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Existing state and future opportunities to use selected fuels and alternative propulsion systems in Poland

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Abstract. The article presents the state of existing and future forecasts for a vehicle park equipped with fuel cells in the world. Reference has also been made to the current and future situation in the area of hydrogen refueling infrastructure in the world. The situation in the above-mentioned area in Germany is discussed, which is one of the leading countries in the hydrogenization of motor transport. A proposal for the development of hydrogen propulsion technology in Poland has been presented. In a similar scope, reference is made to the issue of electromobility in road transport, both in the world, in the EU, and in Poland.

1 Introduction

The Law On Electro-Mobility and Alternative Fuels, adopted by the Polish Parliament and the Polish Senate on January 11, implements, within the scope of its regulations, the European Parliament and EC directive (2014/94, dated October 22, 2014), on the deployment of alternative fuels infrastructure, defines alternative fuels as fuels and electrical energy used to power the engines of automotive vehicles or floating vessels which serve as a substitute for oil-derived fuels, or those produced as a result of oil processing, including in particular electrical energy, hydrogen, liquid biofuels, synthetic and paraffin fuels, Compressed Natural Gas (CNG), including gas derived from biomethane, Liquefied Natural Gas (LNG), including gas derived from biomethane, or Liquefied Petroleum Gas (LPG).

Electrical energy may be used to, among others, power electrical engines of fully electric vehicles (BEV - Battery Electric Vehicle), hybrids (HEV - Hybrid Electric Vehicle), plug-in type hybrids (PHEV - Plug-in Hybrid Electric Vehicle), REEV (Range Extended Electric Vehicle) or fuel cell-equipped hydrogen vehicles (FCEV - Fuel Cell Electric Vehicle). The following sections of this article refer to the existing state relating to the majority of these vehicles, outlining further opportunities for their use. Since appropriate infrastructure is essential for wider introduction of this type of vehicles, such issue has also been addressed.

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2 Fuels, alternative propulsion systems and low-emission vehicles

The global vehicle fleet in 2014 totaled 1.2 billion vehicles (95% of them passenger cars) [1]. This forces one to reflect, on the one hand on the issue of depletability of oil-based fuels used in automotive, and the emission of harmful fume components or greenhouse gasses on the other [1].

The very significant progress in the development of combustion engines and efforts to reduce emission of harmful fume components, for example by controlling these emissions under actual traffic conditions [2–4], in the direction of the development of low-emission cars with combustion engines powered by conventional fuels (gasoline, diesel oil), is not entirely able to address these challenges. Hence, continuation of work to improve combustion engines and their circuits responsible for the emission of harmful fume components are accompanied by work to develop alternative propulsion systems, including combination of such systems with conventional combustion engines [1].

One very promising, forward-looking solution is the introduction of passenger cars and public transport buses equipped with fuel cells (FCEV) and the deployment of refuelling infrastructure for these vehicles, which is being rolled out currently in a number of countries.

3 Hydrogenization of vehicle transport

In recent years, two automotive companies (Hyundai, Toyota), have launched serial production of fuel cell vehicles (hereinafter also referred to 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 Refuelling Stations). In 2016 there were only c. 200 such stations available worldwide [5]. It is expected that by 2020, the number of HRS should come to c. 1,000 and by 2025 – to c. 3,500. In 2025 this HRS footprint should be able to service approximately 2 million hydrogen vehicles [5].

Currently, approximately 3,000 vehicles fuelled with hydrogen are used globally, including more than 1,000 in the US and Japan and several hundred in Western Europe. A dynamic growth of hydrogen vehicle fleet is planned – for example China expects to have 50,000 hydrogen vehicles in 2025, to eventually exceed one million in 2030, whereas Japan will have a fleet of 200,000 hydrogen vehicles in 2025 and c. 800,000 in 2030. According to projections from 2014 – the European fleet of hydrogen vehicles is expected to have 350,000 vehicles in 2020, the fleet in Japan – 100,000, in Korea – 50,000 and in the US – 20,000 [6].

Also, the fleet of hydrogen-fuelled buses is to be developed – in Europe it will have 1,000 buses in 2020, while for instance in South Korea – almost 30,000 buses by 2030 [6].

In Poland, there are currently virtually no fuel cell vehicles due to the lack of hydrogen refuelling infrastructure. This should change soon.

Meanwhile, in Germany for example, studies on the use of hydrogen in transportation were initiated as part of the Clean Energy Partnership (CEP), established in 2002 under the auspices of the Federal Ministry of Transportation and Digitization [7].

As a result of the works conducted, in 2006 the National Innovation Programme Hydrogen and Fuel Cell Technology (NIP I) was adopted, functioning in 2006–2016. In order to manage the above program, in 2008 a government organization, the National Organization Hydrogen and Fuel Cell Technology - NOW was established in 2008. This organization also manages the NIP II Program, initiated in 2017.

Approximately 50 entities of various types were involved in NIP I, a total of 1.4 billion euro was spent, including 700 million euro from government funds (including 500 million euro allocated for demo projects and 200 million euro on R&D), while 700 million euro came from the industry [7].

At the first stage, by 2015, it was planned to build 50 hydrogen refuelling stations, financed by NOW, regardless of the scale of the development of hydrogen vehicle fleet. In practice, 20 publicly available hydrogen fuelling stations were commissioned in Germany by the end of 2015 (the first one in Berlin, in 2004), and 150 hydrogen-fuelled vehicles (passenger cars and buses) were put into use, traveling a total of more than 4 million kilometers [7].

According to the NOW Report dated 2015 and quoted earlier, achievement of the original goal of the first stage of deployment of hydrogen infrastructure, consisting of 50 public hydrogen refuelling stations, is being planned for 2018 (according to original arrangements, this year 100 hydrogen stations were supposed to be in operation in Germany).

It is assumed that out of the approximately 100 hydrogen stations which, according to current version of the plan will be built by 2020, the majority will be concentrated in six metropolitan areas, Berlin, Hamburg, Frankfurt, Munich, Stuttgart and the Ruhr Basin (up to 10 stations per region) [7].

The second stage of development of the German hydrogen infrastructure, which should, according to latest decisions, conclude in 2023 instead of the year 2020, is supposed to ensure operation of c. 400 hydrogen refuelling stations in the country.

At the third stage, based on full commercialization, in 2030 there should be c. 1,000 hydrogen refuelling stations in use in Germany [8].

In 2009, at the time when the plan was developed, it was assumed that c. 150,000 hydrogen-fuelled vehicles will be used in Germany in 2020 and in the year 2030, there will be 1.5 million such vehicles [9].

3.1 Circu Circumstances of the national plan for hydrogenization 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 hydrogen refuelling stations (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 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.

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 [10].

In any of the said stages the group of 3–5 basic characteristics were adopted which determine, according to 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 [10]. 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" [10].

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.

In the first place taken into account were:

- already existing refuelling opportunities in the neighboring countries,
- the expected future HRS locations in the Baltic countries,
- 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:

- a size of average passenger car traffic intensity along the selected national roads according to available data, the average traffic volume projected for 2020,
- development of HRS network ensuring gradually increasing the area of accessibility of other Polish regions by hydrogen cars,
- development of HRS in areas with potentially high demand for hydrogen fuel also by the fleet of city buses and taxis [10].

With the above criteria, the order of preliminary proposals to build base 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. 1).

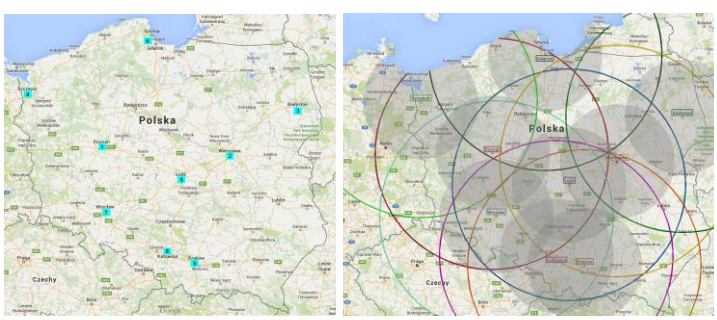

Fig. 1. Map of Poland with marked sites of the proposed public hydrogen refuelling station locations and the movement area of cars using fuel cells based on 9 base hydrogen refuelling stations situated on the national TEN-T road network by the 2030 [10]; a) when driving in one direction (large circles - to approx. 600 km), b) when driving there and back (small circles - to approx. 300 km).

Assuming that at the end of pre-commercial stage (year 2030), 15,000 passenger cars (FCEV) and 100 buses (FCEV) will be in operation and 60,000 cars (FCEV) will be moving through Poland (transit traffic), it will be necessary to operate 30 HRS stations [10]. Meanwhile, at the full commercialization stage (year 2040–2050), with 600,000–2 million cars and 500–1000 buses in use and 100,000–300,000 cars in transit, it will be necessary to operate 200–600 HRS [10].

Due to intensive deployment of the infrastructure of public HRS stations in EU countries, including those neighboring Poland (e.g. Germany, Sweden), the planned rollout of such stations in countries such as Estonia or Latvia, the placement of these stations in Poland, as proposed above and in such sequence, appears to be the best solution. If it becomes necessary to roll out the stations in stages, at the first stage they should be located, for example, along one of the TEN-T corridors: North Sea - Baltic Sea, Baltic Sea - Adriatic, but another configuration that takes into consideration both of these corridors is also an option. One solution would be to take the first step by placing, for example four HRS stations (Poznań, Łódź, Warsaw, Gdańsk), which would secure vehicle transit from Western Europe to Scandinavia and at the same time ensure the development of hydrogen propulsion technology in a large part of the country (Fig. 2).

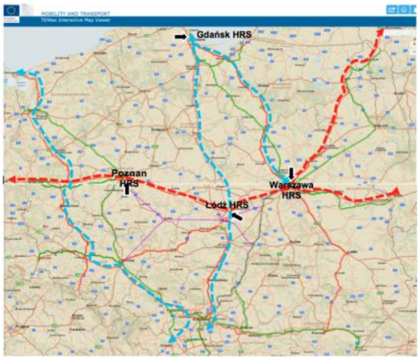

Fig. 2. A proposal for the location of the first four HRS stations.

One must reckon that currently, i.e. at the turn of 2017 and 2018, we are at a critical moment in the development of hydrogen propulsion technology and the attempt, made primarily by the public administration, including within the framework of the many international programs, to expand the hydrogen refuelling station infrastructure and the gradual development of the vehicle fleet equipped with fuel cells, could spark a development impulse.

As mentioned above, on January 11 of this year, the Polish Parliament and the Polish Senate have adopted the Law on Electro-Mobility and Alternative Fuels, which implements, within the scope of its regulations, the European Parliament and EC directive (2014/94, dated October 22, 2014), on the deployment of alternative fuels infrastructure, a law which also refers to hydrogenization of vehicle transport, indicating that the General Director for National Roads and Motorways, can incorporate locations of hydrogen refuelling points in the plans for locations for electrical vehicle charging points and natural gas stations. [14, 15].

4 Electromobility

The total number of Hybrid Electric Vehicles (HEV) manufactured worldwide up to now is estimated at c. 12.5 million, of which, by the end of 2015, c. 4 million vehicles were sold in the US, over 1.1 million in Europe and c. 4.3 million in Japan [1].

Combined global fleet of Plug-In Hybrid Electric Vehicles (PHEV), has only slightly exceeded 500,000 by the end of 2015, accounting for barely 0.05% of the global passenger vehicle fleet. The United States had the greatest number of PHEV vehicles (c. 200,000), followed by China (c. 86,000), Japan (c. 56,000) and the Netherlands (c. 78,000), which accounted for nearly 50% of the total number of such cars registered in Europe. Sizable numbers of PHEV vehicles were found in the United Kingdom (28,000) and Germany (c. 19,000) [1].

With respect to fully electric vehicles (BEV), their global fleet totaled, respectively, c. 51,000 vehicles in 2011, c. 109,000 in 2012, c. 223,000 in 2013, c. 411,000 in 2014, c. 740,000 in 2015, of which in Europe (2015), there were c. 182,000 cars (including c. 122,000 cars in EU28 countries) [1]. The most numerous fleet of electric cars of this type was found in (2015) China (c. 226,000 vehicles), the US (c. 210,000 vehicles), Japan (c. 71,000 vehicles), Norway (c. 61,000 vehicles), France (c. 45,000 vehicles) and Germany (c. 31,000 vehicles).

Out of the 2.1 million electric vehicles (BEV and PHEV) registered worldwide, at the end of 2016 c. 650,000 each were registered in Europe (including c. 450,000 vehicles in EU28 countries) and in China, as well as c. 570,000 vehicles in the US. Combined, in 2016 the above electric vehicles (BEV and PHEV) still accounted for less than 0.02% of the global passenger car fleet [1].

In Poland, the total number of hybrid cars registered at the end of 2016, can be estimated at c. 21,000 vehicles, of which 95% were HEV-type vehicles [1]. The share of hybrid electric vehicles (PHEV) is very small (c. 400 vehicles of this type registered at the end of 2016 [11]).

The number of BEV vehicles registered in Poland at the end of 2016 totaled 164, their number is estimated at c. 300 [1, 11].

However, government assumptions indicate that 1 million new electric vehicles may be in use by the end of 2025 [12]. In 2020 there is supposed to be 1,000 electric city buses in the country, while for example China, wants to force automotive concerns to produce 2 million electric cars per year, while in the US prices of electric and diesel cars will reach parity as early as 2020 [12].

The numbers of electric vehicles under various scenarios in specific years, estimated for Poland up to the year 2030 during the European project electromobility – scenario based Market potential, Assessment and Policy options (eMAP), carried out in a consortium of research institutes and organizations from Germany (including BAST Federal Highway Research Institute, German Aerospace Center(DLR)), Finland (Technical Research Centre of Finland (VTT)) and Poland (Motor Transport Institute), are shown in Fig. 3.

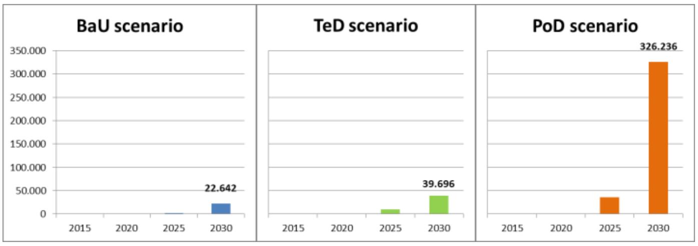

Fig. 3. Development of EVs (Polish scenarios) [13] (Source: Program Vector 21, KEC).

The BaU scenario incorporates current policies and technologies as can be expected from today (2014). This in turn means that the status of today concerning CO_2 limits, taxation schemes, energy system, infrastructure, powertrain efficiencies and suchlike is not frozen but does develop over time: e.g. the EU CO_2 limit for passenger cars is assumed to be lowered to 75 g CO_2/km in 2030 [13].

The TeD scenario assumes that the political and economic framework does not change but that electric technologies become more efficient than in BaU and that traction battery costs decrease faster than compared to BaU [13].

The PoD scenario incorporates a stronger European climate protection policy by further decreasing the EU CO_2 limit for passenger cars to 60 g CO_2/km in 2030, the limit curve thus being 130 g/km in 2015, 95 g/km in 2021 and 60 g/km in 2030. Furthermore, individual measures to promote electrified vehicles are modelled per country: Poland (from 2016) on:

- lowering purchase costs by 1050 € for electrified vehicles (BEV, PHEV, REEV, FCEV) by tax exemptions or purchase premiums,
- raising awareness for electrified vehicles by advertisement campaigns, lighthouse and showcase projects (and thus increasing the customers' willingness-to-pay by 10% (in relative terms compared to the BaU scenario)) [13].

Figures 4 and 5 present the forecasts for market shares (EU28), in percentages, of the various types of passenger cars by 2030 under the BaU scenario, TeD scenario and PoD scenario [13]. The projected market share of BEV, REEV and PHEV passenger cars is still relatively low, at 10–15%. It appears, however, that contemporarily (2017–2018), similar to the development of hydrogen propulsion, in the case of electro-mobility we are also at a breakthrough moment in the development of such technology and the market share of electric vehicles, primarily BEV and PHEV, may increase significantly.

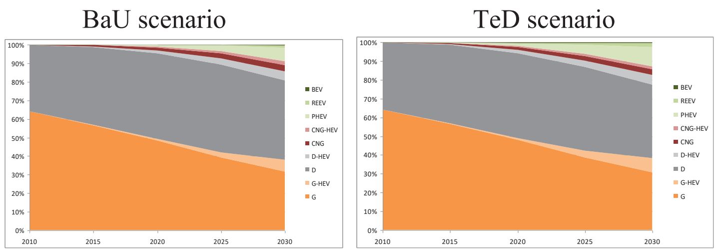

Fig. 4. Projected market share (EU28), in percentages, of the various types of passenger cars by 2030 under BaU and TeD scenarios [13].

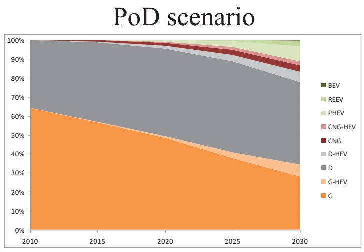

Fig.5. Projected market share (EU28), in percentages, of the various types of passenger cars by 2030 under PoD scenario [13].

Provision of battery charging, by building relevant infrastructure, plays a very important role in the creation of the market for electric cars.

The Energy Ministry estimates that currently in Poland there are relatively few, over 300 electric car charging stations (points) - (Germany, 20,000 charging stations, Norway, 9000 charging stations). It is expected that by the end of the year 2020, the network of charging stations will consist of 6800 chargers (rated at 22 kW or less) and c. 400 fast charging stations, rated over 22 kW) [11, 12].

5 Conclusion

The Law on Electro-Mobility and Alternative Fuels adopted recently (11.01.2018) by the Polish Parliament and the Polish Senate contains provisions which, for example, state the following:

- the supreme and central bodies of state administration ensure that the share of electric vehicles in the vehicle fleet used by the office or state institution or another entity which provides personal transportation services, is equal or higher than 50% and that, for example:
- in order to prevent the negative impact on human health and the environment due to emission of pollutants into the environment, clean transport zones may be established in compact residential housing areas with a concentration of public utilities, restricting the entry of vehicles other than:
  - electric,
  - hydrogen-fueled,
  - fueled by natural gas [14].

This increases future opportunities for the use of hydrogen (FCEV vehicles) and electric cars in Poland.

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