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The use of hydrogen as an alternative fuel in urban transport

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ABSTRACT

This paper shows the analyses of hydrogen vehicles within urban centres, which have been gaining increasing importance lately. In fact, due to the negative impact of conventional vehicles on human health and environment, the need is imposed for implementation of eco-powered vehicles that also tend to be sustainable in transport. Gradual removal of fossil fuels and the use of alternative road transport technologies are among the primary objectives of most countries. This paper aims to examine the impact of hydrogen technology in urban transport, ie to point out how hydrogen vehicles have affected the satisfaction of customers and users through individual projects. Furthermore, the paper analyses the current situation in the application of hydrogen vehicles in the world, as well as future investments in infrastructure through strategies aimed at boosting higher demand for clean energy.

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1 Introduction

Road transport is one of the most significant polluters of the environment, mostly due to its high dependence on fossil fuels. Although oil is known as the dominant fuel in use, the price of oil supply today varies drastically due to various geopolitical factors and policies of economically strong countries, which is reflected in the economy of transport. In urban traffic, pedestrians and vehicles participate in traffic, so it is necessary to emphasize the consequences of using ICE (internal combustion engine) vehicles in urban areas. Preservation of the environment and human health in cities with further economic development depends on sustainable development, which is increasingly burdened by population growth and their needs.

The use of hydrogen as an alternative energy source within cities would greatly contribute to reducing CO_2 emissions in transport, which would ultimately have a positive impact on the quality of life. Since hydrogen has been used in the industry for more than 40 years as an industrial chemical and fuel for space exploration, some countries of North America, Europe and Asia began in the 1990s with the application of hydrogen within public transport. Although ICE vehicles marked the 20th century as the most dominant propulsion system, currently the electric propulsion systems are approaching ICE in terms of driving quality while retaining eco-benefits.

Today's global trends are geared towards energy production from "green" or alternative sources, while striving to eliminate fossil fuels. Over the past few years, there has been a sharp increase in sales of electric vehicles, and according to the Global EV Outlook [1] 2018 report, the number of electric vehicle sales exceeded 3 million. These trends stem from the Directive 2009/33/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of clean and energy-efficient vehicles in road transport aimed at fostering a market for clean and energy-efficient vehicles in road transport. In particular, the Directive affects the market for standardised vehicles produced in larger quantities, such as passenger vehicles, buses and trucks, by ensuring the level of demand for clean and energy-efficient vehicles in road transport that would be large enough to encourage manufacturers and industry to invest and further develop low-energy vehicles, CO_2 emissions and pollutant emissions [2].

Hydrogen as an energy source with environmental benefits emerges as an opportunity to reduce CO_2 emissions in transport and directs mobility towards a sustainable and ecological pathway over a short and long period. Although the introduction of electricity or BEV (battery electric vehicles) in road transport was initially considered a primary choice for decarbonisation, the results of electrification did not meet expectations [3].

Hydrogen with the merits of sustainable green fuel is an incentive for much further research for transport purposes. For example "Building a hydrogen infrastructure in the EU" [4] by reviewing the technological status and costs of technologies for production, distribution, hydrogen storage highlights the importance of the hydrogen charging infrastructure in road transport. It also lists the ongoing and planned EU initiatives that would encourage further development and implementation of FCEV (fuel cell electric vehicle) in the transport sector. They have a similar attitude "Key challenges in the development of an infrastructure for hydrogen production, delivery, storage and use" [5], they further point out that overcoming obstacles such as high costs and further incentives from government policies for the use of hydrogen in road transport will reduce dependence on fossil fuels.

With many benefits of hydrogen, the economics of sustainability is not guaranteed. The process of producing, transporting and storing hydrogen as fuel requires a large amount of energy versus high-efficiency BEV, which raises a contentious issue in the selection of alternative fuels. Therefore, the analyses of the comparison highlighted in the works "Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles" [6], „Which energy source for road transport in the future? A comparison of battery, hybrid and fuel cell vehicles" [7], and „Hydrogen-fueled road automobiles – Passenger cars and buses" [8] aim to indicate the optimal choice of fuel or to highlight the fuel with the highest efficiency. Also, in addition to the main differences between propulsion system technologies, there are potential technological solutions for the application of FCEV and challenges that make it difficult to deploy hydrogen vehicles into the transport sector such as the installation of hydrogen charging stations, and problems with costs and commercialisation.

The aim of this paper is to analyse the impact of the use of hydrogen as an alternative fuel in urban environments on population and environment. Given the poor battery efficiency in heavy vehicles, hydrogen is imposed as the optimal solution to this problem, especially for buses in urban environments.

2 Vehicles powered by hydrogen fuel cells

The introduction of EVs (electric vehicles) into urban transport would certainly reduce pollutants as well as noise pollution, which are the main reasons for their application. Today there are several types of EVs, and the biggest difference is manifested in the energy source. Although most electric vehicles have a high-capacity battery, there is also another type of drive that is an alternative to the classic EV in terms of charging time.

The environmental acceptability of the vehicle is met if the propulsion system does not produce harmful gases, and moreover, it is for this reason that vehicles with alternative propulsion systems are produced. The ideal propulsion system meets the environmental criteria and therefore the hydrogen propulsion system can be classified in this category as it emits water vapour as exhaust gas. The environmental impact of the use of fuel cell technology depends on the production of hydrogen used as a propellant. Hydrogen production is carried out by electrolysis of water with the help of electricity that can be used from renewable energy sources or fossil fuels. If the electricity for the production of hydrogen is "obtained" using fossil fuels, such vehicles continue to have a negative impact on the environment. However, hydrogen-powered vehicles powered by electrolysis using electricity from renewable energy sources are considered to be fully environment-friendly vehicles.

Hydrogen vehicle uses fuel cell technology, but due to the use of an electric motor, it is considered an electric vehicle or FCEV (fuel cell electric vehicle). The biggest difference between FCEV and BEV is manifested in the independent production of electricity in FCEV. By the reverse electrolysis process, hydrogen reacts with oxygen in the fuel cell and as a result of the reaction it generates electricity, heat and water emitted through exhaust gases as water vapour. Hydrogen is placed in one or more tanks embedded in the FCEV, while oxygen comes from the ambient air. According to driving needs, the electricity produced in fuel cells can either go directly into the electric motor or be "stored" in the battery. Given the possibility of generating electricity, FCEV takes precedence over BEV in terms of smaller and lighter batteries. Like other EVs, FCEVs have the ability to regenerate braking energy using an electric motor that converts the kinetic energy into electricity, and then stores it in a battery [9].

The production of hydrogen vehicles has not yet been industrialised due to the high cost of production of such vehicles affected by the type of material. The use of fuel cells or electricity to be produced in hydrogen vehicles requires the expensive platinum used for catalyst purposes.

The energy efficiency of hydrogen as a fuel is not only reflected by the use of vehicles but rather plays an important role in the mode of transport and storage. For easier transport and storage, hydrogen is most often in liquid condition due to complex energy requirements. Since only electricity and water are needed for hydrogen production, the choice of locations for production units is very wide, which directly affects the reduction in transport distance. Although the energy efficiency is highest in BEV, this advantage is significantly reduced due to the high weight of batteries, especially in heavy-duty vehicles [10].

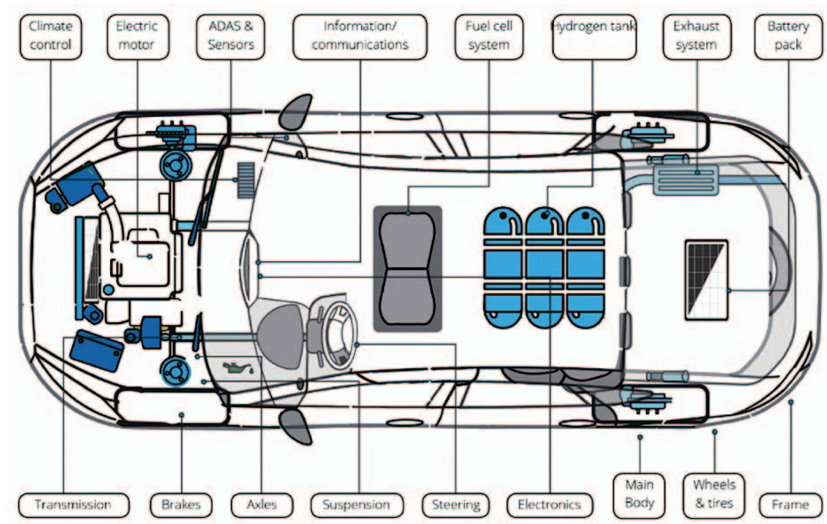


Figure 1 FCEV components

Source: [10]

The risk of uncontrolled hydrogen and oxygen reactions in FCEV is almost non-existent because hydrogen is stored in liquid vehicles behind thick tank walls that have passed numerous collision tests [9].

Hydrogen vehicles are generally larger, since hydrogen tanks take up a lot of space, while the propulsion electric motor can also fit in smaller vehicles, giving BEV vehicles an advantage in this segment. Although FCEV seems to be very complex and sophisticated manner due to non-standard use in road transport, hydrogen-powered vehicles are generally fairly simple designs. Figure 1 shows the components of the FCEV vehicle.

Like most of today's vehicles, FCEV vehicles consist of basic components such as the propulsion system, chassis, automotive industrial electronics, and body. Electricity is provided using a propulsion system and a fuel system, and an electric motor. In addition to the propulsion system, other parts of the vehicle are identical to ICE vehicles and BEVs.

The composition of the FCEB (fuel *cell electric buses)* i.e. its components do not differ significantly from the LDV (light-duty vehicle) components. The biggest difference is in the size of the hydrogen tank since heavy vehicles require additional storage. In FCEB hydrogen tanks are

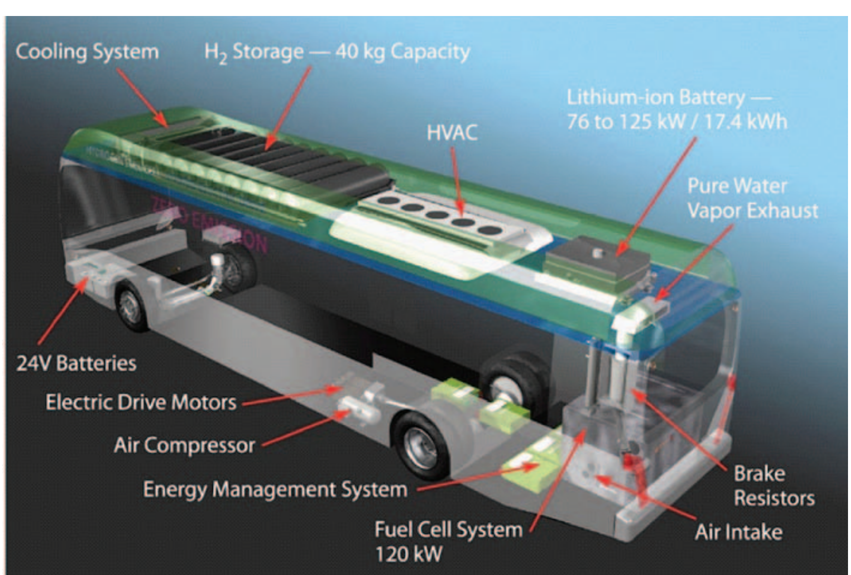


Figure 2 FCEB components

Source: [11]

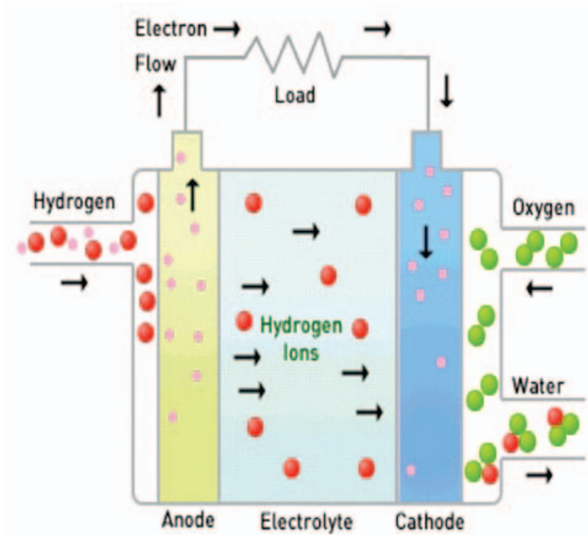


Figure 3 Illustration of a generic individual cell

Source: [11]

mainly mounted on the roof and weigh about 40 kg. Figure 2 shows the FCEB components [11].

The process of producing electricity using fuel cells at FCEB is the same as with LDV, i.e. the fuel cell generates electricity via hydrogen and oxygen using two electrodes (cathode and anode). Hydrogen from the vehicle tank comes from one side while the air containing the necessary oxygen enters from the other side as shown in Figure 3 [11].

Advantages provided by FCEV to users over ICE vehicles are a significant noise reduction (the same as the BEV) and the full torque of the electric motor at low speeds. Furthermore, it dominates over BEV in terms of charging time of about 5 minutes, while BEV may take several hours. Also, the range of the vehicle is in most cases on the FCEV side (range about 480 km), while the BEV can achieve a similar range only with very large batteries, which further increases the vehicle's weight and charg-

Table 1 Recent advantages and disadvantages of BEV, FCEV and ICE vehicles worldwide

Fuel type	ICE vehicle	BEV	FCEV
	Petrol	Electricity	Hydrogen
Available number	287	13	3
Average fuel economy	11.30pm	105.2 mpge	58.5 mpge
Fuel economy range	12 - 50 mpg	84 – 119 mpge	50 – 67 mpge
Effective cost per mile	$0.10	$0.04	$0.09
Well-to-wheels GHG emissions (g/km)	356 - 409	214	260 - 364
Well-to-wheels total petroleum usage (Btu/mi)	3791 - 4959	54	27 - 67
Driving range (average)	418 mi	110 mi	289 mi
Driving range (min-max)	348 – 680 mi	62 – 257 mi	265 – 312 mi
Time to refuel	~ 5 min	20 – 30 min (DC Level 2) 3.5 – 12 hr (AC Level 2)	5 – 30 min
High voltage	№	Yes	Yes
High pressure	№	№	Yes
Availability of qualified mechanics	Yes	Limited	Limited
Availability of qualified emergency responders	Yes	Yes	Limited
Vehicle maintenance issues	–	Lower maintenance than gasoline; possible battery replacement required during vehicle lifetime	Lower maintenance than gasoline; high-pressure tanks may require inspection and maintenance

Source: Created by authors according to [12] ing time. The production of electricity in fuel cells does not depend on the external influence i.e. temperature. The main deficiency in hydrogen production is manifested in losses during the electrolysis process while the overall energy efficiency is approximately by one half lower than in BEV. However, at times when the supply of electricity is too high, hydrogen can be produced through renewable energy sources or the solar or wind energy that would be used for hydrogen production [9].

The drive technology of the vehicle with the economy, which is conditional on purchase costs and operating costs, affects the acceptance of the vehicle and the interest of customers. In vehicles using hydrogen as a propellant the operating cost does not depend on the price of fuel. For example, FCEV can drive 45 miles with 1lb (0.45 kg) of hydrogen, which costs about $4.80 in Germany, while the price of hydrogen in the United States is nearly twice as expensive as $14. The costs of electric-powered vehicles (BEV) per mile are twice as much as the cost of vehicles using hydrogen as propelling fuel. The cost gap will decrease as the demand for hydrogen vehicles increases [9].

The branched electrical grid is the main parameter according to which BEVs are currently the first alternative option in the transport sector, at least in terms of LDV. Also, for the sake of fuel economy or the lowest fuel cost per mile, they take precedence over FCEV. However, FCEV continues to compete with BEV given the huge advantage it achieves in a significantly shorter charging time and almost double range. The number of available vehicle models is convincingly on the BEVs side, resulting from poor demand for FCEVs mainly due to the lack of developed infrastructure, high fuel cost and the vehicle itself. Further expansion of the BEV charging network has been significantly facilitated compared to FCEV charging stations, as the electric grid exists in almost all parts of the world. The cost of installing a public charging station for BEVs ranges from $10,000 to $100,000, while the price for setting up an FCEV charging station ranges from $3 million to $5 million [12].

3 Application of hydrogen within urban transport

A topic of paramount importance for citizens around the world concerns sustainable urban mobility. It is a commonly known fact that road transport is the biggest cause of air pollution and greenhouse gas emissions within urban areas. More than 400,000 premature deaths a year in the EU are caused by air pollution [13]. Floating particles (PM), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ground ozone (O_3) belong to the current group of the most harmful pollutants in the air [14]. Therefore, the European Parliament and the Council of the European Union adopted Directive 2008750/EC of 21 May 2008 on air quality and cleaner air for Europe to avoid, prevent or reduce adverse effects on human health and the environment as a whole [2].

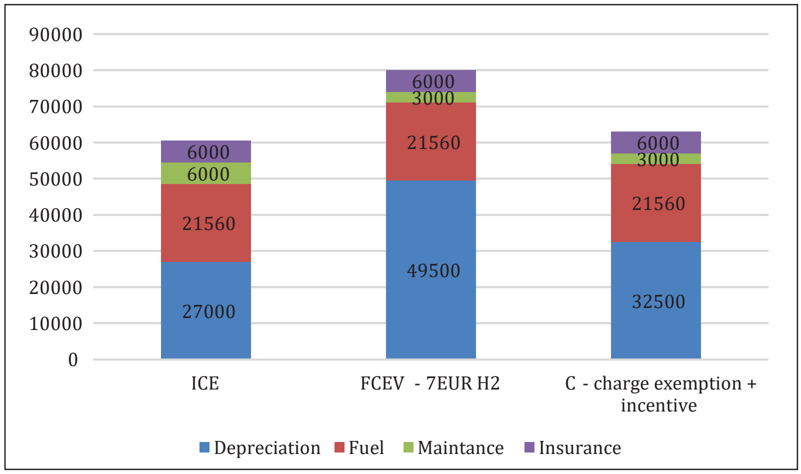
Countries focused on "green energy" in the past few years have launched several pilot projects aimed at using fuel cells in urban transport. Furthermore, projects aim to encourage the use of hydrogen vehicles and bring their use closer to the wider market. Through the implementation of hydrogen taxi vehicles and buses in the urban transport sector, the biggest benefits for city dwellers would result from much reduced soot and noise pollution.

Thus, in September 2017, the ZEFER (Zero Emission Fleet Vehicles for European Roll-out) project began, which proposed solutions that would bring FCEV closer to customers. Until September 2022, when the end of the project is expected, FCEV fleets should be closed to which the intensive use of vehicles and infrastructure would pay off with the benefit of free passage through the toll zones for pollution of the city centre. The aim is to boost the sale of hydrogen vehicles in European cities. Therefore, 180 FCEV are deployed in Brussels, London and Paris, of which 170 FCEV are intended for the taxi or private hire vehicles, while the remaining 10 vehicles are for the needs of the police. FCEV customers are also business partners in the project and participate in the vehicle performance testing phase. In Paris and Brussels, for example, vehicles will drive more than 90,000 km/year, while in London vehicles will drive around 40,000 km/year, demonstrating vehicle reliability [15].

One of the first cases of the use of more hydrogen vehicles in urban transport as a taxi was in Paris in 2015 within the STEP (Société du Taxi Electrique Parisien) project. At the beginning of the project, 5 hydrogen vehicles of the Hype fleet were put into service and by the end of 2020 the number of vehicles is expected to reach 600. The potential of these vehicles is most evident through environmental advantages and driving comfort (range about 500 km, charging time about 5 min), similar to conventional vehicles [16].

The most common participants in projects are private or public users, municipalities, large private companies, taxis, etc. Hydrogen infrastructure operators are also frequent participants in hydrogen vehicle deployment projects, while vehicle exchange operators and car-sharing are underrepresented. The demand for hydrogen vehicles or user profiles of potential users depends mostly on the way they drive and the routes of movement. Given the similarity between the reach, performance and charging of vehicles, ICE vehicle users can more easily adapt to FCEVs. The primary requirements of the user are mainly directed towards the infrastructure or the branched network of vehicle charging stations while complying with all high safety standards. According to key aspects of the FCEV in contrast to the BEV, they stand out owing to a smaller battery size, better operating at low temperatures, longer reach and shorter charging time.

The greatest potential in urban environments of FCEV vehicles is realized according to environmental social and economic aspects. Zero emissions of air pollution from vehicle exhaust pipes (mainly NOx) and greenhouse gases (NOx) are the main features of FCEV vehicles in an ecological sense, while on the economic side with a lower TCO (with demand growth and development, lower hydro-



Graph 1 Total cost of ownership

Source: Created by authors from source [18]

gen prices and lower capital costs expected), the fuel cell technology represents the potential for further innovation and economic growth. In addition, with the introduction of FCEV there is the possibility for public authority to generate additional revenue through the licensing of FCEV taxis. The social advantages of introducing FCEV vehicles are highlighted through the driving comfort concerning vehicle range and short charging time similar to ICE vehicles. Since hydrogen vehicles fall into the "zero-emission" group of vehicles, the shift towards clean energy increases significantly, while on the other hand countries' dependence on fossil fuel imports decreases [17].

Graph 1 shows the total cost of ownership (TCO) data. The analysis is based on the average London taxi that goes 40,000 miles a year.

Graph 1 data show the positive impact of incentive measures for hydrogen vehicles as in the London example. High costs are one of the main obstacles to the application of FCEV, however, with FCEV taxi incentives have significantly reduced their costs and come within easy reach of ICE taxis according to the TCO analysis. The largest cost differences are expressed in vehicle depreciation, where ICE vehicles benefit greatly, while maintenance costs are in favour of FCEV vehicles.

Table 2 Recent Fuel Cell Passenger Vehicle application status worldwide

	China	Japan	Europe	US
Typical 2015 available	– plug-in hybrid FC version of Roewe 950	– Toyota Mirai	– Toyota Mirai	– Toyota Mirai
	– Grove (China's first fuel-cell passenger vehicle in 2019)	– Honda Clarity (leased only)	– Honda Clarity (leased only) – Hyundai Tucson – Hyundai Nexo	– Honda Clarity (leased only) – Hyundai Tucson – Hyundai Nexo
Image/Report Status	– In 2018, no sales of fuel-cell passenger vehicles	– 575 and 766 Toyota Mirai were sold in Japan in 2017 and 2018 respectively	– 132 and 160 Toyota Mirai were sold in Europe in 2017 and 2018	– 1700 and 1838 Toyota Mirai was sold in 2017 and 2018 respectively
	– 50 plug-in hybrid fuel cell version of Roewe 950 were used in a demonstration operation of the project and car-sharing services in Shanghai		– Clever Shuttle and BeeZero are car-sharing companies operating with 20 and 50 FCEVs	
Level of application (models Mirai and Nexo)	<100 vehicles	> 500 vehicles	100-500 vehicles	> 500 vehicles

Source: Created by authors from source [10]

Table 3 Recent status of FCEB application worldwide

<table>
<tr><th></th><th>China</th><th>Japan</th><th>Europe</th><th>US</th></tr>
<tr><td rowspan="3">Image/Report status and cases</td><td>– 2003, first hydrogen fuel cell buses were tested in Beijing</td><td rowspan="3">– 2018, Toyota launched its first FCEB, Sora</td><td>– deployed 60 buses in 8 countries during 2010-2016 (project CHIC*)</td><td rowspan="3">– as of April 2019, there were 35 FCEBs were inactive demonstrations in the US</td></tr>
<tr><td>– First commercially operated fuel cell bus line in China (Foshan Yunfu)</td><td>– The JIVE** project (Phase 1) starting from 2017, will deploy 139 FCEBs in 5 countries</td></tr>
<tr><td>– as of 2018, over 200 FCEBs are operating in cities</td><td>– Combing phase 2, JIVE will deploy nearly 300 FCEBs</td></tr>
<tr><td rowspan="4">Major OEMs</td><td>– Photon AUV</td><td rowspan="4">– Toyota</td><td>– Van Hool</td><td>– New Flyer</td></tr>
<tr><td>– Yutong</td><td>– Solaris</td><td rowspan="3">– ENC Group</td></tr>
<tr><td>– Yong Man</td><td rowspan="2">– Wrightbus</td></tr>
<tr><td>– Zhongtong</td></tr>
<tr><td>Level of application</td><td>>200 FCEB</td><td><50 FCEB</td><td>>200 FCEB</td><td><50 FCEB</td></tr>
</table>

Source: Created by authors from source [10]

Hydrogen, as a choice of alternative fuel, enjoys great support; however, the sales of FCEV are still low. There is currently no significant number of FCEV models on the market, and the price of middle-class vehicle ranges around $80,000, which corresponds to the price of approximately two BEV or hybrid vehicles. High production and vehicle sales costs are the major obstacle to the commercialisation of the sector [9].

In 2014, Toyota was the first company to produce FCEV for commercial purposes. However, the number of vehicles produced did not exceed several thousand annually and were destined for the US, Europe and Japan market. FCEVs represent “green vehicles” or zero-emission vehicles with advantages over ICE vehicles concerning, for example, vehicle fast charging and high reach with a single tank. The first specimens were mostly used for leasing purposes to fleet operating companies and government agencies. They are rarely used for private purposes given the lack of vehicle charging infrastructure.

FCEBs currently have the highest acceptance in the use of fuel cells as they have pre-known movement routes and thus reduce the need for branched charging stations. Bus operators are also mainly influenced by public authorities who can more easily contribute to the application of alternative fuels, especially in urban transport. Although there are some drawbacks to FCEB, they are negligible about these advantages. Some technical defects are possible on some buses since hydrogen is used as a fuel by a “young” and high technology. Low hydrogen gas density also makes transport and storage significantly difficult and also has a major impact on price formation. However, notwithstanding the fact, FCEB continues to enjoy the greatest potential in the use of hybrid vehicles.

Over the past ten years, the chic project has been one of the origins in showing FCEB’s readiness for commercial services and by 2016 it has delivered about 60 buses which successfully master road miles in eight European countries, the most prominent of which is Germany. The satisfaction of manufacturers and users of services is mutual, so in 2017 the new JIVE and JIVE2 projects envisaged upgrading of the existing implementation of hydrogen vehicles and infrastructures [18].

4 Future trends in infrastructure investments

In the beginning of 2020, the emergence of the Covid-19 virus alarmed the entire world. The virus has penetrated almost every country of the world and left a mark in each of them. The consequences are present in all aspects of life, especially in national economies. Most countries have been committed primarily to saving people’s lives and maintaining the health system since the beginning of the pandemic. Although the pandemic peak has passed, the number of newly infected is still significant as well as the negative effects on national economies. Driven by the epidemiological situation, most countries have begun rebalancing previous plans to recover their economies from the crisis.

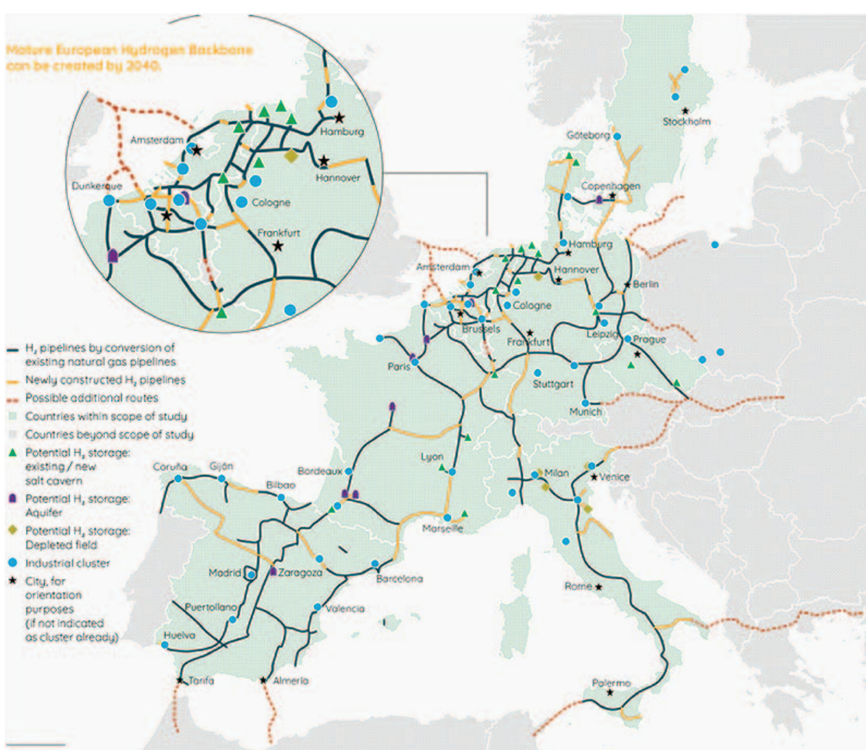
Neither the European Union has remained indifferent to the comprehensive situation caused by the Covid-19 pandemic. Europe’s soil has shaken up as well as other continents, so the EU is working tirelessly to combat the consequences of the virus. By adopting and taking various measures, it aims to assist the Member States in all pandemic segments. Thus, on 8 July 2020, the EU also adopted two strategies that form the backbone of the Clean Energy Investment Plan, relating to the integration of the energy system and the hydrogen strategy for climate-neutral Europe. The plan was made in line with the recovery packages relating to the European Green Plan and the Next Generation EU [19].

The integration of the energy system is combined with three main works relating to the energy system with a more pronounced circular dimension, direct electrification of the final consumption sector and the promotion of clean fuel including hydrogen. The hydrogen strategy covers the consideration of hydrogen as a major future potential that needs to be developed and applied in reality. As further assistance in the deliberation, the Commission launched the European Clean Hydrogen Alliance with leading industries, society leaders and the European Investment Bank. Furthermore, the Commission wants the European Green Plan to achieve sustainability of the EU economy, strengthen the industry and achieve climate neutrality by 2050. To achieve the objectives, a package of economic recovery from the root of the virus set out in the Next Generation EU budget plan presented by the Commission on 27 May 2020 is essential.

A week after the adoption of the Hydrogen Strategy by the Commission, a group of partners made up of eleven European companies presented the concept of transnational infrastructure for hydrogen transport. The concept is gradually planned from mid-2020 to 2040 to expand hydrogen transport system infrastructure in the range of 23,000 kilometres. The first part of the concept covers 6800 km of the initial length of the hydrogen network by 2030. The remainder of the planned network is foreseen in the second and third phases, which are due to be completed by 2035, after which the network will be extended in all directions until the end of 2040 when it is due to reach a final length range of 23,000 kilometres. The outcome should include two parallel networks i.e. one hydrogen and one (bio) methane network through which hydrogen transport will be carried out.

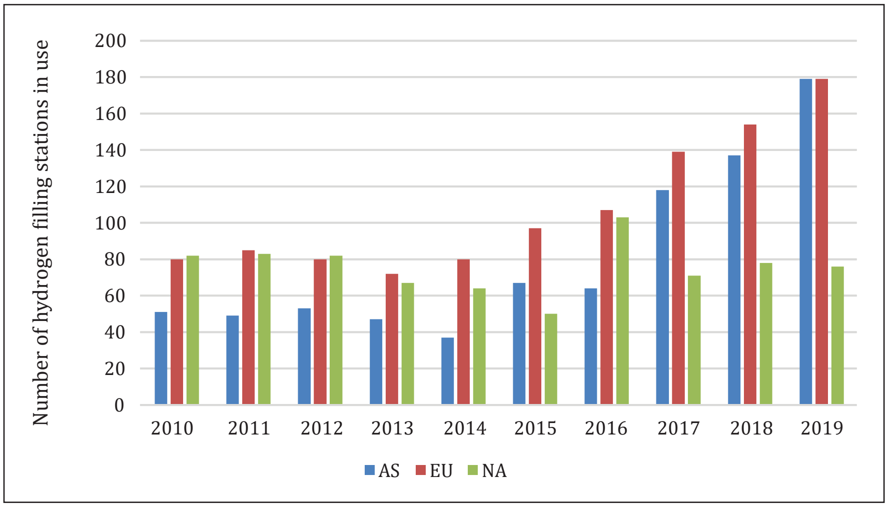
Map 1 presents the planned state of the hydrogen network in Europe in 2040. Green indicates the countries covered by the concept. New hydrogen pipelines marked with a yellow line are also visible and are in a smaller ratio to the green line representing the existing converted pipelines for the application of hydrogen. The intermittent red line indicates possible additional routes with countries not covered by the concept, while small symbols show potential hydrogen warehouses. To build a new and repurposed infrastructure hydrogen network, the mentioned companies say in the concept that 27 to 64 billion Euros need to be spent.

Particular attention is paid to the necessary infrastructure which must meet the current needs of hydrogen vehicles. The infrastructure includes a hydrogen refuelling station (HRS) charging stations designed as basic units and as basic units with production units that would allow hydrogen production in place. For the construction of such stations, special technical components are required, including appropriate hydrogen storage sizes, hydrogen compressors to the desired gas pressure level, pre-cooling system and fuel delivery dispensers [21]. It is also important to emphasize that there are different concepts of sta-



Map 1 Hydrogen pipeline network

Source: [20]



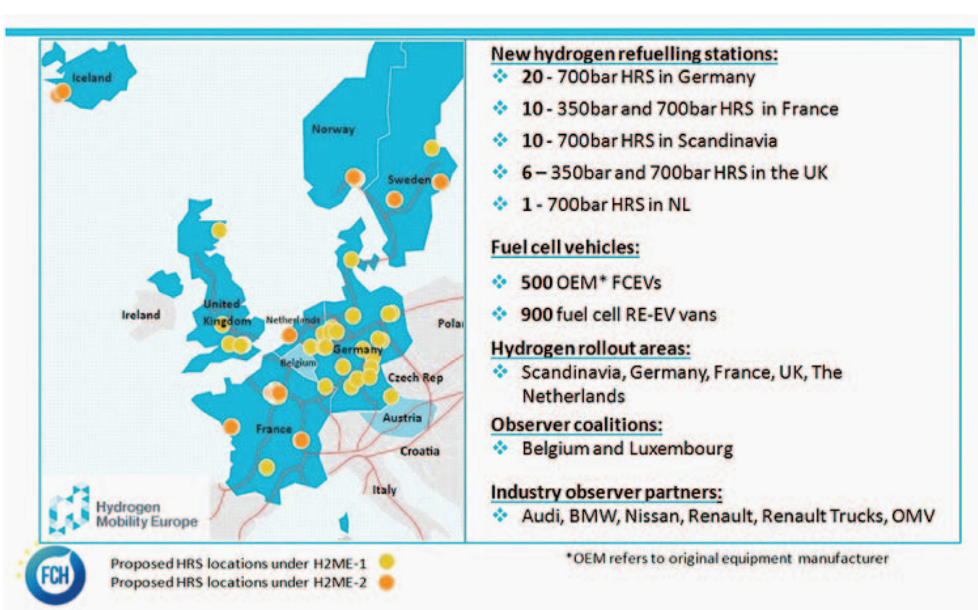
Graph 2 Development of hydrogen filling stations by region

Source: Created by authors from source [22]

tion infrastructure, depending on the amount of demand for hydrogen, i.e. whether one or more cars need to be filled or more. Either way, the density of hydrogen charging stations must meet transport needs, as more stations around the world create a greater opportunity to grow the hydrogen market.

In the example of Graph 2, the development of hydrogen charging stations by region over the past five years has seen a double increase in the number of hydrogen cells in the vehicle charging world. In 2019, 434 stations were available worldwide, the largest number of which is in Europe and Asia, then in the US and California respectively. An insight into the number of cells shows a positive trend in the growth of hydrogen as the alternative fuel of the future. Unfortunately, however, the number of FCEVs in Europe is still limited due to low utilisation, i.e. limited infrastructure that requires the construction of an initial network of stations. In response to the limiting factors, Europeans are eagerly awaiting the completion of the Hydrogen Mobility Europe project. The project should give FCEVs drivers access to the first real hydrogen Pan-European network, which will have 49 new state-of-the-art petrol stations and over 1400 vehicles available.

New gas stations according to the Map 2 Project Hydrogen Mobility Europe (HRS) will be most prevalent in Germany, France and Scandinavia, where hydrogen will



Map 2 Project Hydrogen Mobility Europe (HRS)

Source: [23]

be compressed at a pressure of 350-700 bars. The distribution of such gas will be similar to that of other conventional vehicles via a dispenser. The costs of investing in new infrastructure are much higher and this is the reason why these significant figures are actually small. Investors in the HRS station need more financial support to justify initial investments before starting the serial production of FCHVs, which can be expected shortly according to experts.

5 Conclusion

The use of fossil fuels has led the planet to a growing global problem that manifests itself through climate change. Every branch of transport has a significant impact on pollution and environmental formation as well as on the health of people that are increasingly at risk. Over the past few years, most countries have advocated for environmental awareness and the application of different models of sustainable development within cities. Global trends have started with the production of clean energy, i.e. increasingly choosing various alternative sources of road transport fuel to contribute to a more positive ecological picture of the world. Although it was previously known by scientists that they were keeping up with the times and were striving to eliminate negative environmental impacts, sometimes this was unfeasible.

Today's experts seek for commercial application of hydrogen within urban centres, which they want to provide future generations with a potential source of green fuel. Although hydrogen had been known before and has been used in the industry for years, its characteristics are regarded as an ideal propulsion system. It emits water vapour as the exhaust gas which does not pollute the environment because CO_2 emissions are not released. Hydrogen-powered vehicles use fuel cells and hydrogen production itself is carried out by electrolysis. The greatest advantages of hydrogen as an alternative fuel are manifested in significant noise reduction, full torque of the electric motor at low speeds and, most importantly, the production of electricity does not depend on external influence. The main drawback is highlighted during the electrolysis process, where energy is lost during hydrogen production. Since the application of FCEV and FCEB in cities has a relatively young origin, certain obstacles are understood as usual phenomena and are currently not regarded as a limiting factor for their further implementation.

Society has divided opinions about the use of hydrogen in everyday life, as many sceptics still like to recall the fatal landing of Zeppelin Hindenburg, which in 1937 used hydrogen and eventually caught fire 30 metres from the ground of New Jersey. Hydrogen proponents, however, believe in its use because they are aware of the fact that the gas passed various safety tests before it was released. Some companies such as Shell, Bosch, Solaris, BMW, Toyota, Hyundai etc. with their "work" aim to enable all branches of transport to fully integrate hydrogen as a propellant.

Current demand for hydrogen-based vehicles is still low because there is currently no significant number of FCEV models on the market due to the branching of charging stations that do not meet the needs of users due to the high initial costs of the cell network. Unlike FCEV, hydrogen-powered buses have shown a dependent advantage since their movement routes are already known in advance and do not need a dense network of hydrogen stations.

The leaders of the world's leading countries are adamant that they want to build the necessary hydrogen infrastructure despite the current crisis caused by the Corona virus pandemic, which has shaken economies around the world in 2020. The countries' policies have already begun implementing various measures and reorganising previous plans, thus remaining consistent in their efforts to ensure the implementation of hydrogen in the future.

Hydrogen opportunities as a source of hope for green energy have proved most successful in heavy vehicles so far, with smaller vehicles yet expected to follow. Reduced battery size and a greater range of conventional vehicles, as well as a branched charging infrastructure, would greatly contribute to a better and more acceptable status of hydrogen as a fuel in society.

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