

Hydrogen and fuel cells: Eight important questions & answers for the media





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Question 1: What is hydrogen and how is it used in transport and other sectors of the economy?

Hydrogen is a chemical element and occurs for the most part in bound form in nature: individual hydrogen atoms combine to form molecules and then usually react with oxygen to form water. The boiling point of hydrogen is extremely low at $-252\text{ }^{\circ}\text{C}$, with pure hydrogen occurring as a gas at ambient temperature, which can be used, for example, to refuel fuel cell electric vehicles, or FCEVs. Based on its weight, the energy density of hydrogen is very high. However, based on its volume, it is very low. Therefore, in order to use hydrogen as a fuel it must be highly compressed which, on the one hand, worsens the energy footprint, but on the other facilitates a long vehicle range. Hydrogen can be manufactured using a variety of methods using fossil as well as renewable energies.^{1,2} While the majority of the hydrogen used worldwide today is produced using fossil fuels, manufacturing it on a renewable basis for climate protection is steadily increasing in importance.

Hydrogen has been used in large quantities in various industrial sectors for over 100 years and is employed, for example, in the desulphurisation of conventional fuels in refineries. Since the first serious efforts were undertaken to develop FCEVs about 20 years ago, hydrogen is playing a greater role as a fuel. Today, various international automotive manufacturers are marketing or testing FCEVs fuelled by pure hydrogen. Worldwide, companies are producing passenger cars, buses and other types of hydrogen-run vehicles for commercial sale and for demonstration projects (see Question 4). Hydrogen is also deployed in rail vehicles, ships and aircraft with fuel cell drives or aggregates. For example, two ready-for-market Alstom hydrogen trains are currently being tested in Germany and will be supplemented by twelve additional trains in the future. Hydrogen has also found a place in stationary energy supply, e.g. for fuel cell heating units and systems for uninterruptible power supply.³

In Germany, the potential of hydrogen for the integration of renewable energy in transport and other sectors of business was also recognised in the course of the energy transition. Strongly growing shares of fluctuating wind and solar power must be stabilised and integrated into the transport and energy sectors. This is one of the

¹ A good introduction to the topic area is provided by: Adolf, J., Arnold, K., Balzer, C., Fishedick, M., Louis, J., Pastowski, A., Schabla, U. and Schüwer, D.: 'Shell Wasserstoff-Studie: Energie der Zukunft? Nachhaltige Mobilität durch Brennstoffzelle und H₂' (Shell Hydrogen Study: Energy of the future? Sustainable mobility through fuel cells and H₂), Hamburg 2017: Shell Deutschland Oil GmbH.

² The Germany Hydrogen and Fuel Cell Association (Deutsche Wasserstoff- und Brennstoffzellen-Verband, DWV) also provides basic information as well as current developments at www.dwv-info.de.

³ The websites of the National Organisation Hydrogen and Fuel Cell Technology (www.now-gmbh.de) and the Fuel Cells and Hydrogen Joint Undertaking (www.fch.europa.eu) report on R&D and demonstration projects as well as on political developments in Germany and the EU.

reasons why renewable hydrogen is predominantly used in FCEV demonstration and commercialisation projects funded by the German government.⁴ Stakeholders in the natural gas industry are developing power-to-gas plants and feeding hydrogen from wind power into natural gas grids.⁵ The substitution of fossil-produced industrial hydrogen with renewable hydrogen is being tested in various projects. Hydrogen can play an important role in linking different economic sectors through the complementary use of renewable energies, known as sector coupling. For example, renewable hydrogen can be produced cost-effectively in large electrolysis plants and then used across sectors, in transport, stationary energy supply and industry.⁶

Question 2: How are fuel cell vehicles designed and where are they deployed?

In principle, fuel cells can be used in most types of vehicles and replace, for example, conventional combustion engines. Proton exchange membrane (PEM) fuel cells are used almost exclusively to power fuel cell vehicles and generate power through the controlled reaction of hydrogen with oxygen, whereby only water is produced as 'exhaust'. The hydrogen is usually stored in gaseous form and at pressures of up to 700 bar in compression vessels, while the oxygen is extracted from the ambient air. The electricity produced powers an electric motor or, in certain driving situations, is fed into a buffer battery, which in other situations delivers power to the motor. Power electronics and components for recuperating braking energy are also standard components of an FCEV drive train.⁷ In principle, this configuration is the same for passenger cars, buses and other commercial vehicles, although there are naturally significant differences in the specific design of systems and components.⁸

The basic idea behind the design of fuel cell vehicles is to offer users a fully-fledged replacement for conventionally powered vehicles, without requiring any changes in their use behaviour. Therefore, driving dynamics, range and refuelling times come

⁴ Ehret, O. and Bonhoff, K.: 'Hydrogen as a fuel and energy storage: Success factors for the German Energiewende', in: *International Journal of Hydrogen Energy*, Vol. 40, 2015, No. 15, pp. 5526–5533.

⁵ Key players have joined forces in the Power to Gas strategy platform of the German Energy Agency and in the DWV specialist commission performing energy. (see www.dena.de/themen-projekte/projekte/energiesysteme/strategieplattform-power-to-gas and www.dwv-info.de/performing-energy/).

⁶ Ehret, O., Müller-Syring, G., Henel, M., Wehling, A. and Weiße, M.: 'Wirtschaftlichkeit nachgewiesen: Metastudie zu Potenzialen von Wasserstoff' (Economic efficiency proven: Metastudy on potentials of hydrogen), in: *HZwei: Das Magazin für Wasserstoff und Brennstoffzellen*, Vol. 16, 2016, Issue 4, pp. 18–19.

⁷ The websites of the Clean Energy Partnership (CEP) and H2 MOBILITY provide good overviews of fuel cell vehicles and hydrogen infrastructure (cleanenergypartnership.de and h2.live/h2mobility).

⁸ Further information on vehicle technology can be found on the FCEV manufacturer websites (Question 4).

close to the 'specifications' of conventional engines. However, there are considerable differences with regard to the sustainability of the drive concepts: fuel cells facilitate the use of renewable instead of fossil-based energies as fuel and also have about twice the energy efficiency of a combustion engine. There are no greenhouse gas or pollutant emissions and there is virtually no engine noise during driving.⁹ FCEVs are highly suitable for inner-city operation because they minimise local environmental pollution and are particularly energy efficient.

Yet FCEVs also boast significant advantages where electric vehicles with a long range and high weight are required. The ranges of most battery electric vehicles (BEVs), which are mostly relatively small cars or light commercial vehicles, have so far been less than 300 km in everyday operation.¹⁰ Battery-powered buses and delivery vehicles are subject to significant restrictions in terms of range and payload, as long ranges and the required high drive power inevitably require the installation of large-capacity batteries that are heavy and reduce payloads.¹¹ Despite the fact that battery-powered vehicles achieve a higher level of drive efficiency than FCEVs, for example, and that significant technological improvements can be expected, fuel cells offer a particularly attractive option, especially for large and heavy vehicles.

As outlined in Questions 4 and 5, the real range stated by test drivers of today's commercially available and relatively large fuel cell passenger cars is about 500 km. Current fuel cell buses have reached a level of technological development that meets everyday requirements completely and are in the phase of early commercialisation. Fuel cell-powered trucks of various payload classes are being developed and tested with a view to market launch in the near future. The timetable for climate-friendly road transport drawn up by the Federal Ministry of Transport and Digital Infrastructure considers hydrogen and fuel cells to be particularly promising drive options for the future. The rationale for the selection is the particular suitability of FCEVs for long ranges and heavy vehicles.¹² As diesel engines are used almost exclusively for heavy passenger cars and commercial vehicles in Germany today, fuel cells are a potential substitute for diesel.

⁹ Ehret, O. and Dignum, M.: 'Introducing hydrogen and fuel cell vehicles in Germany', in: Geels, F., Kemp, R., Dudley, G. and Lyons, G. (eds.) *Automobility in Transition? A Socio-Technical Analysis of Sustainable Transport*, New York (USA) and Abingdon (UK) 2012: Routledge, pp. 229–249.

¹⁰ Bratzel, S., Ehret, O. and Tellermann, R.: 'Branchenstudie Elektromobilität 2018: Analyse der Markt- und Innovationstrends in Deutschland und internationalen Kernmärkten' (Sector Study Electric Mobility 2018: Analysis of Market and Innovation Trends in Germany and International Core Markets), Bergisch Gladbach 2018: Center of Automotive Management.

¹¹ Altenburg, S., Auf der Maur, A., Eckert, S., Faltenbacher, M., Labinsky, A. and Reuter, B.: 'Nullemissionsnutzfahrzeuge: Vom ökologischen Hoffnungsträger zur ökonomischen Alternative' (Zero-emission commercial vehicles: From ecological hope to economic alternative), Stuttgart 2017: e-mobil BW GmbH.

¹² www.bmvi.de/SharedDocs/DE/Anlage/MKS/initiative-klimafreundlicher-strassengueterverkehr.pdf?__blob=publicationFile.

Most of the FCEVs available worldwide are sold as passenger cars and – in significantly smaller numbers – as city buses (see question 4). This corresponds on the one hand to the fact that passenger cars generally dominate the sales figures of most automobile companies that also manufacture FCEVs. On the other hand, city buses can best exploit the above-mentioned environmental advantages and operate as fleet vehicles in a resource-efficient manner with only low demands on the refuelling infrastructure. The same components are also often used in cars and buses and important lessons can be learnt with regard to technical optimisation and cost reduction by exploiting synergy effects. At the same time, the basis will be laid for the development and use of more powerful fuel cells and next-generation powertrains that can be used in both passenger cars and commercial vehicles.

Question 3: Are fuel cell vehicles considered to be a part of electric mobility?

Fuel cell vehicles are powered electrically and the drive train consists mainly of electrical or electrochemical components (see Question 2). FCEVs use many components that correspond with or are identical to pure battery-powered vehicles, such as electric motors or supercaps to recuperate braking energy. Fuel cell and battery vehicles are designed by manufacturers with a view to using identical components as far as possible, as has been the case with Daimler's f-cell and e-cell electric vehicles, for example.¹³ All FCEVs are hybrid vehicles and are equipped with a battery integrated into the power electronics, which enables low-wear operation of the fuel cell and harmonises the various energy flows in the vehicle.¹⁴ As far as the drive system and installed components are concerned, FCEVs can therefore clearly be classified as electric mobility.

In the political debate, however, the understanding of electric mobility is largely restricted to battery vehicles. The National Platform for Electric Mobility (Nationale Plattform Elektromobilität), initiated by the German federal government and important for the market ramp-up of electric vehicles, concentrates on battery-powered vehicles with and without range extenders, as well as plug-in hybrids. The platform makes charging from the mains power supply a condition of its definition of electric vehicles or electric mobility and does not deal with FCEVs.¹⁵ In principle, however,

¹³ Bonhoff, K.: 'Brennstoffzellen und Batterien – die ideale Ergänzung in vielen Anwendungen' (Fuel cells and batteries – the ideal complement in many applications), Lecture for Batterieforum Deutschland, 06.–08.04.2016, Berlin.

¹⁴ The design of the batteries is comparable to that of other electric vehicles, but the energy storage capacity is significantly lower compared to pure battery vehicles.

¹⁵ nationale-plattform-elektromobilitaet.de/hintergrund/der-ansatz/#tabs. The National Platform for Electric Mobility (Nationale Plattform Elektromobilität) is currently being transformed into a newly conceived National Platform for the Future of Mobility (Nationale Plattform Zukunft der Mobilität).

the federal government's view is technologically neutral and leaves room for the inclusion of fuel cells in electric mobility. Since 2006, the federal government has been promoting the market preparation and early commercialisation of FCEVs and hydrogen infrastructure in the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP).¹⁶ Accordingly, at the end of 2016, the then Federal Minister of Transport and Digital Infrastructure described the fuel cell as a key technology in electric mobility.¹⁷ The government's view is legally binding both in the Electric Mobility Act of 2015 and in the Environmental Bonus of 2016: FCEVs benefit from privileges with regard to vehicle use as well as from purchase premiums to promote the sale of electric vehicles.¹⁸ As such, FCEVs are also part of electric mobility in political terms.

Question 4: Are fuel cell vehicles already commercially available?

Fuel cell vehicles have already been on sale or leased by Asian automotive companies for several years.¹⁹ South Korean manufacturer Hyundai launched its fuel cell SUV ix35 Fuel Cell with a 100 kW engine and a nominal range of almost 600 km at the end of 2013. The vehicles were initially destined for the domestic market and later for California and Europe.²⁰ By mid-2017, Hyundai had sold around 1,000 SUVs worldwide, 500 of which were sold in Europe at a retail price of €65,450.²¹ About 200 vehicles went to Germany, of which 50 were used by the BeeZero car-sharing company for two years.²² In mid-2017, Hyundai announced the start of sales and production of an initial 3,600 units of a technically significantly improved successor model.²³ The Nexu has a 120 kW engine and a nominal range of approximately 750 km. The fuel cell SUV has been sold in Germany since summer 2018 at a price of €69,000 and, according to generally positive test reports, achieves a real

¹⁶ www.now-gmbh.de/de/nationales-innovationsprogramm/foerderprogramm.

¹⁷ www.bmvi.de/SharedDocs/DE/Artikel/K/zehn-jahre-elektromobilitaet.html.

¹⁸ www.bmub.bund.de/themen/luft-laerm-verkehr/verkehr/elektromobilitaet and www.bafa.de/DE/Energie/Energieeffizienz/Elektromobilitaet/elektromobilitaet_node.html.

¹⁹ Different sources often provide different information on the stock and sales targets of FCEVs. The following figures are based on manufacturer information and have been validated.

²⁰ www.hyundai.de/News/Modelle/Hyundai-ix35-Fuel-Cell-bei-allen-deutschen-Vertrag.html and www.hyundai.de/News/Unternehmen/Ubergabe-von-50-Hyundai-ix35-Fuel-Cell-anden-Cars.html.

²¹ Personal communication from Oliver Gutt, Hyundai Motor Deutschland GmbH, 08.09.2017.

²² Geitmann, S.: 'Linde beendet Beezero' (Linde ends Beezero), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 18, 2018, Issue 3, p. 18.

²³ www.electrive.net/2017/06/20/hyundai-nennt-produktionszahlen-des-fe-fuel-cell-concept.

range of about 550 km.²⁴ Hyundai also builds fuel cell commercial vehicles and has announced that it will deliver 1,000 trucks to Swiss customers over the next few years.²⁵

Since the end of 2014, the Japanese car manufacturer Toyota has sold the fuel cell Mirai, which has a 113 kW engine and a real range of around 480 km, for a little under €79,000.²⁶ Most of these FCEVs were sold or leased in Japan and California, as well as in Europe – albeit in much smaller numbers. While sales in Germany began sluggishly with 27 Mirai units in 2016, 400 vehicles were sold by autumn 2018.²⁷ Many of the FCEVs are being used by the ride-sharing service provider CleverShuttle, which is supported by the German government.²⁸ By early 2018, Toyota had sold around 6,000 FCEVs worldwide.²⁹ The company has also been testing a pre-production fuel cell bus named FC Bus in Japan since the beginning of 2017 and is aiming for a deployment of 100 units in the near future. The FC Bus integrates the central components of the Mirai and uses, for example, two fuel cells rather than just one.³⁰ The market launch of the next passenger car generation is planned for 2020 with an annual production volume of 30,000 units. For 2025, Toyota has announced the beginning of a further significantly increased commitment.³¹

The Japanese car manufacturer Honda commenced series production of its Clarity Fuel Cell vehicle in spring 2016. It features a 130 kW engine and a range specified as approximately 650 km.³² In 2016, 150 right-hand drive vehicles were initially launched on the Japanese market.³³ Production for California began at the end

²⁴ Kroher, T.: 'Das rollende Kraftwerk' (The rolling powerhouse), in: ADAC Motorwelt, 2018, Issue 2, pp. 22–24.

²⁵ fuelcellworks.com/news/hyundai-and-h2-energy-sign-deal-to-sell-1000-hydrogen-powered-trucks-in-switzerland.

²⁶ www.toyota.de/automobile/der-toyota-mirai.json.

²⁷ Geitmann, S.: 'Toyota setzt auf die Brennstoffzelle: Probefahrt mit dem Mirai' (Toyota focuses on fuel cells: Test drive of the Mirai), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 2, pp. 28–29 and Wieler, J.: 'Nah am Wasser', in: ADAC Motorwelt, 2018, Issue 10, pp. 32–37.

²⁸ www.now-gmbh.de/de/aktuelles/presse/clevershuttle-startet-service-in-stuttgart and www.now-gmbh.de/de/aktuelles/presse/nip-3-2-millionen-euro-fuer-brennstoffzellen-pkw.

²⁹ Geitmann, S.: 'Nexo-Premiere in Offenbach: Hyundai präsentiert neues Brennstoffzellenmodell' (Nexo premiere in Offenbach: Hyundai presents new fuel cell model), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 18, 2018, Issue 2, pp. 32–33.

³⁰ Sonoda, Y.: 'The Future of Fuel Cell Vehicles (FCV)', paper given at: evs 30: The 30th International Electric Vehicle Symposium & Exhibition, 9.-11.10.2017, Stuttgart and www.toyota.de/news/details-2017-023.json.

³¹ Geitmann, S.: 'Toyota setzt auf die Brennstoffzelle' (Toyota focuses on the fuel cell) (footnote 27).

³² automobiles.honda.com/clarity and www.honda.de/cars/honda-welt/news-events/2016-11-30-honda-clarity-fuel-cell-kommt-nach-europa.html and <http://hondanews.eu/at/de/cars/media/pressreleases/107266/honda-clarity-fuel-cell-2017-pressemappe>.

³³ world.honda.com/news/2015/4151028eng.html and world.honda.com/news/2016/4160310eng.html.

of 2016, and by May 2017 more than 250 vehicles had been leased in California at a unit price of US\$57,000, including a hydrogen refuelling credit amounting to US\$15,000. At the end of 2016, the first of a total of 10 FCEVs destined for Europe were delivered and deployed in European demonstration projects. The vehicle will be commercially sold in Japan and California. A successor was announced for the early 2020s and is to be sold at a significantly lower price and in larger quantities.³⁴

Daimler has been developing and testing fuel cell cars and buses for around two decades. In 2017 it unveiled a new fuel cell compact car based on the GLC. It became known early on that, in contrast to other FCEVs, the vehicle would have a relatively large lithium-ion battery including a plug-in module and would enable a purely battery-electric journey of 50 km.³⁵ The Mercedes-Benz GLC F-CELL, which is referred to as a pre-series model, was prominently used for the first time in July 2017 and was officially presented at the International Motor Show in September.^{36,37} The engine has an output of 147 kW and a nominal range of 500 km. According to Daimler's own figures from April 2018, Daimler is "rigorously preparing for the production of the Mercedes-Benz GLC F-CELL."³⁸ However, details of the production volume and sales forecasts have not been disclosed. Observers expect production figures in the triple-digit range for the next few years.

Most of the FCEVs manufactured worldwide are currently sold in Japan and California, and – to a much lesser extent – in Europe.³⁹ The sale of FCEVs depends to a large degree on political support measures and the availability of hydrogen refuelling stations. Both in Japan and California, vehicle purchases and infrastructure are heavily subsidised by the state. In Europe and Germany, research and development (R&D) as well as demonstration measures have been promoted to date, while measures to support market entry have only gained importance in recent years.⁴⁰ At the beginning of 2017, the German government announced a funding guideline that will provide coverage of up to 40 percent of the additional investment costs incurred by

³⁴ Personal communication from Thomas Brachmann, Honda R&D Europe (Deutschland) GmbH, 05.09.2017.

³⁵ www.now-gmbh.de/content/1-aktuelles/1-presse/20161214-nip-erfolgreiche-bilanz/9b_prof-mohrdieck-final-sent.pdf.

³⁶ cleanenergypartnership.de/presse/pressemitteilungen.

³⁷ media.daimler.com/marsMediaSite/de/instance/ko/Mercedes-Benz-Cars-auf-der-IAA-2017-Aufsehen-erregende-Fahrzeug-Neuheiten-und-innovative-Veranstaltungsformate-vom-Erfinder-des-Automobils.xhtml?oid=28924491.

³⁸ Geitmann, S.: 'Brennstoffzelle kommt sicherlich nach 2025: Daimler und Ford beenden AFCC' (Fuel cell will certainly come after 2025: Daimler and Ford end AFCC), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 18, 2018, Issue 3, p. 31.

³⁹ Lehner, S. and Hart, D.: 'BZ-Markt: Transportbereich wächst rasant: Fuel Cell Industry Review von E4tech' (FC market: Transport sector growing rapidly: Fuel Cell Industry Review by E4tech), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen Vol. 17, 2017, Issue 2, pp. 45–47.

⁴⁰ www.now-gmbh.de und www.fch.europa.eu.

FCEVs used in fleet operations compared with comparable conventional vehicles.⁴¹ Once this amount has been taken into account, a Hyundai Nexo would cost around €55,000 and a Toyota Mirai around €57,000.⁴²

Besides the latest and commercially released FCEVs, demonstration vehicles of various types and predecessor generations contribute internationally to the total vehicle numbers. There are currently about 400 FCEVs in operation in Germany, most of them passenger cars and some buses. The aforementioned service provider Clever-Shuttle operates the largest number of the passenger cars.⁴³ The partner companies of the Clean Energy Partnership (CEP), formerly a lighthouse project in the NIP and today a consortium of committed companies, also operate a sizeable number of vehicles. As part of the CEP, numerous FCEVs were tested between 2002 and 2016 with the support of the German government. Alongside the four automotive companies presented above, a total of 20 industrial partners were active. FCEVs from Audi, BMW, Daimler, Honda, Hyundai, Toyota, Volkswagen and other manufacturers were tested in varying configurations.⁴⁴ Comparable projects also exist internationally (see Question 8). In Germany and worldwide, however, demonstration projects, especially for passenger cars, have lost much of their importance, as commercialisation is the main focus today.

Fuel cell buses from various manufacturers have been tested and further developed in large-scale international projects. For example, 54 buses from APTS, EvoBus Mercedes-Benz, New Flyer, Van Hool and Wrightbus were tested primarily in European cities as part of the Clean Hydrogen In European Cities (CHIC) project funded by the European Union (EU) which concluded at the end of 2016.⁴⁵ Current projects mainly support the market launch: the successor project Joint Initiative for hydrogen Vehicles across Europe (JIVE), launched in 2017, promotes the procurement of around 140 buses. By ordering a larger number of vehicles, costs can be significantly reduced and commercialisation can be accelerated.

In addition to Van Hool, which is currently the most prominent supplier of fuel cell buses, other companies – e. g. Solaris, Ursus Bus, EvoBus, Hyundai, Toyota and Wrightbus – are also active in terms of commercialisation and are expected to expand their bus portfolio. The buses could, for example, be used in a sched-

⁴¹ www.now-gmbh.de/content/2-nationales-innovationsprogramm/2-foerderprogramm/bundesanzeiger_nip2-frl-ma.pdf.

⁴² Personal communication from Philipp Braunsdorf, NOW GmbH, 17.10.2018 and www.hzwei.info/blog/2017/08/09/40-foerderung-fuer-bz-autos-allerdings-fehlen-die-fahrzeuge/#comments.

⁴³ Personal communication from Philipp Braunsdorf, NOW GmbH, 17.10.2018.

⁴⁴ cleanenergypartnership.de.

⁴⁵ Stolzenburg, K.: 'Brennstoffzellenbusse auf der Überholspur: CHIC-Projektabschluss in London' (Fuel cell buses in the fast lane: CHIC project completion in London), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 1, pp. 20–21.

uled follow-up project of the EU to procure a further 150 vehicles. In terms of procurement, the funding offered by the EU and member states such as Germany complement each other and reduce the additional costs incurred compared with conventional buses considerably. At the same time, numerous European cities are deciding to replace diesel buses with fuel cell buses and other vehicles with no local emissions. It is therefore anticipated that 140 fuel cell buses will be in service in Germany by 2020 and more than 600 throughout Europe.⁴⁶ One example of how commercialisation is beginning is the order for 30 buses from Regionalverkehr Köln GmbH.⁴⁷

Fuel cell-powered trucks are now being developed by manufacturers such as Hyundai, Toyota and the US-based Nikola Motor Company.⁴⁸ While the vehicles are not yet commercially available, the technical development work is well advanced and some large-volume truck orders have already been placed. If the current plans are implemented, e. g. by Hyundai, a speedy market entry can be expected.⁴⁹

Question 5: Are fuel cell vehicles technologically mature?

In the two decades of continuous fuel cell vehicle development, the technology has progressed from early R&D to everyday products. For example, while older generation test vehicles could only be driven at temperatures above freezing, today's fuel cell passenger vehicles such as the Mirai can handle temperatures of -30°C . In the past, the service life of fuel cells was inadequate, but today they achieve service lives comparable to those of conventional vehicles. Previously, liquid hydrogen with high evaporation losses was partly used in passenger cars, but for years now the loss-free pressurised storage of hydrogen gas has prevailed. While storage initially took place at 350 bar, today's 700-bar standard enables vehicles to achieve longer ranges and a refuelling time of three minutes.⁵⁰

⁴⁶ Personal communication from Thorsten Herbert, NOW GmbH, 18.09.2017.

⁴⁷ www.now-gmbh.de/de/aktuelles/presse/koeln-beschafft-groesste-brennstoffzellen-hybrid-bus-flotte-deutschlands.

⁴⁸ www.toyota.de/news/details-2017-032.json and nikolamotor.com.

⁴⁹ This would be in line with a strategy paper of the German Federal Government, which regards fuel cell trucks as important elements of climate-friendly future road freight transport. See www.bmvi.de/SharedDocs/DE/Anlage/MKS/initiative-klimafreundlicher-strassengueterverkehr.pdf?__blob=publicationFile.

⁵⁰ Geitmann, S.: 'Eine Erfolgsgeschichte: NIP wird bis 2026 weitergeführt' (Success story: NIP will continue until 2026), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 1, p. 7.

The power density of the fuel cell has been greatly increased by all manufacturers and in the case of the Mirai more than doubled between 2008 and 2014, which yields considerable advantages in terms of its integration into the vehicle, as well as in terms of weight and costs.⁵¹ Daimler supplies similar data for the new GLC F-CELL and reports a 30 percent downsizing of the fuel cell system at a simultaneous 40 percent output increase compared to previous models.⁵² The costs of the fuel cell powertrain were generally reduced by around 75 percent between 2008 and 2016.⁵³ In fuel cell cars of all manufacturers, the drive power and top speed increased, while fuel consumption decreased. The service life of fuel cells used to be insufficient, whereas today durability values are reached which are comparable to conventional vehicles.

Intensive research and development activities have brought about today's commercially operated FCEVs. Former technical problems have been largely resolved and there is now more of a need for optimisation rather than fundamental R&D – otherwise series production would be inconceivable.⁵⁴ All FCEV vendors discussed above attest to their everyday suitability. Reports from journalists and other test drivers generally confirm suitability for everyday use and how well FCEVs handle on the road. However, it is frequently pointed out that the actual range remains below manufacturer specifications. The ranges specified vary widely in the different drive reports depending on driving style, route and model tested.⁵⁵ As a rough guide, a real range of 500 km can be specified for today's commercial FCEVs.⁵⁶ The insufficient number and reliability of available hydrogen refuelling stations has also been criticised by test drivers.

⁵¹ Toyota: Mirai: The world's first mass-produced hydrogen fuel cell vehicle, brochure: no place, no year.

⁵² www.automobil-produktion.de/hersteller/neue-modelle/die-naechste-wasserstoffwelle-2017-tidenhub-281.html.

⁵³ Geitmann, S.: ‚Eine Erfolgsgeschichte: NIP wird bis 2026 weitergeföhrt‘ (Success story: NIP will continue until 2026), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 1, p. 7.

⁵⁴ The remaining R&D requirement is on a much smaller scale that previously needed, as all fundamental problems are considered overcome. Compare www.now-gmbh.de/content/2-nationales-innovationsprogramm/2-foerderprogramm/nip2_massnahmekatalog.pdf.

⁵⁵ Compare e. g. Efler, S.: ‚Wo gibt's neuen Stoff?‘, (Where can we find new fuel?) in: ADAC motorwelt, 2017, Issue. 07/08, pp. 18-21, Geitmann, S.: ‚Toyota setzt auf die Brennstoffzelle‘ (Toyota focuses on the fuel cell) (Footnote 27), www.focus.de/auto/elektroauto/fahrbericht-honda-clarity-fuel-cell-das-ende-des-oels-koennte-so-aussehen-brennstoffzellen-honda-im-test_id_7073417.html, www.wiwo.de/unternehmen/auto/honda-clarity-fuel-cell-technologie-highlight-mit-ungewisser-zukunft/19849994.html and www.zeit.de/mobilitaet/2017-07/toyota-mirai-brennstoffzelle-testfahrt/komplettansicht.

⁵⁶ It is difficult to compare the ranges of FCEVs of different generations because the test cycles used differ. Current data determined using the WLTP measurement method are much closer to reality than previous values based on NEDC.

In addition, the continued high costs of FCEVs remains a problem and explains to a large extent the sluggish pace of commercialisation. Usually, the broad market entry of new technologies is promoted by a combination of measures aimed at R&D as well as the establishment of mass production processes and supply chains. At the German and international level, industry is taking appropriate measures and is being supported by publicly funded studies and hardware projects. For example, the projects Autostack-Industrie and DIGIMAN, funded by Germany and the EU respectively, are developing cost-effective processes for the mass production of automotive fuel cells.⁵⁷ The results achieved so far are promising.

With the overcoming of the technological hurdles, political support measures to reduce the additional costs of FCEVs compared to conventional vehicles are becoming increasingly important. The federal government's purchase subsidies described above, for example, significantly reduce the acquisition costs and the associated cost disadvantages. FCEVs are highly innovative technologies and in principle lead to a higher willingness to pay on the part of environmentally conscious and innovation-savvy groups of buyers (early adopters).

The technological maturity of fuel cell buses is approaching that of fuel cell cars. However, the reliability of some models in the CHIC project mentioned above is still inadequate and they worsen the overall assessment. Other models on the other hand, prove themselves to be fully equal compared to conventional reference vehicles and demonstrate the high maturity of the technology.⁵⁸ Otherwise the current measures for large volume procurement of fuel cell buses for regular service would be unthinkable. The technology currently in development stage for heavy goods vehicles must, of course, first be proven in deployment.

⁵⁷ www.now-gmbh.de/de/aktuelles/presse/nip-foerderung-deutsche-industrie-bereitet-serienproduktion-von-brennstoffzellen-vor and www.fch.europa.eu/project/digital-materials-characterisation-proof-process-auto-assembly.

⁵⁸ Stolzenburg, K.: 'Brennstoffzellenbusse auf der Überholspur', (Fuel cell buses in the fast lane) (Footnote 54) and personal communication from Boris Jermer, HyCologne, 10.10.2017.

Question 6: How environmentally-friendly are fuel cell vehicles?

As explained in Question 2, fuel cell vehicles have some fundamental ecological advantages. In line with the requirements of the energy transition, they enable the use of renewable energy as fuel and can convert this into kinetic energy with high efficiency to thereby significantly reduce greenhouse gas emissions.⁵⁹ Similar to battery-powered vehicles, there are no greenhouse gas or pollutant emissions and virtually no noise when driving. FCEVs can thus make a significant contribution to reducing traffic-related emissions and meeting legal requirements for air quality, particularly in cities.

When determining emissions occurring during vehicle operation, current legislation only requires that the tank-to-wheel emissions – i. e. only those emissions that are produced directly by the vehicle – need to be taken into account. Electric vehicles are therefore considered zero-emission vehicles as the emissions occurring during the production of electricity or hydrogen are not considered. Much more meaningful in regard to the actual environmental impact are well-to-wheel emission and energy balances, which also take into account emissions and energy consumption during the production, distribution and delivery of fuels. The following illustration⁶⁰ compares well-to-wheel greenhouse gas emissions and energy consumption of electric, fossil and biofuel-powered vehicles.⁶¹

It shows that well-to-wheel greenhouse gas emissions from both fuel cell and battery vehicles are significantly lower than those from diesel and petrol vehicles. And compared to biofuels, electric cars can score with significantly higher levels of energy efficiency. Due to the combination of low emissions and high efficiency, electric vehicles can be considered as being particularly environmentally friendly.

A detailed analysis of electric vehicles shows that fuel cell and battery vehicles both have extremely low greenhouse gas emissions, especially when using renewable energy, with BEVs producing even less than FCEVs. The emission balance deteriorates when fossil fuels are used. Both BEVs and FCEVs consume very little energy, whereas the efficiency of BEVs is even better than that of FCEVs. The environmental advantages of BEVs are explained by the fact that fewer loss-making

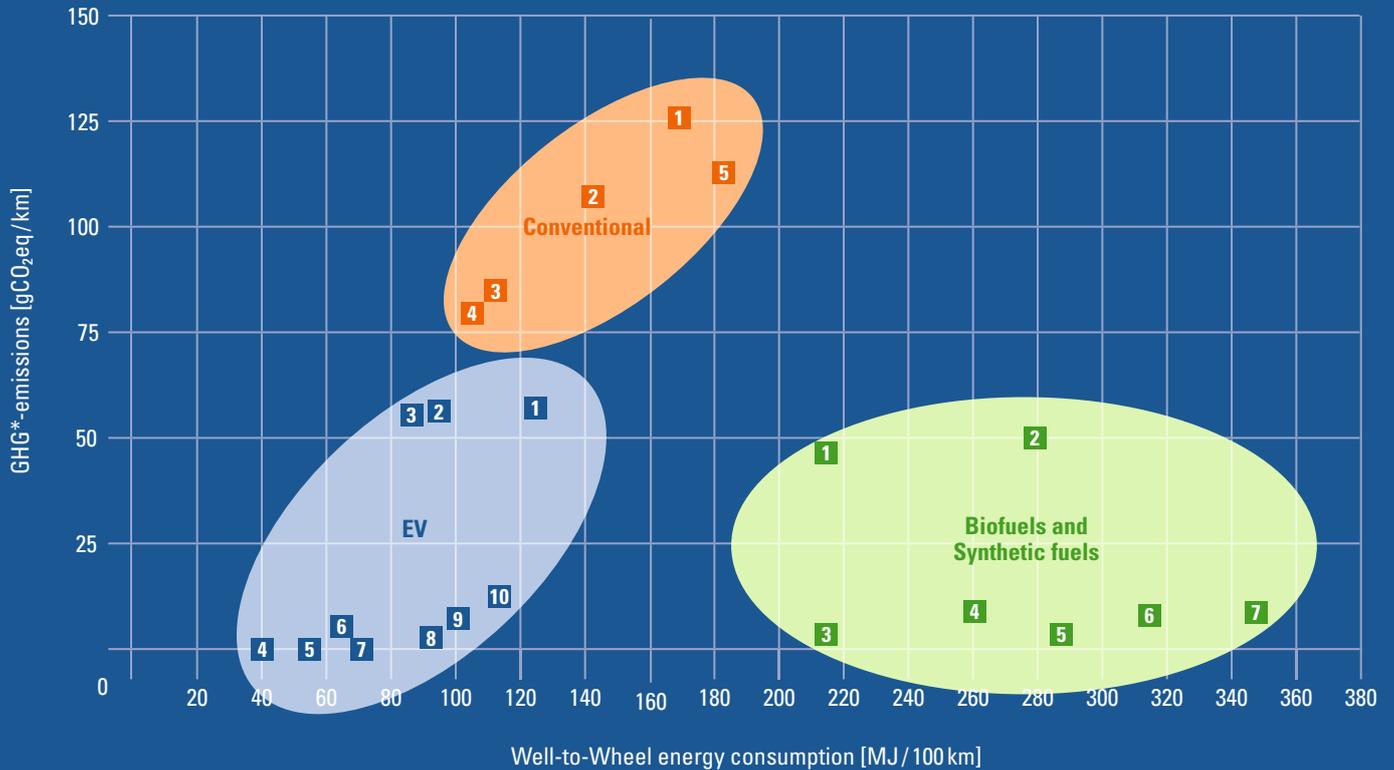
⁵⁹ Refer to detailed discussion in in Ehret, O. and Bonhoff, K.: 'Hydrogen as a fuel and energy storage' (Footnote 4).

⁶⁰ Source of illustration: Dr. Jörg Wind, Daimler AG, 06.09.2017.

⁶¹ Illustration is based on the internationally recognised data collected in cooperation between the European Commission and the petroleum and automotive industries. The key report can be found at iet.jrc.ec.europa.eu/about-jec/sites/iet.jrc.ec.europa.eu/about-jec/files/documents/report_2014/wtt_report_v4a.pdf.



Well-to-Wheel Comparison of Greenhouse Gas Emissions and Energy Consumption of EUCAR Reference Vehicles (C-segment passenger car) 2020+



- | | | |
|---------------------------------------|--|--|
| 1 Gasoline (Crude oil) | 1 BEV (EU-Mix) | 1 DICl (Biodiesel FAME) |
| 2 Diesel (Crude oil) | 2 FCEV (Natural Gas) | 2 DISI (Ethanol Wheat) |
| 3 Gasoline Hybrid (Crude oil) | 3 BEV (Natural Gas) | 3 Syn. Diesel from ren. Energy, CO ₂ from exhaust gas |
| 4 Diesel Hybrid (Crude oil) | 4 BEV (Wind) | 4 DICl (BTL Wood) |
| 5 CNG (Compressed Natural Gas) | 5 Pump Storage | 5 Syn. Diesel from ren. Energy (CO ₂ from air) |
| | 6 Hybridisation FC-Powertrain (Plug-In) | 6 PISl CNG (H ₂ from ren. Energy, CO ₂ from Biogas) |
| | 7 H ₂ -Cavern Storage | 7 PISl CNG (H ₂ from ren. Energy, CO ₂ from air) |
| | 8 BEV (Biomass) | |
| | 9 FCEV (Wind) | |
| | 10 FCEV (Biomass) | |

*GHG: Greenhouse gas

energy conversion steps are required during the production of this fuel and also in its use in the vehicle.⁶²

With regard to fuel production, it should be noted that the federal government strongly supports the use of renewable energies for electric vehicles. In addition, European law requires the use of renewable energy in the transport sector and recognises both renewable electricity and hydrogen as eligible for certain quotas to be met.⁶³ This creates an incentive for the industry involved to use renewables for vehicle propulsion. Accordingly, the Clean Energy Partnership demanded the use of at least 50 percent renewable hydrogen.⁶⁴ It can be assumed, that also in the future, a not insignificant share of hydrogen will be of renewable origin and that the associated environmental advantages can thereby be taken advantage of.

In the context of the environmental friendliness of fuel cell technologies, the characteristic of renewable hydrogen as a cross-sectoral energy carrier is also relevant. As outlined above, hydrogen can be used not only in road transport but also in other transport sectors such as rail. In addition, the integration of growing quantities of renewable energies into various economic sectors will in future also require large-capacity storage facilities. Hydrogen can be stored on a large scale, e. g. in underground caverns or in the natural gas network, and – depending on the purity of the hydrogen and the technical requirements of the consumer – can be made available across sectors for transport, stationary energy supply or for use in industrial facilities as well.⁶⁵ The use of comparatively few and large hydrogen production plants and infrastructure components for various applications reduces costs along with the complexity of the energy system.⁶⁶ With the cross-sector integration of renewable energies, hydrogen offers a further significant benefit for the energy transition.

⁶² The very energy-intensive production of batteries has, however, a negative impact on the environmental balance (www.forum-qualitaetsjournalismus.de/wp-content/uploads/2016/05/FQJ.dossier-Elektromobilit%C3%A4t.pdf). But since the production of vehicles is not included in well-to-wheel balances, it cannot be treated systematically here.

⁶³ See www.certify.eu.

⁶⁴ www.now-gmbh.de/content/1-aktuelles/1-presse/20161214-nip-erfolgreiche-bilanz/7_zoernerproduktion.pdf.

⁶⁵ www.now-gmbh.de/content/7-service/4-publikationen/4-nip-wasserstoff-und-brennstoffzellentechnologie/abschlussbericht_integrations_von_wind-wasserstoff-systemen_in_das_energiesystem.pdf

⁶⁶ www.dvgw.de/medien/dvgw/leistungen/forschung/berichte/g201415.pdf.

Question 7: What infrastructure exists for the refuelling of fuel cell vehicles?

Between 2002 and the end of 2016, hydrogen infrastructure for the refuelling of fuel cell vehicles in Germany was established primarily within the framework of the Clean Energy Partnership. While 350-bar pressure refuelling stations and a number of liquid hydrogen refuelling systems were initially developed and tested, 700-bar pressure refuelling became the usual standard for passenger cars from 2008 onwards and enabled complete vehicle refuelling within three minutes.⁶⁷ Over time, the original CEP region of Berlin was joined by Hamburg, North Rhine-Westphalia, Baden-Württemberg and Hesse. In each of these regions, several refuelling stations were in operation and the network was supplemented by further refuelling stations in corridors connecting the regions. In addition to car refuelling systems, larger 350-bar pressure refuelling systems for buses were also tested. On the infrastructure side, petroleum, gas and energy companies were mainly involved in the CEP; the initiative was financially supported by the federal government as a lighthouse project in the NIP.⁶⁸

By the end of 2016, 30 publicly accessible refuelling stations had been built and around 25 further facilities were under construction or at an advanced stage of planning. However, due to pending permits and maintenance or repair work, not all the completed service stations were operational.⁶⁹ The refuelling stations were tested as R&D or demonstration facilities and differed considerably from each other in terms of design and reliability. The facilities were continuously improved by the CEP partners and newer refuelling stations generally had significantly better performance and availability than older facilities. The hydrogen was sold for €9.50 per kilogram and produced using at least 50 percent renewable energy.⁷⁰

From the beginning of 2017 at the latest, H2 MOBILITY Deutschland GmbH & Co. KG played a central role in establishing the hydrogen infrastructure for passenger cars in Germany. Whereas companies had previously developed, built and tested pre-commercial refuelling stations within the framework of the CEP, H2 MOBILITY aims to establish a blanket hydrogen infrastructure in the early market phase. The company was founded in 2015 by Air Liquide, Daimler, Linde, OMV, Shell and TOTAL.

⁶⁷ www.now-gmbh.de/content/7-service/4-publikationen/4-nip-wasserstoff-und-brennstoffzellentechnologie/cep_abschlussdokumentation_de.pdf.

⁶⁸ www.now-gmbh.de/content/1-aktuelles/1-presse/20161214-nip-erfolgreiche-bilanz/4_lang_infrastruktur_final.pdf.

⁶⁹ Geitmann, S.: 'H2-Infrastruktur wächst weiter: ... aber nicht alle Stationen sind betriebsbereit' (H2 infrastructure continues to expand: ... but not all stations are ready for operation), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 1, p. 24.

⁷⁰ The consumption of current FCEVs is at approx. 1 kg per 100 km.

As associated partners, the automobile manufacturers BMW, Honda, Hyundai, Toyota and Volkswagen coordinate their market-related plans for fuel cell vehicles with the six H2 MOBILITY shareholders. The National Organisation Hydrogen and Fuel Cell Technology, which, as the representative of the federal government, already played a central role in the implementation of funding measures in the CEP, advises H2 MOBILITY on political issues.⁷¹

H2 MOBILITY's mission is to facilitate the market entry of fuel cell passenger cars in Germany by establishing a network of 700 bar hydrogen refuelling stations. The current number of 52 publicly accessible refuelling stations is to rise to 100 by 2018/19 and to 400 by 2023, thus ensuring a basic nationwide hydrogen supply that can be expanded on in the future.⁷² While the refuelling stations planned until 2018/19 are to be built in any event and 42 additional refuelling stations are also already being constructed in addition to the facilities currently available, the further expansion of the network until 2023 will also depend on the numbers of new FCEV registrations. Refuelling stations are to be built initially primarily in urban centres and also along connecting corridors, e. g. along motorways, to enable journeys throughout Germany. In addition, a limited number of refuelling stations are to be built in less central regions. H2 MOBILITY is also responsible for the operation of the refuelling stations.⁷³

H2 MOBILITY has taken over 30 of the refuelling stations set up as part of the CEP. The remaining CEP refuelling stations will continue to be operated independently of H2 MOBILITY by other companies and partly within the framework of the still existing CEP. The availability of hydrogen refuelling stations has been further improved, but does not yet reach the standards of conventional refuelling stations. To achieve the target of 100 refuelling stations by 2018/19, H2 MOBILITY will set up the required refuelling stations above and beyond the facilities taken over from CEP, independently. Approximately half of the costs will be financed by H2 MOBILITY and the remaining half through public funding programmes.⁷⁴ Where the CEP funding requirement was justified by the need to solve technical issues, the funding programmes used by H2 MOBILITY aim to develop an early commercial infrastructure. Hydrogen will continue to be sold for €9.50 per kilogram and its production is to be based on increasing proportions of renewable energy.

⁷¹ h2.live/h2mobility.

⁷² h2.live/tankstellen.

⁷³ h2.live and Geitmann, S.: 'H2 MOBILITY – Übernehmen Sie: Wechsel von CEP zu H2 MOBILITY' (H2 MOBILITY - Take over: Change from CEP to H2 MOBILITY), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 3, pp. 27–29.

⁷⁴ Personal communication from Philipp Braunsdorf, NOW GmbH and Sybille Riepe, H2 MOBILITY, each on 08.09.2017.

The following map of Germany illustrates the plans for the construction of the first 100 H2 MOBILITY refuelling stations, most of which have now been implemented.⁷⁵ In addition to the public refuelling stations operated and planned by H2 MOBILITY and the CEP companies, private refuelling stations are also maintained, e. g. by automobile companies. In addition, fuel cell bus refuelling facilities are operated in demonstration projects and in the course of market activation. In the EU project CHIC outlined earlier, for example, not only were vehicles tested, but also nine hydrogen refuelling stations.⁷⁶ In turn, JIVE is flanked by the MERHLIN project, which financially supports the construction of seven large refuelling facilities for buses.

In addition, national budgets, such as the NIP, provide complementary funding for refuelling stations.⁷⁷ The following map, however, only depicts the H2 MOBILITY systems. Some international activities for the development of hydrogen infrastructure are outlined as examples under Question 8.

Question 8: How is Germany positioned when compared internationally?

About two decades ago, Daimler and other automotive companies around the world announced their commitment to the development of fuel cell vehicles, thereby broadening public awareness of the topic. The increasing R&D activities of industry and science in various application areas of hydrogen and fuel cells were supported by policymakers and coordinated in the National Hydrogen and Fuel Cell Technology Innovation Programme (NIP), which was adopted in 2006.⁷⁸ The NIP made a significant contribution to the development of technology as well as reducing costs and has been extended beyond its original term of ten years until 2026. In total, funding of well over €1 billion will be made available for R&D and demonstration projects as well as market activation measures.⁷⁹

With the Clean Energy Partnership, Germany is home to one of the world's largest and longest existing alliances for the testing and further development of FCEVs and hydrogen infrastructure. H2 MOBILITY is one of the first initiatives to play a leading international role in the nationwide development of an early commercial hydrogen

⁷⁵ Source: h2-mobility.de/h2-stationen. As at mid 2018.

⁷⁶ See Stolzenburg, K.: ‚Brennstoffzellenbusse auf der Überholspur‘ (Fuel Cell Buses in the Fast Lane) (Footnote 45).

⁷⁷ www.fch.europa.eu/sites/default/files/JIVE%20MEHRLIN%20Project%20Launch%20Press%20Release%20%28ID%202895328%29_1.pdf.

⁷⁸ www.now-gmbh.de/content/7-service/4-publikationen/4-nip-wasserstoff-und-brennstoffzellentechnologie/nationales-innovationsprogramm-wasserstoff-und-brennstoffzellen-technologie.pdf.

⁷⁹ www.now-gmbh.de/de/nationales-innovationsprogramm/foerderprogramm.

 H2 MOBILITY Stations



2019/100 H2 Stations

2023/400 H2 Stations



Up to 10 H2 stations in metropolitan regions



Unconditional expansion in metropolitan regions and corridors



Nationwide expansion dependent on vehicle numbers

refuelling station infrastructure. With 100 refuelling stations by 2018/19 and 400 facilities by 2023, H2 MOBILITY is setting ambitious targets. With the official launch of the Mercedes-Benz GLC F-CELL, a major German automotive company has announced the production of an FCEV. The funding support provided under the NIP for the acquisition of FCEVs significantly reduces the additional costs compared with conventional vehicles. Growing political pressure on diesel and other internal combustion engines could have a positive impact on the demand for FCEVs, which are particularly suitable as diesel replacements.

With regard to technology development and the commercialisation of FCEVs and hydrogen infrastructure, Germany is therefore well positioned internationally. However, it has already become clear that Japanese and Korean companies have taken the lead in the manufacture and sale of FCEVs. As the following discussion shows, Asia and California have also developed into lead markets for FCEVs and are partly accompanying the rapid growth of their vehicle fleets with ambitious infrastructure development and technology policy goals. Despite a good starting position, Germany will need to step up its commitment in order not to lose touch with the international leadership in the commercialisation of FCEVs and infrastructure.⁸⁰

Hydrogen and fuel cell technologies are also being brought to market maturity in the European Union and some of its member states, particularly in the transport sector. At an EU level, the most important institution is the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), which was founded in 2008 and, after extending its original term, now has a mandate until 2024. With a funding budget of more than €1 billion, FCH JU is driving relevant technological and market developments forward in its projects. For example, the Hydrogen Mobility Europe project supports the operation of several hundred fuel cell cars and the construction of some 30 service stations in Germany, Scandinavia, France and the United Kingdom.⁸¹ The previously mentioned JIVE and MERHLIN projects support fuel cell buses and refuelling facilities.⁸² Other EU institutions also contribute to the commercialisation of vehicles and infrastructure and complement initiatives financed by national budgets in various European countries. The EU as a whole is thus developing into an internationally important player in the technological development and commercialisation of FCEVs and infrastructure. However, both Europe and Germany are confronted with strong competitors, especially from Asia.

⁸⁰ Scandinavia is also one of the leading regions in the commercialisation of FCEVs and infrastructure, but will not be discussed further here.

⁸¹ www.fch.europa.eu and www.fch.europa.eu/project/hydrogen-mobility-europe.

⁸² www.fch.europa.eu/sites/default/files/JIVE%20MEHRLIN%20Project%20Launch%20Press%20Release%20%28ID%202895328%29_1.pdf.

The United States of America, and California in particular, has traditionally been a leader in the development and early commercialisation of fuel cell vehicles. Due to considerable traffic-related air pollution, Californian legislation has long required the sale of zero-emission or electric vehicles. Within the framework of the California Fuel Cell Partnership (CaFCP), fuel cell cars, buses and trucks of various manufacturers and generations have been tested since 1999, alongside refuelling stations. A large proportion of the FCEVs sold commercially worldwide are shipped to California and contribute to a fleet consisting of around 5,000 fuel cell vehicles in 2018.⁸³ The FCEVs use the 40 CaFCP filling stations currently available along the Californian coast. The CaFCP expects 13,500 FCEVs in 2019 and plans to expand the refuelling station network to 64 facilities by 2020. A target of 1,000,000 FCEVs and 1,000 refuelling stations is set for 2030.⁸⁴ Both the purchase of FCEVs and the development of the infrastructure are supported by the government. Some states in the eastern USA are also demanding the use of zero-emission vehicles and are establishing refuelling facilities for FCEVs. Although American automobile companies do not sell commercial FCEVs to date, the USA and California are nevertheless well positioned.

With Toyota and Honda, Japan has two leading manufacturers of commercial FCEVs, which together supply the majority of the vehicles sold worldwide. With strong and continuous political support, the development and ultimately the commercialisation of FCEVs and infrastructure has received longstanding support. By 2017, more than 2,000 fuel cell cars and more than 90 refuelling stations, some of them mobile, were already in operation in Japan. The prices of FCEVs are to be lowered to the level of hybrid vehicles by 2025 and the price of hydrogen fuel is to be significantly reduced before then. On this basis, around 40,000 FCEVs are to be driven on Japan's roads by 2020. This number is expected to rise to 200,000 by 2025 and 800,000 by 2030. To supply them with fuel, 160 refuelling stations are planned by 2020 and 320 stations by 2025. The ambitious plans are supported by generous government support programmes for the construction and operation of the infrastructure as well as the purchase of vehicles. Hydrogen should also play a central role in the general energy supply by 2040. Until then, the goal of a hydrogen-based society, which has been expressed at the highest political level, is to be realised.⁸⁵ Japan is therefore undoubtedly one of the international pioneers.

⁸³ cafcp.org/sites/default/files/FCEV-Sales-Tracking.pdf.

⁸⁴ cafcp.org/sites/default/files/AB8-2018-Webinar.pdf.

⁸⁵ Rose, R.: 'Aufbau einer H₂-Wirtschaft: Japan bekennt sich zu Wasserstoff' (Development of an H₂ economy: Japan commits to hydrogen), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, 2017, Issue 2, pp. 50–51 and Rose, R.: 'Die Trumpfkarte für Energiesicherheit: Japanischer Ministerpräsident Abe pusht Wasserstoff' (The trump card for energy security: Japanese Prime Minister Abe pushes for hydrogen), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 3, pp. 48–49.

South Korea is successfully represented in international markets by Hyundai, a provider of low-cost FCEVs, while at the same time developing its domestic market. As early as 2016, about 500 FCEVs and 25 refuelling stations were in operation in Korea. According to a government roadmap, approximately 10,000 FCEVs will be in service by 2020 and about 630,000 by 2030. At the same time, the number of refuelling stations is to increase to 100 by 2020 and to 520 by 2030. The procurement of vehicles and infrastructure is heavily subsidised by the government. In addition to passenger cars, buses are also of considerable strategic importance: Korea is planning to gradually replace its extensive fleet of natural gas buses with fuel cell buses.⁸⁶ As a result, Korea is establishing itself as one of the most important international players in the field of commercial FCEVs and refuelling infrastructure.

As a future market and production site for fuel cell vehicles and hydrogen infrastructure that is currently in development, China is probably attracting the most attention at present. In view of serious traffic-related environmental problems, the government of the world's largest automobile market is pursuing a strategy of electrifying powertrains. The 13th Five-Year Plan adopted in 2016 aims at substantial economic growth based on innovative industrial production and identifies battery and fuel cell-based electric mobility as a key strategic growth area. At the end of 2016, the government announced a target of 50,000 FCEVs by 2025 and at least 1,000,000 FCEVs by 2030. To this end, about 300 hydrogen refuelling stations are to be put into operation by 2025 and around 1,000 by 2030. To achieve these objectives, the government is providing attractive subsidies.⁸⁷

Chinese industry is responding on the one hand by massively expanding its own technological and manufacturing expertise, and on the other, by intensifying cooperation with foreign partners.⁸⁸ In line with the motto Made in China 2025, appealing and large-volume orders to international technology leaders are often linked to their production in China.⁸⁹ For example, the Canadian fuel cell manufacturer Ballard Power Systems opened a production facility for fuel cell stacks in mid-2017 in a joint venture with the Chinese company Guangdong Nation Synergy Hydrogen Power Technology. Production of 6,000 stacks per year for fuel cell buses and other commercial vehicles began in 2017 and is to be expanded later to 20,000 stacks per

⁸⁶ www.cte.tv/wp-content/uploads/2016/12/4_Jeon.pdf.

⁸⁷ www.fuelcellcars.com/hydrogen-fuel-cell-car-development-intensifies-in-china and businesskorea.co.kr/english/news/industry/16601-hydrogen-car-competition-korea-japan-lead-global-fcev-market-two-frontrunners.

⁸⁸ Wang, Y.: 'Prospect of Hydrogen Energy Industry in China', paper given at: f-cell 2018, 18–19.09.2018, Stuttgart.

⁸⁹ Jösting, S.: 'Asien gibt den Takt vor: Aktienanalyse von Sven Jösting' (Asia sets the pace: Stock analysis by Sven Jösting), in: HZwei: Das Magazin für Wasserstoff und Brennstoffzellen, Vol. 17, 2017, Issue 2, pp. 34–37 and Lehner, S. and Hart, D.: 'BZ-Markt: Transportbereich wächst rasant' (FC market: transport sector growing rapidly) (Footnote 39).

year.⁹⁰ Other foreign technology leaders are also active in China as suppliers and partners of local companies.

China is clearly developing into a heavyweight among the leading international users and manufacturers of hydrogen and fuel cell technologies. As one of the most important sales markets – also for the German automotive industry – China sets standards with regard to technological requirements and will in future also impose compliance with statutory minimum quotas for electric vehicles on importers. As a result, German automotive companies will therefore be confronted with strong Chinese competitors on the one hand and clearly defined demand for FCEVs on the other. In view of these challenges, a stronger commitment to the commercialisation of FCEVs would appear advisable.

⁹⁰ www.ballard.com/about-ballard/newsroom/news-releases/2017/09/06/ceremonial-opening-of-ballard-s-china-stack-joint-venture-production-facility.

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January 2019

