making generous investment and support measures available, has created a solid foundation for establishing a green hydrogen economy that is supplemented by imports. However, right now, this future green hydrogen economy can be likened to a large construction site in which thick dust clouds are obscuring the color and contours of the new building. Only when the dust finally settles will it reveal its shade and shape.

Fig. 2: This summer, a total of 27 Hyundai XCIENT Fuel Cell were delivered by ship directly from the Hyundai plant in South Korea to Germany [Source: Hyundai]

OUTLOOK ON THE NEW GOVERNMENT Much of what is being done today harks back to President Moon's liberal administration which governed from May 2017 until May this year. It was this previous government that initiated, among other things, a reform of the already adopted hydrogen law and this amendment was passed just as power changed hands. Paralleling the European debate, the main thrust of the reform was the stipulation of legally binding definitions of clean hydrogen which distinguish between hydrogen that is associated "with a small amount" of greenhouse gas emissions and hydrogen that produces none at all. In other words, it centers on how to deal with hydrogen that is not 100% green.

Furthermore, an agreement was reached on a legal price cap for gas that is intended for the production of hydrogen. The most important addition, however, was the provision relating to Clean Hydrogen Portfolio Standards or CHPS which gives suppliers and other market participants quotas for hydrogen production, takeoff and power conversion. This was well received by the stock market and the industry alike.

Nevertheless, the recently elected conservative government led by President Yoon has now brought the expansion of nuclear energy back into play, a development which has caused mixed reactions. While the new government has declared its intention to continue growing the hydrogen economy in its strategy paper, a question mark hangs over whether pragmatism will actually accelerate climate reversal or quite the opposite. ||

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Magnet-Schultz GmbH & Co. KG, High-pressure-cut-off-, safety–shut-off-, flow-control valves for H_2, Allgäuer Str. 30, 87700 Memmingen, Germany, Phone +49-8331-104-0, Fax -333, *www.magnet-schultz.com*

Nova Werke AG, H_2 High Pressure Solenoid Valves, Vogelsangstr. 24, 8307 Effretikon, Switzerland, Phone +41-52-3541616, *www.novaswiss.com*

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*

Schwer Fittings, Manufacturer of stainless steel pipe connections, screw connections, fittings, valves and complete pipelines. Tel. +49 7424-98250, *info@schwer.com, www.schwer.com*

FUEL CELLS

SFC Energy AG, EFOY Fuel Cells, Eugen-Sänger-Ring 7, 85649 Brunnthal, Germany, Phone +49-89-673592–555, *info@sfc.com, www.sfc.com, www.efoy-pro.com*

Siqens GmbH, Landsberger Str. 318d, 80687 München, Germany, Phone +49-89-4524463-0, *info@siqens.de, www.siqens.de*

FUEL RECIRCULATION AND AIR SUPPLY

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Celeroton AG, highly compact turbo compressors for fuel cell air supply, Industriestr. 22, 8604 Volketswil, Switzerland, Phone +41-44-25052-20, *info@celeroton.com, www.celeroton.com*

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

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

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 GENERATION

RIX Industries, 4900 Industrial Way, Benicia, CA 94510, USA, Phone +1-707-747-5900, *learnmore@rixindustries.com, www.rixindustries.com*

Rouge H_2 Engineering GmbH, Reininghausstr. 13, 8020 Graz, Austria, Phone +43-316-375-007 Germany: Rouge H_2 Engineering Deutschland GmbH, Maurener Str. 11/1, 71155 Altdorf, Phone +49-2175-6688-575, *www.rgh2.com*

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

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

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

f-cell 2022 | Hydrogen & Fuel Cell Conference and Trade Fair, 4-5 October 2022, Messe Stuttgart, Germany, *www.f-cell.de*

Tobias Renz FAIR, Berlin, Tobias Renz, *tobias@h2fc-fair.com,* Phone +49-30-60984556, *www.h2fc-fair.com*

REFORMERS

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

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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*

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STORAGE

AMBARtec AG, Supplier of compact, efficient and sustainable H_2-storage systems, Erna-Berger-Str. 17, 01097 Dresden, Germany, Phone +49-351-30993666, *www.ambartec.de*

GKN Powder Metallurgy Holding GmbH, Pennefeldsweg 11-15, 53177 Bonn, Germany, *www.gknhydrogen.com*

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

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

Kerafol Keramische Folien GmbH & Co. KG, Ceramic Electrolytes, Solid Oxide Cells, Glass Tapes, 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*

Sandvik High Precision Tube, ZN der SMT D GmbH, 33824 Werther, Germany, Phone +49-5203-91090, *info.hpt@sandvik.com,* H_2 Stainless Steel Tube Applications / Coil Container Service – On Site Tubing Solution

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

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Maximator GmbH, High Pressure Hydrogen Technology, Testing Equipment, Customer Testing Services, Lange Strasse 6, 99734 Nordhausen, Germany, Phone +49-3631-9533-5040, *info@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-(0)501-6877, *h2sales@resato.com, www.resato.com*

Sonplas GmbH, H_2 test stand, Testing of hydrogen-carrying components with real fuel, Sachsenring 57, 94315 Straubing, Germany, Phone +49-9431-9275-0, *info@sonplas.de, www.sonplas.com*

TesTneT Engineering GmbH, Eschenallee 11, 85445 Oberding Phone +49-(0)89-237109-39, *info@h2-test.net, www.h2-test.net*

Zeltwanger, Leak and Functional Testing, Automated Lines for Laser Applications and Assembly Tasks, Maltschachstr. 32, 72144 Dußlingen, Germany, Phone +49-7071-3663-106, *a.nobel@zeltwanger.de, www.zeltwanger.de*

TEST STANDS

DAM Group, 200 Rue Léon Blum, 69100 Villeurbanne, France, Phone +33-478-269583, *www.damgroup.fr*

EVENTS

You can also find upcoming online and live events as well as possible changes to these at www.h2-international.com/events.

NOVEMBER

HOC – Mission Hydrogen
HYDROGEN ONLINE CONFERENCE
November 8, 2022 – online
www.hydrogen-online-conference.com/

Forum Hydrogen Business for Climate
Territories – Business – Innovation
November 8 – 9, 2022 – Montbéliard
www.hydrogenbusinessforclimate.com

gat | wat 2022
Der Leitkongress der Energie- und Wasserwirtschaft
13. November, online
www.gat-wat.de

DECEMBER

f-cell China at Shanghai Automobile Exhibition Center
organized by Nanjing Stuttgart Joint Exhibition Ltd
December 1 – 3, 2022, Shanghai, China,
www.f-cell.com.cn

Infrastruktur für die sichere Energieversorgung
LNG- und H_2-Terminals
December 6, 2022 – online
www.dvgw-kongress.de

Berlin Electrolyser Conference
December 7 – 8, 2022, Berlin, Germany
www.nextgen-electrolysers.com/

EVENTS 2023

JANUARY

20th International Conference on Renewable Mobility
FUEL OF THE FUTURE 2023
January 23 – 24, 2023 – in Berlin at the City Cube
www.kraftstoffe-der-zukunft.com/

HyVolution 2023
February 1 – 2, 2023 – in Paris Expo Porte de Versaillese
www.paris.hyvolution.com

Hydrogen & Fuel Cells Energy Summit
Updates on the European Hydrogen & Fuel Cells market
March 8 – 9, 2023 – in Lisbon, Portugal
mahsan@acieu.net | *www.wplgroup.com*

FC Expo
March 15 – 17, 2023, Tokyo Big Sight, Japan
www.fcexpo.jp

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