Motor transport in Poland – hydrogenization

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Abstract. In paper is presented programs of hydrogen technology development in the road transport, in the world. Also is presented: status and trends of the road network changes in Poland, with particular emphasis on the Polish sections of the TEN-T network, production technologies and hydrogen production in Poland, preliminary indications of the future hydrogen refuelling stations locations in Poland, assumptions for the development of hydrogen-powered vehicle fleet in Poland by the 2050, expert forecast of the demand for hydrogen by the road transport in Poland by the 2050 and the ecological effects of the use of hydrogen fuel in the road transport in Poland by the 2050.

1 Introduction

The advantages of hydrogen as an automotive fuel is the lack of pollutants emission from motor vehicles' engines, which is especially important in crowded city centers and with the possibilities of its local production. The use of hydrogen fuel in the road transport to a large degree brings about independence from the import of crude oil and crude oil derived fuels. In the case of producing hydrogen by water electrolysis using electricity from renewable energy sources, the result is the use of "clean" energy [1].

In practice, so far, on the relatively mass scale, Toyota launched the production of fuel cell cars in the autumn of 2014. In 2014 of the Mirai model produced in 700 units, and for 2015 envisaged production of 3500 cars. Cars with fuel cells are also manufactured by Hyundai. Around the half of the first decade of the twenty-first century the countries technologically advanced in automotive production, began to develop draft projects of multi-annual work on the use of hydrogen in transport and new fuel cell technologies [2-5].

The development of hydrogen technology in the road transport in the EU countries is recommended, among the others, in the Directive of the European Parliament and of the Council 2014/94/EU of 22 October 2014 [6]. Under the provisions of the said Directive, it is recommended to EU countries to progressively ensure accessibility to hydrogen cars on their territories, and above all to ensure the possibility of driving hydrogen vehicles between the member States.

One of the major international projects concerning hydrogenization of motor transport is the "Hydrogen mobility Europe – Creating the European Visio for hydrogen transport" project – H2M [7].

The project has a budget of EUR 170 million, of which EU funds amount to EUR 67 million, and brings together 40 entities of 8 countries. Within the framework of the project 41 hydrogen refuelling stations (HRS) are to be launched within years 2015-2022: 20 in Germany, 12 in France, 10 in Scandinavia, 6 in the UK and 1 in the Nether-lands and approx. 1400 hydrogen passenger cars and trucks are to be tested.

According to preliminary results of studies the level of costs per vehicle/km of a conventional vehicle (ICE) equal to 23 cents, a hydrogen vehicle may achieve at the price of 1 kg of hydrogen of EUR 5 and if exempted from taxes [8].

With a price of hydrogen of 10 EUR/kg the cost per vehicle/km shall increase to 32 cents. The hydrogenization of motor transport is the subject of many international re-search projects, e.g. „Clean Hydrogen in European Cities" – CHIC where 23 partners of 8 countries invested EUR 81 million in HRS and 28 hydrogen buses (5 in Bologna, 8 in London, 5 in Oslo, 6 in Hamburg and 4 in Cologne) or „Hydrogen Acceptance In the Transition Phase – Public and Stakeholder Acceptance of Fuel Cell Electric Vehicle In Europe" – HYACINTH. This project brings together 11 partners from 5 countries and a budget of EUR 1 million, of which EU funds total EUR 661 thousand [9-11].

The project comprised questionnaires among over 7 thousand residents of EU and interviews with 455 representatives of entities of potential hydrogen transport market players.

Of special interest is the lecture regarding the plans of hydrogenisation of the British road transport prepared with E4tech [12].

The plan assumes that to 2020 the UK will have 30-65 hydrogen refuelling stations (HRS) and 50-100 hydrogen buses will be used and approx. 500 passenger cars. In 2025 the number of stations is expected to expand to approx. 150 and the number of used hydrogen vehicles should be several thousand. After year 2025 from 10 to 100 HRS, 100 buses and from 10 thousand to several thousand other vehicles with hydrogen drive should appear every year [13].

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The issue of hydrogen in road transport was also addressed by the lecture prepared by the Japanese Institute of Advanced Technologies [14]. Interesting is the fact that in Japanese condition it is more profitable to import hydrogen from Australia (10,000 km) or even Norway (20,000 km) than to produce it from gas reforming or electrolysis.

The territorial accessibility for hydrogen vehicles is determined by the availability of hydrogen refueling infrastructure, in the first place along the TEN-T network [15].

As a result of verification, under Polish conditions, of the original method developed for determining the initial location of the hydrogen refueling station in Poland, in the pre-commercial phase (2020-2030), the said location has been indicated along with the order of investment, taking into account above all the freedom to move around Poland of cars powered by hydrogen visiting Poland and transiting our country between other EU countries.

Despite the strategic importance of developing hydrogen filling stations infrastructure, in the available materials, including various national implementation programs for hydrogen propulsion technology developments, the explicitly formulated programming methodology for the development of these stations, has not been encountered.

2 National implementations plans

National implementation plans are in place in a number of countries, e.g. Belgium, France, the Netherlands, Sweden, etc. In Poland the methodology developed is of multi-stage character. Individual steps leading to the designation of the location of hydrogen refuelling stations in Poland (as the methodology alone seems to be of universal character) are as follows [16]:

Stage I: Method allowing to identify regions in which the hydrogen refuelling stations should be located in the first place.

Stage II: Method allowing to identify urban centres, in which should be located the said stations.

Stage III: Method for determining the area of the station location.

The Table 1 shows method allowing to identify regions (Stage I), urban centres (Stage II), area of the station location (Stage III).

Additionally, while pre-indicating subsequent hydrogen station locations taken into consideration were:

- average passenger car traffic intensity and average traffic volume projected for 2020,
- development of hydrogen filling stations network in the country,
- development of hydrogen refuelling stations in areas with potentially high demand for hydrogen fuel also by fleets of buses and taxis.

The order of investment: while taking into account the initial hydrogen refuelling stations locations (Stages I-III), in the first place included were:

- existing hydrogen refuelling capabilities in the neighbouring countries,
- the assumed future hydrogen refuelling stations locations in the Baltic Sea countries,
- new stations at the distances up to approx. 300 kilometres away from the existing stations or sequentially from the newly-opened stations.

With the above criteria, the order the construction of a hydrogen refuelling stations in Poland: 1 – Poznań, 2 – Warsaw, 3 – Białystok, 4 – Szczecin, 5 – the Lódź region, 6 – the Tri-City region, 7 – Wrocław, 8 – the Katowice region, 9 – Kraków (Fig. 1).

3 Results

As the first city to build a hydrogen car tanks filling station was selected Poznan because it is located at a distance of less than 300 km from the nearest hydrogen refuelling station in Berlin. This would be the first hydrogen refuelling station on the Polish territory located in the North Sea – Baltic Sea TEN-T corridor (E30/A2) leading then via E67/S8 road through Kaunas to Riga and further to Helsinki.

Table 1. Method allowing to identify regions (stage I), urban centres (stage II), area of the station location (stage III) [16].

Stage I	Stage II	Stage III
Average GDP per capita	Average distance of the cities, over 250 thousand inhabitants, from the place of hydrogen manufacture (acquisition)	Results of locating the stations in question obtained in stage I and II, and relying on the results of the measurement of average traffic volume of passenger cars on the roads leading to these cities or on selected road junctions located near these cities
Average population density (inhab./km^2)	Average distance of the cities, over 250 thousand inhabitants from the nearest hydrogen refuelling station located outside Poland	
The number of people living in the largest cities in the region, out of the cities with > 250 thousand inhabitants	Number of taxies in the city	Traffic flow intensity of passenger cars was included on the roads leading to the following cities: Warsaw, Poznań, Kraków, Wrocław, Katowice (Upper Silesia conurbation), Tri-City, Szczecin, Lódź, Białystok
Average traffic volume of passenger cars on the national roads of international significance running through the region (passenger cars/24 hours)	Number of municipal transport buses	

Fig. 1. Map of Poland with marked sites of the proposed public hydrogen refuelling station locations [16].

A second location of the proposed hydrogen refuelling station is in Warsaw. This would be second station in Poland in the TEN-T North Sea - Baltic Sea (E30/A2) corridor and further along the E67/S8 in the same corridor leading to Helsinki. This location is justified by the distance between Warsaw and Poznan, of little more than 300 km.

The third location of hydrogen refuelling stations in the TEN-T North Sea – Baltic Sea corridor should be in Białystok. Białystok is located in the North Sea – Baltic Sea (E67/S8) corridor. The road distance of Bialystok from Warsaw is about 200 km and from Kaunas is about 250 km.

The fourth location of hydrogen filling station is proposed in the Szczecin area in the Baltic – Adriatic TEN-T (the E65/S3) corridor. This hydrogen station will be able to be used, among the others, by the users of hydrogen cars moving through ferry crossings (Świnoujście) and Scandinavia (e.g. Trelleborg, Ystad). Besides Szczecin is away from Berlin at distance of about 150 km and from Poznań (suggested location of the first hydrogen refuelling station in Poland) at the distance of about 240 km (stretch of the TEN-T Baltic – Adriatic corridor: road E65/S3 and the section of the TEN-T North Sea – Baltic Sea corridor: E30/A2).

Fifth hydrogen refuelling station should be built at the junction of the TEN-T Baltic – Adriatic corridor (E75/A1) and TEN-T North Sea – Baltic Sea corridor (E30/A2), near Łódź. Location of the station in this region would shorten the distance between refuelling stations from Poznań to Warsaw (the distance from Poznań to Łódź is 200 km and Łódź–Warsaw is 130 km). Additionally, this location would be a condition for the integration of Tri-City in the emerging hydrogen refuelling network in Poland.

The sixth hydrogen refuelling station on the Polish territory should be located in the Tri-City area. The station would allow passage of vehicles between Tri-City and Stryków (TEN-T Baltic – Adriatic corridor: E75/A1) and then in the TEN-T North Sea – Baltic Sea corridor (E30/A2) and drive to Poznań (stretch of E75/A1 and a part of the E 261 road). The road distance to Łódź region (e.g. northern part of Łódź) via TEN-T Baltic – Adriatic corridor (E75/A1) slightly exceeds 300 km. The road distance between Tri-City and Poznań (stretch of E75/A1 and a part of the E261 road) is approximately 300 km.

The choice of the next, seventh hydrogen station location in Wrocław would provide connection with the city of Poznań (the E 261 road – about 200 km), Prague, Dresden (about 300 km).

Location of the eighth, in turn, hydrogen station near Katowice is due to the heavy traffic and the anticipated increase in traffic intensity of passenger cars between Wrocław and towns of Upper Silesia in the Baltic - Adriatic corridor (road E40/A4). The distance between these two cities is the order of 200 km. A high volume of traffic is currently taking place and will occur in the future between Katowice and Warsaw (20,000 and more vehicles per day) along the stretch of the Baltic – Adriatic corridor: E75/A1 and the section of North Sea – Baltic Sea corridor: E67/S8). Within less as 300 kilometres from Katowice is located: Łódź (in the Baltic – Adriatic corridor E75/A1), Warsaw (in the Baltic – Adriatic corridor: stretch of E75/A1 and section of E67/S8) and Kraków (in the Baltic – Adriatic corridor E 40/A4).

Locating of the ninth hydrogen refuelling stations on the Polish territory could possibly be in the area of Kraków. It is a city located directly in the Baltic – Adriatic corridor: E40/A4 and E77/S7).

On the Fig. 2 shown the movement area of cars using fuel cells based on 5 hydrogen refueling stations situated on the national TEN-T road network by the 2025.

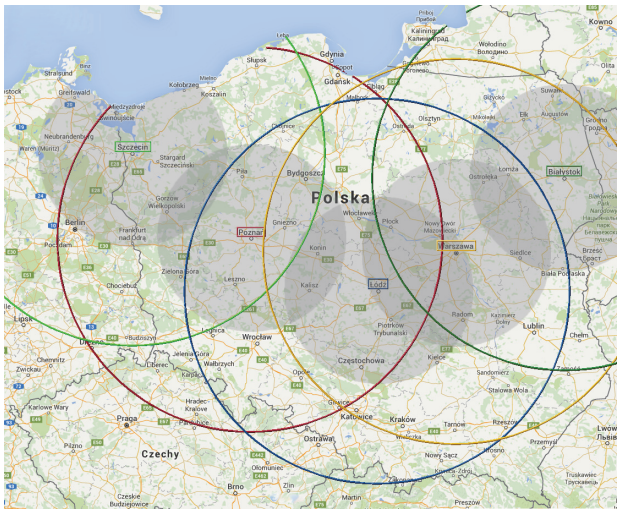

Fig. 2. Penetration area of cars using fuel cells based on 5 hydrogen refuelling stations situated on the national TEN-T road network by the 2025 [16]; when driving in one direction (diameter of large circles – to approx. 600 km), when driving there and back (diameter of small, shaded circles – to approx. 300 km).

On the Fig. 3 shown the movement area of cars using fuel cells based on 9 hydrogen refueling stations situated on the national TEN-T road network by the 2030.

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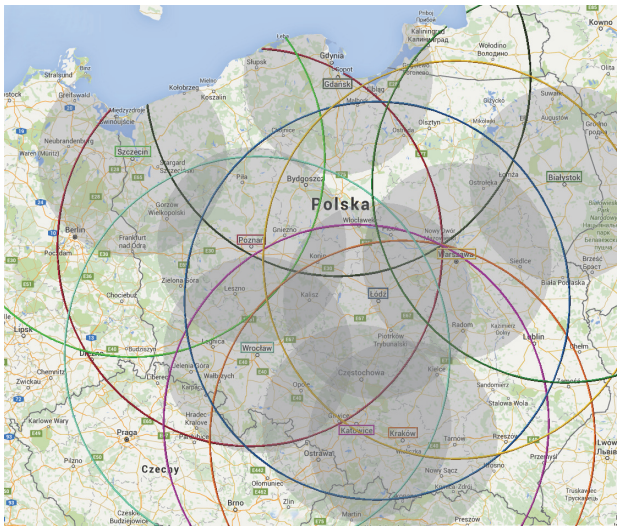

Fig. 3. Penetration area of cars using fuel cells based on 9 hydrogen refuelling stations situated on the national TEN-T road network by the 2030 [16]; when driving in one direction (diameter of large circles – to approx. 600 km), b) when driving there and back (diameter of small, shaded circles – to approx. 300 km).

Full commercialization of hydrogen technology in Poland (the years 2040-2050):

- Respectively: 200-600 hydrogen refueling stations,
- Financial expenditures for the construction of hydrogen refueling infrastructure in the order of 155-190 million €,
- The assumptions: 600 thousand respectively – 2 million passenger cars, 500-1000 buses, 100-300 thousand cars transiting Poland annually.

On the Fig. 4 shown forecast of demand for hydrogen by the vehicles equipped with fuel cells in Poland by the 2050.

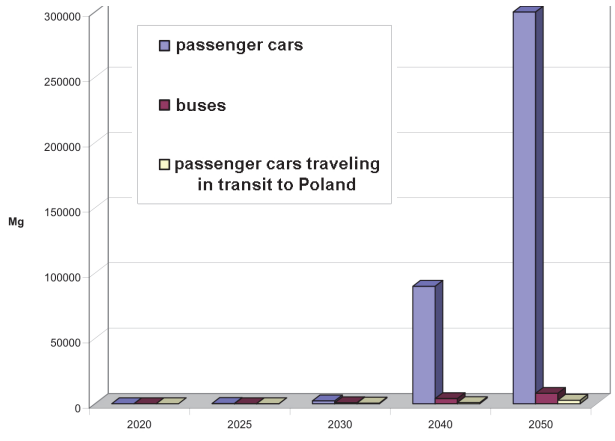

Fig. 4. Forecast of demand for hydrogen by the vehicles equipped with fuel cells in Poland by the 2050 Mg [4].

The implementation of hydrogen technology in the road transport allows to reduce the consumption of petroleum fuels, presented in the Fig. 5.

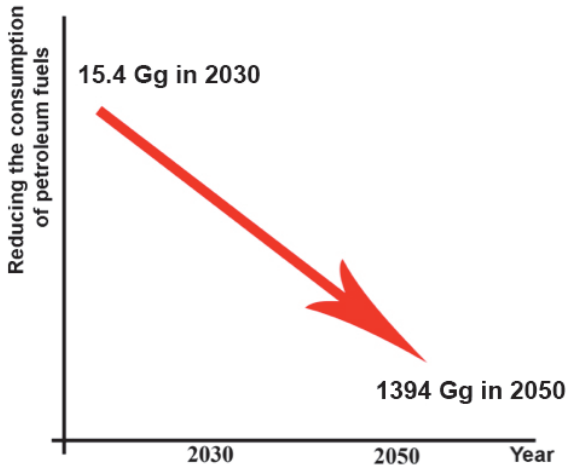

Fig. 5. The implementation of hydrogen technology in the road transport allows to reduce the consumption of fuels.

Reduction in consumption of petroleum-based fuels by the road transport in Poland as a result of the accepted scenario of the hydrogen technology development will affect the reduction in emissions (Tab. 2).

Table 2. Reduction in consumption of petroleum-based fuels by the road transport in Poland as a result of the accepted scenario of the hydrogen technology.

	in 2030	in 2050
Carbon dioxide	47.8 Gg	4314 Gg
Methane	4.4 Mg	426 Mg
Nitrous oxide	1.9 Mg	182 Mg
Carbon monoxide	1055 Mg	109.7 Gg
Nitrogen oxides	186 Mg	15.2 Gg
Non-methane volatile organic compounds	65 Mg	6.1 Gg

The avoided costs related to air pollution as a result of the hydrogen technology development will amount to:

- 2030 – 2772 thousand PLN (649 thousand €),
- 2050 – 287 million PLN (67.3 million €).

4 Summary

In summary it can be stated that:

- The advancement of hydrogen supplied fuel cells technology.
- Hydrogen as an automotive fuel is the lack of pollutants emission from motor vehicles' engines, which is especially important in crowded city centres and with the producing electrical energy used by automobile engines offers a real opportunity for the global automotive industry.
- The advantages of possibilities of its local production.
- The use of hydrogen fuel in the road transport to a large degree brings about independence from the import of crude oil and crude oil derived fuels.

- The source of obtaining hydrogen can be technological processes in the chemical industry, where this gas is, among the others, a by-product or autonomous hydrogen production processes e.g. electrolysis of water, hydrogenation of methane or bioprocesses.
- In the case of producing hydrogen by water electrolysis using electricity from renewable energy sources, the result is the use of "clean" energy.
- Efficient use of electricity produced during periods of excess production of energy or outside of peak electricity demand, can rely on its retention in the form of hydrogen, which is then used subsequently for different purposes, e.g. to power electric vehicles equipped with fuel cells.
- In Poland, at the moment, despite producing more than 1 million tons of hydrogen a year, there is no hydrogen of purity class required by the automotive industry. The production of hydrogen in industrial plants located on the Polish territory, for vehicles with fuel cells would require additional investments, which, however, would be conditional on cost-effectiveness of the operation of new installations.
- The development of hydrogen technology in the road transport in the EU countries is recommended, among the others, in the Directive of the European Parliament and of the Council 2014/94/EU of 22 October 2014 [6]. Under the provisions of the said Directive, it is recommended to EU countries to progressively ensure accessibility to hydrogen cars on their territories, and above all to ensure the possibility of driving hydrogen vehicles between the member States.
- The territorial accessibility for hydrogen vehicles is determined by the availability of hydrogen refuelling infrastructure, in the first place along the TEN-T network.
- The ten-year time sequence of the development of hydrogen technology in relation to the classic electric drive technology, is deepened in the case of Poland, by circa ten years quality and technological backwardness of the motorism.
- As a consequence, the study assumed that pre-commercial phase of the development of hydrogen technology in Poland will take place in the years 2020-2030, and its full commercialization will be possible only in the years 2040-2050.
- As a result of verification, under Polish conditions, of the original method developed for determining the initial location of the hydrogen refuelling station in Poland, in the pre-commercial phase, the said location has been indicated along with the order of investment, taking into account above all the freedom to move around Poland of cars powered by hydrogen visiting Poland and transiting our country between other EU countries.
- The places where it is proposed to built hydrogen refuelling stations should be (in order of their creation, along the TEN-T corridors): 1 – Poznan, 2 – Warsaw, 3 – Bialystok, 4 – Szczecin, 5 – Lodz region, 6 – Tri-City area, 7 – Wroclaw, 8 – Katowice region, 9 – Krakow.
- Under the adopted assumptions, taking into account both the progressive development of the hydrogen car fleet in Poland (15,000 cars, vans and 1,000 buses) and transit traffic (60,000 cars), the construction by the 2030 of thirty refuelling hydrogen stations (including nine bases HRS along the TEN-T corridors, should require a financial outlay of 12-15 million Euro.
- In the full commercialization phase (years 2040-2050) in the country there should operate approximately 200-600 hydrogen fuelling stations serving 600 thousand and 2 million passenger cars respectively, 500-1000 buses and 100-300 thousand cars transiting Poland.
- Due to the innovativeness of the introduction of hydrogen technology in transport, it is expected that the economic efficiency of the actions undertaken will appear only at full commercialization of this technology.
- The pre-commercial phase of development of hydrogen technology will require the use of various instruments to implement the assumed political strategy. They may be varied instruments of economic and administrative nature, addressed both to the users of electric vehicles with fuel cells, and those addressed to the users of vehicles with conventional engines.
- The implementation and spread of hydrogen technology in the Polish transport requires proper lobbying, including the development of a multi-stage information – educational program.

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