H2-international – e-Journal

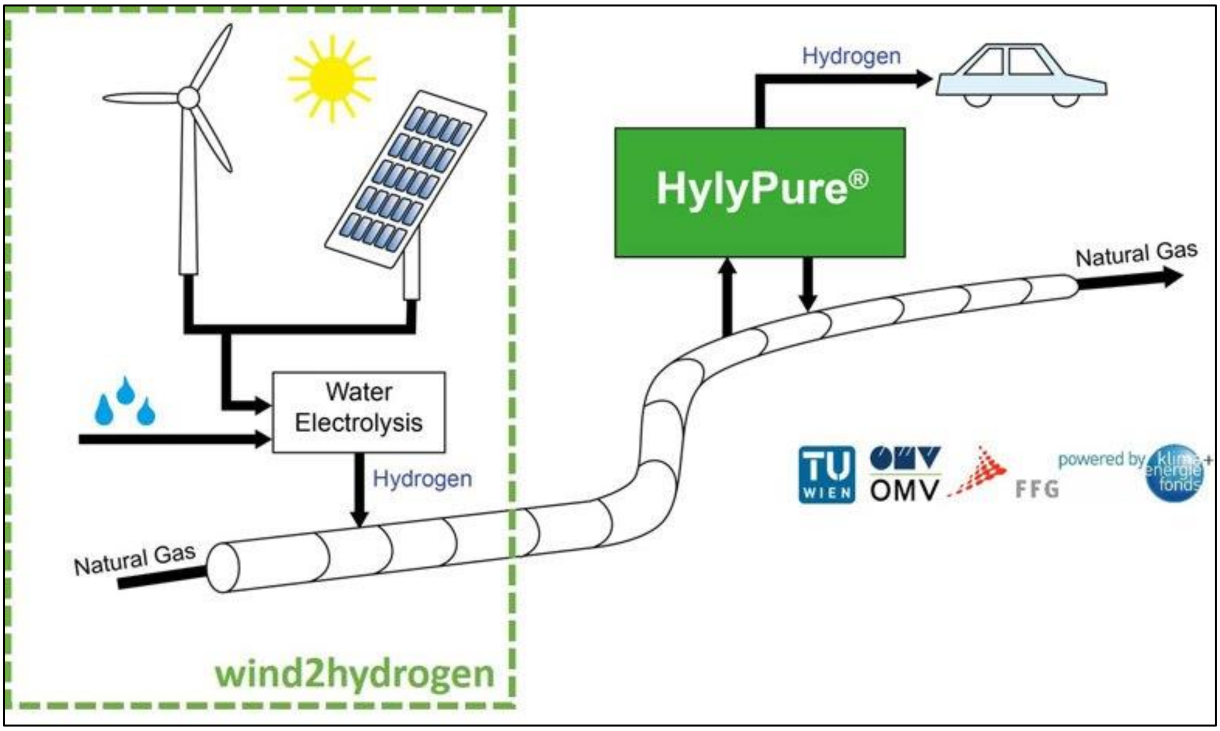
April 2017

Content

How to Cut Costs in Green Hydrogen Transportation

HylyPure: Recover Hydrogen from Natural Gas

Energy Storage



Source: TU Wien

The decentralized production of hydrogen from eco-power – whether used to stabilize the grid or utilize excess capacities – will play an increasingly larger role in future energy systems. The created hydrogen can either be stored locally, converted to methane by adding carbon monoxide or fed directly into the natural gas network. The HylyPure project supported by the Austrian Climate and Energy Fund was the first opportunity for a successful test of a technology that recovers hydrogen fed into the natural gas grid at fuel cell quality.

A key challenge of the energy transformation is the storage of excess electrical energy from regenerative sources (wind, solar) and a promising approach in this field is power-to-gas. Like methane, hydrogen is an ideal energy carrier for storage solutions, as it is highly efficient in end-use scenarios and carbon-neutral.

The objective of HylyPure was to feed hydrogen into the natural gas network (existing infrastructure), transport it cost-effectively and extract it at any given location and at fuel cell quality. The three-year project by Austrian-based TU Wien and OMV aimed at finding a technological solution and carrying out experimental tests at laboratory scale. One important technological benchmark for the application is an energy demand of no more than ten per cent difference to electrolysis.

Three-stage implementation

The HylyPure concept consists of three stages to ensure the most environmentally friendly and economical outcome (see figure): In stage 1, membrane gas separation provides for an energy-efficient increase in hydrogen concentration and a reduction in volume flow, as the gas is transported around 80 to 100 times faster through a selective polymer membrane than methane. In stage 2, a hydrogen-methane mixture is being enriched further inside a pressure swing adsorption system. Stage 3 is optional and can be used to add another adsorption-based precision cleaning to guarantee the desired product quality.

The TU Wien developments have led to the creation of compact plant technology that makes it possible to extract hydrogen of any quality required. The remaining mixture will be raised to outlet pressure and returned to the natural gas line. If the required electrical energy comes from renewable sources, the process is carbon-neutral. Experimental testing was done in a laboratory environment, where characteristic curves on performance were plotted for each enrichment stage – based on a natural gas-hydrogen mixture at 50 bar (5,000 kPa) – to lay the foundation for process design, optimized controls and reduced energy demand during gas purification. Proof of concept was successful as well: The purity grade of the hydrogen after adsorption was, in fact, 99.97 volume per cent.

Basic requirements

- In Austria, the natural gas grid must not contain more than 4 volume per cent of hydrogen. The Wobbe Index and the requirements for net calorific values must be observed as well.
- Fuel cell vehicles need hydrogen at a purity grade of 99.97 volume per cent (based on ISO 14687-2:2012).

Conclusion and suggestions for improvement

In addition to experimental data on membranes and the adsorption process, we mainly used numerical models that we developed on our own. The numerical method combines a finite-difference equation validated through an experiment for simulating the membrane-gas separation with a dynamic adsorption model validated in another experiment in conjunction with a Levenberg-Marquardt algorithm for optimizing process chains. This effective combination can be used to develop and size tailor-made multi-stage plants. The simulation-supported design enables an identification of the optimal circuit layout and the dimensions of individual process steps. The focus, however, was not on optimizing only single links in the process chain. The entire plant was designed to be as efficient and economical as possible.

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From Cryoplane to HYCARUS

Fuel Cells in Aviation

Research & Development

Source: DLR

Although the aviation industry was the starting point for hydrogen developments, commercial applications in that industry have been few and far between. 1783 marked the launch of the first hydrogen-filled hot-air balloon; later, hydrogen-powered airships crossed the Atlantic. But since the Hindenburg disaster in Lakehurst in 1937, the most lightweight element of all has fallen out of favor in every field except for the space industry. But it is not as if H_2 aviation didn't have his proponents who have continued their research and have meanwhile developed much-promising concepts.

Almost twenty years ago, a multi-million euro grant program funded research into the Cryoplane, a hydrogen-powered passenger aircraft. In retrospect, the mostly theoretical work in those days mainly proved one thing, namely that there is little chance for realizing such a project before 2025.

The situation reminds one of the issues surrounding Growian, a large wind power plant set up in the north of Germany in 1983, which has never seen regular operation. Both ideas were bound to fail, as their development was rushed toward the next breakthrough. The wind power industry, however, ultimately succeeded by gradually increasing the size of the systems until Growian was no longer "a breath of fresh air." H_2 passenger airplanes could take the same route: Work on developments such as the HY4 (see Launch of Emission-Free Passenger Aircraft Hy4) may mean that small passenger planes could soon transport not just four, but forty people.

DACAPO, DIANA and Diehl

Another R&D focus besides H_2-based propulsion is the fuel cell, which could supply at least part of the energy required on board. NOW supported BRIST – Fuel Cells, Integration and System Testing – with EUR 7.3 million for over five years. One of its outcomes was the creation of a Fuel Cell Test Center in Hamburg, Germany.

Additionally, BRIST partner Diehl Aerospace based in Überlingen is working on a portable energy supply system for passenger airplanes. Their main power consumer is the onboard galley, which prompted Diehl to develop a movable fuel cell unit. Similar to conventional airline trolleys, it is connected in the kitchen to supply power to galleys and cabins independently of the onboard power supply. Apart from a fuel cell and a fuel container, the trolley includes a reformer developed in-house. Its energy transfer medium is not a gas cylinder but propylene glycol, a non-flammable and non-toxic liquid when mixed with water. It has already been in use in aircraft for cooling and deicing and contains a great deal of hydrogen, which can be extracted through catalysts.

Diehl has been developing the system in collaboration with the Fraunhofer ICT and the German Aerospace Center ever since the idea for it was conceived during a cooperation with Airbus in 2007. In summer 2014, the team of Ronny Knepple, head of the Energy Systems department at Diehl, received the Crystal Cabin Award for its DACAPO (Distributed Autonomous CAbin POwer) idea. Until the end of last year, the development had been part of the DIANA project supported by LuFo, the national aviation research program of the German economy ministry. Knepple told H2-international: “The aim of DIANA was to establish proof of concept. After exactly 50 months of intensive research, a lab-scale demonstrator was used to provide that proof during the ‘Power On’ on March 2, 2016.” A new program, GETpower, was launched in July last year.

There is a strikingly similar project at European level, called HYCARUS (HYdrogen Cells for AiRborne USage). Two of its industry partners are Air Liquide and Zodiac Aerospace.

It’s still too early to tell when hydrogen could become available for wider use in aviation. But it seems as if power-to-liquids will have an important role to play in its success as airplane fuel (see next article: Power-to-Liquids Takes Off).

Easyjet announced in February 2016 that it would start investing in planes with hybrid engines to reduce emissions. A new propulsion design based on fuel cells and regenerative braking systems was said to be developed to reduce carbon-dioxide emissions after the airplane touches the ground. The airline known for its low-cost flights said that it was collaborating with Cranfield University on a new design to enable aircraft to taxi without using their jet engines.

Power-to-Liquids Takes Off

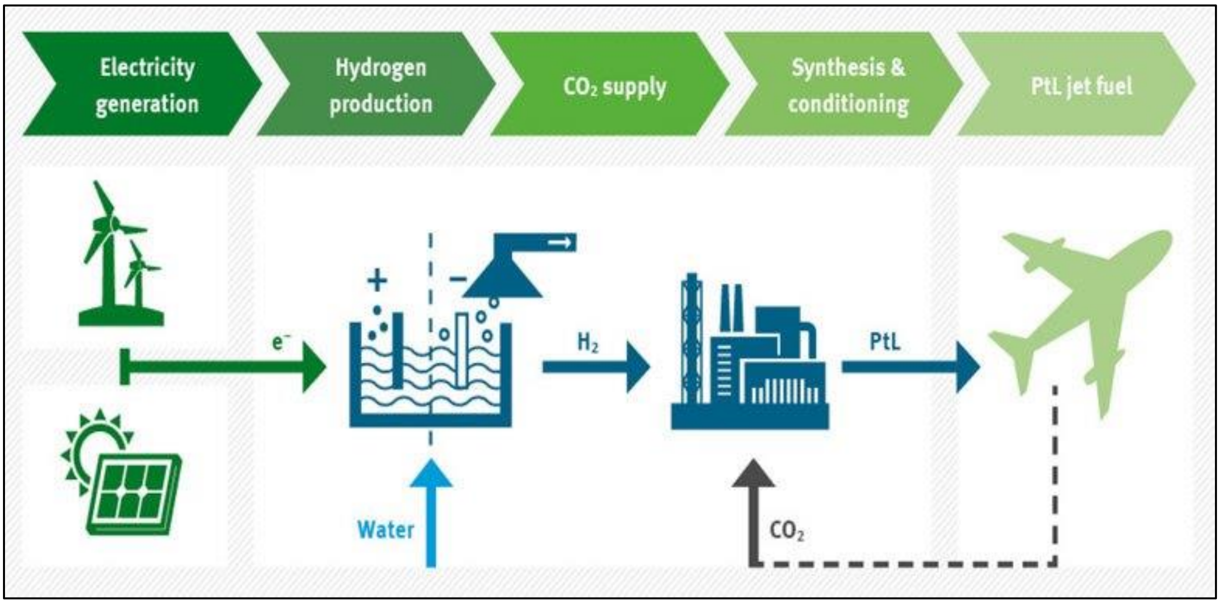
Turning Point in Aviation Industry's Energy Transformation

Research & Development

The aviation industry is aiming for carbon-neutral growth starting in 2020 and a CO_2 reduction of 50 per cent by 2050 compared to 2005 [1]. There are currently two options under discussion to achieve these goals: Emission certificates and biofuels. Both are not immune to criticism because of their direct and indirect impact on the environment. Renewable power has gotten considerably cheaper and is about to become the foundation of future energy supply. In collaboration with the Bauhaus Luftfahrt association, energy and environmental experts from Ludwig-Bölkow-Systemtechnik have analyzed the potential and outlook of jet fuel, a synthesis of renewably sourced hydrogen and CO_2 [2].

The key element of power-to-liquids is hydrogen, which is generated through wind or solar power and synthesized in a PtL system by using carbon monoxide or dioxide (O, CO_2) to create hydrocarbon. The synthesized substance is subsequently processed into liquid fuel that meets the standards and can replace the large fuel amounts used in aviation (see fig. 1).

Fig. 1: Sample diagram showing the production and use of PtL jet fuel from renewable sources



Source: UBA, [2]

PtL production

There have so far been two methods to create PtL, both in very advanced stages of development: The Fischer-Tropsch and the methanol pathway. There is hardly any difference in energy demand between the two. The integration of high-temperature electrolysis (SOEL) and a potential CO_2 extraction from air could lead to PtL production efficiencies of between 45 and 63 per cent.

High-temperature electrolysis utilizes the waste heat of several hundred degrees Celsius from synthesis, which leads to a significantly lower electricity demand that partially closes the gap to low-temperature electrolysis. PtL plant efficiency increases by 5 to 14 percentage points (depending on design and technical maturity), although the technology readiness level of the low-temperature version (8 to 9 of 9) is considerably more advanced than the one of the high-temperature application (5 to 6).

The required process components have been in widespread use for decades (Fischer-Tropsch synthesis, methanol synthesis, purification) or have become established but not employed for larger production volumes (low-temperature electrolysis). The PtL methanol production by Carbon Recycling International in Iceland and Sunfire's PtL demonstration system in Dresden, Germany, have showcased promising avenues for the system integration and technical development of high-temperature electrolysis and air extraction.

Because of their lower energy demand, the best candidates for carbon supply would be concentrated CO_2 sources. However, the availability of CO_2 from these types of biogenic sources is limited both in quantity and location. CO_2 extraction from air seems like the only sensible long-term solution in the fuel industry for mass production with a high share of PtL.

The Fischer-Tropsch synthesis requires CO as a reagent. But there have been no large systems for CO_2 to CO conversion yet. Another development option would be the use of high-temperature electrolysis to convert both water and CO_2 into hydrogen and CO. Methanol synthesis could utilize both CO_2 and CO as a reagent.

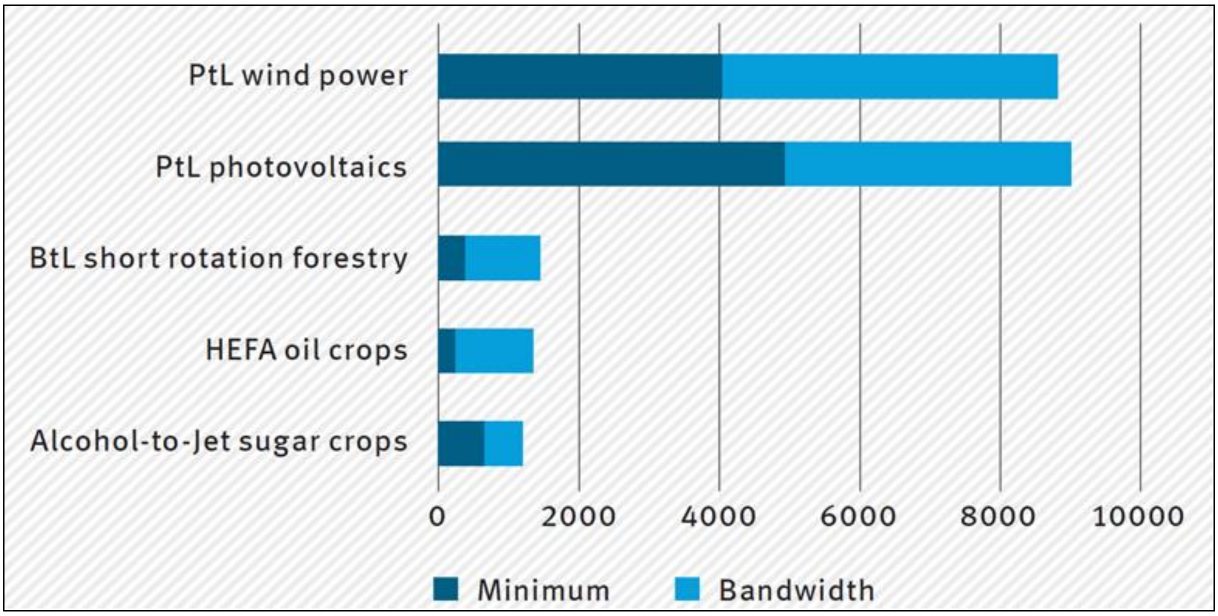
Even today, the ASTM standard on aviation fuels permits adding 50 per cent of energy-efficient Fischer-Tropsch synthesis products to the fossil source of jet fuel. Jet fuel from the methanol pathway has not yet been approved. It would require a project to demonstrate the viability of methanol-to-jet fuel and to provide the required amounts for ASTM's approval process.

PtL sustainability

Compared to other regenerative sources of jet fuel, the environmental benefits of PtL from renewable power, water and CO_2 are huge: As the study shows, the water required is around 1.4 liters per liter of jet fuel, whereas the considered biofuels require between 500 (algae in open pond with water recycling) and 20,000 liters of water per liter of jet fuel (Jatropha oil), meaning several orders of magnitude greater. [2] Typically, the water demand of biofuels is around several thousand liters per liter of fuel.

Another factor in favor of PtL is the competition for land use, which can be roughly described by three indicators: high area-specific energy yields, low area coverage and large potential of suitable land. Fig. 2 shows that the area-specific energy yields of power-to-liquids from wind and PV are several times greater than the ones of biofuels. The plot size required for wind power is determined by the distance between the turbines. However, less than one per cent of the area is used for the tower foundation and the access roads. The remaining 99 per cent can be utilized for other purposes. With PV, area coverage grows to a third based on the distance between the module rows to prevent shading. For example, the ranges shown in figure 2 are the result of differing yield expectations and plant designs.

*Fig. 2: Kilometer range of an Airbus A320neo based on the annual yield of one hectare of land; in km/(hectare*year)*



Source: UBA, [2]

When using renewable power, CO_2 and water, PtL jet fuel production can become almost GHG-neutral. If the emissions associated with the energy produced by renewable power and PtL plants is included, PtL jet fuel shows specific GHG emissions of 11 to 28 grams$_{CO2eq}$/MJ$_{jet\ fuel}$. This value is very low compared to other pathways (see Tab 1).

Table 1: "Well-to-wake" greenhouse gas emissions of various pathways toward jet fuel (in g$_{CO2eq}$/MJ$_{fuel}$) [2]

Jet fuel pathway	GHG emissions without land use change *	GHG emissions with direct land use change
Crude oil (reference)	87.5	-
Switchgrass (BtL)	17.7	-2.0 **
Soybean oil (HEFA)	37	97.8 – 564.2
Palm oil (HEFA)	30.1	39.8 – 698.0
Rapeseed oil (HEFA)	54.9	97.9
Jatropha oil (HEFA)	39.4	-
Algae oil (HEFA)	50.7	-
PtL (wind/PV in Germany)	~1	-
	11 – 28 ***	-

* Not yet considering the impact on the climate in higher regions
** Negative value because soil captures more carbon
*** Including construction of power plants and production facility

Outlook

If the aviation industry wants to grow while becoming more sustainable, it needs future-proof avenues for development. A two-path approach seems sensible considering the risks inherent in new technologies and the long production cycles of aircraft models:

1. Develop (hybrid-)electric propulsion systems for increasingly bigger aircraft
2. Instigate an energy transformation in jet fuel use

The first, radically innovative development pathway aims at minimizing consumption, pollution levels and GHG emissions as well as the impact on the climate in higher regions. However, uncertainties remain regarding the speed of technological development and the overall feasibility of big aircraft models due to a lack of commitment by large stakeholders. The second, parallel pathway to follow is evolutionary in nature, uses renewable PtL jet fuel and is a durable no-regrets approach from an environmental perspective. The renewable power generation (especially from solar and wind) and electrolysis capacities required for the process would be necessary anyway for an energy transformation of the industry – including spill-over effects and synergies with other industries, such as power, heat or basic chemicals.

The development and introduction of new fuels and engines is not guaranteed considering the current jet fuel prices. There needs to be a discussion about suitable market instruments. The ongoing regulatory developments in aviation, such as the Carbon Offsetting and Reduction Scheme for International Aviation passed in early October 2016 by the ICAO in Montreal, establish the right framework. The policy measures currently under review (approved projects for reducing emissions, obligatory and voluntary sustainability criteria, partner countries, etc.) are ambitious in the eyes of stakeholders in the aviation industry. But above all and considering the 1.5 to 2 °C target agreed to in Paris, they are too moderate, too late and overall still not effective enough. Renewable PtL jet fuel would present the aviation industry with a potent environmental measure to counter this trend.

The opinions expressed in this article are the author’s own.

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Hydrogen-Induced Steel Damage

Ruhr University Bochum Analyzes Metal-Hydrogen Interaction

Research & Development

Fig. 1: Tepalcates bridge in Mexico; collapsed because of hydrogen-induced damage to the pre-stressed steel components

Hydrogen has the potential to take a particularly important role within the technological shift away from fossil fuels towards renewable and alternative sources of energy. Plans for using renewably sourced hydrogen as an energy carrier (e.g., power-to-gas) in order to deal with periods of power oversupply have posed special challenges for the energy industry. In addition to environmental and economic considerations, the increase in the amount of hydrogen creates challenges for material use, since hydrogen may cause spontaneous failures of metallic components, a process that is known as "hydrogen embrittlement."

Through humid furnace lining, additives and alloying elements, hydrogen may diffuse into components or semi-finished products during metallurgical production to cause damage such as flakes or fish-eyes. There is a similar risk during welding. Most hydrogen-induced damage, however, occurs when the component has been put into operation.

If the hydrogen causing the damage enters the component during manufacturing or processing steps, e.g. pickling or galvanizing, and is then "activated" due to applied operational stresses, the mechanism is called "delayed fracture." If the hydrogen is only introduced during use of the component, as in the case of cathodic partial reactions of corrosion processes, it is called “cathodic stress corrosion cracking.” In both cases, most of the components fail spontaneously without any prior warning such as deformation.

Atomic, trapped or molecular

Most hydrogen-induced damage is triggered by atomic (diffusible) hydrogen (H^+). Because of the small size of the atoms, diffusion in steel occurs at a very high rate even at room temperature, similar to carbon at 800 °C. Externally applied stresses, which may overlap with residual stresses, will strain the metal lattice elastically, establishing the driving force for atomic hydrogen to diffuse into those areas and accumulate. This process, called Gorsky effect, is intensified by notches and cracks causing a localized stress concentration.

Conversely, so-called trapped hydrogen (H^+_T) accumulates at energetically favorable lattice sides, e.g. dislocations, inclusions, grain boundaries, etc. Trapped hydrogen is no longer diffusible at room temperature and usually does not pose a risk. Only by applying activation energy in the form of rising temperatures, which is characteristic for each type of trap, hydrogen can be released from the traps and diffuse into the metal lattice.

At the molecular level, hydrogen (H_2) can only be expected to be present in steel in voids, such as in pores, or at distinct phase boundaries and is considered harmless.

The total amount of hydrogen contained in a steel component is represented by

$H_{total} = H^+ + H^+_T + H_2$

HEDE or HELP

In current research, the damaging impact of atomic hydrogen is explained by two theories. One, the Hydrogen Enhanced Decohesion Theory (HEDE), postulates that the atomic hydrogen weakens the bonds of iron atoms, which results in material failure at low mechanical stress levels [1]. The Hydrogen Enhanced Localized Plasticity Theory (HELP) states that hydrogen locally lowers the nucleation enthalpy of dislocations, causing the steel to yield at lower stress [2]. Additionally, hydrogen can follow the migrating dislocations due to its high diffusion potential.

The types of steel susceptible to hydrogen-induced damage are said to have a tensile strength above 800 MPa. With increasing material strength, the critical amount of hydrogen causing failure is decreased. A sharp limit for the critical amount of hydrogen is not given, but a diffusible hydrogen content below 1 ppm (0.0001 per cent) is often sufficient.

The fracture of high-strength steel often appears intergranular with gaping grain boundaries and remaining ductility at the fracture face (fig. 2a). Low strength steel shows a “feathered” or “lancet- shaped” transgranular fracture (see fig. 2b).

A frequent difficulty in failure analysis is that it sometimes cannot be said with absolute certainty whether the damage was caused by hydrogen. To unambiguously clarify this situation, samples of the same material are charged with hydrogen in the laboratory and a delayed fracture is triggered autonomously by a three-point bend test. These samples definitely show hydrogen-induced damage and can then be compared to the original one to identify the cause of failure. [3]

Hydrogen analysis

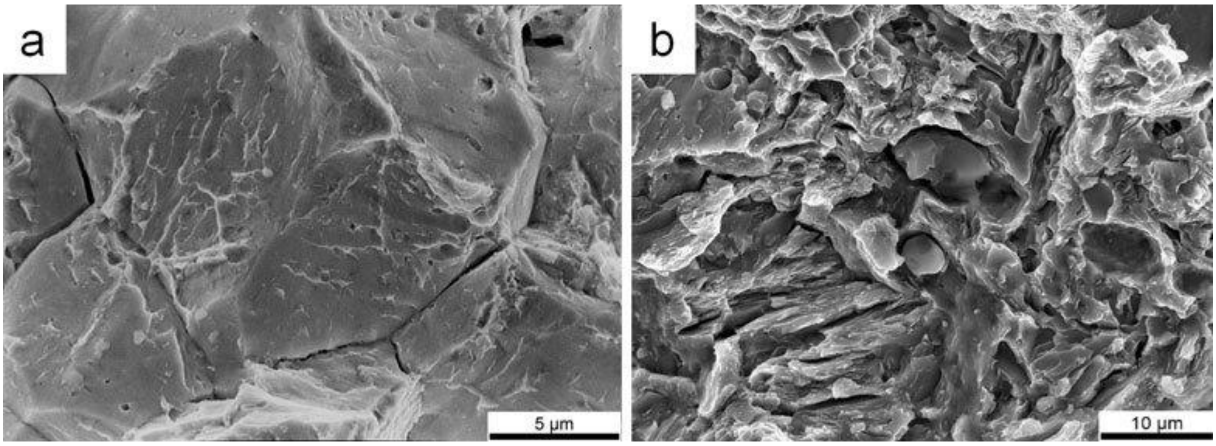
In principle, hydrogen analysis methods are classified by those analyzing the total amount of hydrogen and the ones determining diffusible and trapped amounts of hydrogen. Typically, the total amount of hydrogen is determined by means of melt extraction. This procedure involves melting a sample weighing one to two grams and analyzing the hydrogen when it passes over a thermal conductivity cell. Often, however, the analysis needs to focus only on the damage-inducing, diffusible hydrogen. These kind of measurements are conventionally performed by means of hot gas carrier extraction, with the drawback of inaccurate results due to the measuring principle.

To rectify this situation, researchers at Ruhr-University Bochum developed a method called “Hydrogen Collecting Analysis” (HCA) [4]. A material sample is encapsulated inside an evacuated glass tube and aged at the temperature desired for analysis. The hydrogen will effuse and accumulate within the capsule, and can then be transferred to a conventional thermal conductivity cell after forceful destruction of the tube. The separation of H_2 outgassing from the analysis and the notably higher sample weight will significantly improve the signal-to-noise ratio.

Another method, the Thermal Desorption Spectroscopy, has become increasingly popular, particularly in recent years: It increases the temperature of a material at a specified rate until reaching the temperature desired. The hydrogen released during the process will be analyzed to plot curves and show in very precise terms at which temperature hydrogen was released from the different bonding states. It is also possible to carry out an isothermal analysis, similar to the HCA method.

All the methods described above have the drawback that the integrative amount of hydrogen is being determined across the entire sample volume. Often, however, the focus of interest is placed on the local hydrogen distribution, especially considering the concentration near notches under increased stress. For this purpose, electrochemical methods are particularly suitable, which are mostly used in the form of attachable conductivity cells to measure the oxidation current on the component surface. Other considerable benefits of this method include the transport option for on-site measurement (e.g., in a factory or at a construction site) and the fact that the component is not being destroyed.

Fig. 2: Hydrogen-induced fractures, a: intergranular; b: transgranular cracking pattern



Source: RUB

Steel for power-to-gas plants

The above-mentioned factors are particularly important for the increasing number of power-to-gas plants, as there may be concerns about the durability of materials. A higher hydrogen content in the gas flow may not leave the existing supply networks undamaged.

Most pipelines that have so far been used to transport natural gas consist of low-alloy carbon steel according to DIN EN ISO 3183. The natural gas flow in Germany contains no more than 2 per cent of hydrogen. As was mentioned at the beginning, from a materials technology point of view this content is definitely sufficient to represent a latent risk of hydrogen-induced damage. However, more critical than the hydrogen content within the gas flow itself is that hydrogen needs to be absorbed by the material to cause failure. The diatomic H_2 molecule has to dissociate to two hydrogen atoms at the inner surface of the pipe which are then absorbed into the material. Since H_2 molecules exhibit a high thermodynamic stability these processes require bare metallic surfaces. Due to exposure of the pipeline to ambient air, the inner surface has been passivated leaving dissociation and absorption no longer feasible. In practice, this means that no hydrogen can enter the pipe material. It is for the same reason that steel gas cylinders with a tensile strength of around 1,000 MPa can be filled with pure hydrogen at a pressure of 20 MPa without exploding.

Only when use of a component causes newly created bare metallic surfaces hydrogen could enter the steel at certain points. This might be the case, for example, if there was mechanical damage or gas pressure exceeding the yield strength of the pipe material inducing deformation or cracks on the surface.

Power-to-gas designs aim at an H_2 content in the single digits, which existing natural gas grids are expected to be able to cope with, as several studies have shown [5, 6]. Even an increase to 30 per cent did not lead to any damage of the natural gas grid.

The difficulties connected to an increase of the hydrogen content are significantly more pronounced in regards of end-customer products. Tanks for the automotive industry must contain no more than 2 per cent of hydrogen. Currently installed gas turbines have only been approved for a hydrogen content of one per cent, although newly developed gas turbines are said to permit a hydrogen content of up to 15 per cent. Gas-driven motors are operated with a recommended maximum content of 2 per cent H_2, which makes further feasibility studies necessary [7]. Increasing the hydrogen content will change the ignition properties of the gas mixture.

Monitoring requirements will need to be considered as well, since an even more thorough detection of leaks and an improvement of measuring technology is necessary with increasing hydrogen contents. Today’s gas chromatographs mainly use helium as the carrier gas, which renders hydrogen undetectable.

Based on the studies, it does not seem plausible that an increase in the H_2 concentration in natural gas flow would result in hydrogen-induced damage. There are, however, still many individual issues to deal with. In particular, one needs to ensure that the end customer can process the altered gas mixture.

Summary

Hydrogen can embrittle steel and cause component failure. Knowledge about the damage mechanisms as well as an analytical evaluation have proven to be invaluable. Methods to analyze H_2 content are becoming more advanced and there will be an increasing shift towards measuring the actual components and on-site.

Hydrogen-induced component and plant failures subsumed under the term “hydrogen embrittlement” involve many varying factors, which may influence each other. Only a systematic assignment of hydrogen embrittlement mechanisms to failure modes allows for targeted solutions, which is why the Ruhr University Bochum is offering a workshop called “Hydrogen in Metals.”

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Hydrogen as New Energy Carrier

HYACINTH: Europe-Wide Acceptance Surveys

Research & Development

During the HYACINTH project supported by the EU, the Fraunhofer Institute for Systems and Innovation Research ISI based in Karlsruhe, Germany, and its partners have studied how well-accepted hydrogen technologies are by the general public as well as industry and governmental stakeholders. The result was that overall, there was a more positive attitude toward those technologies in Germany than in other country. The German respondents were more aware of hydrogen-powered vehicles and had a more positive view of them than of stationary systems, although battery-run cars seem to be fierce competition.

The acceptance of a new technology is a decisive factor for its successful implementation: A lack of support by important stakeholders – for example, from politics and industry – and the public could delay or even halt development. The HYACINTH project uses a very broad definition of market acceptance in the sense of the technology being embedded into and accepted by society. This means that in addition to the opinions of ordinary citizens, the study considered the viewpoints of others who play a vital role in innovation, such as people from research, business and politics. The analysis of the current situation included not only questions to 7,148 members of the general public, but also 333 stakeholders of the hydrogen industry. The findings from the latest survey have been the basis for developing the Social Acceptance Management Toolbox (SAMT), which is thought to support stakeholders in furthering the social acceptance of H_2 technologies.

Surveys among experts and the public

Market research agency Norstat asked people who were 16 years or older and lived in one of seven European countries (Belgium, France, Germany, Norway, Slovenia, Spain and the UK) to fill in an online questionnaire about the topic. At the same time, interviews were conducted with experts from five of the countries (France, Germany, Spain, Slovenia and the UK). The target group of the latter were experts on energy and hydrogen (see table 1).

Table 1: Sample sizes of both surveys

	BE	FR	DE	NO	SL	ES	UK
Sample size of public survey N (Total= 7148)	1021	1022	1011	1033	1014	1034	1013
Sample size of expert survey N (Total = 333)	-	73	127	-	12	78	43

Whereas the number of private citizens surveyed was about the same in all countries, the figure varied in the case of asking for expert opinions. Some of the difference could be attributed to the size of the country or the local H_2 community. For example, the sample size in Slovenia was very small, which means that the reliability of this country's results was limited.

One hundred fourteen stakeholders worked for a private-sector business, 57 were employed at government agencies and 53 were part of the staff of NGOs. The remaining participants came from public-sector companies, educational organizations and "Other." More than half of all experts surveyed said that they worked in hydrogen and/or fuel cell research; around one-third were engaged in H_2 production and one-fourth were employed in system integration (more than one answer could be chosen).

Both questionnaires first asked about the popularity of hydrogen technologies and the general attitude toward them. The experts were also queried about their assessment of future market growth. Afterward, the members of the general public were divided into two groups of equal size, with one asked to rate stationary applications (fuel cell heating systems) and the other hydrogen vehicles (FCEV) as well as the related infrastructure. These two groups initially received only impartial information about the most important features of both technologies.

Findings: The public's view

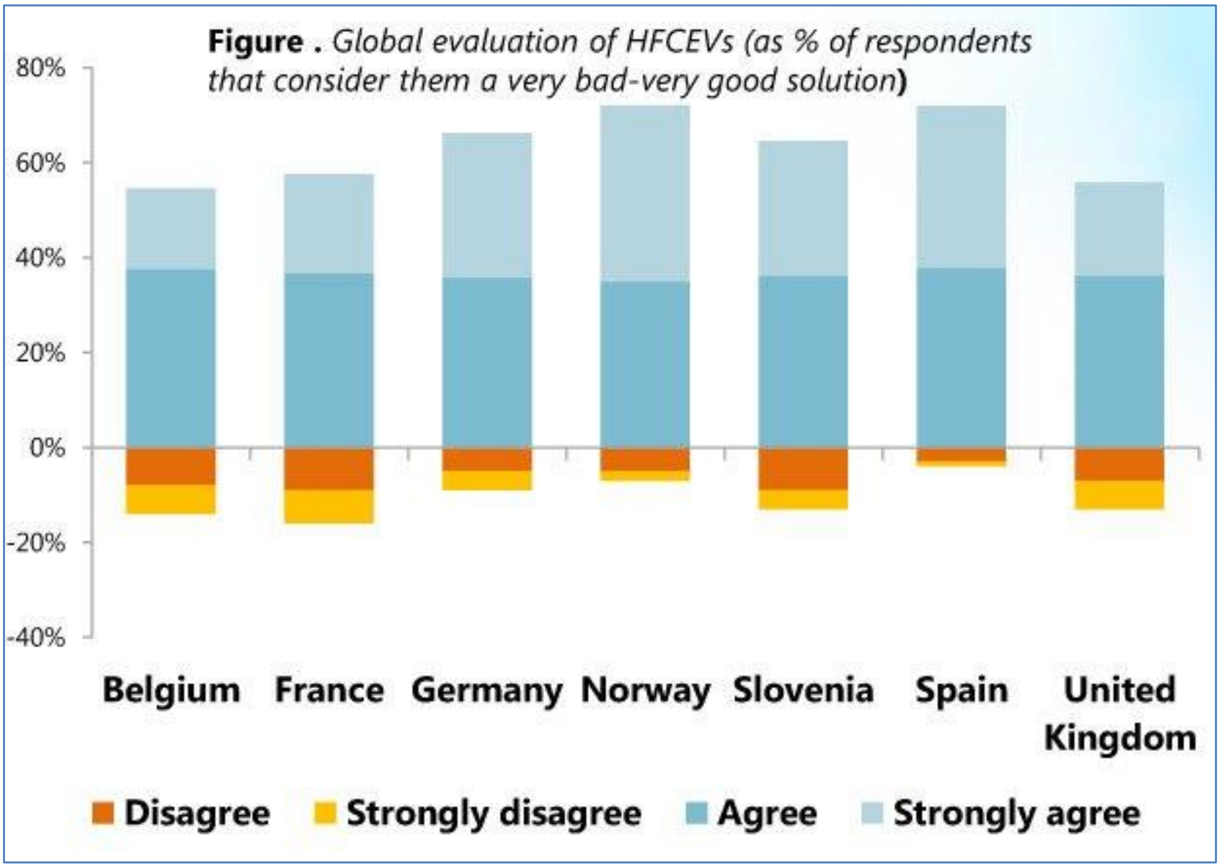
People from all seven countries were hardly or somewhat aware of hydrogen and fuel cell technologies. More than 40 per cent of European citizens had already heard of or read about them. Awareness was above average in Germany and Norway and below average in Spain. Even when a technology sounded familiar, actual knowledge of it was scarce: Only six per cent said that they were familiar with any of them.

Fuel cell heating systems were only known to about a quarter of respondents, with German citizens again being front and center. Familiarity with the application, however, was only stated by five per cent of respondents, although more than 60 per cent expressed interest in the technology. While 64 per cent would favor the installation of a fuel cell heating system in their home (with above-average agreement in Germany, Spain and Slovenia), only around 20 per cent were, in fact, considering a purchase. The most prominent barrier to investment was the price, followed by a perceived lack of technical maturity.

FCEVs were more well-known than stationary systems: Around 45 per cent of respondents had already heard of them. The transportation technology achieved particularly high recognition in Germany and Norway. Additionally, there was a slightly better familiarity with it than with stationary applications, and 60 per cent showed interest in learning more about fuel cell use in transportation. Although respondents favored FCEVs over cars powered by conventional engines and gas, purely battery-driven vehicles and hybrid versions were viewed even more positively (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). The only exception was Germany: Here, the majority found FCEVs to be more appealing than battery-electric cars.

Regarding hydrogen-driven cars, issues important to the survey respondents were environmental benefits, fuel price, range and safety aspects. If all these were identical to vehicles with conventional engines, more than 60 per cent would buy an

FCEV. The willingness to buy a hydrogen car was especially high in Norway and Spain. Interest was greatest among men, people between the ages of 35 and 44 and ones with a college degree. However, only around 20 per cent would seriously consider such a purchase in the future. As with stationary applications, it was the price and doubts about technical maturity that made them hesitate. Another reason was the lack of refueling stations. This corresponds to the finding that fewer than five per cent knew of any H_2 filling station in their region.



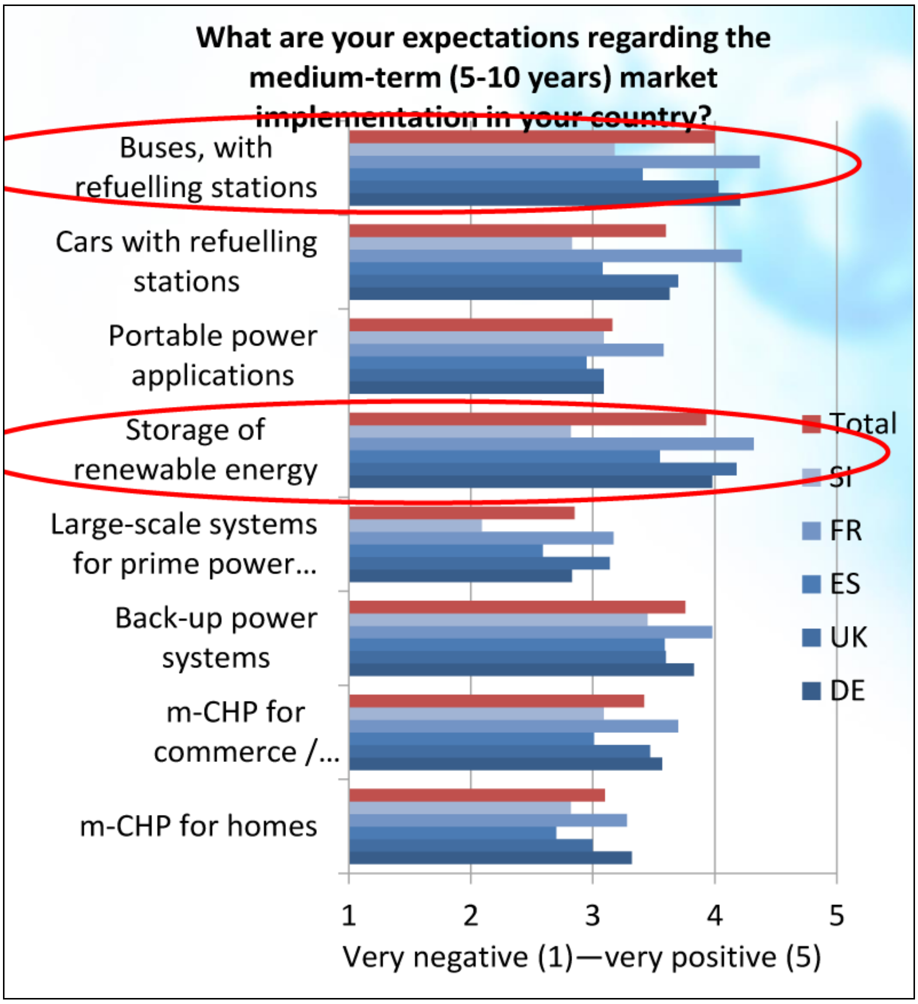
Findings: Expert opinions

The experts were first asked for their general assessment of hydrogen technology as a potential solution for energy and environmental issues. Nearly 90 per cent were in favor of H_2 technologies and this across all countries surveyed, as there were no significant differences in percentages between any of them.

Another part of the survey included a comparison of the expected market development of applications. The experts had a strongly positive outlook of hydrogen-driven buses, followed by hydrogen-based systems for the supply of emergency and backup power. On the other end of the spectrum was the market introduction of large systems for primary energy supply, which garnered the lowest confidence levels. A country comparison shows that experts from France had the most positive expectations, followed by British and German stakeholders. The expectations by stakeholders from Slovenia and Spain were less positive (see fig. 2).

It was the experts' decision whether to answer the more in-depth questions about stationary applications or FCEVs. In all countries except Slovenia, FCEVs were chosen more often than hydrogen technologies for stationary applications (on average, the share was 72 per cent in favor of the vehicle section). This shows that typically, respondents select the application that they hold in higher esteem. Although these were experts whom we asked, they chose a medium level of familiarity with the technology. The experts from Germany were the ones most confident about their knowledge.

Fig. 2: Expectations about different H_2 applications



The cost of stationary systems was also the most important factor for the experts, whereas safety aspects and technical maturity were viewed as of little concern. It was their belief that the availability of green hydrogen would impact public acceptance. They emphasized the need for business models in H_2 infrastructure and regarded further funding of research and development as critical.

The familiarity with hydrogen technologies used in transportation was rated similar to stationary applications. Even across countries, the same pattern showed. The experts considered the biggest challenge for H_2 transportation to be the availability of enough refueling stations and the second-biggest was costs. Safety aspects were again regarded the least troublesome issue of all the ones listed and fuel cells were preferred over all other types of engine power. FCEVs were thought to have the greatest advantage over cars with conventional engines, whereas the perceived benefits compared to purely electric cars were deemed to be the smallest. The development of the latter was additionally considered to be a decisive factor for the market take-up of hydrogen vehicles. The most urgent task ahead was the setup of an infrastructure for refueling as well as support of research and development.

Conclusions for further development

The overall conclusion is that while hydrogen technologies have been well-received by citizens and experts from Europe, the public is hardly aware of them. FCEVs enjoy advantages over stationary systems, but the former have fierce competition from battery-electric cars. A decisive factor will be the expansion of the H_2 infrastructure, so that the higher range and the (currently) shorter refueling times of FCEVs can make a difference. Additionally, it will be necessary to disseminate more information about hydrogen technologies and the latest developments in the field to reduce anxieties in the population, which have no basis in fact, as the experts believe.

When comparing countries, it becomes evident that both the public and the stakeholders in Germany have an overall more positive attitude toward hydrogen technologies than, for example, people from Spain or Slovenia.

The Hydrogen Acceptance in the Transition Phase (HYACINTH) project has received funding from the Fuel Cells and Hydrogen Joint Undertaking through the FCH-JU-2013-1 Call as part of the Seventh Framework Program (FP7; grant agreement no. 621228). The objective of HYACINTH is to achieve a greater understanding of the social acceptance of hydrogen and fuel cell technologies whether they come as stationary, portable or transportation solutions.

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Buzz About Stanford Study

Electric Transportation

A new study that claims battery-only vehicles to be cheaper and more economical than fuel cell vehicles has caused quite a stir in the electric transportation industry. On Nov. 14, 2016, the website of Stanford University showed a press release that made the headlines on several online portals. Reportedly, the main conclusions were that battery-driven vehicles could become cheaper than gasoline-powered cars from

2025 and that the ones running on fuel cells would require more than twice as much electrical energy. It was also noted that battery-powered engines reduced CO_2 emissions at lower costs than fuel cell versions – particularly because of the infrastructure needed to produce hydrogen.

“We looked at how large-scale adoption of electric vehicles would affect total energy use in a community, for buildings as well as transportation,” author Markus Felgenhauer, former visiting scholar at the Stanford Global Climate and Energy Project and a doctoral candidate at TUM, explained in the press release. He added: “We found that investing in all-electric battery vehicles is a more economical choice for reducing carbon dioxide emissions, primarily due to their lower cost and significantly higher energy efficiency.”

Professor Thomas Hamacher was surprised that an article such as this one had created so much buzz. He told H2-internationalthat there is no doubt that batteries were more efficient than fuel cells, which did not mean that battery-only vehicles were cheaper than fuel cell ones every single time. After all, the study did not consider seasonal storage options for hydrogen. Instead, “we simplified the setup,” he said.

Felgenhauer, M. F., Pellow M. A., Benson, S. M., Hamacher, T. (2016). Evaluating co-benefits of battery and fuel cell vehicles in a community in California. *Energy, 114*, 360-368.

Focused on Transportation and P2G

Austria Promotes H_2 and Fuel Cell Use

Global Market

Like Germany, Austria offers government funding and many public-private demonstration projects in support of the introduction of hydrogen and fuel cell technologies. Where potential applications are concerned, the country’s focus is on transportation, albeit interest in energy supply seems to be on the rise (mainly, in power-to-gas). The most important drivers of development are well-known, globally operating businesses such as AVL List, Fronius, Magna, OMV and Plansee, and large universities and research organizations located in Graz, Linz and Vienna.

In contrast to its northern neighbor, however, the country in the Alps has no program that is dedicated exclusively to hydrogen and fuel cells. Financial support for research and development in this field is coming from different government departments. The most extensive funding opportunities are offered by the Federal Ministry for Transport, Innovation and Technology or bmvit. This ministry has been providing years-long support across several research programs for developing components, alternative vehicle and propulsion technologies and fuels and demonstrating their effectiveness.

Additionally, bmvit is in charge of implementing European Directive 2014/94/EU, better known as the Alternative Fuels Infrastructure Directive, that aims to establish an eco-fuel infrastructure. It has prompted the construction of five hydrogen filling stations based on uniform standards by the end of 2016. As in other European countries, the stations mainly serve metropolitan regions and the so-called corridors of the Trans-European Network Transport.

Fig. 1: Research plant Underground Sun Storage in Pilsbach

Source: RAG / steve.haider.com

Austrian CEP

Two important pillars of Austria's plan to implement and showcase H_2 and fuel cell technologies in transportation are the Austrian Agency for Alternative Propulsion Systems or A3PS in Vienna and HyCentA, the Hydrogen Center Austria in Graz. A3PS could be described as Austria's version of the Clean Energy Partnership, although it also includes all other alternative engine and vehicle technologies besides hydrogen fuel and fuel cell vehicles. It was launched by bmvit in 2006 as a public-private platform to bolster existing support programs and has since attracted not only SME partners from industry, but also large corporations of the automotive and mineral oil industry and many Austrian universities and research organizations.

In 2015, A3PS published a technology roadmap called "Eco-Mobility 2025 plus," which focuses on hydrogen and fuel cells. This roadmap underlines Austria's expertise in alternative engine development and describes what strategies need to be employed in industry and research by 2025 and beyond for Austria to remain part of the global competition.

Hydrogen Center Austria

The HyCentA was set up in 2005 at Graz University of Technology with support from Magna Steyr and OMV and was extended in 2015. The research center promotes the use of hydrogen as a renewable energy carrier and the development of electrochemical systems as well as their peripheral components. With its H_2 testing lab for gaseous and liquid hydrogen, an H_2 filling station and a state-of-the-art test stand commissioned in October 2016 to analyze the system integration of fuel cells, HyCentA has been a pioneer for hydrogen-related R&D activities in Austria. This also ensures that the center is in sync with global research activities.

Future transport needs

The research support program Future Mobility launched by bmvit in 2012 runs until 2020 and has placed the focus of its vehicle technology research on hydrogen and fuel cells, (hybrid-)electric engines and renewable fuels as well as their associated infrastructures. The entire program has an annual budget of around EUR 15 million. That is not much compared to Germany, particularly because the money is available for any type of R&D activity in innovative vehicle technologies (e.g., electric motors, electronic control units, batteries, high-performance capacitors, flywheels, fuel cells, hydrogen tanks, etc.), electric engines (hybrid, batteries and fuel cells) and fuels as well as related infrastructures. The program was and has been funding different H_2 and fuel cell projects.

Fig. 2: FC REEV demonstrator

Source: Magna

Two project examples for the range extension of battery-electric vehicles are the FC REEV (Fuel Cell Range Extended Electric Vehicle; see Magna Goes Fuel Cell) and MeStREx (Metallic Stack for Range Extender). The former was designed by Magna Steyr and incorporates a PEM fuel cell system; the latter is a project by a consortium consisting of Plansee, AVL List, PhysTech Coating, Graz University of Technology and Nissan with the aim of finding an SOFC-based solution. In another project titled “FCH REFuel,” the partners led by Fronius are developing a modular and scalable H_2 refueling system, including electrolysis, to supply hydrogen at 350 and 700 bar (around 5,000 and 10,000 psi).

KLIEN & Co.

The federal climate and energy fund KLIEN, which is supported by several Austrian government departments, funds research activities, environmentally friendly transportation projects and measures to introduce resource-saving energy technologies to the market. This also includes hydrogen and fuel cell applications. One showcase is the completed consortium project E-Log BioFleet (I and II), during which battery-electric forklift and pallet trucks were equipped with fuel cell range extenders and tested in day-to-day operation. Additionally, it led to the development and construction of a hydrogen refueling station in a factory hall, with decentralized hydrogen generation from biomethane. KLIEN also funded HylyPure, a project initiated by TU Wien and OMV to refuel vehicles by using greatly purified hydrogen produced from natural gas through membrane gas separation and pressure swing adsorption (see Cut Costs in Green Hydrogen Transportation).

To meet the increasing demand for storage solutions when switching to volatile renewable sources, two power-to-gas projects were launched in 2015: Wind2Hydrogen and Underground Sun Storage. The partners of the Wind2Hydrogen project have tested the use of a high-pressure electrolyzer to produce hydrogen from wind power in Auersthal, Lower Austria. They examined the use of hydrogen both for refueling purposes and feed-in into the natural gas grid. Led by OMW, the researchers seek to determine how renewable hydrogen can be fed into the natural gas network in the most effective way possible and what ideal refueling and use of hydrogen in transportation looks like when considering relevant technical questions and aspects of approval.

Underground Sun Storage has been dedicated to the question of how to increase hydrogen content in the natural gas grid. Its aim is to prove the feasibility of an up to ten per cent mixture. The relevant system will be set up in Pilsbach, Upper Austria, where consortium leader RAG (Rohöl-Aufsuchungs Aktiengesellschaft; see H2 Storage Ground Under) operates a gas storage facility.

Author: Alexandra Huss

Economic incentive in Austria

Fig. 3: A. Rupprechter (Austrian politician from the ÖVP), G. Kerle (Association of Austrian Automotive Importers), J. Leichtfried (Austrian politician from the SPÖ)

emobpaekt03.jpg

Source: bmvit/bka/aigner

Vienna follows the trend: From March 2017, Austrians will be able to apply for the country's own version of an electric car incentive. When purchasing a purely battery-driven or a fuel cell vehicle, the car owner will receive EUR 4,000. Plug-in hybrids will be incentivized with EUR 1,500, electric bikes and mopeds with EUR 375. Setting up a private charging point will be supported with EUR 200, a public one with up to EUR 10,000. Additionally, license plates with a green label will be available from April 2017. They offer benefits similar to the ones in Germany. The regulations will come into force in March, apply retroactively from January 2017, and be valid at most until the end of 2018. Transportation minister Jörg Leichtfried explained: "Our EUR 72 million package will electrify Austria." Environment minister Andrä Rupprechter, who had been in favor of the bigger, EUR 100 million eco-fund, added: "This big package will get 16,000 new electric cars on the road." (sg)

VDMA Committee Gets Dual Leadership

News


Paul Merz *Joachim Döhner* *Source: VDMA*

The Battery Production steering committee of the VDMA, the German Mechanical Engineering Industry Association, has had two new spokespersons since early September 2016. Both work for KUKA Industries, an Augsburg-based provider of fully automated battery production systems. The votes for Paul Merz, sales director of technology solutions EMEA, and Joachim Döhner, vice president of technology solutions, were unanimous. They took over the tasks of Peter Haan from Siemens, who resigned after having led the steering committee since 2012. Döhner explained: “As spokespersons of the steering committee, we intend to maintain and strengthen the role of German mechanical engineering in battery production.” Merz added: “The crucial drivers for market success will be the integration of different battery production segments and cooperation of the businesses involved.”

Induction Essential for Autonomous Driving

Inductive Charging for Electric Car Batteries

Electric Transportation

Fig. 1: Philipp Schumann believes in the benefits of inductive charging

Source: Bosch

Professor Andreas Grzemba about which direction electric transportation will or could take in the future: “We won’t need any cords or our hands to charge electric vehicles.” Today, many experts believe the cord is the best solution to charge car batteries. But as technical manager of the German E-WALD research project, Grzemba thinks that autonomous driving and inductive charging will become two sides of the same coin and the standard over time. E-WALD has been the basis for developing the first approved wireless fast-charge induction system.

The demonstration project for inductive charging was launched in early 2015 at the Deggendorf Institute of Technology with the aim of simplifying electric vehicle charging and providing a more user-friendly experience. One crucial pillar of the project is fast-charging, as most common 3.7-kilowatt induction systems replenish a battery at a much slower pace than units with 22 kilowatts and more.

Thanks to the new IN-DEG system, the university succeeded in lowering inductive charging times from an initial six hours to under half an hour. The only requirement for increasing the speed has been to park the car on top of the charging pad by using an integrated positioning system (tolerance: ± 8 centimeters or around 3.1 inches). When the car is in the right spot, charging will begin automatically after you turn off the ignition. Less than 30 minutes later, the battery is at 80 per cent capacity.

The test vehicles, a Nissan Leaf and a Citroën Berlingo, had been retrofitted for the task with the help of Integrated Infrastructure Solutions, which contributed their know-how of systems used in the magnetic levitation train Transrapid. The scientific evaluation accompanying the tests mainly focused on safety, particularly on the electromagnetic radiation emanating from the underbody. The researchers took 3D measurements to ensure that exposure limits were observed.

E-WALD among top 100

Every year, Germany recognizes the one hundred most innovative businesses operating across the country. In 2016, E-WALD moved into the top 100 and received the award from the hands of business journalist and TV host Ranga Yogeshwar during the German SME Summit in Essen on June 24, 2016.

E-WALD used to be a support program titled “Electric Transportation – Bavarian Forest.” It led to the establishment of E-WALD GmbH, which was founded in Teisnach in 2012 and employs 15 staff.

Transformer on the inside

Energy transfer is based on the principle of electromagnetic induction, which was discovered by British physicist Michael Faraday in 1831. The method is also used in transformers, where two coils are linked by a ferromagnetic core. An alternating current passing through the primary coil produces a changing electromagnetic field in the core. This AC field induces an alternating voltage in the secondary coil. A rectifier is then used to provide direct current for battery charging. This works even if the coils are at a distance from each other, as in the case of electric vehicle charging or electric toothbrushes. The only on-the-road experiences with the technology have been made in Italy, where electric buses were charged at stops in Turin and Genoa from 2002 for more than ten years. In 2014, wireless charging was introduced in Braunschweig, Germany, for electric buses.

Promising developments

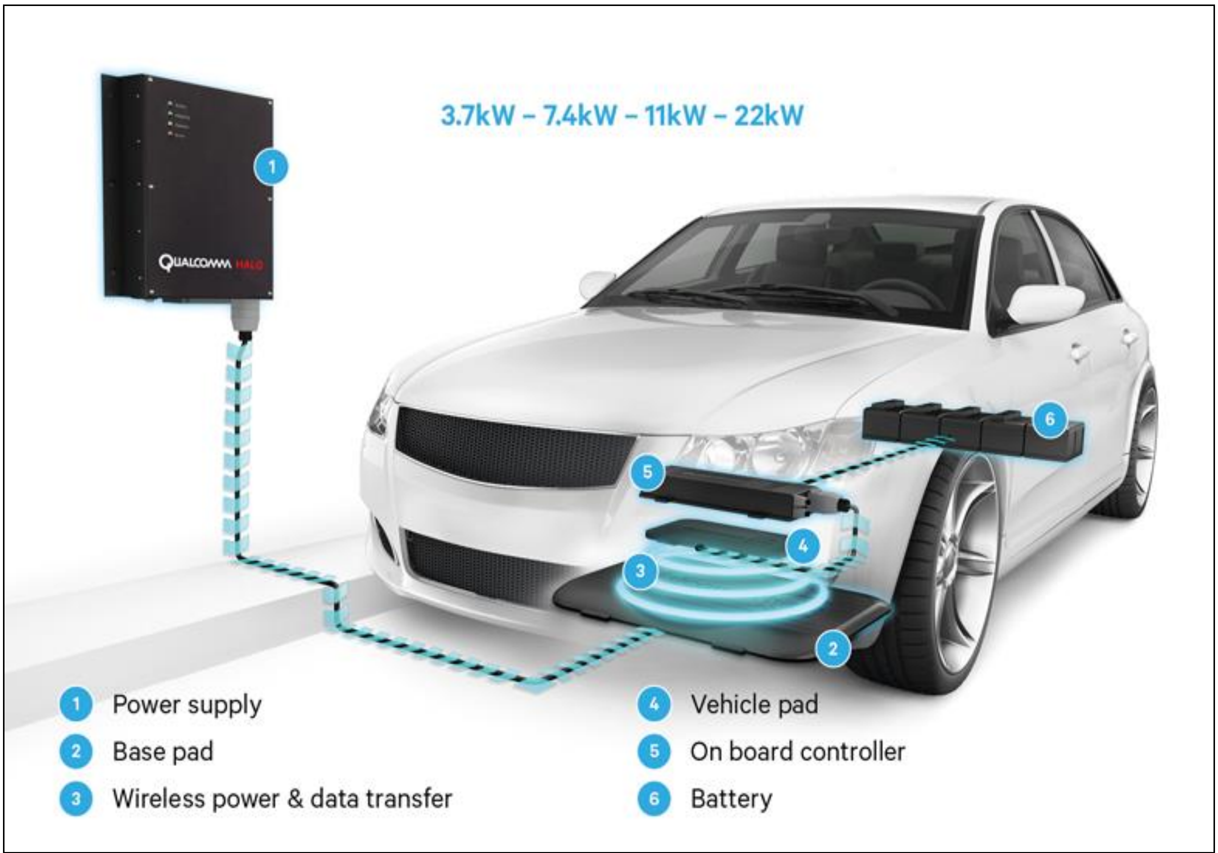
One factor that continues to separate induction from cord-based charging is output: For example, Type 2 connectors are designed for currents of up to 22 kilowatts. Conversely, induction had up to 3.7 kilowatts available, at an efficiency of 90 per cent. But Philipp Schumann, physicist at the Bosch research Campus in Renningen, believes that induction chargers could deliver the same high output as cord-based ones. Even induction efficiency could be at around the same level, 90 to 93 per cent compared with 92 to 95 per cent.

A milestone of more than ten kilowatts of capacity has already been achieved during the joint project Electric Transportation through Inductive Charging or emil.

Researchers from Braunschweig's transit authority, TU Braunschweig and Bombardier initially tested charging of an electric bus, but later used three slightly modified electric cabs (e-Golf), which were charged at the existing stations, during the subsequent project Electric Transportation through Inductive Charging of Cars or emilia. At first, the inductive pickups allowed for 3.7 kW charging, but later ten or 20 kilowatts – without the need to lower the coils as had been required for the buses.

Fig. 2: Inductive charging

1 energy supply, 2 base pad, 3 wireless energy and data transfer, 4 charging pad, 5 onboard controller, 6 battery



Source: Qualcomm

Another difference between cord-based and wireless charging is frequency. Whereas the normal power grid has "only" 50 hertz, inductive charging can use 20 to 150 kilohertz, bringing overall efficiency to more than 90 per cent and, as experts have said, allow the current to pass a 15-centimeter (5.9-inch) air gap. Costs have become controllable too. A charging pad is reportedly priced at EUR 3,000 to 5,000 nowadays. A typical charging point costs between EUR 700 and 1,400 and a fast-charge station more than EUR 10,000 – both excluding installation.

Blue Inductive

At Fraunhofer ISE, engineers developed a method that, by their own account, can cope with a 15-centimeter air gap and is currently the fastest wireless charging technology. With it, a BMW i3 or Smart ED is said to be charged in under one hour – at 95 per cent efficiency and costs similar to cord-based solutions. To commercialize the technology, the four Freiburg-based developers of the technology founded the start-up Blue Inductive. In early 2016, their invention led Forbes Magazine to move co-founder Johannes Mayer into the club of “30 under 30.” This makes Mayer one of 300 young Europeans under 30 who have received this award.

“A self-driving car should be able to recharge on its own.”

Johannes Mayer, co-founder of Blue Inductive

Induction as the sensible solution

Professor Markus Henke from TU Braunschweig, who had worked on the technology during the Showcase project in Lower Saxony from 2011, believes inductive charging is “an important step toward integrating electric transportation with automated driving.” In the same vein, Philipp Schumann, head of the Bosch research campus, said that only inductive charging was a sensible solution in the mid-term: “Imagine leaving your car in front of the parking lot to have it looking for a parking space on its own – only to have to run after it in order to plug in the charger. That doesn’t make any sense.”

Bosch has joined forces with the Fraunhofer Institute for Solar Energy Systems, the Fraunhofer Institute for Industrial Engineering, and Greening to develop the technology during the research project Bidirectional Inductive Charging Systems (BiLawE). The three-year program supported with EUR 2.4 million by the economy ministry aims not only at testing the technology, but also at developing business models for mobile charging systems.

Schumann does not believe that there are any grave health concerns or safety issues to fear: “Magnetic fields have already been part of the things you use each day, for example, induction stoves.” Additionally, shielding was so good that even people with pacemakers would not have to worry. Peter Stolte from Bombardier confirmed that it had been possible to lessen the impact of electromagnetic scattering over the last years. The buses Bombardier retrofitted during emil are equipped with a height-adjustable primary coil that emits 1 µT, which is far below the strictest limits imposed for health reasons (ICNIRP 1998: 6.25 µT).

At the end of December 2012, Pike Research, a US-based consulting business, said in a study that the annual sales of inductive charging units would rise to 280,000 by 2020. Even the Roadmap of The National Platform for Electric Mobility reads that in 2020 “inductive charging will be technically mature,” which seems to have been a bit too optimistic considering the state of the market today.

Formula E testing

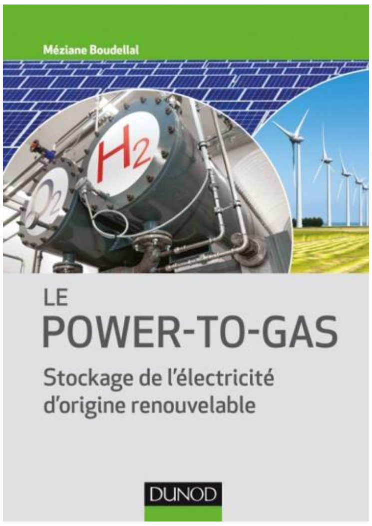
Thomas Nindl from Qualcomm told elektroniknet.de: “Inductive charging has left the pre-development stage and is being used on a regular basis when materials need to be transported on production lines.” He added that researchers from the University of Auckland had already developed a 30-kilowatt system in the late 1990s. Based on their work, HaloIPT designed charging systems for gaps of up to 230 millimeters (around 9.1 inches) at an overall efficiency of more than 90 per cent. Meanwhile, Qualcomm has taken over both HaloIPT and its compact, low-height technology. Nindl said that HaloIPT’s work allowed Qualcomm to develop any type of charging output required by carmakers (3.7 kW, 7.4 kW, 11 kW and 22 kW). Even if the technology was still in the early stages of development, it could be market-ready by 2019.

For example, BMW is testing the technology in its i3 and i8 models, which are used as Medical or Safety Cars in the Formula E. The induction pads by British company Chargemaster, which has acquired a license from Qualcomm for use of the Halo technology, makes it possible to charge the car battery of an i8 in one hour (at 7.2 kW). Meanwhile, Daimler has partnered with Brusa, which also cooperates with BMW and Qualcomm, to create a solution for plug-in hybrids. Their smaller battery capacity would render 3.7 kilowatts sufficient for charging. In Asia, Nissan and Toyota reportedly intend to offer the technology as a regular feature in their car series.

Fig. 3: Primary and secondary coil of a Formula E Medical Car

The perfect spot

It was Dean Martinovic from the Institute of Internal Combustion Engines and Automotive Engineering of the University of Stuttgart who explored the best placement of vehicles above the stationary coil in his doctoral thesis. During the BIPoLplus project, which has received support from the federal education ministry as part of the top cluster Electric Mobility South-West, he was the first in early 2013 to use a pulsed-magnetic field of low frequency to prevent interactions with the metallic underbody of the electric vehicle. A patent-pending prototype that he developed on his own shows to the point the position of the vehicle as soon as both coils are 1.5 meters (about 4.9 feet) away from each other, so that the driver can see in real-time where the car is moving and find the perfect spot to park it.



Le Power-to-Gas

News

In June 2016, Dunod Verlag published a book in French about power-to-gas. The 192-page paperback edition "Le Power-to-Gas - Stockage de l'électricité d'origine renouvelable" (ISBN 13: 978-2-10-074137-3; price: EUR 32) describes the state of the art of P2G technology. Author Méziane Boudellal answers question such as: Where does the power come from? How does an electrolyzer work? Which types of systems have been available so far?

Rating the Safety of Pressure Vessels

News

Springer Vieweg Verlag has published a new 324-page softcover book about "Evaluating the safety of composite tanks." Author Georg W. Mair looks at the potential of statistical methods beyond current regulations to show alternative options for rating the safety of carbon fiber-reinforced tanks. Mair works at the Federal Institute for Materials Research and Testing or BAM and heads the division Pressure Equipment – Pressure Receptacles – Fuel Gas Storage Systems. He is a world-renown expert on the transport of Class 2 hazardous materials (gases). His research focus is composite tanks and containers. His book with about 180 illustrations (ISBN 978-3662481318) is priced at EUR 59.99.

read more: www.h2-international.com

Advert

The Battery Show

April 4th to 6th, 2017, Sindelfingen, Germany

The Battery Show is the leading advanced battery trade fair showcasing manufacturing solutions along the supply chain, including battery materials, manufacturing, equipment, components, testing and recycling, across a range of industries including automotive, electronics, power tools, utilities, telecommunications and defence. The exhibition and conference is due to launch in Sindelfingen, Germany, 4-6 April 2017, bringing together the global battery industry in the manufacturing hub of Europe.

Free Tickets for the trade show. Register here: www.thebatteryshow.eu

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Events

- April 4th to 6th, 2017, **Electric & Hybrid Vehicle Technology Conference Europe**, in Sindelfingen, Germany, www.evtechexpo.eu/
- April 4th to 6th, 2017, The Battery Show, in Sindelfingen, Germany, www.thebatteryshow.eu
- April 20th, 2017, **Klimamobility**, Fiera Bolzano, Italy, www.fierabolzano.it
- April 24th to 28th, 2017, **Hydrogen + Fuel Cells + Batteries Group Exhibit**, part of HANNOVER MESSE, in Hannover, Germany, www.h2fc-fair.com
- May 8th to 12th, 2017, **10th Energy Storage World Forum**, in Berlin, Germany, www.energystorageforum.com
- May 10th to 11th, 2017, **Electric Vehicles**, Berlin, Germany, www.idtechex.com
- May 31st to June 1st, 2017, Fuel Cell & Hydrogen Technical Conference, University of Birmingham, United Kingdom, www.birmingham.ac.uk
- May 31th to June 2nd, 2017, ees Europe & Intersolar, Conference: May 30th to 31st, 2017, in Munich, Germany, www.ees-europe.com

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Companies

Electrolyzers

- **AREVA H2Gen GmbH**, Maarweg 137, 50825 Cologne, Germany, Phone +49-(0)221-888244-88, Fax -67, www.arevah2gen.com
- **Diamond Lite S.A.**, Rheineckerstr. 12, PO Box 9, 9425 Thal, Switzerland, Phone +41-(0)71-880020-0, Fax -1, diamondlite@diamondlite.com, www.diamondlite.com
- **Giner, Inc.**, 89 Rumford Avenue, Newton, Massachusetts 02466, USA, Phone +1-(0)781-529-0500, information@ginerinc.com, www.ginerinc.com
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- **Proton OnSite**, 10 Technology Dr, 06492 Wallingford CT, USA, Phone +1-(0)203-678-2000, info@protononsite.com, www.protononsite.com

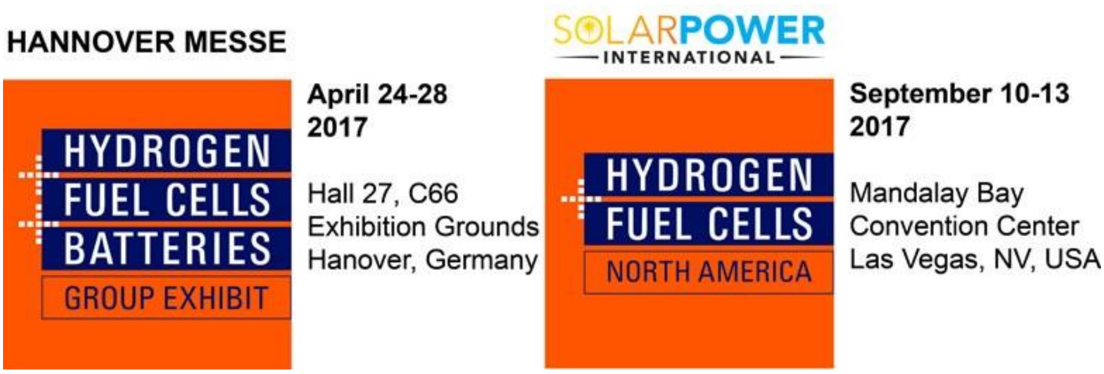
Energy Storage

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

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

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

Event Organizers



- **23rd Group Exhibit Hydrogen + Fuel Cells + Batteries**, HANNOVER MESSE 2017, April 24 – 28, Tobias Renz FAIR, Tobias Renz, tobias@h2fc-fair.com, www.h2fc-fair.com

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

- **Peter Sauber Agentur Messen und Kongresse GmbH**, f-cell and BATTERY+STORAGE, Wankelstr. 1, 70563 Stuttgart, Germany, Phone +49-711-656960-55, Fax -9055, www.f-cell.de, www.battery-storage.de

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

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

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

Fuel Cells

- **SerEnergy A/S**, Reformed Methanol fuel cell systems for stationary and e-mobility, Lyngvej 8, 9000 Aalborg, Denmark, Phone +45-8880-7040, www.serenergy.com

- **Tropical S.A.**, 17 Krokeon Str, 10442, Athens, Greece, Phone: +30-(0)210-5785455, Fax: -7, info@tropical.gr, www.tropical.gr

Fueling-Recirculation and Air-Supply

- **Gebr. Becker GmbH**, Hölker Feld 29-31, 42279 Wuppertal, Germany, Phone +49-(0)202-697-255, Fax -38255, info@becker-international.com, www.becker-international.com
- **Busch Clean Air S.A.**, Chemin des Grandes-Vies 54, 2900 Porrentruy, Switzerland, Phone +41-(0)32-46589-60, Fax -79, info@buschcleanair.com, www.buschcleanair.com

Gas Diffusion Layers (GDL)

- **MeliCon GmbH**, Metallic Lightweight Construction, Porschestr. 6, 41836 Hückelhoven, Germany, Phone +49-(0)2433-44674-0, Fax -22, www.melicon.de
- **SGL Carbon GmbH**, Werner-von-Siemens-Str. 18, 86405 Meitingen, Germany, Phone +48 (0)8271-83-3360, Fax -103360, fuelcellcomponents@sglgroup.com, www.sglgroup.com

Hydrogen Distribution

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

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

Membrane and Separator

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

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

Organization

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

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

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

Reformers

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

Research & Development

- **Fraunhofer ICT-IMM**, Reformer and Heat Exchanger, Carl-Zeiss-Str. 18-20, 55129 Mainz, Germany, Phone +49-(0)6131-9900, info@imm.fraunhofer.de, www.imm.fraunhofer.de
- **Fraunhofer ISE**, Heidenhofstrasse 2, 79110 Freiburg, Germany, Phone +49-(0)761-4588-5208, Fax -9202, www.h2-ise.de

Suppliers

- **Anleg GmbH**, Advanced Technology, Am Schornacker 59, 46485 Wesel, Germany, Phone +49-(0)281-206526-0, Fax -29, www.anleg-gmbh.de
- **Borit NV**, Bipolar plates and interconnects, Lammerdries 18e, 2440 Geel, Belgium, Phone +32-(0)14-25090-0, Fax -9, contact@borit.be, www.borit.be
- **ElectroChem Inc.**, 400 W Cummings Park, Woburn, MA 01801, USA, Phone +1-781-9385300, www.fuelcell.com

- **HIAT gGmbH**, Schwerin, Germany, CCMs / MEAs / GDEs for PEFC, DMFC & PEM-Electrolysis, www.hiat.de
- **Kerafol Keramische Folien GmbH**, Koppe-Platz 1, 92676 Eschenbach, Germany, Phone +49-(0)9645-884-30, Fax -90, www.kerafol.com/sofc
- **WEKA AG**, Schuerlistr. 8, 8344 Baeretswil, Switzerland, Phone +41-(0)43-833434-3, Fax -9, info@weka-ag.ch, www.weka-ag.ch

System Integration

- **Areva GmbH**, Paul-Gossen-Str. 100, 91052 Erlangen, Germany, Contact: Mrs. Gemmer-Berkbilek, Phone +49-(0)9131-90095221, www.areva.de
- **Deutsche Zentrum für Luft- und Raumfahrt (DLR) / German Aerospace Center**, Institute of Engineering Thermodynamics Energy System Integration, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany, Phone +49-(0)711-6862-672, Fax -747, www.dlr.de/tt, www.dlr.de/tt

Testing

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

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

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Imprint

H2-international – The e-Journal on Hydrogen and Fuel Cells

ISSN-Online: 2367-3931

Publisher: Hydrogeit Verlag, Sven Geitmann, Gartenweg 5, 16727 Oberkraemer, Germany, Phone +49 (0)33055-21322, Fax +49 (0)33055-21320

UID/VAT: DE221143829

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