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ECOLOGICAL AND ECONOMIC CONDITIONS FOR IMPLEMENTING HYDROGEN FUEL

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Abstract

Hydrogenation of the motor transport has become the highest form of broadly understood contemporary electro mobility, with the use of hybrid vehicles through fully electrical vehicles to fuel cell vehicles. This article presents development of hydrogen technology applying fuel cells, in particular in road transport.

The emission of greenhouse gases in the production cycles of the said fuel were discussed, depending on the use of various energy carriers in its production. Emphasis was given to the rationale underlying the production of hydrogen for the needs of fuel cells. Furthermore, the advantages were presented of exploiting electrical power for the production of hydrogen with the use of renewable sources of energy. The example of France was used to discuss the advantages of the hydrogen fuel technology for reducing the emission of combustion pollutants, in particular the emission of carbon dioxide.

The article also evaluates – on the example of Poland – average unit costs (PLN/km) for using fuel cell vehicles. At present, they will be higher than in case of vehicles with conventional drivers. High cost is one of the causes – apart from limited production of fuel cell vehicles – of slacked development of the hydrogen fuel technology. The article also presents premises for the road transport hydrogenation national plan in Poland.

Keywords: *road transport, hydrogenation, ecological, economic conditions*

1. Introduction

Hydrogen as a source of energy is one of the primary means of solving the energy & climate dilemmas faced by the world's population.

Works on the use of hydrogen as an energy carrier have a long-standing tradition, nevertheless those works combined with efforts to popularise the resulting solutions entered into a dynamic pace with the start of 2000, precisely at the turn of the 1st and 2nd decade of the 21st century. In 2005-2014 years, members of Hydrogen Council alone spent on research on the use of hydrogen for energy and commercialisation of the study results over a billion EUR annually. Those outlays are expected to come to approx. 1.4 billion EUR per year in 2015 – 2017 and in 2018 – 2022 will total up to 2 billion EUR annually [1].

At present, the implementation of the hydrogen technology on a numeric scale is the greatest in residential building industry. Almost 200 thousand buildings are heated with the use of fuel cell technology in the world, in Japan alone it is expected that by 2030 such installations will be applied in more than 5 million buildings. [2]

Another area for practical use of hydrogen as a fuel carrier is transport, including in particular road transport. In recent years 2 motor companies (Hyundai, Toyota) have launched the serial production of fuel cell vehicles (hereinafter referred to also as hydrogen-fuelled or hydrogen vehicles) and others such as Volkswagen, Mercedes Benz, BMW, General Motors also produce such vehicles. The start of serial production by those companies depends on the availability of expanded hydrogen refuelling network of HRS (Hydrogen Refueling Stations). In 2016, there were only c.a. 200 such stations available in the world. It is expected that by 2020 the number of HRS should come to approx. 1000 and by 2025 – to c.a. 3500 (Tab. 1).

Tab. 1. Number of public HRS worldwide in 2016 and their projected number in 2020-2025

Year	USA	Europe	Asia	Total
2016	60	100	103	263
2020	130	520	340	990
2025	600	2000	830	3430

Source: H2 Mobility, USDOE, Hydrogen Europe, Air Liquid – cited from How hydrogen empowers the energy transition, Hydrogen Council 2017, p. 9

This HRS in 2025 should provide service for approx. 2 million hydrogen vehicles.

Currently approx. 3 thousand vehicles fuelled with hydrogen are used in the world, including more than 1000 in the US and Japan and several hundred in Western Europe. A dynamic growth of fleets of hydrogen vehicles is planned – for example, China expects to have 50 thousand hydrogen vehicles in 2025, eventually to exceed one million in 2030, whereas Japan will have a fleet of 200 thousand hydrogen vehicles in 2025 and approx. 800 thousand in 2030. According to projections of 2014 – the European fleet of hydrogen vehicles is expected to have 350 thousand vehicles in 2020, the fleet in Japan – 100 thousand, in Korea – 50 thousand and in the US – 20 thousand [3].

In addition, the fleet of hydrogen-fuelled buses is to be developed – in Europe, it will have 1000 buses in 2020, while for instance in South Korea – almost 30 thousand buses by 2030. Also, other means of transport fuelled with hydrogen are developed, e.g. vessels, trams and railway engines (in 2017 the first hydrogen railway is to start in Germany) and even airplanes (German four-seat HY4 airplane tested in 2016).

2. Ecological aspects of implementing hydrogen fuel

The reason to stimulate research on the development of technology that uses alternative sources of energy in the road transport is, on the one hand a political issue resulting from the security of the oil acquisition and on the other hand, the question of the assumptions (also of a political nature) aimed at limiting in absolute terms, or at least limiting the growth of the pollutants emissions from internal combustion engines, including the reduction of greenhouse gases emission [4].

The ecological concerns include premise for transport policy in the EU. According to the transport strategy of the European Commission (EC White Paper of 2011) by the 2050, the vehicles powered by combustion engines are to disappear from the European cities. By the 2030, by a half is to be reduced the number of cars with internal combustion engines operating in the cities. Public transport relying on electric, hybrid and hydrogen vehicles is to, among the others; take over the majority of passenger transport. This European Commission's strategy is to affect the reduction in fossil fuel consumption and improving the air quality, especially in cities [4].

Regardless of the realistic evaluation of conclusions from the White Paper from the point of view of the Polish economy, the European Commission and some Member States will aim to accept the targets of significant reduction in pollutants emissions from transport. One of the promising alternatives seems to be a market for electric vehicles, including cars equipped with fuel cells that require hydrogen supply.

Hydrogen fuel used in the future, primarily in the fuel cells used to generate electricity that powers the electric motors of vehicles, is one of the alternative routes leading to the achievement of the objectives formulated in the European Commission's White Paper.

Hydrogen production as the result of the water electrolysis or e.g. methane reforming is the best possible action from the point of view of protecting the natural environment against the destructive effects of transport, including the motorisation. However, the basic condition that must be met in order the hydrogen could replace energy sources traditionally used in road transport is to develop economic, efficient and rapid method of hydrogen production based on energy from renewable sources. Currently, 48% of the produced hydrogen is obtained through reforming of methane using steam, 30% from crude oil (mainly in refineries), 18% from carbon, and the remaining 4% from the water electrolysis [5].

To fully understand emission when hydrogen is used for fuelling vehicles, it is necessary to analyse the life cycle of that fuel (greenhouse gas emissions for every energy carrier used for its production).

In hydrogen production, there are significant differences in environmental impact, depending on the method of its production. Three main options that seem most likely at present result in different emission of greenhouse gases, i.e. in the cycle of hydrogen production (Tab. 2) [6].

Tab. 2. Emission of greenhouse gases with the production of hydrogen [6]

Origin	kg $CO_{2\text{-ekv}}$/kg H_2
Natural gas (reforming)	11.9 [7]
Biomass (gasification)	4.8 [8]
Electricity (electrolysis; with the use of wind energy)	0.97 [9]

There is a great variety in the use of raw materials as – for example – gasification based on biomass of lower carbon content results in reduced estimated overall emission of CO_2. The previously mentioned emission is conservative, considering for instance the emission of methane.

In electrolysis according to the above example – over 75% of the said emission is generated by production and assembly of wind turbines. During electrolysis, the origin of electrical energy is of key importance for the levels of emissions.

Figure 1 presents CO_2 emissions for BEV and FCEV depending on the origin of the used electrical energy [6].

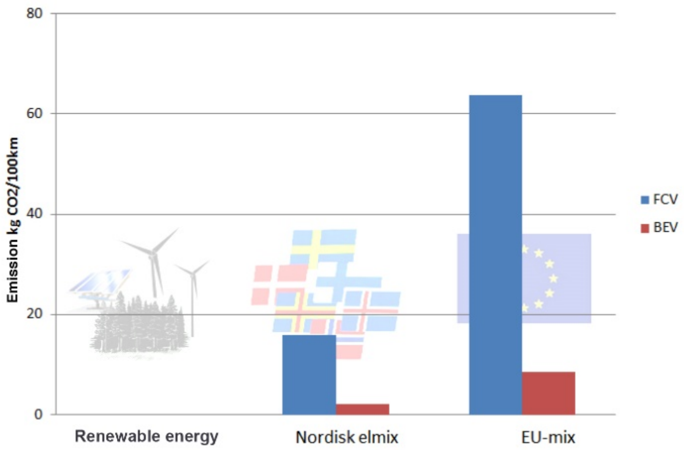

Fig. 1. CO_2 emissions for (BEV) and (FCEV) depending on the origin of the used electrical energy [6]

Table 3 below regarding emission of greenhouse gases in the use of various fuels shows average emission levels for biogas and E85 fuel [6].

Other harmful emissions (NO_X, SO_X, PM) had been reduced significantly since 1990 for all vehicles, including also petrol and diesel-fuelled vehicles. However, emission limits of combustion pollutants are still exceeded in real traffic conditions, especially in urban areas. Those emissions generate additional external costs due to health impairment, damages to buildings, etc. and occur in result of all types of combustion in engines of vehicles, except for fully electrical vehicles (BEV) or fuel cell vehicles (FCEV) [6].

Significant ecological effects of implementing hydrogen fuel are expected for example in France.

Tab. 3. Emission of greenhouse gases in the use of various fuels [6]

Type and origin of a fuel	Direct emissions by vehicles [kg $CO_{2\ eqv}$/100 km]	Total gross emission together with emissions from fuel production [kg $CO_{2\ eqv}$/100 km]
Vehicle using biogas [10]	< 8.4	8.4
Vehicle with a self-ignition engine, effective in terms of fuel consumption [1]	9.8	>9.8
Vehicle fuelled with E85 [11]	5.0	Depends on the origin of ethanol
Average emission for new vehicles in Sweden in 2012 (vehicles fuelled with petrol of low additives content and using diesel oil) [1]	13.5	>13.5
EU emission target for new vehicles in 2020 [12]	9.5	>9.5
Vehicle with fuel cell, hydrogen from natural gas [7]	0	11.9
Vehicle using fuel cell, hydrogen from biomass [8]	0	4.8
Vehicle using fuel cell, wind power [9]	0	0.9*

** Including 0.7 from wind turbine production; [1] average for vehicles of several producers*

In 2030 the projected fleet of about 800 thousand hydrogen vehicles – assuming average annual mileage of a statistical car of 16 thousand km and production of 75% of hydrogen used by transport, with the use of electrolysers located in HRS, should ensure reduction of CO_2 emission of 1.2 Mt (a volume corresponding to emission generated by 780 thousand diesel-fuelled vehicles) and in 2050 – even up to 10.4 Mt [13].

The use hydrogen vehicles in 2030 should help reduce – apart from CO_2 emission – also the emission of NO_x, SO_2 and PM in total mass of 1300 tons, which would bring roughly EUR 100 million savings in terms of external costs.

The annual overall external costs including – apart from costs of harmful emissions also costs of noise – would be reduced in 2030 from EUR 510 /car with a traditional diesel engine to EUR 160/ hydrogen-fuelled car, which – assuming the development of a fleet of hydrogen vehicles – would produce savings of approx. EUR 140 million annually in external costs and in the period 2015 – 2030 of EUR 500 million annually [13].

In physical terms, the costs of CO_2 emission in result of the development of a fleet of hydrogen vehicles should come to 1% of the global emission of CO_2 generated by a fleet of light vehicles in 2030, 5% of emission in 2040 and 9% of emission in 2050.

It should be emphasised that hydrogen is the fuel that will never run out, as 94% of the matter in the Universe is hydrogen. Moreover, it has a high calorific value (lower) when compared with other fuels (about. 120 MJ/kg). It also has drawbacks, such as, storage problems, the absence of a free state or very broad combustibility limits.

3. Economic aspects of implementing hydrogen fuel

The research conducted by ITS [14] shows that the average unit costs of mileage of the makes and models of passenger cars dominating in Poland, with engines exceeding 900 cm^3, in the first year of operation amount to 1.50 PLN/km in the first five years – 1.01 PLN/km, and in the period of 10 years from new stand at 0.86 PLN/km, and in this the costs arising from the decline of market value of vehicles range from 0.80 PLN/km in the first year of vehicle's operation, through to 0.40 PLN/km in the period from new to 5 years old and up to 0.28 PLN/km over the lifetime from new to 10 years old (Tab. 4).

Tab. 4. The average costs of 1 km mileage of passenger cars with engines exceeding 900 cm³ (petrol and Diesel) in the first year, from the first to the fifth and the first to the tenth year of operation, arranged according to the types of costs [PLN/km]

	In the 1-st year	1-5 years	1-10 years
Fuel costs	0.33	0.32	0.32
Technical maintenance costs recommended by the manufacturer	0.01	0.03	0.04
Purchase cost and tyres replacement costs	0.08	0.04	0.03
Costs resulting from the vehicle’s value decline	0.80	0.40	0.28
Vehicle’s insurance costs	0.27	0.22	0.19
Technical inspections costs	0.00	0.00	0.00
Operating costs in total	1.50	1.01	0.86

Source: ITS paper No. 7100/ZBE; Note: The figures computer rounded to two decimal places

Assuming:

1. that the average price of electric passenger car equipped with fuel cells will be around 260 thousand PLN,
2. the average annual decline of value of the car during the first 10 years of operation will be around 25 thousand PLN,
3. the average price for 1 kg of hydrogen will be 9.5 Euros,
4. the car will consume on average about 1 kg of hydrogen per 100 km mileage,
5. the average annual car mileage will reach 15.5 thousand km and the average unit costs of the tires, technical maintenance and insurance of the vehicle will be at the level of unit costs of cars with conventional engines,

then the average cost of one vehicle-kilometre of the mileage of electric car with fuel cells was estimated to be about 2.32 PLN/km.

This would be at present cost about 2.7 times higher compared with the average unit cost of a typical representative passenger cars operated in Poland, equipped with an internal combustion engine of the capacity above 900 cm^3.

Due to the fact purchasing power of the Polish society currently limited and most likely to remain limited in the coming years, it is expected that the development of the market of fuel cells equipped cars by the 2030 with their much higher presently operating costs compared with vehicles with conventional drives and without appropriate support of public administration, will be extremely limited and aimed at the fleet vehicles market.

The success of research undertaken at that time and experiments relating to both the construction of hydrogen vehicles but above all their basic component, i.e. fuel cell and also the construction and studies of various types of hydrogen refilling stations justified optimistic projections of the dynamics and the scale of the growth of hydrogen transport.

However, the reality proved more difficult than the plans. On one side there were high costs of all elements comprising the hydrogen system technology (vehicles, HRS), on the other side – relatively low prices of conventional fuels and regular progress in reducing hazardous combustion emission from internal combustion engines. In consequence, among various prototypes of hydrogen vehicles practically so far only Hyundai and Toyota launched a small industrial production of such vehicles, which presently does not exceed several thousand vehicles annually. The slower pace of the development of hydrogen vehicles fleet is caused by the slower pace of development of hydrogen refilling stations.

The comparison of objectives assumed in years 2015 – 2020 in the plans of development of the hydrogen technology for years in most of the interested countries with the existing condition proves a significant delay in their accomplishment, coming to at least 5 years in countries such as Germany and Japan. Also in Poland, the hydrogenation of the motor transport may be delayed.

4. Premises for the vehicle transport hydrogenation national plan in Poland

An essential element and direction for the development of road transport based on hydrogen-powered fuel cells is to create an alternative hydrogen-refuelling infrastructure.

Despite the strategic importance of developing HRS network, the explicitly formulated programming methodology for the development of these stations, has not been encountered.

The methodology developed is of multi-stage character. Individual steps leading to the designation of the location of HRS in Poland (as the methodology alone seems to be of universal character) are as follows:

Stage I: Method allowing identifying regions in which the hydrogen refuelling stations should be located in the first place.
Stage II: Method allowing identifying urban centres, in which should be located the said stations.
Stage III: Method for determining the area of the station location.
Stage IV: Method used to indicate a specific location of hydrogen refuelling station.
Stage V: Method indicating the preferred order of building investments in creating future network of hydrogen filling stations on the Polish territory.

In any of the said stages the group of 3-5 basic characteristics was adopted that determine, according to the experts, the potential future demand for hydrogen fuel, whose likely impact strength was determined by giving them the appropriate rank on a scale of 1 to 5 [4]. Detailed assumptions, acting procedures, numerical information, etc. contained by the task No. 5 entitled "The selection criteria for the location of HRS on the Polish TEN-T network" [4].

According to the guidelines of the HIT-2-Corridors project, as the indications of development of the network of HRS on the territory Polish, was the assumption taking into account firstly the possibility of refuelling with hydrogen connecting the areas between the Polish western border and the Baltic countries and next e.g. via ferry – with Finland**.** This idea is adhered to by enabling the safe use of hydrogen cars by their owners crossing the northern border of Poland (via ferry). This would provide, in the first place, opportunity for maintaining continuity of the passage of hydrogen cars along the transport corridors in these international directions within the EU.

Pointing to the proposed order of investments in the construction of HRS in Poland and taking into account the above-mentioned reasons, the preliminary aspect of locations in the cities or urban areas selected according to the rankings stages I to III, was considered.

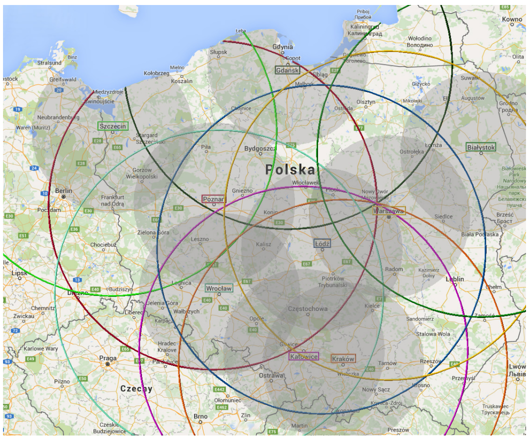

Fig. 2. The movement area of cars using fuel cells based on 9 hydrogen refuelling stations situated on the national TEN-T road network by the 2030 [4], *a) when driving in one direction (large circles – to approx. 600 km), b) when driving there and back (small circles – to approx. 300 km)*

In the first place taken into account were:
1. already existing refuelling opportunities in the neighbouring countries,
2. the expected future HRS locations in the Baltic countries,

3. gradually increasing the area available for hydrogen-powered cars as a result of the subsequent location of new stations at distances up to 300 km from the existing or sequentially from the newly opened ones.

In addition, while pre-indicating another HRS locations, taken into account were:

1. a size of average passenger car traffic intensity along the selected national roads according to available data, the average traffic volume projected for 2020,
2. development of HRS network ensuring gradually increasing the area of accessibility of other Polish regions by hydrogen cars,
3. development of HRS in areas with potentially high demand for hydrogen fuel, also by the fleet of city buses and taxis.

With the above criteria, the order of preliminary proposals to build HRS in Poland are as follows: 1 – Poznan 2 – Warsaw, 3 – Bialystok, 4 – Szczecin, 5 – Lodz area, 6 – Tri-City area, 7 – Wroclaw, 8 – Katowice region, 9 – Krakow (Fig. 2).

5. Summary

It seems that presently (2017) the practical development of the hydrogen technology is in a groundbreaking phase. The fact that many international programs are dedicated to the expansion of the HRS network and gradual enlargement of the fleet of hydrogen vehicles, especially with many such initiatives launched by the public administration a number of countries, may help overcome the deadlock.

It may be possible to overcome the impasse also owing to the fact that costs of building HRS, hydrogen vehicles and hydrogen itself are gradually decreasing.

The cost of constructing one HRS which already dropped from EUR 1.5 million to approx. EUR 1 million, are expected to decrease to EUR 400 – 470 thousand in 2030 [15].

The costs of production of hydrogen-fuelled passenger cars should decrease from EUR 62 thousand in 2015 to EUR 25 thousand in 2020, EUR 22.6 thousand in 2025, EUR 20 thousand in 2030, EUR 18.7 thousand in 2040 and finally up to EUR 18 thousand in 2050 [16]. In addition, the unit price of hydrogen and the annual service costs of a hydrogen vehicle are expected to decrease [15].

Maintaining in many countries the financial and non-financial support systems, purchase and use of low-emission and emission-free vehicles combined with reduced costs of the hydrogen fuel technology ought to bring the start of a real, commercial use of the said technology.

Poland should in the coming years to create a network of base HRS thereby allowing the transit of hydrogen cars.

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