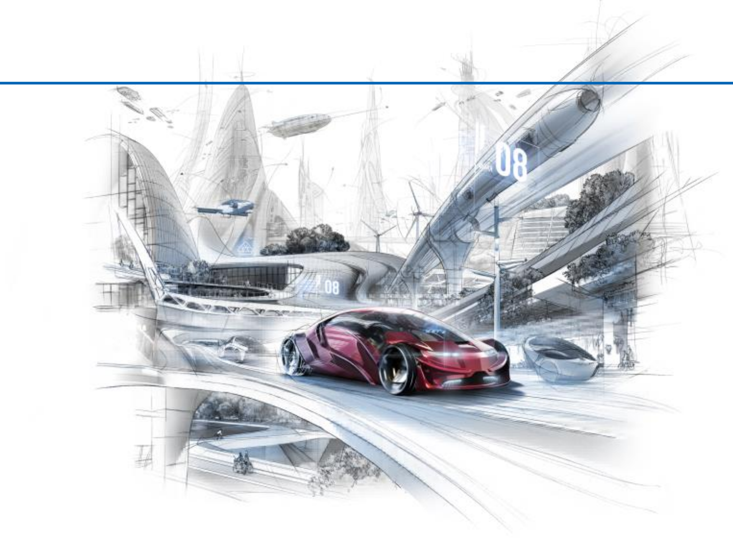
VDE Fact Check



Hydrogen in Mobility

With an increasing share of fluctuating renewable energies, the need for storage technology is also increasing. At the same time, the demand for alternative fuels in the transport sector is also increasing. By coupling the sectors, both developments are combined and contribute toward achieving the climate policy goals in the Paris Agreement. Hydrogen plays an important key role. Although storing and transporting hydrogen is complicated, it is a versatile medium that can make the coupling of the sectors.

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Hydrogen – a special molecule

Hydrogen is not only the first element in the universe, with a mass portion of 75%, it is also the most common element, has the lowest density and its gravimetric heat value is three times higher than that of diesel. Under normal conditions, hydrogen is a colorless and odorless gas. It usually doesn't occur individually, but as a solid bond in the form of a hydrogen molecule (H_2). In the chemically bound form with oxygen, it is found in nearly every organic compound. Despite the high volume, the high gravimetric energy density in comparison to crude oil, the use of renewable energies and the diverse applications in, among other things, the transport sector, are decisive factors for hydrogen as a versatile source of energy. By using chemical or electrical energy, the molecular hydrogen bond is dissolved. Hydrogen can be stored in large quantities in pressurized containers either in a gaseous state or fluid aggregate state. It is also used to produce CO_2-neutral e-fuels. However, hydrogen does not fluidize until it reaches -252 degrees. In the gaseous state, compressed to 700 bar for fuel cell passenger vehicles and at 350 bar for utility vehicles, hydrogen is transported to filling stations on roads. In the long term, pipelines will be used. A corresponding filling station infrastructure is currently being constructed. While fossil fuels are bound to their geographic occurrence, hydrogen can theoretically be generated from renewable energies everywhere it is needed. Currently, hydrogen is primarily gained by reforming fossil fuels.

However, the cost-efficient method of production also generates harmful greenhouse gases. Only a small portion is produced using electrolysis, i.e., by using electrical current. Production using electrolysis is more expensive, but it is also significantly more environmentally friendly, if the electricity comes from renewable energy sources. It also offers the major benefit that fluctuations in renewable energies like solar and wind power can be balanced and grid stability can be supported. If, for instance, excess power is generated due to a temporarily high feed from wind power (power demand is lower than the power supplied), this power can be used for hydrogen production by activating the electrolysis of this power. The energy sources gained in this manner can be stored, as needed, for later use.

In the future, it can be expected that, as production capacities increase, the manufacturing costs will decrease, and this portion of hydrogen production will increase significantly. Both storage and transport are complicated but, in comparison to electricity, hydrogen can be better transported and stored in large quantities for a longer period. A differentiation is made between the material use of hydrogen in industry and the use as an energy source. As with many storage media, when using hydrogen, the energy can either be converted using a combustion engine or a fuel cell.

Currently, the use of hydrogen in fuel cell systems is being tested. Fuel cell systems are used in means of transport as a clean and sustainable energy option for the portable supply of electricity for electrical devices and in cogeneration (CHP) and small power plants. For the achievement of the CO_2-neutral mobility of tomorrow, hydrogen can play a significant role as an energy storage medium, and thus, the coupling of the sectors.

Fuel cell technology

The concept of fuel cells arose in the 19th century in the form of the “galvanic gas battery”. Its functional principle is also used in modern fuel cells. The chemical reaction of hydrogen and oxygen (or other fuels) in the fuel cell, results in electrical power and heat. This reaction heat can be used for heating. After the hydrogen is split into two protons and two electrons, the protons move to the oxygen side via the electrolytes where there is a lack of electrons. During this process, they are routed via an electrical circuit. Water is created from the protons, electrons, and oxygen. There are various technologies which differ in the anode, cathode, membrane, catalyst, and electrolyte materials used therein. As a part of a vehicle drive, the fuel cells convert the hydrogen into propulsion power for the electrical engine. This is a controlled reaction between the hydrogen and atmospheric oxygen which generates water vapor. A major benefit of this type of energy generation is that no gases are released, no noise is generated, and no moving parts are required. As a propulsion method for means of transport, fuel cell technology, in comparison to conventional and battery electric-operated vehicles, offers several benefits with respect to the systemic overall balance of CO_2 emissions, range and charging time. As a result of the longer energy conversion chain in comparison to battery electric-operated vehicles, more primary energy is required because there are higher conversion losses.

Green mobility with hydrogen

When hydrogen is generated from renewable energies like water, wind, or sun (“green hydrogen”) for the propulsion of fuel cells, fuel cell technology is a climate-friendly propulsion concept. It is particularly suitable for use in means of transport which, soon, will be difficult to electrify, e.g., long-distance, heavy-load or maritime transport. There are already initial concepts with respect to the question of how fuels cells can be supplied with hydrogen from renewable energy sources. Thus, since March 2012, Fraunhofer-Institute for Solar Energy Systems (ISE) has been operating a hydrogen filling station which is supplied with energy for on-site production of hydrogen via solar energy systems. First, hydrogen is generated, prepared, and condensed before it is compressed and stored in a high-pressure tank.

National and international activities

To support the market introduction of the first products, the federal government has promoted fuel cell technology since the 1980s and, in 2016, it bundled various initiatives into the government program “National Innovation Program for Hydrogen and Fuel Cell Technology” (NIP) with the objective of preparing the market. With the continuation of the NIP Program II, hydrogen and fuel technology is slated to be competitively established in the transport sector and on the energy market by the middle of the next century. The federal government continued this path and, in June 2020, announced the national “hydrogen strategy”. By 2040, electrolysis plants with a total capacity of 10 gigawatts will be constructed in Germany. Subsidies, totaling nine billion Euros, are available for setting up a national hydrogen system. The European Commission sets a goal of 40 gigawatts of electrolyzers by 2030 in its “Hydrogen Strategy”. Asian countries are betting on hydrogen and fuel cell technology. Japan is the first country that is developing a “Basic Hydrogen Strategy”. In China, 5,000 fuel cell vehicles are currently in use and South Korea also plans to become one of the most important providers of the hydrogen economy.

Status quo in Germany

German policymakers have also recognized the potential of hydrogen and, in cooperation with industry, have set necessary framework conditions to consistently activate the market. In Germany, hydrogen is already being tested in many applications to make mobility more sustainable and environmentally friendly. These are usually pilot projects with small quantities, since production is expensive, and the technology is not fully developed and first must transition to serial production.

The automotive industry has been experimenting with fuel cell technology for decades. The first retrofitted hydrogen car was built in 1978. To date, however, only a few hydrogen-driven models have been offered for private use. The fuel cell, in combination with hydrogen storage in the passenger vehicle segment, can allow for ranges of more than 500 kilometers which are comparable with vehicles with an installed combustion engine. Other benefits are the familiar filling process and the recovery of braking energy. Fuel cell vehicles require the buffer battery to intercept the load peak when accelerating and supporting start-up and acceleration. Due to the high manufacturing costs and the use of rare metals like platinum, the models are found in the higher price segment and thus more expensive than conventional vehicles. Since vehicles and filling stations must be introduced at the same time to the greatest extent possible, the “chicken-egg problem” is also a factor that prevents rapid market penetration. Worldwide, Germany is one of the countries with the most hydrogen filling stations; currently 90 are open (version: January 2021).

There are also initial pilot projects with fuel cell-operated industrial trucks (forklifts, tractors, etc.) in the goods and passenger transport sectors. Battery electric vehicles can also be retrofitted. Both variants are still awaiting market introduction in Germany and are primarily used in pilot projects and funding projects for market activation. Around three hundred vehicles are currently in use. In the “Clean Energy Partnership”, omnibuses with hydrogen combustion engines and fuel cell hybrid buses are in use in the public transport sector. They offer a significantly higher range than electrical buses but cost approximately double that of comparable diesel buses. In comparison to buses and passenger vehicles, the use of fuel cells in trucks has been less comprehensively researched. The technology is suitable for use in trucks because, because of the high range and low volume of fuel cells, diesel and fuel-operated trucks can be easily replaced. To fulfill the EU climate policy requirements for trucks, the CO_2 emissions must be reduced, on average, by 15 percent by 2025 and 30 percent by 2030. Therefore, German companies are working on producing serial electrical trucks that are operated using fuel cells. This includes, for instance, the joint venture between Daimler and Volvo with the objective of discontinuing the supply of trucks with diesel engines in 2039. Toyota and Hyundai as well as start-ups like Nikola, are entering the market.

In the railway sector, the company Alstom is the first manufacturer in the world that produces trains operated using fuel cells and, since 2018, it has also tested the first prototypes in real operation in Lower Saxony. A range of 800 to 1000 kilometers on one full tank is possible according to the manufacturer. The Rhein-Main Verkehrsverbund (RMV) is also betting on green railway transport and has ordered 27 fuel cell trains which are slated for use starting at the end of 2022. The two German corporations Siemens Mobility and Siemens Energy are planning to develop a holistic hydrogen system for railways and thus further drive forward the decarbonization of the energy systems. An electrolysis and filling solution for rapid filling of hydrogen trains to be developed by Siemens Mobility is to be used. The fuel cells will also be used by the German rail company Deutsche Bahn (DB) as an emergency power system.

To make maritime transport more climate friendly in the future, the federal government is subsidizing projects with fuels cells in ships, for instance the push boat ELEKTRA. German shipyards, shipping companies, fuel cell manufacturers, suppliers, etc. have founded the “e4ships” consortium. Companies in the aviation sector also want to test hydrogen as an alternative for airplane propulsion in the future. The airplane manufacturer Airbus and the supplier ElringKlinger are co-operating on the development of fuel cells for the aviation sector. Airbus’ objective is to introduce a fuel cell-operated airplane in 2035. The jet engine manufacturer MTU Aero Engines is planning to further reduce emissions using the technology.

VDE for the hydrogen economy

The DKE (German Commission for Electrotechnology, Electronics, Information in DIN and VDE) has been addressing the various applications of fuel cells in the DKE/K 384 “Fuel Cells” committee (since 1999). As a national mirror committee to IEC/TC 105, with the development of standards for fuel cell technologies, it is responsible for a wide range of areas of application, e.g., stationary fuel cells, fuel cells for transport (fuel cell drives and peripheral energy generation systems) and portable fuel cell energy generation systems. The committee includes, from the mobility sector, for instance industrial trucks, forklifts, construction machinery, excavators, and drones. Applications in road vehicles are not included.

On the international level, the committee deals with various applications of fuel cells and related safety and capacity requirements in the IEC 62282 series. As a result, in fuel cell technology several projects have been established and safety standards such as DIN EN IEC 62282-2-100 or DIN EN 62282-4-101 are being developed which implement a reliable and safe application of the fuel cell technology. This includes the field of household heat and power supply in the framework of cogeneration.

On the national level, there is an interdisciplinary joint committee consisting of VDE ETG and VDI GEU regarding the topics of hydrogen and fuel cells. In addition to the publication of relevant studies, a valuable interdisciplinary exchange between the experts takes place in the committees. The standardization activities with a special focus on road traffic is underway on the international level in the ISO/TC 22 “Road Vehicles” committee. This series of standards is currently being revised. In the area of railway vehicles, the fuel cell is being addressed on the international level in, among others, IEC/TC 105 “Fuel Cell Technologies” and IEC/TC 9 “Electrical Equipment and Systems for Railway”. The DIN EN ISO 19884 and ISO 19880-1 safety standards also need to be mentioned and deal with the requirements for designing and manufacturing bottles and pressurized containers for hydrogen as well as handling, installing, inspecting and maintaining fuel dispensers for gaseous hydrogen. This is where the DIN EN 17127 standard picks up which will contain requirements and specifications for outdoor hydrogen filling stations. Further standards for the production and storage of hydrogen are being planned.

Activities

The focus of the standardization work for fuel cell technology is on the application of fuel cell energy systems as micro, stationary or portable fuel cells. Safety-related requirements and testing requirements and definitions for determining capacity and characteristic data are being developed for these standards. The primary series of standards, IEC 62282, is continuously updated and expanded for these purposes, for instance, by means of the revision of Part 5-1 regarding the safety of portable fuel cell energy systems which was adopted on the national level. On the international level, efforts are being made to develop a new standard for the use of fuel cell energy systems in work and construction machinery, e.g., excavators and forklifts.

The VDE study “Assessment of climate-neutral alternatives to diesel train sets” (version: July 2020) examined the economic efficiency of climate-neutral alternatives to diesel train sets with the result that the fuel cells are currently the most expensive and economically inefficient in comparison to battery train sets and diesel train sets due to their energy and replacement costs. The VDE study “Alternatives to diesel train sets in regional rail transport” (version: May 2019) demonstrated that alternatives with electrical engines like the electrical train set with overhead lines and the battery and fuel cell train set are sensible alternatives for replacing the diesel train set. The VDI VDE study “Fuel cells for the electromobility of tomorrow” illuminates the assessment of technical, ecological, and economic aspects of battery electric and hydrogen-operated vehicles (version: June 2019).

Forecast

Water electrolysis, in combination with fuel cell technology has the potential to make a major contribution toward reducing greenhouse gas emissions. Hydrogen can be produced from water using renewable energies, transported, and stored which offers benefits in comparison to electricity. This allows for the fuel cells to be used for a variety of uses in sector coupling and applications in the transport sector.

Hydrogen is therefore an essential element of the mobility of the future. Other applications, for instance with respect to mining raw materials are being tested to meet the emissions thresholds in the mining sector. There are opportunities and challenges in the serial production of vehicles and the continuous set-up of a charging infrastructure of hydrogen filling stations.