INSTYTUT TRANSPORTU SAMOCHODOWEGO

Circumstances of the national plan for hydrogenization of road transport in Poland

Report prepared as part of the HIT-2-Corridors project

/Synthesis/

HYDROGEN INFRASTRUCTURE FOR TRANSPORT
HIT-2-CORRIDORS

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Ministerstwo Nauki i Szkolnictwa Wyższego

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Project Partners

Sweco International AB (SE) (coordinator)	AGA Gas AB (SE)	Woikoski Oy (FI)
Riga Municipality (LV)	Ministry of Infrastructure and the Environment (NL)	HyER (Hydrogen Fuel Cells and Electro-mobility in European Regions) (BE)
Hydrogen Sweden (SE)	Motor Transport Institute (PL)	WaterstofNet (BE)

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Members of the team:

Substantive concept, supervision and editorial work:
Gis Wojciech
Menes Edward
Waśkiewicz Jerzy

Expert personnel:
Ślęzak Marcin
Gis Wojciech
Menes Edward
Waśkiewicz Jerzy
Kijeński Jacek
Kordel Zdzisław
Żółtowski Andrzej

Support personnel:
Balke Iwona
Balke Marcin
Damm Andrzej
Hitczenko Dorota
Jarosiński Wojciech
Karpiński Robert
Krupiński Mikołaj
Krysiuk Cezary
Menes Maciej
Pawlak Piotr
Skarbek-Żabkin Anna
Sowiński Adam
Szczepański Bartosz
Waśkiewicz Przemysław
Wilk Krystian
Wiśniowski Piotr
Zakrzewski Bartosz
Zysińska Małgorzata

Auxiliary personnel:
Drecki Tomasz
Grudzień Monika
Matuszewska Małgorzata
Mazurkiewicz Dominika

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Contents of the report

- Status and trends in the development of mobility in Poland compared to other EU countries.
- Status of the passenger cars fleet in Poland and the directions of its development, including those with unconventional energy carriers.
- Political, ecological, economic and legal aspects of the implementation of innovative vehicles propulsion technologies, including hydrogen technology.
- Programs of hydrogen technology development in the road transport, in the world.
- 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.
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Status of the hydrogen technology development in Europe

- After years of research and experiments hydrogen propulsion technology begins to enter the market. The current (2015), pre-commercial phase, involves the construction in Europe, of about 200 - 300 hydrogen refuelling stations located primarily in large urban agglomerations and along the TEN-T network. It is to handle about 5,000 passenger cars and 500 buses equipped with fuel cells. The early commercial phase of hydrogen propulsion technology should appear in Europe around 2020 and

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ensure the creation of a hydrogen infrastructure including approximately 2,000 hydrogen filling stations / min 1000 / along the strategic transport routes, serving 500 thousand passenger cars and 1,000 buses equipped with fuel cells. The commercial development phase of the hydrogen power technology should begin at the end of the third decade of the twenty-first century.

- In Europe, the most advanced program of the transport hydrogenization, with a budget of 1.4 billion Euro has Germany. The program entitled -"National Innovation Programme Hydrogen and Fuel Cell Technology" is coordinated by the Nationale Organisation Wasserstoff – und Brennstoftzellentechnologie (NOW GmbH).

The main barriers to the development of hydrogen technology in the road transport

- The high price of electric vehicle with fuel cells powered by hydrogen (by the 2020 the price of the car with fuel cells, however, should catch up with the price of a hybrid vehicle (PHEV - diesel).
- The need for high expenditures for the development of hydrogen distribution infrastructure network.
- Lack of profitability of the hydrogen refuelling stations in the early years of implementation of hydrogen technology.

Factors contributing to the development of hydrogen technology in the road transport

- The environmental benefits: reducing emissions of greenhouse gases and other pollutants from the cars fleet, as a result of replacing cars with engines running on fuels derived from crude oil, by electric vehicles with fuel cells powered by hydrogen obtained e.g. by water electrolysis, using electricity from renewable energy sources (RES).

  For example, as a result of the scenario adopted by experts for the hydrogen technology development in transport in Poland, in 2050, one can expect the reduction of carbon dioxide emissions by at least 4314 Gg, methane by about 426 Mg, nitrous oxide

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by 182 Mg, carbon monoxide 109.7 Gg, nitrogen oxides by 15.2 Gg, non-methane volatile organic compounds by 6.1 Gg, total particulate matter by 33.6 Mg.

- Increase of the energy security of the country: With the adopted scenario of the hydrogen technology development in the road transport in Poland, in 2050 the reduction of the energy consumption from imported crude-oil derived fuels, would be approximately 61300 TJ (1400 Gg).The possibility of storing temporary surplus energy produced in the form of hydrogen.

Factors contributing to a possible interest in the development of hydrogen technology in the road transport in Poland

- The current and planned dynamic development of hydrogen refuelling infrastructure in the Poland's neighbouring countries (Germany, Baltic Sea region countries).
- The legitimacy of the development of hydrogen refuelling infrastructure in Poland to ensure the continuity of movement of hydrogen cars across the EU, firstly along the TEN-T network.

Preliminary indications for the hydrogen refuelling stations locations in Poland

- The places where it is proposed to (with the adopted criteria) construct hydrogen refuelling stations should be (in order of their creation): 1 - Poznań 2 - Warsaw, 3 - Białystok, 4 - Szczecin, 5 – the Lódź region, 6 - Tri-City area 7 - Wrocław, 8 - the Katowice region, 9 - Kraków.
- The selected cities of the future locations of hydrogen refuelling stations ensure hydrogenization of the fundamental European transport routes along the Polish sections, namely:
- in the West - East corridor (A2 motorway) stations located in Poznań, in the Łódź region and Warsaw, as well as further to the North - East in Białystok,

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- in the North - South corridor (A1 motorway) stations located in the Tri-City, in the Łódź area, Warsaw and Katowice conurbation (Upper Silesia conurbation)
- in the running through Polish territory, southern West - East corridor (A4 motorway), stations located in Wrocław, Katowice conurbation (Upper Silesia conurbation) and Kraków.
- During the pre-commercial phase of the hydrogen power technology development in Poland (years 2020-2030), with the assumptions taking into account both the progressive development of the hydrogen cars fleet in Poland (15 thou. Passenger cars and 100 buses) and transit traffic (60 thou. cars), it is assumed to construct, by the 2030, thirty hydrogen refuelling stations, which would require investment of 12 - 15 million Euro.
- In the full commercialization phase (years 2040-2050) in Poland there should operate approximately 200 - 600 hydrogen fuelling stations serving 600 thousand and 2 million passenger cars, 500 - 1 000 buses and 100 - 300 thousand cars transiting Poland, respectively.
- The proposed numbers of hydrogen refuelling stations, the regions of locations and the periods of their start-up, will enable future operation of both the registered in Poland electric vehicles with fuel cells, as well as enable the development of the hydrogen car traffic, for which Poland is a country of destination or vehicles in transit through Poland.

Factors boosting the development of hydrogen technology in the transport

- Due to the innovativeness of the introduction of hydrogen technology in transport, it should be expected that economic effectiveness of the actions taken will only be evident in the full commercialization phase of the technology.
- The pre-commercial phase of the development of hydrogen technology will require the use of various instruments enabling the implementation of the assumed political strategy. They should be varied instruments of economic and administrative nature,

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addressed both to the users of electric vehicles with fuel cells, and 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 - education program.

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General information on Poland

Population: 38.5 million (2014) [19]

Area: 312.7 thousand km^2

Gross domestic product: 1 728 677 million PLN (2014) [20]

Gross domestic product per capita: US $ 14,379 (2014) [93]

Primary energy consumption in 2013: 94 Mtoe (million tons of oil equivalent) [92]

Demand for the final energy in the country in [67]:

2015 year – 67,3 Mtoe

2020 year – 72,7 Mtoe

2030 year – 84,4 Mtoe

The total final energy consumption: 66.65 Mtoe (2015 year)

including transport: 15.10 Mtoe

of that road transport: 14,97 Mtoe

The share of energy from renewable sources in the final gross energy consumption in 2012: 11%

The share of energy from renewable sources in gross final energy consumption in 2030: 15% (the expected value) [67].

Dependence on energy imports in 2012: 31%

Gross domestic demand for final energy from renewable (ktoe) [67]:

2015 year 63979 (11,6% - percent share of renewable energy)

2020 year 69203 (15,0%)

2030 year 80951 (16,0%)

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Gross domestic demand for electricity [TWh] [67]:

2015 - 152,8

2020 – 169,3

2030 – 217,4

Consumption of automotive and aviation gasoline in 2013: 3.6 million Mg (162.8 PJ)

Diesel oil consumption in 2013: 11.1 million Mg (483.0 PJ)

Carbon dioxide emission in 2012: 320.9 million Mg [21] (2020 year: 280,3 mln Mg; 2030 r.: 303,9 mln Mg) [67] including carbon dioxide emissions from the road transport in 2012: 45.1 million Mg [21] of that passenger cars: 22.6 million Mg, trucks with a maximum weight exceeding 3.5 Mg: 12.8 million Mg.

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Introduction

Intensive work on the use of hydrogen in road transport was taken up yet back in the nineties of the last century. Hydrogen can be used to propel a vehicle in two ways, either as a fuel in a conventional engine, where it is burnt in the engine combustion chamber or in the fuel cells to generate energy driving electric motor. Due to the numerous advantages (light weight, ease, speed of refuelling) and the absence of significant disadvantages associated with the technology of direct combustion of hydrogen in the engine combustion chamber (pre-ignition, energy consumption in the storage of hydrogen in a liquid state, etc.) especially the technology that uses hydrogen to generate energy by the cell fuels is being developed.

The cars that use fuel cells are equipped with electric motors, batteries and brake energy recovery system. Traditional engines and liquid fuel tanks in conventional vehicles are replaced with fuel cells and hydrogen tanks. Fuel cells produce energy in the oxidation reaction of hydrogen, and the vehicles powered by them emit only water vapour. In contrast to the electric vehicles using batteries, with a range of approximately 100 - 150 km and the need for a conventional charging for several hours (with so-called, fast charging, in the order of several minutes (shorter battery life), the vehicles with fuel cells can be filled with hydrogen in a matter of few minutes, and the full tank enables driving range similar to that of vehicles powered by combustion engines.

Studies of the cars with fuel cells have taken almost two decades. The first mass-produced fuel cell cars appeared practically only in 2014.

The main barriers to developing hydrogen propulsion technologies were cost and safety considerations for the entire hydrogen distribution chain, from the place of its production to the place of consumption in the car.

The purchase price, despite repeated reductions in the period of just a few years, is unfortunately still uncompetitive, as Mirai costs in Japan and the USA 57.5 thousand dollars, and in Europe 66 thousand Euro + VAT. It should also be stressed that the public

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administration in Japan will subsidize the purchase of Mirai by almost 20 thousand dollars and the US administration by 8 thousand dollars. It is estimated, however, that by 2020 the price of the car with fuel cells could catch up even with the price of a hybrid vehicle (PHEV - diesel) [79].

Much more favourable are, however, comparative operating costs of such cars. The passenger car consumes approx. 1 kg of hydrogen per 100 km (bus approx. 10 kg), which at a price (8-9 Euro/kg of hydrogen) causes that the hydrogen fuel consumption costs are on par, plus – minus, with the costs of conventional liquid fuels.

According to the experts the dissemination of hydrogen propulsion technology is only growing and is approx. 10 years behind the development of electric cars. At present, in 2015, we have a pre-commercial phase, which envisages the construction in Europe alone approx. 200/300 hydrogen stations in various urban regions for 5000 cars and approx. 500 buses equipped with fuel cells (called FCEV). The early commercial phase of hydrogen propulsion technologies should appear in Europe, approx. in 2020 and ensure the creation of hydrogen infrastructure along the strategic transport routes, numbering approx. 2,000 hydrogen filling stations / min 1000 /, serving 500 thousand passenger cars and 1,000 buses equipped with fuel cells. The commercial phase of the hydrogen propulsion technology development should be approx. in the year 2025 [33].

Ultimately, in 2020 the price of fuel cells equipped car should not exceed 50 thousand dollars, which will represent 1/40 of the costs of a first prototype of 2008 (in 2010 costs accounted for 1/3 of the costs of the prototype from 2008. In 2012, 1/6 of the costs of the prototype of 2008, in 2015 -1/20 of the costs of 2008 prototype). About 80% of the costs of the new generation car resulted from the costs of fuel cells [41]. The price of the fuel cell car should continue to decrease, especially after 2025 as a result of the development of mass production. At present, there are over 60 models of cars powered by fuel cells in various stages of technical and market development, prepared by practically all major automotive companies [33].

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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 the plan for 2015 envisages 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.

In Europe, currently the largest transport hydrogenization program, with a budget of 1.4 billion Euros, is conducted by Germany. The program entitled "National Innovation Programme Hydrogen and Fuel Cell Technology" is coordinated by the Nationale Organisation Wasserstoff – und Brennstoftzellentechnologie (NOW GmbH).

In the UK work on the program of hydrogenization of the economy was started yet back in 2004 [78]. In India, the National Programme of Hydrogenization of the economy was adopted in 2006. During the 11-th (years 2007-2011) and the 12-th (2012-2017) Economic Plan it was possible to arrange, among the others, 50% of the funding for research related to the popularisation of hydrogen as an energy carrier for the industrial sector and 100% for the scientific sector [43].

In Japan, an organization that promotes hydrogenization of road transport and development of vehicles equipped with fuel cells – the Fuel Cell Commercialization Conference of Japan (FCCJ) was established in March of 2001. Currently, it gathers 105 businesses and 15 organizations, including major Japanese carmakers.

One of the key elements of the transport hydrogenization plan in Brazil (Program of Science, Technology and Innovation for H2 and FC) is the Fuel Cell Bus Project assuming hydrogenization of the city buses [43].

Also, Canada has taken steps in view of the world research undertaken on the hydrogenization of transport (APMA Association project (Perts Automotive Manufactures Association of Canada) and the Canadian Hydrogen and Fuel Cell Association [50].

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In South Korea, under the government program to support the development of hydrogen drive technologies, in 2009-2012 there were 2.5 million Euros spent.

In total, by the 2010 public administration spent on research related to road transport hydrogenization, one billion US dollars (including 0.5 billion, in the US, the EU - 250 million dollars, Japan - 300 million dollars, South Korea - 100 million dollars, China - 60 million dollars).

There are several options for delivering hydrogen to the HRS. Each of them has an impact on the construction and operation of the HRS, but all stations capable of delivering hydrogen to vehicles at a pressure of 350 bar (buses) or 700 bar (passenger cars). The above-mentioned options are[83]:

- hydrogen production on site by means of electrolysis of water,
- hydrogen production on-site using reforming of methane ,
- centralised production and distribution of compressed hydrogen in gaseous form (CGH2) to the HRS in the tanks (200 bar, 300 kg), or by the use of high pressure vessels (up to 500 bar and 1000 kg), using trucks,
- centralised production and distribution of hydrogen in gaseous form (CGH2) to the HRS by pipeline (pressure depends on the location and will be about 8 - 60 bar),
- centralised production and obtaining hydrogen in liquid form and distribution of liquid hydrogen (LH2) in the tank (of the weight up to approx. 4000 kg), using trucks.

As part of the European HIT-2-Corridors project, the international consortium of:

- Sweco International AB (SE),
- AGA Gas AB (SE),
- Woikoski Oy (FI),
- Riga Municipality (LV),
- Ministry of Infrastructure and the Environment (NL),
- HyER (Hydrogen Fuels Cells and Electromobility in European Regions (BE),
- Hydrogen Sweden (SE),

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- Motor Transport Institute (PL),
- WaterstofNet (BE)

currently conducts:

- the national research and analyses to realize the implementation of hydrogenization of the road transport. The hydrogenization draft plans will be created in Belgium, Finland and Poland. In Riga, the draft plan will be developed for the Latvian capital and its region. The said projects will be based on the experiences gained during implementation of plans for hydrogenization of the road transport in Sweden, Denmark, the Netherlands and France. The new draft plans will be based on the German, English and Norwegian experiences. The developed draft plans will enable the implementation of the hydrogenization in the above four countries and its widening in other countries, consortium members,
- practical realization - implementation and deployment of three new hydrogen distribution stations (HRS) along the two corridors of the TEN - T road network: Scandinavia - Mediterranean Sea and the North Sea and Scandinavia via the Baltic states (Estonia, Latvia, Lithuania) to Poland,
- the said studies will provide essential information and practical tools for decision makers and infrastructure managers for the implementation of HRS stations primarily along the TEN - T road network. This network will be *sine qua non* condition for the fuel cells equipped motor vehicles.

1. Purpose, scope and method of preparing the report

The essential objective of the study is to identify the initial locations of the prototype hydrogen car refuelling stations along the selected road network in Poland.

There were two stages adopted for preparing this paper. The first stage, which is this paper, is of a synthetic. It represents a general presentation of the specified tasks in the planned scope of work. The second stage will be a clarification of the individual, the most important tasks to achieve the adopted target.

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The scope of the study includes the following tasks:

- trends of the development of transport and mobility in Poland and in the selected EU countries,
- hydrogen propulsion technology, as one of the directions of the development of motorism,
- status and directions of the development of national and international road network in Poland with particular emphasis on the Polish sections of the TEN-T network,
- hydrogen management in Poland (production, use and distribution channels),
- conditions for development of hydrogen technology in the road transport in the EU, including in Poland,
- concept of the development of hydrogen fuel distribution infrastructure in Poland.

The study undertaken by the Motor Transport Institute (ITS) is of a pioneering character in Poland. It includes within its scope both general issues dealing with future (the year 2030) demand for passenger transport in Poland, the development of road infrastructure, technical conditions, legal and economic ones for development of the hydrogenization of transport.

This study utilises, both the results of the ITS's own studies on the development of transport sector, especially the development of the motorism and the economic problems of the operation of passenger cars, as well as the available work results of other scientific development centres e.g. University of Gdańsk or traffic intensity forecasts along the primary road network in Poland. The rich subject literature was also analysed.

It uses, the method developed allowing to stage by stage indicating of the locations for hydrogen refuelling stations.

2. Development trends in transport and mobility in Poland

The development of mobility and freight transport has in the last two decades become one of the key challenges of the European social, environmental and transport

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policy. This dilemma has its special dimension in Central and Eastern Europe, including in Poland, where under conditions of systemic transformation after 1989 there has been a rapid growth and change in the ways of meeting transport needs. These needs will grow more strongly than in other developed countries.

2.1. Mobility in Poland against other EU countries

In 2010 the mobility of the Poles, executed by land transport means amounting to approx. 9 thousand km / person, taking into account 10.27 thousand km / person by air transport, now reaches 75% of the average Western European mobility (annual mobility of statistical inhabitant of Western Europe considered as a whole, covering air and sea transport within the EU reached 13060 km / person in 2011) [32]. This mobility has increased by nearly 90% compared to the mobility of the late eighties of the last century, when it amounted to approx. 4.8 thousand passenger-km / person / year [23].

The statistical mobility increase was influenced by the rapid growth of affluence of the part of society and the consequent rapid development of individual motorism, (several million cars were bought) development of private entrepreneurship, open borders and freedom of travel, the development of private house building including the weekend type of houses (the Poles have 1.5 million recreational allotments and nearly 600 thousand dachas), and in the recent years a large economic emigration and the development of low cost airlines. It is worth noting that according to the first survey of this kind conducted by CSO in 2009, up to 2.3 million people worked in places that are not their place of permanent residence [33].

Achieved level of mobility points to a further detachment of our society from the civilization standards which characterize highly developed countries. The level of realized mobility and its branch structure, however, constantly evaluates and will evaluate towards the structures characterizing highly developed countries.

In 2010, the share of individual transport (passenger cars and two-wheelers) in serving the public transport needs reached nearly 76%, while the share of rail and bus

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transport fell to 4.5% and 5.5% respectively and urban public transport to 3.5 %. Note an increase in the share of air transport to approx. 10% of the total passenger traffic.

Assuming that Poland achieves, around 2020, today's average indicators of socio-economic development of the EU members one can expect that the current statistical mobility indicator should be further increased. Under current trends and not counter actions leading to change in transport behaviour of the population, the growth will concentrate mainly in the group of travel by passenger cars and to a lesser extent, air transport.

Table 2.1. Average annual amount and branch structure of the passenger- kilometre coved by mechanized transport of a statistical Pole in 2010 and hypothetical one in 2020, in km/person

Specification	By all transport modes per person / per year	In that:				
		By rail transport	By coaches	By tram and underground	By air transport	By passenger cars and two-wheelers
2010	10270	470	570	360	1070	7 800
2020 a) minimal variant	12600	490	730	130	1485	9770
b) maximum variant	13500	500	760	130	1700	10390

Source: Own calculations based on Burnewicz J., Transport Development Strategy until 2020 (with an outlook until 2030), the Ministry of Transport, Construction and Maritime Economy, Warsaw, January 2013, p.37

Based on these estimates it is possible to determine that while the Polish population now numbering in 2010 (38.1 million) has covered about 392 billion passenger-kilometres, then in 2020 this population (37.8 million people) will cover annually total of 477 billion to 505 billion passenger-kilometres, of which approx. 370 billion passenger-kilometres by cars, 18 billion passenger-kilometres by rail transport, 18 billion passenger-kilometres by extra-urban coaches, over 14 billion passenger-kilometres by public transport and 56-60 billion passenger-kilometres by air transport.

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2.2. Auto-mobility of the Poles

Already, nearly 80% of their mobility the Poles realize by using passenger cars. According to a survey conducted in 2014 it appears that the average annual car mileage amounted to 13.7 thousand km and 15.3 thousand km taking into account vehicles being actually exploited.

The intensity of the use of passenger cars in Poland ranks among the countries with the highest average annual car mileages (Ireland, Denmark, Belgium). This demonstrates fascination of the Poles with cars, which became widely accessible goods only less than 20 years ago. This will affect the persistence for the next few years of the pro-motor vehicle consumer attitudes.

2.3. The forecast for the passenger transport in Poland by the 2030 with particular emphasis on the individual transport

The forecast of the global demand of passenger transport by all branches and forms of transport in Poland (performed both by Polish and foreign carriers) shows that carriages will increase from 55.5 billion people in 2010 to 59,0 – 64,9 billion people in 2030. Forecasts assumed that the total number of passenger transportation, using mechanized transport in one year period in Poland for the years 2010 – 2030 will increase from 30,7 billion to 37,6 – 41,6 billion people [77] (an increase of 22 – 35%). It is provided that global transport work performed by mechanized transport including aviation, shipping and two-wheelers will increase in this period from 390 billion pkm to 554 – 626 billion pkm (an increase of 42 – 60 %). The increase in average mobility realized by passenger cars in Poland will be from 7,3 thou. km/person in 2010 to 10 - 11 thou. km/person in 2030 [22].

Transportation by passenger cars amounted to approximately 24,8 billion people in 2010, in 2030 will increase from 30,9 to 34,6 billion people (an increase of 124 – 139%). Transportation by passenger cars in global transportation done by mechanized transport will increase from 80 % in 2010 to 82 – 83% in 2030.

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Transport work done by passenger cars in 2010 was amounted to approximately 279,7 billion pkm. In the year 2030 it will increase to 369,8 – 419,4 billion pkm (an increase from 142% to 160%). Share of transport work done by passenger cars in transport work done by mechanized transport amounted in 2010 to about 72% will decrease in 2030 to 67%. The presumed decrease is a result of estimated enrichment of rail transport offer.

2.4. Forecast of the size of the cars fleet in Poland until 2030

2.4.1. Forecast of the total number of passenger cars

By the end of 2014, the number of registered in Poland passenger cars amounted to 20 million [25].

According to current forecast, the total number of passenger cars in Poland in 2030 should increase at least to about 22.7 million (an increase of approximately 14%) [17].

2.4.2. Structure of the passenger cars fleet in Poland, by petrol and diesel engines and trends of the changes

Analysis of trends and determinants of development of passenger cars fleet leads to the conclusion that in Poland by the 2030 further increase of the number of cars in operation will be primarily was based on vehicles powered by combustion engines.

In 2013 cars with petrol engines were accounted for about 57% and in 2030 its share will decrease to 55,5%.

According to expert forecasts, it is assumed that in Poland by the 2030 there will be a decline in the share of passenger cars with diesel engines from 28 to 26% [81].

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2.4.3. Trends in development of the passenger cars fleet powered by liquid petroleum gas in Poland

As of the end of 2013 the number of passenger cars with LPG systems in Poland amounted to 2846.9 thousand (15%) [24].

The network of LPG fuel stations in Poland is very well developed (5520 autogas refuelling points at the end of 2013) [87]. It has been expertly assumed that by the year 2030 the share of cars powered by LPG will be 16% [81].

2.4.4. Trends in development of the passenger cars fleet running on natural gas in Poland

According to the NGVA Europe data (European Natural & Bio Gas Vehicle Association), in July 2014 in Poland there were 3 thousand CNG passenger cars [89]. The number of CNG filling stations in Poland as of April 2015 was 25 stations [88].

It has been expertly assumed that in the structure of passenger cars vehicle fleet in Poland in 2020 the participation of passenger cars using natural gas will be in order of 0.1%, and in 2030 - around 2.5%. It is also possible to increase the share e.g. of the public buses powered by CNG or LNG and biomethane use in buses of this type, taking into account the expected development methanation of the road transport.

2.4.5. Prospects for the development of electric cars in Poland

The scale of development in Poland of electric cars is currently marginal. It is estimated that in 2014 there were about 200 electric cars (BEV) [37] and around 5,8 thousand hybrid cars hybrid (electric – combustion) registered in Poland.

The number of public charging points for electric cars in Poland at the end of the first quarter of 2015 was approximately 60 [92].

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One should not probably expect in the next few years a significant quantitative development of electric cars in Poland including may be fuel cells cars because there is no policy to support the development of electromobility at central and local levels.

With regard to the expected quantitative development of electric vehicles fleet on the Polish market, it has been expertly assumed that the numerical share of electric passenger cars in the total number of passenger cars in Poland in 2020 will amount to 0.02%, and in 2030 it will amount to 0.1% [81], which amounted approximately 4 thousand and about 23 thousand electric cars accordingly. However, according to scenarios: BaU (Business as Usual) – the baseline scenario, TeD (Technology Driven) - scenario associated with technological development of electric drives and batteries and PoD (Politically Driven) - a scenario which takes into account political support in the development of electromobility, of the presented as part of the European eMAP [91] project, number of electric cars, including those with fuel cells are for Poland in 2030 as follows: 22642 (BaU), 39696 (TeD), and 326,236 (PoD)

3. Political, environmental and economic aspects of the development of alternative power sources in the road transport

3.1. Political conditions

3.1.1. EU policy on the development of road transport in the EU documents

The White Paper - "Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system" published in March 2011 assumes a 60% decrease of the greenhouse gases emission from the transport sector by the 2050 in relation to its level in 1990 [84].

The aim is for the member states to reduce by the 2030 greenhouse gases emissions in transport by 20% compared to the level of 2008. Given the significant increase of the said emissions in the transport sector over the past 20 years, they would still be 8% higher than in 1990.

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General transport development strategy in the EU envisages creation of a single transport area allowing for achieving a competitive and resource efficient transport system [84]. It is understood that sustainable transport system should be a mechanism driving the economy. The strategy envisages state financial assistance to support the development of alternative fuels.

Generally, the EU's transport strategy assumes a maximum transfer, most of all, of the freight from the road transport to environmentally friendly modes of transport, including rail transport and to reduce the emission of harmful substances into the environment. In the carriage of passengers is assumes the reduction of individual transport, especially in the cities, in favour of public transport.

The actions undertaken are not only to change the modal structure of transport, but also to reduce, among the others, the road congestion, create more jobs and accelerate economic growth. They are to ensure the smooth functioning of the internal market and the inclusion of all EU regions into the global economy.

Taking into account the depletion of crude oil resources, as well as progressive climate changes, requires both in the short and the long term a radical restructuring of the EU's transport system. Among the measures designed to ensure attaining the above objectives of transport policy there are, among the others, proposals such as: gradual phasing-out of the conventionally-powered cars from the cities by the 2050 and transferring in the same time horizon, 50% of passenger transport over medium distances and the freight one over long distances, from the roads over to other modes of transport.

New technologies for vehicles and traffic management will be the key to decreasing pollutants emissions from transport. The race in the field of sustainable mobility is a global one. However, in the concept of a new transport policy by the 2050 limiting the mobility is not intended.

The emergence of new modes of transport are anticipated which will allow the transportation of freight and passengers to be done using the most efficient means or a combination of such measures. Individual transport should be limited to the last

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sections of the journey. This situation has already occurred in many European cities, which introduced a ban on entry of passenger cars not meeting the accepted pollutants emissions criteria.

Further development of the transport sector in the EU, which the European Commission confirms very clearly, the must be based on improving the energy efficiency of vehicles in all modes of transport, including the introduction of alternative energy sources also using renewable energy sources.

3.1.2. Determinants of the road transport development policy in Poland, including those with regard to hydrogen technology

"The Polish Government has repeatedly signalled its objections to the proposal of the European Commission presented in the White Paper of 2011. In its assessment the reduction target by the 2050 was set based on the reduction needs, but without considering the fact of the lack of effective and sufficiently mature transport technologies ensuring its implementation" [27].

These objections were strengthened by the fact that the forecasts for the development of Polish transport assume higher growth rate of the passengers' mobility and the magnitude of the freight carried than in the EU-15 countries, which is associated with the gradual equalization of the levels of socio-economic development.

This does not change the fact that the cited study concluded that "the sooner Poland takes measures to rationalize functioning of the transport system, the costs of this transformation will be lower" and that "one of the promising market segment seems to be electric cars, whose development can contribute to a significant reduction in emissions from transport in Poland". The material quoted did not assume, however, the development in Poland of cars equipped with hydrogen fuel cells.

The vehicles equipped with hydrogen fuel cells, were however mentioned in the prepared by the Ministry of Transport, Construction and Maritime Economy "Transport development strategy until 2020 (with an outlook until 2030). In the § 7.3 above study,

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entitled - "The directions of interventions of technological and innovative character" in the second item it reads: "The increasing use of environmentally friendly means of transport: „clean" and energy efficient cars and municipal vehicles (e.g. using fuel cells and hydrogen, drives: electric, gas, hybrid, compressed air) – together with creating country-wide network of charging stations or electric battery replacement ones, and hydrogen refuelling network" [77].

The "Forecast for the demand for fuel and energy until 2030" says, in turn, that „development of technologies enabling to obtain liquid and gaseous fuels from domestic raw materials will be supported" [34].

Beside these general formulations at the national level there has not been any practical or legislative, organizational or technical action taken supporting development of the use of alternative fuels to power the transport means, or alternative drives.

As a result, at the end of 2014 there were only about 200 electric cars registered in Poland and few dozens of public electricity charging stations operational.

Thus the Measure 5.1. - Diffusion of the innovations of the program "Building the market of electric vehicles and their charging infrastructure – the basis for energy security", assuming equipping five largest Polish cities with 120 stations (360 of plug-in connections) for motor vehicles electricity charging, adopted within the Operational Programme Innovative Economy, has not been implemented [13].

The issue of building a hydrogen refuelling stations has not been so far in the country considered at all. "In Poland the subject of building hydrogen infrastructure for transport has not yet been recognized as an important task in the strategy for the innovativeness development of the country, despite the emergence of the Polish Technology Platform for Hydrogen and Fuel Cells" [16].

A similar situation also functions at the level of regional documents.

The regional development strategies by the 2020, which were created in each region, sum up the problem of electric cars with either one sentence, and not even directly, or not at all, and there is no mention about vehicles with fuel-cell powered by hydrogen at all (e.g. see "Updated Strategy for Development of Wielkopolski Region by the 2020"

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of 2012, „Mazowieckie Region development strategy until 2030, Innovative Mazowsze" of 2013, or the „Zachodniopomorski Region development strategy up till 2020" of 2010 and the accompanying "Transport sector development strategy for the Zachodniopomorski Region by the 2020").

At the same time, the Regional Operational Programme of the Podkarpackie Region for the years 2014 - 2020 in the field of sustainable urban mobility, has envisaged as legitimate to purchase city buses that meet the Euro VI emissions standard, while as priority should be treated the purchase of buses with alternative drive systems such as electric or hybrid using biofuels or hydrogen.

There is no denying that the "Development of a fleet of electric and hydrogen cars implies the need to build from scratch and throughout the country the network of charging or electrical batteries replacement stations, and hydrogen refuelling network [16].

The European Commission has regarded the problem of infrastructure for drives and alternative fuels even as a critical element for the dissemination and development of new technologies.

Although the social and economic conditions currently present in Poland do not create the determinants for assuming, in the next few years, the numerically significant development of the fleet of cars with hydrogen fuel cells, this work has been taken on considering that even a limited number of hydrogen refuelling stations is a *sine qua non* condition for a full inclusion of a Polish transport in the European transport system.

The Polish component of a European network of hydrogen refuelling stations, increasing significantly the territorial scope of the possible use of hydrogen vehicles (both in North-South directions, as well as East-West ones) could make a significant contribution to the market success of the new technology, and hence to boost its development on the European scale.

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3.2. Ecological conditions

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, which is a basic raw material for the production of motor fuels, 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.

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.

At present one can critically evaluate the EC's proposals contained in the White Paper, if only for the fact that those objectives have been determined primarily based on the premise to reduce pollutant emissions from internal combustion engines of vehicles. The absence of, at least sufficiently mature technologies for the production and storage of energy carriers to ensure their implementation, has not been taken into account. Also the economic and investment capabilities of the individual EU countries (including Poland) have not been taken into account, in the field of new technologies for producing energy carriers, or the expected limited economic opportunities of individual populations in terms of absorbing new technology of transport means.

Given the assumed higher, than the average in the EU-15 countries, the pace of development of the Polish economy by the 2050 and the projected increase

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in the mobility of the population in Poland, envisaging the same rate of reduction of pollutants emissions as the average for the entire EU (i.e. by min. 60%) would entail very drastic restrictions in this respect in the years 2030 - 2050, which seems unlikely. The solution could be actions leading to a significant reduction in the mobility of society, but this would be contrary what is called for in the White Paper [27].

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. The important, is however, (especially for Poland) the development of the energy industry based on technologies using renewable energy sources, i. a., used for the production of hydrogen.

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 motorism. 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 [90].

Hydrogen is the fuel that will never run out as 94% of the matter in the Universe is a 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.

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3.3. Economic conditions

The research conducted by ITS [80] 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. 3.3.1.).

Table 3.3.1. The average costs of 1 km mileage of passenger cars with engines exceeding 900 cm^3 (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,

- that the average price of electric passenger car equipped with fuel cells will be around 260 thousand PLN (the price of Toyota Mirai on the German market will be around 66 thousand Euro),
- the average annual decline of value of the car during the first 10 years of operation will be around 25 thousand PLN,
- the average price for 1 kg of hydrogen will be 9.5 Euros (TOTAL station price in Berlin in May 2015),

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- the car will consume on average about 1 kg of hydrogen per 100 km mileage,
- 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 that in Poland in the last 10 years, among the passenger cars entering the market each year, approximately 2/3 were used cars due to their price and 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.

4. Hydrogen propulsion technology, as one of directions of the development of automotive industry

4.1. Status and forecast for the development of hydrogen technology in the road transport by the year 2050

The world's first hydrogen refuelling station was opened in Dearborn in the USA. The following single hydrogen refuelling stations were activated usually on the occasion of major world events such as: EXPO in Osaka in 2005, in Zaragoza in 2007, in Shanghai in 2010, the Olympic Games in Beijing in 2008, etc.

The dynamic development of the number of hydrogen refuelling stations occurred at the beginning of the second decade of the twenty-first century. For example, in 2012

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there were 27 new hydrogen refuelling stations opened in the world, in 2014 17 stations. In July, 2014 the Linde Company began mass production of hydrogen refuelling stations (28 already ordered by Japan). Launching of the new hydrogen refuelling stations was accompanied by the closure or temporary suspension of the operation of some stations already opened - mostly in the United States (20 stations), but also, for example in Italy (16 stations), or Spain (3 stations).

As a result, in March 2015 there were 184 hydrogen refuelling stations operating in the world (82 in Europe, 63 in North America, 3 in South America, 38 in Asia), while yet back in 2013 there were 252 of such stations functioning in the world.

It should be noted that only 40% hydrogen refuelling stations (74 stations) were of a public character. The remaining ones frequently functioned within various types of research centres, industrial facilities and energy units, or as private use stations.

According to the available global projections, the number of hydrogen refuelling stations in the world in 2020 should exceed 1000 (currently, including the existing inactive stations that are to be restarted, there are another 129 stations with the confirmed location, of which there are 53 in Europe, including 24 in Germany), in 2025 - 2.5 thousand and in 2030 - 4000. This is probably the understated number, since only Japan assumes for the 2030 to have 5,000 stations (with 1,000 in Germany and 500 in France or South Korea) (Table 4.1.1.).

An even greater degree of uncertainty has the data on numerousness of the FCV-hydrogen-powered cars fleet. The current global fleet of such cars can be estimated at 2-3 thousand, while yet recently it was assumed that only in Europe it will reached a level of 5,000 passenger cars and 1,000 buses.

According to the forecast of 2010 the number of FCV cars was to reach in 2020 - 2.8 million, with production of 450 thousand in 2025, a million in 2027 years and 2 million in 2030.

According to other data from the forecast cited in Table 4.1.1, the number of FCV cars in 2020 has been set at approx. 600 thousand, including 500 thousand in the EU countries. Also, this data raises questions in the context of the available forecasts

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from individual countries assuming in 2020, for example, in France - 23 000 vehicles, in the Netherlands 1000 vehicles, and in Japan - 6000 vehicles.

Table 4.1.1. Status and forecast the development of hydrogen technology in road transport in the perspective of 2050 [(a)]

Wyszczególnienie	2015 - marzec		2020		2025		2030		2050	
	Vehicles	Refuelling stations	Vehicles	Refuelling stations	Vehicles	Refuelling stations	Vehicles	Refuelling stations	Vehicles	Refuelling stations
Austria [(1)]	•	2	•	•	•	•	•	•	•	•
Belgium [(1)]	•	1	•	•	•	•	•	•	•	•
Denmark [(3)]	17	8+6 under construction	•	•	25 000 - 100 000	100-200	•	•	700 000- 1 400 000	500-1000
Finland [(1)]	•	2	•	•	•	•	•	•	•	•
France [(4)]	400 [(x)]	6	23 000	96 [(xx)]	167 000	355	800 000	530	•	•
Spain [(5)]	•	5 including 3 funcioning	•	•	•	•	•	•	•	•
Netherlands [(6)]	10	4	100-1 000 [(x)]	30-50 [(x)]	•	•	10 000 [(xx)]	50-200 [(xx)]	40% of the feet	1400 [(xxx)]
Germany [(7)]	135	29		100 [(x)]	•	400 [(xx)]	•	1 000	•	•
Sweden [(1)]	•	4	•	•	•	•	•	•	•	•
United Kingdom [(8)]	40	15	•	65	•	•	1 500 000	1 150 [(x)]	•	•
Italy [(1)]	•	21including 5 funcioning	•	•	•	•	•	•	15 000 000 [(xx)]	•
The European Union [(2)]	500 [(x)]	82 [(xx)]	500 000	400	•	•	1 600 000 [(xx)]	•	40% of the feet [(xx)]	•
China [(9)]	1 000 [(x)]	9 [(xx)]	•	•	•	•	•	•	•	•
Japan [(10)]	•	36	6 000	500	2 000 000	1 000	•	5 000	•	•
South Korea [(11)]	1 000 [(x)]	11 i 10 under construction	100 000	168	•	•	•	500	•	•
USA [(12)]	1 400 [(x)]	55 [(xx)]	50 000	•	•	•	•	•	•	•

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The world (13)	•	184 (x)	•	1 050	•	2 500	•	4 000	•	•

(a) Note: Due to different data sources, the data is not addible.

(1) Assesment of Implementation of European alternative fuels strategy and possible supportive proposals, Project Move/L/1497/-1-2011, Exergia, Energy and Environment Consultants, sierpień 2012
(x) - H2 stations.org, strona prowadzona przez Ludwig-Bolkow-Systemtechnik Gmbh i TUV Sud.
(xx) DiMario F., Mattucci A., Ronchetti M., Hydrogen Infrastructures, The Italian present situation and perspective, ENEA, 2010.

(2) Assesment of implementation of a European alternative fuels strategy and possible supportive proposals, Project Move /l1/497/-1-2011, Exergia, Energy and Environment Consultants, sierpień 2012.
(x) – dane szacunkowe z 2015 r. wobec planowanych w 2011 r. 5000 pojazdów,
(xx) – H2 stations.org. (strona web prowadzona przez Ludwig-Bolkow-Systemtechnic Gmbh i TUV Sud.

(3) HIT NIP Denmark, National Implementation Plan for Hydrogen Refuelling Infrastructure, 3 wyd. 06.2014.

(4) H2 Mobilite France. Study for a Fuel Cells Electric Vehicle national deployment plan, Mobilite Hydrogene France, www.afhypac.org/images/h2_mobilitat_france
(x) – plan, (xx) – 2022 r.

(5) Garcia-Conde A.G.: Hydrogen and Fuel Cells in Spain, luty 2012.

(6) NIP-NL, Energy Research Centre of the Netherlands, LE Petten, czerwiec 2014.
(x) – lata 2018-2023, (xx) - lata 2024-2030, (xxx) – po roku 2030.

(7) The Mobility and Fuels Strategy of the German Government, Bundesministerium fur Verhehr, Bau und Stadtenwicklung, czerwiec 2013.
(x) – 2017 r., (xx) – 2023 r.

(8) UK HFCA welcomes government plans for multi million pounds founding for hydrogen infrastructure and fuel cell electric vehicle, październik 2014 oraz UK Plans on 1,5 million Hydrogen Car by 2030, www.cnh2.es/.../uk-plans-on-1-5-million-hydrogen-cars
(x) - Fallon M.: Future of hydrogen powered cars mapped out, Department for Business, Innovation & Skills, luty 2013.

(9) Chendony Huang: Vision and Strategy on FCV Commercialization, SAIC Motor Corporation, Szanghai
(x) – Chinase hydrogen fuel cell industrialization prospects, czerwiec 2012-SAIC planuje wyprodukowanie 1000 FCV w 2015 r. www.chinafcb.org.cn/chinafcb.../, (xx) - rok 2012, w tym 5 stacji mobilnych.

(10) Hirose K.: Toyota's Approach to Sustainability Mobility and Fuel Cell Vehicle Development, Toyota Motor Corporation, 2013 oraz Hanley S.: Japan spending Big on Hydrogen Fuel Ahead of Olimpic http://gas2org/2015/01/25/japan-spending...

(11) Pier-Etienne F.: Fuel Cell and Hydrogen Sector On the road to markets: Key Issue and early take aways, listopad 2011 oraz Byung Ki Ahn: Development of Fuel Cell Electric Vehicle in Hyundai Motor, Hyundai Motor Group, listopad 2011.
(x) - Produkcja pojazdów

(12) Dunwoody E.: Hydrogen and renewables in California, listopad 2011.
(x) - tylko Kalifornia, 50 tys. pojazdów w 2017 r.,
(xx) – 10 stacji publicznych i 45 stacji prywatnych – Alternative Fuelling Station Counts by State, US Departament of Energy, maj 2015.

(13) NIP–NL, Energy Research Centre of the Netherlands, czerwiec 2014 oraz H2 stations org. strona web prowadzona przez Ludwig–Bolkow–Systemtechnik Gmbh i TUV Sud.

According to the same sources, in 2025, the FCV cars fleet, for example in France, would count 167,000 cars, in Denmark from 25 thousand up to 100 thousand, in Japan - 2 million, and by 2030: 800 thousand vehicles in France, 10 thousand

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in the Netherlands, 1.5 million in the UK. This puts into question the forecast for 2030 number of 16 million FCV cars in the EU.

It seems that the only real market data related to the launch of mass production and introduction to the public sales of FCV cars (Toyota Mirai, Hyundai ix35 Tucson, Honda FCV Concept) will allow for the verification of virtual, until now, forecasts of the growth of this segment of the automotive industry in the coming decades.

4.2. Technologies for using hydrogen as an energy carrier in the automotive industry

Currently, the most common way to use hydrogen in the automotive industry is its use, among the others, due to the range of vehicles, in passenger cars, city buses, and motorcycles [10].

In these vehicles, hydrogen can be used as fuel for internal combustion engines and fuel cells of the vehicles.

4.2.1. Combustion in the combustion chambers

Supplying internal combustion engines with hydrogen (HICE) was, but still is currently the subject of much research and development. To run on hydrogen adapted are mainly spark ignition engines (SI), but it is also possible to adapt the self ignition engine (diesel). The diesel engines may be operate only on dual fuel basis and have generally too large, requiring a reduction, compression ratio, due to knocking. The SI engines just the opposite - have too low compression ratio needing to be increased to achieve adequate combustion efficiency. Hydrogen can also be used to supply gasoline dual-fuel engines.

Supplying internal combustion engines with hydrogen must be considered depending on the engine cycle, as follows:

1. The use of hydrogen as a fuel or additive to gasoline or LPG or methane in spark-ignition engines.
2. The use of hydrogen as an additive to diesel oil in self ignition engines.

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A detailed discussion of the issues on the use of hydrogen as a fuel for internal combustion engines is included in the paper [54].

4.2.2. Fuel cells

Fuel cells are electrochemical devices that convert chemical energy of reaction directly into electricity [35], [36], [75], [85], [90]. The by-products of this type of conversions are heat and water. If pure hydrogen is used to supply fuel cells, they emit virtually no pollutants [65], [75]. If to produce hydrogen are used renewable energy sources, the greenhouse gases emission is small compared to that for fossil fuels [79].

Reversible voltage of the cell is correlated with the molar Gibbs free energy being a function of pressure and temperature [35], [36], [75]. The thermodynamic efficiency of the fuel cell decreases with increase of temperature [35], [36], [75].

It is important to recognize the fuel cell voltage losses caused by kinetic constraints. This is enabled by the analysis of the kinetics of these cells [75].

Transfer of electrons in electrochemical reactions, is of a surface character. The resulting current is a measure of the progress of the reaction. The rate of the said reaction (current) is proportional to the surface on which it occurs. Activation barriers impede the conversion of reactants to products. A certain portion of the cell voltage is used to reduce activation barriers [35], [36]. This increases, conversion of reactants to products, and thus the density of the resulting current. The sacrificed voltage (losses) is called overvoltage [35], [36], [65], [75].

Losses of the activation overvoltage are minimized by maximizing the so-called forced current density coefficient (the exponential Butler-Volmer function) [35], [36], [75]. There are basically four ways to reduce the said losses [35], [36], [65], [75]:

- increasing the concentration of reactants,
- increasing the reaction temperature,
- decreasing the activation barrier through the use of catalysts,
- increasing the number of activation centres (using electrodes with high surface area in three-dimensional structure).

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Fuel cells work mostly at high current densities and high activation overvoltage [35], [36], [75]. The kinetics of hydrogen in the fuel cell gives small activation losses while the oxygen kinetics the large ones (slow progress of the reaction - a significant activation losses (at low temperature)) [35], [36], [65], [75].

The kinetics of the fuel cells depends on the type of fuel, the electrolyte's chemical nature and on the temperature [35], [36], [75]. The applicable catalysts include platinum catalysts (low-temperature cells), nickel or ceramic catalysts (high temperature cells) [35], [36], [75].

The requirements for the above catalysts are [75]: activity, conductivity, stability (thermal, mechanical, chemical, under operating conditions).

The transport of charge in fuel cells is under the influence of a voltage gradient (i.e. conductivity). The voltage used for transportation of charges is a waste of energy generated in the fuel cell - is called ohmic overvoltage arising from ohmic resistance of the cell [35], [36], [65], [75].

In the fuel cells there are basically three types of electrolytes: liquid, polymer, ceramic. The conductivity of the polymer electrolyte depends on the water content (the greater it is, the conductivity is greater) [35], [36], [65], [75].

The mass transport in electrolytes of the fuel cell is dominated by diffusion, whereas in transmission systems by convection. Diffusion results from the reactants concentration gradient [35], [36], [65], [75].

Fuel cells operate on the following principles [35], [36], [75]:

- hydrogen (or the fuel containing it) is supplied to the anode zone. The catalyst separates electrons from protons ($2H_2 \rightarrow 4H^+ + 4e^-$),
- at the cathode, oxygen combines with electrons (in some cases with protons and water) resulting in a water ($O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$) or hydroxyl ions,
- the protons move through the electrolyte to the cathode where they combine with oxygen and electrons, producing water and heat (fuel cells in the form of a polymer membrane). In the case of fuel cells with alkali metal electrodes (with molten carbonates

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or solid oxides) the negative ions move in the electrolyte to the anode where they combine with hydrogen producing water and electrons,

- the electrons from the anode zone of the cell can not pass through the electrolyte to the positively charged cathode, and have to move through an external electrical circuit to reach the other side of the cell.

Most fuel cells contain [35], [36], [75], [85], [90]:

- stack (package) - here the electricity is produced in the form of the current being direct result of chemical reaction in the cell,
- processor (converter) – converting the fuel to the form utilized by the cell,
- inverter and conditioner - adapting the current flowing from the cell to the needs of devices that use it,
- heat recovery system (cells generate a lot of heat).

The components of the fuel cells are [35], [36], [75], [85], [90]: membrane cell set, the anode, cathode, catalyst (each electrode is coated only on one side with a layer of the catalyst that increases the rate of reaction of oxygen and hydrogen), components (e.g. the plates, one for the anode, the second on the cathode, of porous structure that provides effective diffusion of each gas to the membrane / electrode set catalyst). The plates support the water management in the cell. Between the plates there are bipolar plates, which act as current collectors.

Fuel cells are classified mainly due to the electrolyte used (it determines the type of electrochemical reactions occurring in the cell, decides on the catalyst type, required scope of cell's operation, etc.) [75], [85], [90].

The most common types of fuel cells are currently [35], [36], [75], [85], [90]:

- cells with the proton-exchangeable polymer membrane (PEMFC) - the most suitable for the vehicle (due to the short time of start up, low operating temperature and advantageous power to weight ratio (produce also a high energy density, have a low weight and a small volume in relation to other cells, the their disadvantage is sensitivity of the, most commonly, a platinum catalyst, to a CO poisoning)) [35], [36], [75], [79].
- cells with alkaline electrolyte (AFC),

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- cells with phosphoric acid as the electrolyte (PAFC) used sometimes for heavy vehicles,
- cells with the molten carbonates (MCFC),
- cells with solid oxides (SOFC).

The table 4.2.1.1 presents user advantages of the said fuel cells [75]. The next table 4.2.1.2. shows examples of energy consumption and costs in the use of fuel cells in urban buses [79].

Table 4.2.1.1. User advantages of the fuel cells [75].

Type of the cell	Electrical efficiency, %	Power density mW/cm2	Power range kW	Application	Advantages	Disadvantages
PEMFC	40-50	300-1000	0,001-1000	-transport -current generation - power supplies	-low operating temperature - quick start up - no corrosion	-expensive catalyst -high sensitivity to poison
AFC	50	150-400	1-100	-space exploration -military	- quick start up - high efficiency	-expensive catalyst -sensitivity to poison
PAFC	40	150-300	50-1000	-transport -current generation	-cogeneration efficiency up to 85% -resistance to poisons present in H_2	-necessary Pt catalyst -low electrical efficiency -large weight and volume
MCFC	45-55	100-300	100-100000	-current generation -heat generation	- high efficiency -fuel flexibility -catalyst flexibility	-high corrosiveness -high susceptibility to failure -expensive materials
SOFC	50-60	250-350	100-100000	-current generation -heat generation	- high efficiency - fuel flexibility -catalyst flexibility	-expensive high-temperature materials -difficulty with sealing -necessary heat shields

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Table 4.2.1.2. Energy consumption and costs in the case of fuel cell buses (green field = existing technology yellow field = expected performance) [79].

	Fuel cells buses (2012 year)	Buses with compression-ignition engines (2012 year)	Fuel cells buses (2020 year)	Buses with compression-ignition engines (2012 year)
Energy consumption (kWh/100 km)	233 – 424[1,2]	343 - 490[1]	<316[3]	257 – 367[4]
Purchase price (MSEK)[6]	10,4 – 15,6[1,2]	1,5 – 2,6[1]	3,5 – 3,6[1,2]	-
Total operating costs (SEK/km)[6]	29,4 – 46,7[1,5]	18,2[5]	10,4 -28,6[1,5]	7,8 – 19,9[1,5]
Commercial Status	Demonstration	Commercial technology	-	-

[1] Data for the urban bus (12m) [Zaetta et al. 2010]
[2] [NREL 2012]
[3] Long-term DOE goal for buses with fuel cells, which in some test buses is being attained today [NREL, 2012; Zaetta et al.2010]
[4] Possible improvement through hybridization [Zaetta et al. 2010]
[5] Data for urban buses (12m) [McKinsey 2012]
[6] 1USD –ok. 8,2 SEK at present

Reliability of the fuel cell vehicles is estimated at present up to about 5000 operating hours at a temperature of 40 – 80 ^{0}C (when used in internal combustion engines it is currently approx. 5,000 hours of operation (300 000 km)) [75], [79]. The ACAL Energy company says that fuel cell systems tested in the laboratory worked reliably for 10 000 hours, which would represent vehicle mileage of approx. 300 000 km [1], [79]. Hyundai company believes that it is possible to achieve at least 200 000 km of vehicle mileage in the real operating conditions [79].

The reliability of lithium-ion batteries is determined currently at approx. 8 years (1000 - 3000 charging cycles) [73], [79]. For Nissan Leaf cars with a previous range of 120 km (now even 180 km) this is the reliability in the order of 120 000 – 360 000 km depending, however, on the charging method (fast charging reduces the above reliability of operation

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to a significant degree) [58], [79]. The use of a fuel cell cars currently intensifying, will be a practical verification of the discussed reliability of these vehicles.

Currently, there are intensive work under way of consortia Daimler / Nissan / Ford as well as Toyota / BMW or Honda / GM and VW / Ballard, including Hyundai on the modern fuel cells of the power density of 2,0 (2,5)-3,0 kW/dm^3. Those consortia declare the production in the next few years of hundreds of thousands of vehicles equipped with fuel cell [79]. The production costs of these cars is estimated, as stated in the introduction to this study, at approx. 50 000 USD [79]. Refuelling cars equipped with fuel cells takes 3 to 4 minutes, and therefore, like conventional vehicles of this type, shorter than for electric cars (approx. 20 - 30 minutes to several hours) [79]. Refuelling fuel cell buses takes longer, up to 20 min. [79]. The expected mileage of vehicles equipped with fuel cells is 500 - 700 (even 900 km) [79], which is on par with mileage of the electric premium class passenger cars i.e. Tesla S (approx. 400 - 500 km). The vehicle equipped with fuel cells, such as Hyundai ix35 currently on sale can be operated in temperatures even -25 ^{0}C [79].

5. Conditions for development of hydrogen technology in the road transport in the EU, including Poland

5.1. Legal conditions of type-approval and operation of hydrogen-powered cars

The Framework Directive 2007/46/EU [30] defines the following types of approvals for new vehicles:

- EC type-approval of vehicles,
- EC type-approval for vehicles produced in small series,
- National type-approval for vehicles produced in small series,
- National type-approval - an individual admissibility.

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According to this directive the whole vehicle type-approval of M and N category vehicles is carried out. It also concerns hydrogen vehicles, including those equipped with fuel cells.

In the UNE-CE type-approval system the in-force partial regulations regarding these vehicles include:

- Nr.134 UNE-CE Regulation-" Uniform provisions concerning the approval of motor vehicles and their components with regard to the safety- related to hydrogen fuelled vehicles (HFCV) [68].

And, in the EU's type-approval system the applicable partial provisions are:

- Regulation of the European Parliament and of the Council (EU) No 79/2009 on the type-approval of hydrogen powered motor vehicles [69] and amending Directive 2007/46/EU,
- Regulation (EU) No 406/2010 implementing Regulation of the European Parliament and of the Council No. 79/2009 on the type-approval of hydrogen powered motor vehicles [26].

Based on the above Framework Directive 2007/46 / EU with the amendments, the type-approval was issued for Toyota Mirai (June 2005) and Hyunday TUCSON ix35 (October 2012).

Hydrogen vehicles are also subject of the GTR Regulation 13 (*Global Technical Regulation on hydrogen and fuel cell vehicles*) [38] under what is known as Agreement of 1998. The parties of the aforementioned agreements include, among the others, the European Union, the USA and Japan [12].

Factual and legal situation in terms of technical requirements and regulations for admitting into operation of vehicles adapted to run on hydrogen, in the current national law system, is undetermined.

In the absence of relevant provisions in the Polish legislation concerning technical inspections of the hydrogen vehicles, we requested members of the International Motor Vehicle Inspection Committee to fill in the questionnaire, asking about any regulations operating in other countries.

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According to the answers obtained from eighteen countries it appears that so far there have not been any special technical inspection procedures developed or implemented for motor vehicles equipped with hydrogen fuel cells. A specialized testing procedure regarding these vehicles has so far only been introduced in Belgium. The test procedure for hydrogen powered vehicles in Belgium is as follows:

Prior to commencing the test, the elements affecting safety are carried out outside the building and include:

- checking the operation of the hydrogen switch,
- checking the system leaks signalling,
- checking the hydrogen circuit pressure (maximum value is 100 bar, if it is higher the test is not being continued),
- checking the gas density using gas detector (checking for leaks),
- visual inspection of all visible parts of the system (state, fixtures),
- switching over to electric mode (vehicle enters the VIS on electric power).

Detailed examination of the installation and other vehicle components:

- verifying the presence of caps on tanks,
- verifying the validity of tanks serviceability documents,
- verifying the system type-approval document.

Verified is also the presence of markings at the front and rear of the vehicle as well as on either side of the doors and by the fuel filler.

The use of hydrogen to power vehicles can be divided in two main ways. The first way is to changes in the design of systems, assemblies and parts of the vehicle so that the internal combustion engine of the vehicle could be powered directly by hydrogen. The second way is to change the design of the vehicle in order to supply hydrogen to fuel cell for powering the electric motor.

The indicated division is however legally fused in the general internationally adopted definition that says: "hydrogen powered vehicle means any motor vehicle that uses hydrogen as fuel to propel the vehicle".

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Such a status of hydrogen installations determines the unified organization of technical and diagnostic tests. The key provisions of the appropriate Commission Regulation (EU) No 406/2010 of 26 April 2010 should form the basis for Member States to adopt systemic solutions concerning the organization of periodic technical inspection of vehicles powered by hydrogen. These provisions are as follows:

1. The manufacturers bring forward: recommendations for inspections or testing hydrogen system over the period of use; information on the need for periodic inspections and their frequency published in the user manual of the vehicle or on a label affixed near the data plate pursuant to Council Directive 76/114 / EEC.
2. Manufacturers shall make available the information referred to in paragraph 1 to the type-approval authorities and the competent authorities in the Member States responsible for the periodic technical examination of vehicles in the form of instructions or on electronic media (CD-ROM, online services).
3. Every hydrogen system shall be subject to mandatory diagnostic inspection which is carried out at least every 48 months from the start of operation and each time following re installation.
4. Diagnostic inspection is performed by technical service in accordance with the manufacturer's specifications.
5. The hydrogen propelled vehicles must bear a special external signs described in the said EC Regulation.

The present general system rule, which assumes that from 2016 all vehicle inspection stations must examine gas propelled vehicles, can not be applied in the case of vehicles running on hydrogen. It would not be rational and economically justified to commit some 4,500 entrepreneurs running vehicle inspection stations to incur the costs of technical, organizational, etc. preparations, associated with the performing periodic technical inspection of hydrogen powered vehicles. It would also be unreasonable to order about 15,000 eligible diagnosticians to incur the costs of specialist training in the field of technical inspection of vehicles fuelled by hydrogen. In the coming years there will not be a sufficient

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number of vehicles for such a special periodical annual technical inspection of vehicles powered by hydrogen. Bearing in mind that the H_2 gas fuelled vehicles are covered by the duty of going through the type-approval procedure and so called European one (EC) resulting from the rank of legislation (Regulation EC), the principles of periodic roadworthiness tests, both before the first registration and subsequent ones, must be based on the fundamental premise that the diagnostic inspection of the vehicle's hydrogen system itself is performed outside the inspection station. The basis for such a concept system solution provides the content of the legal provision in the Part 3 of Annex 1 to the Commission Regulation (EU) No 406/2010 of 26 April 2010 on the implementation of the European Parliament and Council Regulation (EC) No 79/2009 regarding the type-approval of hydrogen-powered motor vehicles. The content of the provision envisages that each hydrogen system installation shall be subject to mandatory diagnostic inspection which is carried out at least every 48 months from the start of operation and each time following re-installation. The inspection is performed by technical service in accordance with the manufacturer's specifications set out in Part 3 of Annex I of the Regulation EC No 406/2010. It should be understood in such a manner that specialized diagnostic testing of the hydrogen system will be conducted at the service stations of the vehicle manufacturer or authorized hydrogen system service. Identical system solutions existed in Poland for vehicles powered by LPG, in particular in the early stages of LPG technology development, i.e. in the 90s of the last century.

According to the authors, the Law on Road Traffic, in Art. 66 should be amended by adding the following paragraphs:

1h. *Motor vehicle of the M and N type-approval category can be equipped with hydrogen system installed by the manufacturer or his authorized representative.*

1i. *Diagnostic inspections of the hydrogen system proving its serviceability are carried out every 12 (alternatively to consider 24) months.*

1j. *The hydrogen system manufacturer or his authorized representative performs diagnostic testing of the hydrogen system and issues a document confirming its serviceability.*

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1l. Minister responsible for transport issues shall specify, by the regulation, the form of the document confirming the serviceability of the hydrogen system.

The specific objectives of the proposed solutions are to point at the hydrogen system manufacturer, as the sole entity responsible directly for at the diagnostic verification of the hydrogen installation. Such an inspection system of the hydrogen installation serviceability is the most efficient in the case of a very small number of new vehicles with unusual, not every day encountered technical solution, because it does not require all vehicle inspection stations and all eligible diagnosticians to make irrational investments in technical equipment of inspection stations and the training for diagnosticians.

The proposed draft of the system provisions is an attempt to bring together the idea of Annex XIII to the Directive 2007/46, as later amended with the proposed national solutions in this area in the recent years and some specialized provisions of EC regulations and directives in this Regulation EC No 406/2010.

The specific objectives of the proposed systemic solutions are to point to the hydrogen system manufacturer as the sole entity responsible directly for its diagnostic verification.

The target systemic solution should be appointing, within approximately 10 years, sixteen regional (one per region) district vehicle inspection stations run by e.g. Transport Technical Supervision (TDT), which apart from the tasks related to technical supervision, currently holds organizationally limited oversight over vehicles inspection stations, along with the local authorities. The TDT stations would perform, as the only players in the country, pilot and technical inspections related to the innovative technologies used for the first time in vehicles, for example, powered by hydrogen. Such a systemic solution would ensure adequate proficiency, the required elitism of qualifications and authorized TDT diagnosticians dealing on a daily basis mainly with such cases. It would also dramatically lower the costs of conducting technical inspections.

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5.2. Guidelines and technical regulations for hydrogen refuelling stations

Filling stations play a key role in the infrastructure of hydrogen-powered vehicles. Unlike traditional stations where fuel is delivered by the tankers, in the case of hydrogen it is also possible to supply it by pipelines or locate its production on site at the filling station. Apart from the many possible configurations for the construction of filling stations in most cases their will comprise:

- hydrogen generator (only for stations where production takes place on site),
- hydrogen purification system to meet the requirements for fuel cell vehicles (in case of the production of hydrogen by reforming),
- tanks for gaseous or liquid hydrogen,
- compressor: allowing to reduce the volume of the tank and compressing the fuel to a high pressure (350 bar, 700 bar) at which it is supplied to the tank of the vehicle,
- safety components (relief valves, venting chimneys, hydrogen sensors, insulating fence off safety measures)
- mechanical equipment (such as underground pipe lines, valves),
- electrical equipment (e.g. control panels, high voltage lines, meters).

Hydrogen refuelling stations generally may exist in different configurations in terms of producing hydrogen as well as its delivery [61].

5.2.1. Types of filling stations due to the way of producing hydrogen

Most often currently used filling stations, with regards to the way of obtaining hydrogen include:

- Refuelling stations that can be equipped with the devices for steam methane reforming to produce hydrogen from natural gas, biogas, or other fuels. This method relies on subjecting the methane to the catalytic process at a high temperature, yielding a synthesis gas consisting of hydrogen and carbon monoxide. The station of this type is equipped with a water tank, a reformer (converter) to convert hydrocarbons into a gas

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mixture of hydrogen and carbon components called "reformate", purification system, hydrogen compressor and filters, dehumidifiers, pumps filling the hydrogen Production of hydrogen at such a station may typically be in the order of 100-1000 kg per day [61].

– Refuelling stations equipped with the devices for the water electrolysis. This process produces hydrogen and oxygen. Most devices of this type achieves efficiency of more than 75%, some even 80 - 85% and demonstration ones in the laboratories up to 90%. Such a station usually consists of a water reservoir, deionizer, electrolyser, purification system, compressors, dryers, filters and filling system. Production of hydrogen on such a station may be in the order of 30-100 kg per day [61].

According to the US estimates, centralized supply of hydrogen by mainly pipelines will constitute 90% of the market; only 10% of the hydrogen production will be located directly at the service stations. Ultimately, it is expected that the cheapest and most reasonable solution in the long term will be the use of existing pipelines supplying hydrogen as a gas, but one must keep in mind that the construction of new pipelines requires an analysis of a number of problems, for example embrittlement of construction steel hydrogen leaks, etc.

5.2.2. Provisions relating to hydrogen refuelling stations in Poland

There are no regulations directly governing the hydrogen stations in Poland. Applying for a building permit one must meet a number of general requirements regarding fuel stations at all. Moreover, in the case of the delivery of compressed hydrogen, special requirements must be met by the station offering it as a compressed fuel.

In the case of delivery of hydrogen in a liquid form the applicable requirements are higher than for the compressed gas. This is more efficient solution but also more complicated. For example, for this case, the requirements in the United States are on a higher level than for the compressed gas. It is estimated that for the liquid hydrogen it is difficult to meet the requirements, to be able to locate such a station in the densely built-up

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area. In Poland there are appropriate provisions, which are used in the authorizing the operation of the LNG refuelling stations.

5.2.3. The European example of the procedure to obtain authorization for the construction of hydrogen refuelling stations based on the German experiences [51]

This procedure consists of three phases: application, construction and operation.

1. Application

1.1. Expertise (Technical Inspection Agency)

1.2. CE certification for HRS tank

1.3. The construction project containing a fire protection plan

1.4. Project illustrating the action

1.5. Additional materials such as, e.g. taking into account the provisions of „Rights of water resources", etc.

2. Construction

2.1. Type-approval of the construction

2.2. Type-approval of the actions

2.3. Explosion protection - ATEX (fr. *Atmospheus Explosibles*) containing the appropriate documentation)

2.4. Additional requirements (e.g. damage sensor in the gun dispenser)

2.5. Certificate of the commissioning.

2.6. Commissioning by the local authorities

2.7. Verification by the fire fighting authority

3. Action

3.1. The guidelines of the manufacturer (e.g. the procedure for filling and refuelling)

3.2. Approval of the report of filling (SAE J2601)

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3.3. Training of the personnel

3.4. Instructing the clients.

Generally, the hydrogen filling stations must also satisfy several requirements of international standards. The most important of these include ISO/TS 20100 (liquid hydrogen - filling stations) [49], SAE J2601 201407 (methods for filling light hydrogen gas vehicles) [70], SAE J2601-2 201409 (methods of filling heavy hydrogen gas vehicles) [71] and SAE J2601-3 201306 (methods for filling heavy industrial hydrogen vehicles) [72].

In addition, hydrogen production and processing into fuel must meet the requirements of ISO 16110 [47], and the electrolysers the requirements of ISO 22734 [48].

5.3. Legal conditions for the development of hydrogen technology in the road transport taking into account the safety of refuelling and car operation

The development of hydrogen technology in the road transport is affect by not only the research conducted. Given that hydrogen fuels, as an energy carrier, are considered to be "the fuel of the future", the development of this field is served and will served by legal solutions relating in particular to the safety of refuelling and operation of vehicles powered by such fuel.

5.3.1. Design, construction and maintenance of hydrogen fuel filling stations

The national law does not contain specified legal regulations relating directly to hydrogen fuel filling stations, in terms of their design, construction and maintenance. The project aiming at creating such type of building construction can therefore be carried based on the regulations governing the construction process, among which the fundamental significance will have standards contained in the Act of 7 July 1994 - *Construction Law* (unified text: J. of L. 2013., item 1409 as later amended). There should, however, be taken into account existing in this respect the said European regulations or possibly the US ones.

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5.3.1.1. The technical and construction provisions for the building constructions which are petrol stations

While designing and constructing the given construction object it is necessary to ensure that the requirements concerning, among the others, structural safety, fire safety and safety use, are complied with. They should also ensure usage conditions consistent with the purpose of the building, the capability to maintain proper technical condition, health and safety aspects of work, the appropriate location on the construction site and respecting the legitimate interests of the third parties that are affected by situating the object of construction. These principles apply to broadly understood construction process, and not just for a building project involving the design and construction of refuelling stations.

The current legal norms in force envisage, first of all, that the building construction together with the associated construction devices must be designed and constructed in the manner specified in the regulations, including technical and building regulations, and in accordance with the principles of good technical practice and knowledge. The technical and building regulations include those that define, among the others technical conditions to be met by building structures and their location.

It is worth to note the fact of putting, in the legal framework, the technical conditions to be met by liquid fuels stations (including liquid gases) and independent liquid gas stations and their location. The currently in force legal act in this aspect is the Regulation of the Minister of Economy of 21 November 2005, - *on the technical conditions to be met by bases and liquid fuels stations, far-reaching transmission pipelines used to transport crude oil and petroleum products and their location* (unified text: J. of L. of 2014, item 1853 as later amended).

In respect to the liquid fuels stations, the above-mentioned regulation contains rules on the location of the liquid fuels stations, including setting minimum distances, among the others of a liquid fuels meter from the buildings (including the station pavilion) and the border of neighbouring plots. It also regulates minimum distances of tanks and technological pipelines in these stations, among the others, from the foundations

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of the buildings, gas pipelines, water mains, sewer lines, *etc*., as well as minimum distances between tanks themselves.

The subject of the said regulations are also rules relating to the liquid fuel station buildings, including the liquid fuels pavilion of the station, roofings, service and diagnostic stands for motor vehicles, where special attention is paid to the use of fire retardant elements and location of individual objects beyond the areas in danger of explosion.

Also important are regulations for liquid fuel stations equipment, particularly the water supply, sanitation and rain-industrial systems as well as water treatment facilities to the level specified in the regulations on the conditions to be met for the introduction of sewage into the water or soil, and in the provisions relating to the substance particularly harmful to the water environment. In accordance with the said regulation of this kind of constructions should also be equipped with devices to prevent oil product penetration into the soil, surface and groundwater and the signalling devices for this type of leak.

Particularly noteworthy are also those provisions of the aforementioned regulations concerning the requirements to be met by liquid fuel station equipment, including those relating, among the others, to protect steel tanks, guiding technological pipelines, proper placement of liquid fuel dispensers and their protection against being run over by the vehicles, being serviced as well as proper construction and deployment of the service stands, driveways and islets. There is also an obligation for the liquid fuels station to have fire-fighting equipment and the appropriate road signs and warning&information ones.

The said regulation contains additional provisions relating to the storage and distribution of liquid petroleum gas, by providing, in this respect, among the others, special arrangements for the location of tanks for storage of liquid gas and the liquid gas dispensers for refuelling motor vehicles, as well as design requirements for the dispensers of liquid gas and technological pipelines supplying them.

With regards supplying the liquid fuel stations, the cited regulation provides that supplying the stations' storage tanks with liquid fuels should be carried out by means of tankers or other means of transport, authorized to carry dangerous goods in accordance with the European Agreement concerning the International Carriage of Dangerous Goods by

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Road (ADR), compiled in Geneva on September 30, 1957 (J. of L. of 2013 item 815) and the Regulations of the International Carriage of Dangerous Goods by Rail (RID). Supplying the tanks of liquid fuel stations with LPG can be done by road tankers or other means of transport also in line with the above mentioned legislation.

To sum up, the above legal solutions refer explicitly to the liquid fuels station (including liquid gases). Designing, construction and maintenance of stations to enable to refuelling with hydrogen fuel would require to extend in this direction the legal regulations in the area of special technical building regulations. Due to the high flammability of hydrogen the paramount issue is safety, the warranting of which will benefit such investments without the risk of meeting with a broad public resistance.

5.3.1.2. Conditions for obtaining a permission for the construction of a building

According to the construction law the applicable rule it is that the construction works can begin only based on a final decision on the permission to build. The building permit applies to the entire building project.

The Act states that a building permit may be issued after conducting an evaluation of the environmental impact of the project and to obtaining by the investor permits, agreements or opinions of other bodies required by specific legislation. The building permit can be issued only to the one who filed an application for this matter to the competent authority together with the required attachments, i.e., among the others, building design drawings, opinions, arrangements, permits and other documents required by specific provisions.

From the point of view of the issues in question, of some importance, may be a legal regulation stating that an application for permission to construct buildings, whose erecting or use may pose a serious danger to the users (such as: nuclear power facilities, refineries, chemical plants, dams) or whose construction projects include new, untested in national practice, technical solutions, not to be found in the provisions and the Polish Standards, must be accompanied by expert opinion issued by a natural person or an organization designated by the competent minister.

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In addition to verifying compliance of the plot/land development project with the regulations, including technical and construction regulations, before issuing a decision on the construction permit the competent authority is obliged to check the compliance of the construction project with the provisions of the local spatial development plan or the decision on zoning and land development, as well as environmental protection requirements.

If the requirements contained in the construction law standards are met, the competent authority can not refuse to issue a decision on the construction permit.

5.3.2. Technical supervision

The technical supervision represents legally defined measures to ensure the safe operation of technical devices. Technical supervision takes place in the case of technical equipment in the course of their design, manufacturing, including the production of materials and components, repair and maintenance, marketing and operation. Rules, scope and forms of performing technical supervision and the competent bodies to exercise it are specified in the Act of 21 December 2000. – *on technical supervision* (J. of L. of 2013, item 963 with later amendments) and the executive acts issued based on it.

It should be noted that based on the foregoing provisions the principle was adopted that the exercising of the technical inspection by the technical inspection units does not relieve those who design, manufacture, operate, repair and modernize technical equipment from the responsibility for the quality and condition of these devices that have an impact on their safety, according to regulations on technical supervision and special provisions.

The term "technical equipment" is legally defined. As the technical equipment ought to be understood device that may pose a threat to human life or health, property and the environment as a result of: a) the expansion of liquids or gases under pressure other than atmospheric; b) the release of potential or kinetic energy in moving people or goods, in a limited range; c) the spread of the hazardous materials during their storage or transport.

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The types of technical equipment subject to technical supervision are determined by regulation of the Council of Ministers of 7 December 2012 - *on the types of devices subject to technical supervision* (J. of L. of 2012, item 1468). Among these technical devices, the provisions of that regulation, list among the others: pressure equipment which contain liquids or gases under pressure different than atmospheric (including boilers, tanks, tankers, pipelines), tanks for the storage of hazardous materials of toxic or corrosive properties and for storage of flammable liquids, as well as tanks, including tankers for the transport of hazardous materials.

Technical devices should meet the technical conditions of technical supervision set out by the relevant ministers referring to: the design of technical equipment, materials and components used in the manufacture, repair and modernization of technical equipment, manufacture of technical equipment, operating technical equipment as well as repair and modernization of technical equipment. In this context, a particular attention should be paid to the regulations contained in: the Regulation of the Minister of Economy, Labour and Social Policy of 9 July 2003 - *on the technical conditions of technical supervision with respect to the use of certain pressure equipment* (J. of L. of 2003, No. 135, item 1269, as later amended), Regulation of the Minister of Economy of 18 September 2001 - *on the technical requirements of technical inspection to be met by non-pressure and low-pressure vessels for storage of liquid inflammable materials* (J. of L. of 2001, No. 113, item 1211, as later amended), the Regulation of the Minister of Economy dated 16 April 2002 - *on the technical requirements of technical inspection to be met by non-pressure and low-pressure vessels used for storage of poisonous or corrosive materials* (J. of L. of 2002, No. 63, item 572), the Regulation of the Minister of Transport of 20 September 2006. - *on the technical requirements of technical inspection to be met by equipment for filling and emptying transport vessels* (J. of L. of 2015., Pos. 34) and the Regulation of the Minister of Transport dated 20 October 2006. - *on the technical conditions of technical supervision in the design, manufacture, operation, repair and upgrading of specialist pressure equipment* (J. of L. of 2014, item 1465).

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5.3.3. Rules for the safe use of hydrogen

The parameters characterizing hydrogen as a fuel, are as follows [6], [75]:

- flash-point,
- flammability range,
- explosiveness range,
- self ignition temperature,
- ignition energy,
- combustion rate.

Hydrogen has a high calorific value calculated in units of mass, 2.5-3.0 - times greater than the heat of combustion of common motor fuels. The strength of hydrogen explosion is hence 2.5 - fold greater than the commonly used hydrocarbon fuels [75].

The hydrogen flash point is -253°C, while methane's -188°C or gasoline -43°C [6], [75], [79].

The flammability range of hydrogen in air is 4-7,5% V / V compared to [75]:

- methane (5,3-15% V/V),
- gasoline (1,0-7,6% V/V),
- diesel oil (0,6-5,5% V/V).

The hydrogen explosiveness range, in the case of hydrogen detonation is its concentration in the air of 18-59% V / V, or even less, about 11% V/V [75] for gasoline 1,1-3,3 % V/V).

Direct detonation of gaseous hydrogen cloud is less possible than the deflagrative explosion [75].

The hydrogen self-ignition temperature is 585°C, while that of a methane is 540°C, and gasoline 230-480°C [6], [75], [79].

The hydrogen ignition energy of is very small, one order of magnitude smaller than commonly used in automotive fuels and is 0,02 mJ [6], [75].

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The hydrogen combustion rates 2,65-3,25 m / s. and it is one order of magnitude greater than the rate of combustion of methane or gasoline [6], [75].

An important issue from the point of view of the safe handling of hydrogen is to prevent its leakage. With the high pressure hydrogen storage each of the leakage flow will be in the audible range. Hydrogen flows out e.g. 2.8 times faster than methane (volumetric outflow) [75]. In the incidents with hydrogen in the industry, 53% of accidents arise as a result of leakage, rupture of the equipment and de-gassing [75].

There is, for example a risk of frostbite due to a leakage of liquid hydrogen and contact with this cryogenic fuel [6], [75].

The use of fuels in motor vehicles is in most cases associated with some form of risk, fire or explosion. It is important to understand what property a given fuel has, keeping in mind however, that vehicles, refuelling stations (including hydrogen ones) are subject to a significant number of regulations and are safe [79].

In fact, although hydrogen is a relatively dangerous fuel, because for example of a wide range of flammability or explosiveness, but it has a high ignition temperature and being lighter than air quickly evaporates and dilutes in the air. The risk associated with its use should not be exaggerated [79].

The fuel tanks of modern cars with fuel cells and their refuelling are safe [79]. They are made of special carbon fibres, while hydrogen refuelling is carried out by specially designed connectors having a good earthing and the tight connections are ensured with the connectors of the refuelling stations.

The tanks are equipped with safety valves which release hydrogen from the tank when the temperature rises (fire) or the pressure increases above the allowed limit.

The vehicles using hydrogen have a safety system, shutting off its supply in the case of a road accident. They have the necessary type-approvals (e.g. Toyota Mirai or Hyundai Tucson).

The safety measures for car parks and tunnels are in some respects similar to those used for other fuels, refuelling stations are so designed as to avoid enclosed spaces and are built according to the same rules that apply to other fuelling stations [79]. In the case of hydrogen

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transport same rules apply as in the case of transport of dangerous goods. There are good experiences in refineries and chemical plants for the production of hydrogen. It is essential to use these experiences for the production of hydrogen for new and smaller installations, staffed by new, trained service employees [79].

6. The status and directions of development of the national and international road network in Poland with particular emphasis on the Polish TEN-T network sections

6.1. The status and directions of development of the Polish transport infrastructure with particular emphasis on the road network

Polish network of the paved roads totalling, in 2012, 286 thousand km, amounted to even 6.5% of the road network length of the "Top Fifteen" countries, (it was 5.6% in 1980), but still Polish motorways comprising, in 2012, 1400 km accounted for only 2.2% of the length of motorways in the countries of the " Top Fifteen" (while in 1980-1995 this ratio was less than 0.5%) [24].

Next to the paved roads, in Poland there are still 129 967.5 km (31%) of unsurfaced roads. With 416 thousand km of paved and unsurfaced roads, the urban roads accounted for 69.2 thousand km (17%) and extra urban roads - 346.8 thousand km (83%) of all public roads. The total density of hard surface roads in 2013 was 133 km per 100 km^2 [24]

The largest (58%) share in the Polish road network represent municipal roads with 242 999 km. Further ones, in terms of length, are county roads - 125 273.9 km, with a 30% share. Regional roads have 28 479.5 km, and they represent only 7% of all public roads in Poland and the national roads have 19 295.8 kilometres (5% share) [24].

The main challenge remains mainly low quality of the paved road network (both urban and extra-urban) composed in almost 83% of county and municipal roads (with generally low parameters and technical condition), and in only 6.8% of national

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roads (18, 6 thou. km, of which about 60% is in good condition), in the 10.4% of regional roads and in only 0.56% of motorways and expressways (2010) [15].

In 2014 length of motorways increased by 74 km and in the end of the year amounted to 1556 km. This means that per 1000 km^2 of the area of the country, the length of motorways accounted for 5.0 km, while per the 100 thousand of the country's population there were 4.0 km. Despite a significant increase in the length of motorways in 2014 it is still one of the lowest indicators in the European Union (in 2011 the verage for the 27 EU countries amounted to 16 km and 14 km respectively). In comparison to 2013 the length of expressways (single and dual carriageways) increased by 204 km and the end of 2014 it was 1,448 km [25]

The surface of only a little over 1/5 of national roads was adapted to the required, by modern transport, pressure of 115/kN/axle [15].

The weakness of road infrastructure in Poland is also:

- inadequate network of connections between the south and north of the country,
- lack of road networks enabling efficient travel in the cities and their surroundings (no bypasses, many national and regional roads run through town centres or villages),
- poor quality of connections between regional cities [15], [46].

Currently, 58% of the population of the country is within the road isochrone of 60 minutes (which can be identified with a range of labour market) with respect to the regional centres.

The extensive modernization work conducted has not so far led to the creation of at least one entirely completed road route.

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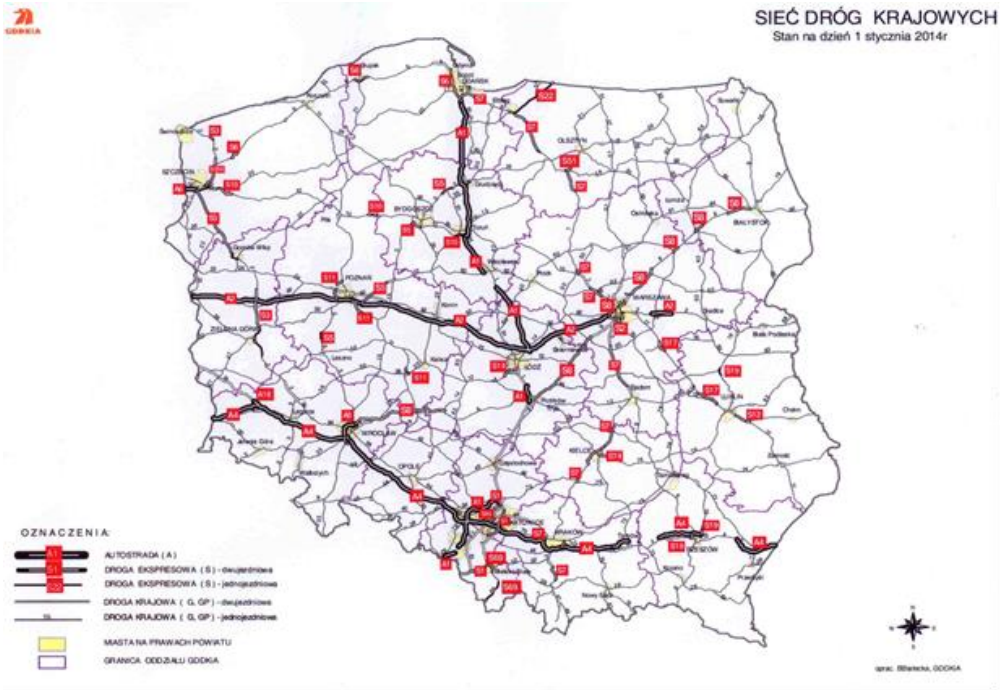

Fig. 6.1. The network of national roads in Poland - as of 01.01.2014.
Source: GDDKiA website.

By the 2023, i.e. till the completion of the investment for the years 2014-2020, there should be functioning 88% of core TEN-T road network and 33% of the comprehensive TEN-T road network. These projects will be implemented basically in order of the points ranking.

In the last available version of the "National Road Construction Programme for the years 2014 - 2020" from November 2014, Ministry of Infrastructure and Development reiterated its intention to build 7400 km of roads of the highest standard, but changed, once again, a number of priorities [56]. The program assumes that by the 2021 there will be, about 1,650 km of new expressways built in Poland (by the October 2014 there were 1326 km of such roads functioning) and 57 km of A-1 motorway from Czestochowa to Katowice and 15 km A-2 motorway from Warsaw to already functioning Minsk Mazowiecki bypass (with 1521 km of existing motorways in October 2014). This would mean that by the 2021 in Poland there would be functioning 4570 km of roads with the highest standards, which would represent slightly more than 60% of the planned target network of such roads.

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The project also envisages accelerating the construction of more urban bypasses i.e. 35 instead of the previously planned 14.

The total length of TEN-T road network in Poland is around 7 400 km (core and comprehensive network) [3], [64]. Currently, the sections of roads with the higher classes included in the trans-European TEN-T road network in Poland lack continuity. It is assumed to obtain the following result indicators for core and comprehensive TEN-T network Table 6.1.

Table. 6.1. The length of the road network in the core and comprehensive TEN-T network

TEN-T network	Current status (2015)	Planned status (2023)
Core	61%	88%
Comprehensive	16%	33%

Source: Implementation Document for Transport Development Strategy up till 2020. (With a view to 2030). The Ministry of Infrastructure and Development. Warsaw, October 2014., p. 18.

In the years 2014-2020, the emphasis will be on completing sections between Poland and the neighbouring countries.

6.2. The core TEN-T network in Poland

The core TEN-T network in Poland comprises:

- Baltic-Adriatic corridor - runs from Polish ports of Gdańsk and Gdynia and Szczecin and Świnoujście, then through the Czech Republic or Slovakia and eastern Austria to the Slovenian port of Koper and the Italian ports of Trieste, Venice and Ravenna. It covers routes by rail, road, ports, airports and rail-road terminals.
- North Sea-Baltic corridor - stretches from the North Sea ports of Antwerp, Rotterdam, Amsterdam, Bremen and Hamburg via Poland to Belarusian border and ports of the Baltic States in Klaipeda, Ventspils, Riga and Tallinn, as well as Helsinki. It covers routes by rail, road, airports, rail-road terminals, inland waterway- " Mittelland Kanal" and the connections of the" sea motorway" to Finland.

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6.3. International transport corridors in Poland

International transport corridors are to infrastructurally integrate Central and Eastern Europe by the 2020 with all the countries of the European Union. Four of these corridors run through Poland bringing together different parts of Europe. The routings of these corridors which pass by through Poland were established as follows:

- Corridor I: Helsinki-Tallinn-Riga-Kaunas-Warsaw; (Branch IA: Riga-Kaliningrad-Gdańsk);
- Corridor No. II Berlin-Warsaw-Minsk-Moscow-Nizhny Novgorod;
- Corridor No. III: Berlin-Wrocław-Katowice-Lviv-Kyiv; (Branch III A Dresden-Wrocław);
- Corridor No. VI: Gdańsk-Grudziądz -Warsaw-Katowice-Zilina (with a branch from Katowice via Ostrava to Corridor IV and with a branch via Toruń-Poznań).

6.4. Traffic on the TEN-T network in Poland

The average daily traffic of motor vehicles (SDR) in 2010 on the national road network was 9888 veh. / 24 hours [39]. On the international roads, the SDR in 2010 amounted to 16667 veh. / 24 hours, and at other national roads - 7097 veh. / 24 hours.

The average 24-hours traffic of passenger cars (SDR) in 2010 on the core network of national roads amounted to 11 167 veh. / 24 hours (all motor vehicles 16 667 veh. / 24 hours). The busiest roads belonging to the TEN-T in Poland were: section S1 and the E40 and E75, on which SDR of passenger cars amounted to over 14 thousand. veh. / 24 hours, and in case of S1 over 20 thousand. veh. / 24 hours. These traffic volumes are averages for the entire length of the road, while the SDR on individual sections of these roads was significantly differentiated).

Graphic illustration of the averaged daily traffic volume of passenger cars is shown in Fig. 6.2.

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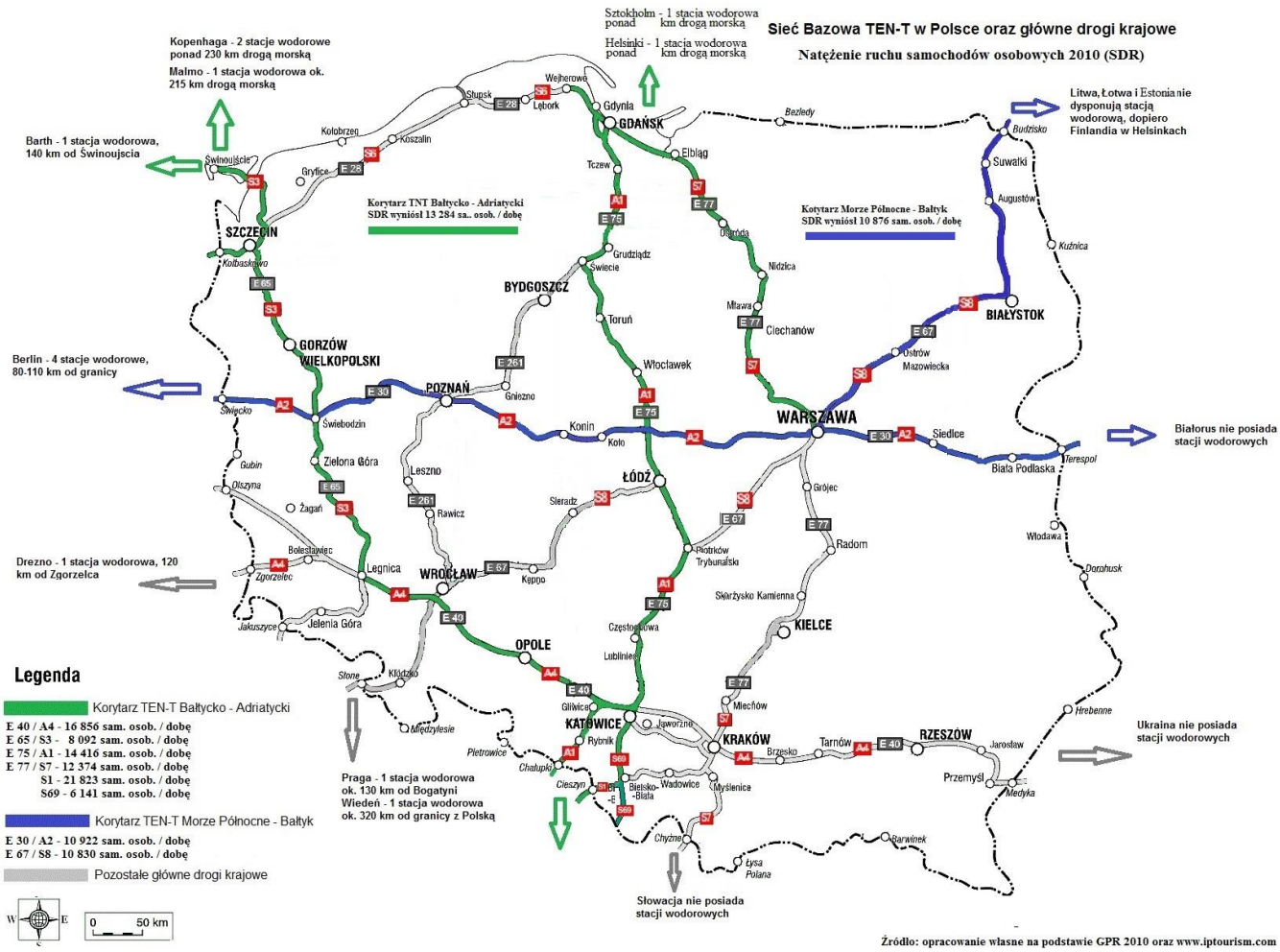

Fig. 6.2. The SDR of passenger cars on the Core TEN-T network in Poland
Source: own compilation based on data from the GPR 2010, and www.iptourism.com

For the TEN-T network in Poland, average traffic intensity on the roads in the Baltic - Adriatic corridor an amounted to 13 284 veh. / 24 hours (E40, E65, E75, E77, S1, S69), while of the roads in the North Sea - Baltic Sea corridor - 10 876 veh. / 24 hours (E30, E67).

Along the international on national roads, by far the largest traffic load, of more than 35 thousand veh. / 24 hours (including almost 24 thousand passenger cars / 24 hours), occurred in the region of Śląsk (Silesia), then 26 513 veh. / 24 hours (including 17 764 passenger cars / 24 hours) in the Opole region. Large traffic intensity ranging on average, at more than 20 thousand veh. / 24 hours (including over 13 thousand passenger cars / 24 hours), was also registered in the Małopolskie and Mazowieckie regions.

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On other national roads by far the most traffic, amounting to an average of over 11 thousand. veh. / 24 hours (including 8 214 passenger cars / 24 hours), occurred in Silesia. Very high network load on other national roads, amounting to an average of over 9 thousand veh. / 24 hours (including over 6 thousand passenger cars / 24 hours), also occurred in the regions: Małopolskie and Wielkopolskie.

6.5. Traffic intensity forecasts

Traffic forecast till the year 2020 has been developed for the current national road network, assuming that no changes will occur on it and there will be no significant factors that could have an impact on transport behaviours [86].

According to Fig. 6.3, the largest load on the roads of this forecast will take place around the largest urban areas in Poland (Warsaw, Katowice and Kraków, Poznań, Wrocław, Tri-City), where the average 24 hours traffic volume will exceed 20 thousand vehicles.

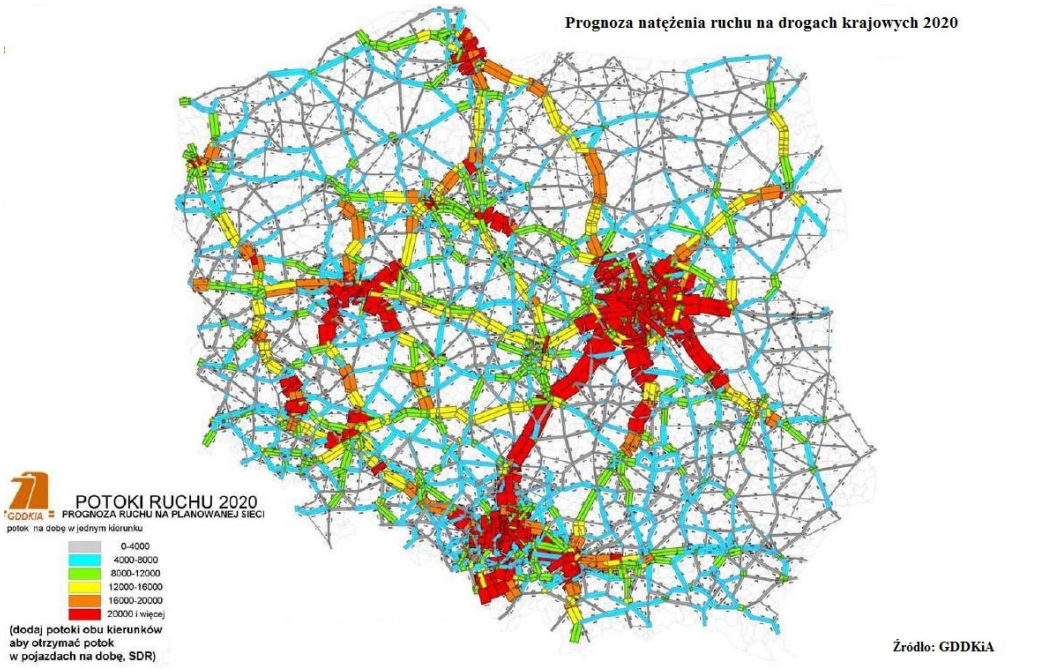

Fig. 6.3. Forecast of the traffic intensity on the national roads in 2020
Source: http://www.gddkia.gov.pl/pl/987/gpr-2010

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6.6. Motor fuels distribution infrastructure along the TEN-T network

In Poland, according to the data at the end of 2014 there were 6479 petrol stations functioning (decrease compared to 2010 by 4%). They were dominated by stations owned by PKN "Orlen" (27.3% of the petrol station). The petrol stations are located along the Polish road network relatively evenly, with the apparent density in the south - west and central regions with special emphasis on large urban areas. Currently, along the TEN-T network in Poland there are 360 fuel stations operating, including 100 stations in the corridor M. North - Baltic on the A2 motorway and by the S8 expressway along the stretch Warsaw - border with Lithuania (58 stations).

In the Baltic - Adriatic corridor on the S3expressway from Świnoujście to Legnica there are 72 stations, on the section of the A4 motorway from Legnica for Katowice to the S1 expressway there are 14 stations located.

7. Hydrogen management in Poland (production, use and distribution channels)

7.1. Hydrogen, as an alternative source of energy used in road transport

Regardless of mastering new methods of obtaining energy carriers from mineral raw materials sources hitherto not extensively used (heavy crude oil from the Arabian Peninsula, shale gas and shale oil in North America), the world faces global energy deficit. The growth in demand for energy is 1% per annum in highly industrialized countries and 5% per year in developing countries. The energy consumption is dependent on the increase in the population (by the 2050 the population in developed countries will increase by 15%, while in the developing countries it will double [28]), economic growth (improved standard of living) and development needs. The International Energy Agency (IEA) has estimated that by the 2030, the global energy demand will reach 50%, of which 2/3 will represent the needs of developing countries [4].

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The transportation is a very important element in the balance of the world energy consumption. At the end of the first decade of the twenty-first century, it was estimated [5], that 50% of world oil production is used in the engines of road vehicles. At the beginning of the XXI century on the roads of the world there were 1 billion vehicles It is expected that in 2030 there will be ok. 1.3 billion, and in 2050 slightly more than 2 billion of them.

Putting together the needs with the capabilities of exploring conventional energy carriers indicates the need for global and national strategies for replacing mineral energy and raw materials sources with the alternative ones, with particular attention to the fuel sector.

Alongside the need to meet the growing deficit, the second warrant stimulating substituting the propulsion materials of the mineral origin with their counterparts of biological origin is widely understood environmental protection. Emissions from car engines dominate in the environmental pollution. The combustion of conventional engines fuels is attributed to more than 70% of the total CO emissions, more than 40% of the total NO_x, emissions, about 50% of the total emissions of hydrocarbons and nearly 80% of the total emissions of benzene and 19% of global CO_2 emissions of anthropogenic origin [52].

New energy carriers' sources must be as widely available as possible, renewable, economically viable to operate, burn cleanly and not deepen the unfavourable balance of carbon in the atmosphere, and finally not to affect the engine operating conditions and shorten its lifetime.

The criteria listed are partly meet by the biofuels and hydrogen, but only if obtained from inexpensive, environmentally friendly raw materials sources. The use of FAME and FAEE esters is increasingly being limited due to the relatively unfavourable energy balance of their production, less significant than anticipated effects of their use on the improvement of the natural environment and finally the negative impact of these propulsion materials on a number elements of the standard diesel engine in the event of a their large proportion in the fuel. In turn, the ethanol has significantly lower energy density than the hydrocarbon fuels. The introduced ban for the technical processing and food production competition to the same part of the plant causes that the starch fermentation towards

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the ethanol to be used as a fuel will be significantly limited. The previous attempts of the industrial implementation of the cellulose alcoholic fermentation process have halted at the cost level far distant from the competitiveness with the processing of sugar cane, beet and corn. Thus, in searching for fuels of biological origin that may, under conditions of meeting at least part of the aforementioned criteria, gradually replace the conventional fuels of natural origin, one ought to concentrate on two solutions:

- production of synthesis gas and hydrogen by the gasification process, or a combination of pyrolysis and gasification of biomass,
- obtaining *Green Diesel* by decarboxylation of fatty acid glycerides of vegetable or animal origin [76].

Further processing of the synthesis gas may be carried out by known methods of dużej great tradition and technical perfection (Fischer-Tropsch for hydrocarbons, synthesis of methanol, being the basis of the product tree of many chemicals and propellants, as well as by steam reforming of an effective hydrogen source).

The obvious disadvantage of hydrogen as a fuel is its low density (ok. 0.08 kg /Nm^3). The energy of 1 gallon of gasoline (121.7 MJ) is an energy equivalent to 1 kg of hydrogen (122 MJ). Therefore, its storage in the vehicles remains a major challenge. So far, the commercial nature have today the solutions of the storage of hydrogen in a vehicles in the form of a compressed gas (pressurized to 700 bar) or in liquid form in cryogenic tanks [9]. For the fuel cell powered vehicles, recommended are high-pressure tanks, taking into consideration the conditions of the vehicle structure, safety and costs [2]. The advantages of this method of storing hydrogen fuel are reliability, ease of use, acceptable costs and no limits on the storage time. The disadvantage of this solution is still low density of the energy stored, which can be increased by increasing the pressure, and this in turn produces a significant increase in costs. It is believed sometimes that this solution should not be regarded as forward-looking [94]. Perhaps a solution is to store hydrogen in liquid form, but its drawback is primarily, a high energy consumption of the process.

We are also to decide on the final choice of how to transform hydrogen into energy. Direct combustion is easier, but the future fuel cells may be more efficient. The road to such

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a cell is relatively long and the obstacles are very difficult to solve constraints (mainly kinetic) of the electrode processes. There is also a purely commercial restriction - there is a view that in the case when the mass of platinum contained in the fuel cell noticeably exceeds its weight in a conventional catalytic reactor, the car manufacturers will lose interest in implementing a hydrogen economy based on obtaining energy in the fuel cells.

The use of hydrogen obtained from renewable sources or water will undoubtedly contribute to improving the environment and reducing CO_2 emissions. The scenario of replacing conventional energy carriers with hydrogen was proposed *by International Institute for Applied Systems Analysis* (IIASA) as part of the project - *Environmentally Compatible Energy Strategies* in 2003. This scenario assumes that, hydrogen from renewable sources, by the end of the twenty-first century will have 49% share of the global energy balance [8].

The optimism of this scenario must raise doubts in comparison with the current situation - 96% of hydrogen is produced from the mineral sources (the rest in the processes of electrolysis of, primarily, NaCl solutions), and it is only a few percent of global energy consumption. The restrictions on the scenario implementation may be, first of all [53] unconvincing, in terms of the economy and energy balance, scheme for obtaining synthetic fuel – hydrogen, by the electrolysis of water using a primary carrier, i.e. electricity [11]. The electrical energy may be directly used to power electric and hybrid cars, and its processing for less effective and relatively dangerous fuel is in conflict with the third law of thermodynamics. The energy and economic credibility of this solution could be achieved by using the energy from alternative sources in the process of decomposition of water. Such sources are unlikely to be:

– nuclear power - high-temperature nuclear reactors HTGR produce helium at too low a temperature to decompose H_2O, and otherwise they are currently in the initial stage of development and even the implementation of the European RAPHAEL project (ReActor for Process heat Hydrogen And ELectricity generation)) does not promise their imminent industrial implementation,

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– solar energy - it can be estimated that at the modern state of photovoltaic technology, to produce 1 ton of hydrogen per hour one should cover about 10 hectares with panels, so irrespective of the environmental aspects, economically this project is totally unprofitable,
– wind energy – also in this case the necessary number of transmitters of energy (windmills) needed to obtain 1 Mg of hydrogen per hour, at present the competitiveness of such undertaking may be doubtful.

What remains therefore is energy and raw material processing (directly to hydrogen) of biomass. The best solution seems gasification of biomass or fermentation. However, there is still lack of a defined resource base for these processes (mentioned earlier abandoning the edible plants to be used for technical purposes) and finally defined effective and profitable processes of gasification and fermentation. The costs of producing hydrogen from biomass are still higher when compared with hydrogen from natural gas and carbon (2.33 - 4.0 USD / kg to 0.32 - US $ 1.82 / kg respectively), although some of the former ones being estimated with a number of problematic assumptions take into account the economical utilization of the by-products of biomass processing. It can be said today that any alternative source of hydrogen providing hydrogen at a lower price than the price of traditional liquid fuels will be accepted with enthusiasm and has a real practical chance.

7.2. Hydrogen production technologies

There are many known methods of hydrogen production, used mainly in the chemical industry. Among them could be mentioned [52]:

– Steam reforming of natural gas,
– Gasification of coal,
– Polygeneration - gasification of coal in the steam reforming of methane,
– Gasification of waste plastics,
– The use of industrial waste gases,
– Alternative methods of hydrogen production, including:
  – Thermochemical cracking,

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  - Use of biomass,
  - Pyrolysis of biomass,
  - Gasification of biomass,
  - Gasification of biomass with water,
- Biological methods,
- Hydrogen fermentation,
- Electrolysis, including:
  - Alkaline electrolysis,
  - Membrane electrolysis,
  - Electrolysis with solid oxides as electrolytes.

The extraction methods differ depending on the source of hydrogen. The main sources of the hydrogen and the methods of its acquisition for the needs of motorism are [14], [31], [40], [44], [45], [62], [65], [75], [79], [83]:

- methane (steam reforming),
- water (electrolysis),
- biomass (gasification at high temperature).

Methane is the major component of both natural gas and biogas. The purified biogas to biomethane quality does not however cause, practically in its life-cycle, the carbon dioxide emission. There are also numerous other sources of obtaining hydrogen, for example: artificial photosynthesis (decomposition of water using sunlight) or the use of photo-biological methods (algae producing hydrogen using sunlight) [79].

The table below shows the essential methods of hydrogen production with reference to their technological advancement, possible effective production and hydrogen manufacturing costs [79].

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Table 7.2.1. The principal methods of hydrogen production for the automotive industry with reference to their technological advancement, possible production efficiency and hydrogen production costs

	Technological advancement	Production efficiency	Production costs
Reforming	Widely used in the industry 1/	70%	Probably the cheapest method, but with large scale production for thousands of vehicles purchased at low prices
Electrolysis	Widely used in the industry 2/	60-70%	Strong dependency on electricity prices, which can be variable depending on the seasons
Gasification	Research and development	30 – 70%	Uncertainty as to costs, may have a higher costs than those found with electrolysis

1/ e.g. the US produce 6.9 million tons of hydrogen per year by reforming method
2/ e.g. the US produce 300 thousand tons of hydrogen per year by electrolysis method

Reforming - the main area of application is the refining industry. The application at the refuelling stations is growing. There are still relatively few refuelling stations based on this technology. The technology is currently considered to be too expensive for commercial applications. The hydrogen obtained has to be cleaned (e.g. removal of sulphur, carbon monoxide) before refuelling the vehicle [79].

Electrolysis - depending on the type of the electrolyser, hydrogen can be supplied at the pressure range from atmospheric pressure up to 80 bar. The higher the pressure of the hydrogen produced, the smaller the cost of its further compression at the filling station. Well-developed technology, used for over a hundred years, allowing to obtain high-purity hydrogen required for use in fuel cells [79].

Gasification - hydrogen production by gasification of biomass (wood, agricultural waste, but also coal) is in the development and pilot testing stage [79].

Hydrogen as an industrial by-product can be used for fuel cells, but it must be cleaned before it can be used in them. Where the electrolysers, they are large enough, to

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produce hydrogen for transport, in addition to the amount of hydrogen produced for the industry [79].

Further in this paper there are methods of hydrogen production presented in detail and the estimated its amount produced for the needs of the industry in this country.

Currently, the most widespread forms of hydrogen production for the needs of motorism are [40], [62], [75], [79], [83]:

1. In the central factories, where hydrogen is available in the form of compressed gas or cryogenic liquid,
2. In the filling stations: from methane (purified hydrogen compressed to a suitable pressure) and by the electrolysis of water,
3. Generating hydrogen using the example of the vehicle by steam reforming of methanol or methane gas (hydrogen is fed directly to fuel cells), is of less importance.

Ad.1. Centralized hydrogen production is significantly cheaper than production at the local filling stations [75]. The advantage of centralized hydrogen production is lower investment costs (per unit of hydrogen produced) [79]. The plants of this type should preferably be localized in the vicinity of wind turbines, solar or biomass landfills, although the renewable energy sources are at present more expensive than natural sources (location near natural energy resources such as coal, crude oil, natural gas is cheaper, but the by-product of their processing involves significant emission of CO_2 [75].

The most important issue with respect to the central plants is a high cost of hydrogen transport to customers often far away from such plants [75].

The cheapest transport option is to carry tanks of liquid hydrogen by trucks [75], [79]. Condensing hydrogen is, as mentioned previously, highly energy-intensive operation.

Transferring gaseous hydrogen by pipeline is less energy intensive, but utilizing costs are the highest [7], [59], [75]. Large capital costs are related to e.g. the very

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construction of transfer lines, their location, etc., unless this type of infrastructure already exists [75], [79].

The option for centralized hydrogen production can be half - centralized production, i.e., centralized combined with hydrogen production at the local filling stations.

The dispersed hydrogen production, i.e. locally at the filling stations, it is currently carried out by two different methods. By electrolysis of water and reforming methane to hydrogen. This last method is currently used in relatively few cases due to the cost of hydrogen production this way [79].

Ad. 2. Production of hydrogen at the local filling stations

The data presented in [60], [65], [75] show that in the case of a local filling station with a small production capacity of 40-60 kg of hydrogen a day (capable of filling 10 passenger cars) the sole hydrogen production costs do not exceed $ 2.5 / kg. Such a station enables the production of hydrogen by steam reforming of methane, CO conversion, purification of hydrogen, and its compression and storage. Conversion efficiency of the gas is 78-83%, and hydrogen meets the requirements for the content of H_2O, CO_2 and CO [75].

The cost of hydrogen production from natural gas in small plants may be 4.4 USD / kg. A more convenient option for local production of hydrogen at the local filling stations is its production based on water electrolysis. In this case, the cost of hydrogen production may be larger and equal to 12 USD / kg [75].

The cost of hydrogen production using water electrolysis depends on the electricity source [60]:

- Grid: 6 – 7 USD/kg, in a later perspective - 4 USD/kg,
- Wind power stations: 7 – 11 USD/kg, in a later perspective - 3 - 4 USD/kg (including the cost of wind turbine manufacture),
- Solar panels: 10 – 30 USD/kg, in a later perspective - 3 – 4 USD/kg.

Ad. 3. Generating hydrogen on board the motor vehicle

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Producing hydrogen on board the motor vehicle from raw materials (e.g. mineral energy resources, i.e. fossil fuels, raw biochemical materials e.g. agricultural products or of so-called free goods character (e.g. water, air), requires more research before it becomes cost effective [75].

Reforming of gasoline or methanol is less effective than the same process carried out under stationary conditions [75].

Greenhouse gases emission and primary energy consumption are higher in the case of producing hydrogen on-board than in the case of hybrid petrol-electrical vehicles [75]. Reforming of methane on board the car is even less justified from an economic point of view. Methanol is produced from natural gas it is therefore possible to produce hydrogen directly from the gas without using a methanol [75].

7.3. Storage of hydrogen

There are currently three basic methods for hydrogen storage: as compressed gas, in the liquid form and in metal hydrides. The table 7.3.1. shows how much of the internal hydrogen energy is necessary to achieve the required pressure for its storage or keeping it in liquid form or in the metal hydrides [79]:

Table 7.3.1. Demand for internal energy of the hydrogen at its storage

Parameter of hydrogen	Internal hydrogen energy demand
Gas at a pressure of 200 bar	11%
Gas at a pressure of 350 bar	14%
Gas at a pressure of 700 bar	18%
Liquid (-2530)	37%
Metal hydrides	16 – 34%

In today's technological solutions in the chemical industry, the hydrogen is produced on site in the quantities required for immediate use and delivered just in time by pipelines to

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the installations in which it is used. In the future the same will be with hydrogen power, where H_2 will be generated on-site for use by stationary fuel cells.

One form of storing large surplus of hydrogen is keeping it in salt caverns [14].

Storage of large amounts of hydrogen in a small space is possible in metal hydrides. They are characterized however by large mass, much higher than the one associated with storage of hydrogen in the gaseous or liquid phase. Extracting hydrogen from metal hydride is time consuming. Metal hydrides storing hydrogen are every time a subject to degrading, which is associated with the need to replace them after a certain time [79]. The research on hydrogen storage in metal hydride is underway and is connected with an attempt to reduce their weight [75], [79].

7.3.1. Storage of hydrogen in a compressed state

Compressed hydrogen in gaseous form is currently used in vehicles. At most fuelling stations, the hydrogen is stored at a much lower pressure than that at refuelling vehicles since storing hydrogen at lower pressure causes a decrease of costs [79]. Typically, this is done at 200 bars, because then it is possible to use steel cylinders the same as those used in supplying hydrogen for the industry [79]. At higher pressures there are used containers made of composite material (glass fibre, carbon fibre). The cheapest method of stationary hydrogen storage is storing it at a pressure of 30-80 bars, which can be obtained directly from electrolyser [79].

On a larger scale, it is possible to feed the hydrogen into the natural gas network and use it in vehicles or power plants, separating it at the refuelling stations [79].

In general, the use of compressed hydrogen technology is the most common and cheapest. However, hydrogen at a pressure of approx. 700 bar has an energy density of 4500 MJ/m^3 (in the liquid phase - 8491 MJ/m^3) while the energy density of gasoline under these conditions (15^{0}C) is 31150 (MJ/m^3) [75]. The hydrogen compression process is a multistage one, and energy consumption is usually 10-15% of useful fuel energy [75].

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The cost of storing compressed hydrogen increases with the pressure. Compression of 1 kg of hydrogen to the pressure of 700 bar on board of the car requires 5 kWh of energy (3,2 kg CO_2 emitted into the atmosphere, which corresponds to CO_2 emissions from the combustion of one US gallon of gasoline (3,785 dm^3)) [75].

Currently, the hydrogen tanks in a passenger car are fit for the pressure of 700 bar (to ensure the passenger car's range of 500-700 km). They are filled for fast charging at a pressure of about 900 bar [79]. The (city) buses use tanks fit for the pressure of 350 bar because of the greater availability of space (tanks can be placed on the roof of the bus) [79].

The energy consumption to produce 1 kg of hydrogen (electrolysis) is currently 55 kWh [62].

According to the leading manufacturers of hydrogen compressors, the most active are multi-stage systems with intercoolers operating in conditions between adiabat and isotherm. The energy needed for the five-stage compression of 1000 kg of H_2 per hour from atmospheric pressure to 200 bar is 8% of the energy contained in this mass of hydrogen. Thus, at least 1.08 of the hydrogen energy unit must be spent for storing one unit of this energy under a pressure of 200 bar. This value will exceed 1.12 for the compression to 800 bar during transferring the hydrogen into standard vehicles tanks at a pressure of 700 bar [11]. Taking into account the mechanical and electrical losses, the amount of electricity needed to locate the hydrogen at the said pressure in the tank car may exceed 20% of the energy released to power the vehicle.

7.3.2. Storage of hydrogen in a liquid form

Liquid hydrogen occupies less space than compressed one. The process of condensation of hydrogen to this state, however, requires a large amount of energy (approx. 40% of the liquefied hydrogen) [42], [75], [79].

Energy consumption for the condensing of 1 kg of hydrogen is 12.5 - 15 kWh. If the current in the grid comes from coal-fired power station then in the course

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of its preparation there are emitted 8,0 – 9,5 kg CO_2 into the atmosphere [75], [79]. For comparison, burning 1 US gallon of gasoline (3,785 dm^3) having approximately the same amount of energy as 1 kg of hydrogen is associated with the emission of 9 kg CO_2 [75].

For example also, the hydrogen cryogenic tank holding 130 dm^3 has a weight of 90 kg and contains 4.6 kg of this fuel [75].

The major disadvantage is that some of the liquid hydrogen is constantly converted into the form of gas, due to the large temperature differences between the liquid hydrogen present in the tank (-253^{0}C) and the surroundings [79]. It is therefore essential to have a continuous hydrogen feeding (a large number of vehicles being refuelled). The hydrogen refuelled in the gaseous form (at a temp.-32 ÷ -40^{0}C) may be quickly delivered to the vehicles' tanks, which do not heat up [75], [79]. For example in Germany storing hydrogen in liquid form is used significantly [79].

From the liquid hydrogen tank in the vehicle there may daily evaporate approx. 1 - 4% of hydrogen depending on the type of vehicle (car, bus) [75]. The stationary tanks with very good insulation have daily evaporation of hydrogen not exceeding 0.03% [75].

Condensing the hydrogen is a multistage process [11] and includes a three-stage propane cooling system of hydrogen at about 70 K, and then multi-stage nitrogen expansion, allowing to cool hydrogen to 77 K, and finally the multi-stage helium compression - expansion system to condense hydrogen at 20.3 K at atmospheric pressure. For very small condensing installations (< 5 kg $H_{2(c)} \bullet h^{-1}$) the energy demand may exceed energy contained in the gas being condensed [11].

Even in the case of installation condensing 10000 kg of H_2 per hour (i.e. about four times greater than used today), 25% of the energy contained in the hydrogen is consumed for its condensing. For the solutions currently used, the energy consumption for condensing may be estimated at 40% [11].

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7.4. Transport of hydrogen

The hydrogen transferring infrastructure may comprise [75], [79]:

- Pipelines,
- Appropriate trucks to transport tanks with hydrogen,
- Rail way carriages,
- Ships, barges.

Pipeline transport

The length of hydrogen pipelines is the largest in the US (but only 1100 km) [75].Transport of hydrogen via existing pipelines is an option the lowest costs. Adapting part of the natural gas infrastructure to meet the needs of hydrogen may be a quick way for deployment of hydrogen infrastructure [7], [59], [75], [79].

A method of transporting hydrogen depends on the scale and the distance it travels. On the mass scale and at distances from a few to several hundred kilometres, for transport of hydrogen are used pipelines. The average distance of pipeline transport of hydrogen in Germany is 500 km, and locally 10 km [14]. The construction costs of the hydrogen pipeline with a cross-section of 300 mm are estimated at 650 Euros / metre, and of a section 100 mm - 325 Euros / metre.

Road transport

Road transport can deliver hydrogen in the form of [75]:

- compressed gas,
- cryogenic liquid,
- gas adsorbed on carriers hydrogen (having now little application).

Transport of hydrogen in the form of compressed gas is expensive particularly over a distance of more than 300 km [75]. Carriage in tanks at a pressure greater, e.g. more than 700 bar is in this case most cost effective [75], [79].

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Over longer distances, hydrogen is transported as a liquid in super - insulated cryogenic tanks. The gaseous hydrogen is liquefied (cooling to a temperature below -253 ^{0}C and stored in large insulated tanks. Liquid hydrogen then poured into smaller containers and transported to the retail distribution of hydrogen where it is expanded and evaporated to form gas under high pressure used for filling cars' pressure vessels [75], [79].Transporting liquid hydrogen over long distances is more economical than compressed in pressure tanks (greater weight of hydrogen taken by truck than in the case of mass of hydrogen in cylinders even under very high pressure) [75].

However, one should bear in mind the high cost of liquefaction of hydrogen (40% of the energy of the liquefied gas) and losses due to evaporation or boiling point of liquid hydrogen (particularly for small containers of a high surface to volume ratio) [75], [79].

When transferring smaller amounts of hydrogen, especially over longer distances, up to several hundred kilometres, the dominant form of transportation still remains hydrogen transport. The fourty ton trucks carry up to 350 kg of hydrogen gas at a pressure of 200 bar or 3500 kg in a liquid form. In the case of the transport of compressed gas, only 80% is transferred at the client's, the other 20% remains in the tank. In turn, the transportation of liquid H_2 is limited by the volume of the vessel, the typical trucks can carry up to 60 m^3 liquid H_2. Transport of the compressed hydrogen consumes an equivalent of about 7% of the energy contained in the gas, which is 13 times more than for the transport of gasoline. In the case of transport of liquid H_2 the energy absorbed for the carriage is 3.5 times higher than for gasoline [11].

<u>Other forms of hydrogen transport</u>

In the form of free particles adsorbed in the pores and on the surfaces of organic or inorganic sorbents remains in the sphere of tests [79].

The national hydrogen supply infrastructure should be systematically built. It should be varied depending on the economic infrastructure and the type of market, i.e. according to

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the urban, industrial, rural, inter-city areas, first of all along the TEN-T road network [57], [75], [79].

In the initial period of development of hydrogen technologies, due to negligible demand for hydrogen because of a small number of cars or buses in the country powered by hydrogen, but also a small number of cars of this type driving from abroad and only few hydrogen filling stations functioning in the country by the 2020, the hydrogen of sufficient purity for use in fuel cells of the said cars, should be provided in the compressed form by road.

Ultimately, one should seek centralized production of hydrogen using technology of compressed, or liquid hydrogen, depending on existing production capacity, its economy and the type of energy sources for the purpose of filling stations located within 300 km from such plant. The transport of hydrogen would take place with the use of trucks. One should also develop parallel local production of hydrogen based on water electrolysis technology for more distant than 300 km areas of hydrogen distribution from a central plant.

An option for the above centralized production would be semi - centralized production based on several plants producing hydrogen for industrial purposes. However, one should examine the possibility of purification of hydrogen and associated costs.

7.5. Present status of hydrogen production in Poland

7.5.1. Nitrogen industry

The main producer of hydrogen in Poland is the nitrogen fertilizer industry. The primary intermediate in the production of nitrogen fertilizers is ammonia, whose the production capacities by the domestic producers of mineral fertilizers exceed 2 million tons / year (2008). Ammonia is produced in the reaction of hydrogen with nitrogen ($N_2+3H_2 \leftrightarrows 2NH_3$), which determines the installation of systems producing hydrogen in the ammonia production lines. In the Polish nitrogen industry, the hydrogen is obtained at the synthesis gas producers' in the steam reforming process of methane and half-combustion of methane.

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The producers of ammonia in Poland are the following plants owned by the *Grupa Azoty*: Zakłady Azotowe *Puławy SA*, Zakłady Azotowe *Kędzierzyn SA*, Zakłady Azotowe *Tarnów SA* and Zakłady Chemiczne *Police* as well as subsidiary of *PKN Orlen SA – Anwil SA* in Włocławek.

By far the largest producer of hydrogen among these is *ZA Puławy SA,* in which the hydrogen is used in the production of ammonia (177.5 t / year) and in the caprolactam production process (pure hydrogen - 3600 t / year and complementary hydrogen 7200 t / year). The hydrogen at Puławy is produced on 3 lines of the methane steam reforming of comparable total production capacity. A separate manufacturer meets the caprolactam complex needs of pure and complementary hydrogen. The total production capacity of hydrogen by *ZA Puławy SA* therefore reaches 190 000 t / year.

The main domains of production *ZA Kędzierzyn SA* are nitrogen fertilizers production line and synthesis line of alcohols oxo- 1-butanol and 2-ethylhexanol. The second one in the hydroformylation reactions consumes synthesis gas with of a composition of $CO:H_2$ = 1:1,1. For the needs of the ammonia plant *ZA Kędzierzyn SA* produces 60 600 t / year of hydrogen and 7 100 t / year for the oxo alcohols line. The company has some excess hydrogen from the ammonia production line corresponding to 6 800 t / year destined for resale.

For many years *ZA Kędzierzyn* has made attempts to use coke oven gas (containing ~ 60% of hydrogen) from the nearby Zdzieszowice coking plant, as an alternative source of hydrogen, replacing natural gas (significantly affecting the production costs of hydrogen).

The consumers of hydrogen at *ZA Tarnów SA* are production line of nitrogen fertilizers and caprolactam production line. The nitrogen line uses hydrogen produced in methane steam reforming (one installation) and decomposition of methane (3 installations), and both sections have a comparable capacity 500 t H_2 / day. The hydrogen producer (98% for caprolactam needs) has a production capacity of 6 400 t / year. Annual production of hydrogen for the fertilizer line is 67 000 t / year.

At *ZA Tarnów SA* there was a NaCl electrolysis plant, in which apart from the major products - chlorine and sodium hydroxide, hydrogen is obtained as an additional product. The electrolysis installation in Tarnow was based on mercury cell technology, not compliant

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with the BAT pattern in the European Union. The production capacity of hydrogen from the electrolysis process in ZAT amounted to 560 tons / year. The expensive variant was considered of reconstructing the electrolysis installation into the membrane process. However, the lack of the main recipient of chlorine at ZAT, related to stopping the production of polyvinyl chloride (ZAT still produces HCl and hypochlorites) and the disappearance from the Polish economy the *ZACHEM Chemical Plant*, the main external customer, virtually halted these plans.

Anwil SA in Włocławek has a nitrogen fertilizers production line, as well as polyvinyl chloride production line with the production of monomer - vinyl chloride in the oxyhalogenic process of ethylene. The chlorine for this second line is produced in the membrane electrolysis of NaCl (large plant, in line with BAT), in which, as additional product is obtained hydrogen (at present at about 5500 t / year). The demand of the company for hydrogen, with a certain surplus for the local processing capacities of ammonia is met by the hydrogen produced in the methane reforming process at the quantities of 88 000 t / year.

The membrane electrolysis of NaCl is also carried out at the *PCC Rokita* Plant. The plant capacity is currently at 3,500 t / year.

The same ammonia production capacity as *Anwil SA* has *Police Chemical Plant*. The ammonia synthesis block demand for hydrogen is covered by 2 steam methane reforming plants with a total capacity of 88 000 t / year.

7.5.2. Refinery and petrochemical industry

The refinery and petrochemical company *PKN Orlen SA* produces hydrogen in the process of reforming (semi - regenerative) of CCR, in the olefins plant and at the hydrogen production plant by steam reforming. Not all data on the scale of production is in the public media, but based on the technical specifications of the refineries and the yield indicators in the corresponding operations one can estimate the total production capacity of *PKN Orlen* to be about 140 000 t / year.

According to the data from 2008 the hydrogen produced in the Gdańsk Refinery belonging to *Grupa Lotos* was obtained in the methane reforming installation

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(16 000 t / year) and in the CCR reforming plants (13 800 t / year). The reforming plant of the Gdansk Refinery made operational as part of the, not fully realized, 10+ program (waste gases, methane, fuel fractions) has now achieved the production capacity of 58 800 t / year.

The *Jedlicze Refinery*, as the only small refinery has a hydrogen systems. For the purpose of hydrogen treatment installation of the residual and over-worked oils there is an integrated hub for hydrogen production with a capacity of 350 t / year.

7.5.3. Coke Industry

The coke oven gas contains 58-60% of hydrogen by volume. When utilizing two largest coke plants operating in Poland, to obtain hydrogen from the excess gas streams, i.e.: *Zdzieszowice* (production capacity of 4.2 million tons of coke / year) and *Przyjaźń* (2.3 million tons of coke / year) it could be possible to obtain annually about 149 000 t of hydrogen. The excess coke oven gas is so far unused as a source of chemical raw materials, apart from the previously mentioned use of a stream of gas, from the *Zdzieszowice* coke plant in the *Kędzierzyn - Blachownia* Power Plant.

7.5.4. Food industry

The fat industry conducting vegetable oils hardening produce for their own use hydrogen consumed in a closed circuit. The consumption indicator of hydrogen used or hydrogenation of unsaturated fatty acids is 0.0068 t / t. In a case of a typical curing installation with a production capacity of 120 000 t / year, the amount produced and consumed hydrogen is 820-850 t / year.

7.5.5. Other chemical industry

A significant producer of hydrogen in Poland, among the others, is one of the largest manufacturers of chemical raw materials - SYNTOS SA in Oświęcim, located in the western part of the Małopolski region. The hydrogen, as in other factories of the chemical and petrochemical industry is produced mainly for technological purposes in the course

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of the production process of semi-finished products and the company's products, including synthetic rubber.

Poland is one of the main producers of hydrogen in Europe. A total annual production capacity of hydrogen in Poland can be estimated today at about a million tons. This production capacity level is similar to the production potential of, for example, South Korea, amounting to 1.17 million tons of hydrogen per year [18] and represents more than 10% of hydrogen consumed in Europe (around 9 million tons), of which 2.7 - 3.6 million tons in Germany [14].

7.6. Possibility of using hydrogen produced in the domestic industry for automotive purposes

The hydrogen used as a fuel in the fuel cells must have a 99.9% purity class. None of the hydrogen production streams in the Polish industry meets this criterion (pure hydrogen produced for the purpose of receiving caprolactam has a purity of 98%). At the nitrogen plants producing technical gases there are PSA installations allowing to purify hydrogen to the fuel standard, of course, in small quantities, not exceeding the current overproduction of H_2 at the company.

The prospective massive source of hydrogen for automotive purposes in Poland may possibly seen to be the streams of coke oven gas, on condition of profitability of using PSA method for their treatment [52]. In view of the high energy prices and the lack of any tradition and limited competence in the area of photovoltaic applications in the solar energy conversion, the electrolysis of water in the identifiable time extent may cause doubts as a system solution.

It should also be stressed, with a view of securing mass hydrogen supply for the automotive industry, that in the Polish industry the reserves of hydrogen at its manufacturers' are small or none, because of the rule of obtaining it in the quantities required for use and delivery just in time to the installations where it is processed.

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These statements reflect, of course, the time prospect related to the market dissemination of hydrogen power in Poland.

During the demonstration development phase (2020 - 1-2 hydrogen stations and a dozen of fuel cells equipped vehicles) and in pre-commercial phase (2025 - 3-5 hydrogen stations and about 1 thousand fuel cells electric vehicles), obtaining hydrogen from the water electrolysis process, preferably using electricity from renewable sources, seems to be the most feasible solution.

Conducting electrolysis during excess production of electricity or during so-called "off-peak" periods (such as evenings and holidays) may be of interest both economically and energy-wise [79]. Optimized however, should be: the amount of produced hydrogen and the necessary for its acquisition electrical energy and its stored quantity.

Using electricity from renewable energy sources for hydrogen production is in Poland interested *Polska Grupa Energetyczna*. The State companies: *PGE* and *Gaz-System* intend, in 2015, to prepare a feasibility study for building a plant using surplus electricity from wind turbines to produce hydrogen by electrolysis. The hydrogen would be pumped into the pipelines filled with methane. In this regard, the parties signed a letter of intent for the project called - "Power-to-gas" involving the storage of electricity in the form of hydrogen [56].

8. Criteria for selecting the locations for the hydrogen car tanks filling stations along the Polish TEN-T network

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.

This is demonstrated by both the experiences of many, not only European countries, and also contained in the European Commission documents [29].

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8.1. Method of selecting station location area

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

An attempt to formulate such methodology was undertaken in the course of work on the "Prerequisites for the national plan of hydrogenization of the road transport 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:

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.

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 [82]. Detailed assumptions, acting procedures, numerical information, etc. contained by the task No. 5 entitled "The selection criteria for the location of hydrogen car tanks filling stations on the Polish TEN-T network".

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8.2. Initial location of hydrogen refuelling stations in Poland

With the criteria adopted in the first stage, the seven regions initially indicated for the location on their territory of hydrogen fuelling stations are in the order of ranking Śląskie, Mazowieckie, Małopolskie, Pomorskie, Łódzkie, Dolnośląskie and Wielkopolskie.

Preliminary analysis of the selected regions for future hydrogen fuelling station location allows to formulate the conclusion that these locations have a certain logical coherence in terms of positioning them in the area of trans-European transport corridors, namely:

- in the corridor East - West (motorway A2), stations located in the Mazowieckie, Łódzkie and Wielkopolskie,
- in the North - South corridor (motorway A1), stations located in Pomorskie, Łódzkie, Mazowieckie and Śląskie,
- in the North - South corridor (motorway A1), stations located in Pomorskie, Łódzkie, Mazowieckie and Śląskie.

Among the additional features of the region predisposed primarily for the location on their territory of hydrogen fuelling stations, included the region's location near the borders with other EU countries.

The largest passenger cars traffic intensity on the sections of border roads occurs in the following regions (by rank): Zachodniopomorskie, Dolnośląskie, Lubuskie, Śląskie, Opolskie, Małopolskie, Podlaskie, Podkarpackie. In this the average intensity of the cross-border traffic of passenger cars in the last two regions is significantly smaller than in the others.

In general, the fragmentary traffic structure survey conducted by the Institute in the period June - August 2015 on the national road network confirmed the high proportion of vehicles registered outside Poland, which, depending on the point of the study, day of the week, time of day, etc. fluctuated between 30 % up to about 70%.

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Synthetic summary of the results of the measurements conducted was the task No. 3 of the said project [55].

With the criteria adopted in the second stage, the cities predisposed for the location on their territory of the refuelling hydrogen stations, are in the order of ranking: Warsaw, Katowice (group of towns – Górnośląskie conurbation), Kraków, Tri-City (Gdańsk, Gdynia, Sopot), Łódź, Wroclaw, Poznań.

Additionally, despite the fact that in stage I, the Zachodniopomorskie region took only 10-th place in the ranking of provinces preferred for the location on their territory of hydrogen fuelling stations, in the II stage the city of Szczecin was taken into consideration as a potential city for the location of hydrogen refuelling stations, due to the relatively high number of taxis and buses.

Similarly, the city of Białystok (Podlaskie region in the stage I gained only 15 place in the ranking of regions preferred for the location of hydrogen refuelling stations), in the stage II achieved 9 place and due to the distance of less than 300 kilometres from Kaunas, where in the future the hydrogen refuelling station can be localized, should not be omitted in terms of preliminary indications for hydrogen refuelling station locations on the Polish territory. Additionally, the location of such station in Bialystok would have future importance for the possibility of refuelling hydrogen by cars driving from Poland to the Baltic countries and further to Finland and vice versa.

The analysis of selected (with the assumed criteria) cities of the future location of hydrogen refuelling stations allows the observation that these locations (like in the step I of selecting the regions) feature regularity in terms of positioning them in the area of trans-European transport corridors, namely:

- in the corridor East - West (motorway A2), stations located in Warsaw, in the area of Łódź and Poznań,
- in the North - South corridor (motorway A1), stations located in the Tri-City, in the area of Lódź, Warsaw and Katowice conurbation (Górnośląskie conurbation),

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- in the south corridor East - West (highway A4) running through Polish territory, stations located in Kraków, Katowice conurbation ((Górnośląskie conurbation) and Wrocław.

The indication in the III stage of the hydrogen refuelling station locations in the selected cities or in groups of cities (Warsaw, Katowice (group of towns - Górnośląskie conurbation), Krakow, Tri-City (Gdańsk, Gdynia, Sopot), Łódź, Wrocław, Poznań and Szczecin) was based on the measurement results of the average passenger cars traffic intensity on the roads leading to these cities or on selected road junctions located in the vicinity of these cities [39].

The largest passenger cars traffic intensity in the area of the selected cities occurs on sections of the following roads of international importance:

- Warsaw - road E67 + E77 in a direction of Kraków and Katowice; 59.9 thou. veh / day,
- Katowice (group of towns - Górnośląskie conurbation) - E40 road in the direction of Wrocław; 37.7 thou. veh / day,
- Kraków - roads E40 + E462 in the direction of Katowice; 30.1 thou. veh / day,
- Tri-City (Gdańsk, Gdynia, Sopot) - E75 road in the direction of Łódź; 32.5 thou. veh / day,
- Szczecin - the E65 road in the direction of Świnoujście and Goleniów; 25.3 thou. veh / day,
- Łódź – the E75 road towards Częstochowa; 23.2 thou. veh / day,
- Łódź – the 91 road towards the Tri-City; 18.7 thou. veh / day,
- Wrocław - roads E67 + E261 in the direction of Lódź and Poznań; 33.9 thou. veh / day,
- Poznań - roads E30 + 92 in the direction of Warsaw; 20.4 thou. veh / day.

The above indicated sections of roads in the regions of the cities selected in stage II, along with the directions with the highest passenger cars traffic intensity, should be primarily considered when indicating the future hydrogen refuelling station locations.

This should be guided by the principle that hydrogen refuelling points should be located at the existing or planned public filling stations.

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The location criteria for the hydrogen refuelling stations specified in stages I - III are of course general in nature. It is necessary to consider by the experts the issues of specific site location, such as by the existing or planned service station, near the existing petrol station, or on the plot, on which in accordance with applicable local spatial development plan the said location is possible and there is an interest of potential investor of such a project (stage IV). At this stage the consultations are advisable with the representatives of fuel corporations having distribution network in Poland of conventional fuels (or interested in the development of such networks), with representatives of GDDKiA, representatives of local authorities and representatives of hydrogen producers. In this study, due to the strict rigors of time and financial means available as well as arduousness and length of time necessary to obtain relevant opinions, among the others, from the appropriate government offices, this challenge was not taken up. This range of actions should be the subject of a separate work.

8.3. Preferences in the order of investments creating a forward-looking hydrogen refuelling stations network on the Polish territory

The road transport hydrogenization programs developed in Europe, including plans for construction of a hydrogen car tanks refuelling stations show that in the next 5 - 15 years in the vicinity of Poland, the most dynamic development of electric cars with fuel cells can be expected beyond our western border and in Scandinavia. Hence, understandable is the consequence of the policy pursued in the EU to provide a forward-looking cohesion of the hydrogen refuelling infrastructure allowing the free movement of cars that use this fuel, across the entire Union.

According to the guidelines of the HIT-2-Corridors project, as the indications of development of the network of hydrogen filling stations 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

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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 hydrogen refuelling stations 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 neighbouring countries,
- the expected future hydrogen refuelling station 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 hydrogen station 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 hydrogen filling stations network ensuring gradually increasing the area of accessibility of other Polish regions by hydrogen cars,
- development of hydrogen refuelling stations 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 hydrogen refuelling stations in Poland are as follows: 1 - Poznań 2 - Warsaw, 3 - Białystok, 4 - Szczecin, 5 – Łódź area, 6 - Tri-City area, 7 - Wrocław, 8 - Katowice region, 9 - Kraków (Fig. 8.1).

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

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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 E 67 / S8 road through Kaunas to Riga and further to Helsinki.

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 E 67 / 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 (E 67 / 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 E 65 / 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 E 65 / S3 and the section of the TEN-T North Sea - Baltic Sea corridor: E 30 / 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.

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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: E 75 / A1) and then in the TEN-T North Sea - Baltic Sea corridor (E30 / A2) and drive to Poznań (stretch of E 75 / 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 E 75 / A1 and a part of the E 261 road) is approximately 300 km.

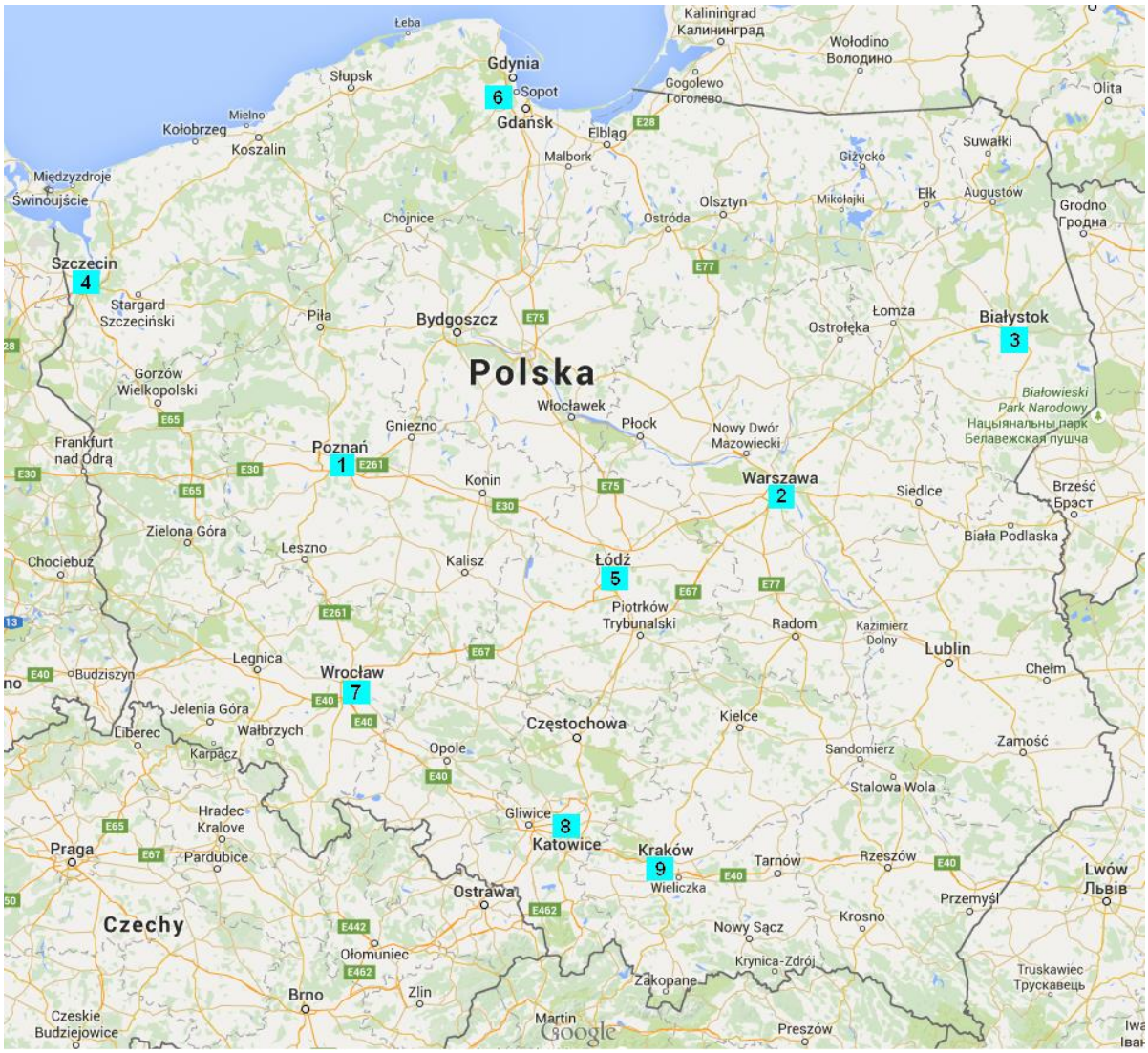

Fig. 8.1. Map of Poland with marked sites of the proposed public hydrogen refuelling station locations

Source: ITS own compilation

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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 E 40 / 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 thous. and more vehicles per day) along the stretch of the Baltic - Adriatic corridor: E 75 / A1 and the section of North Sea - Baltic Sea corridor: E 67 / 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: E 40 / A4 and E 77 / S7).

The directional temporal sequence of the proposed construction in Poland of hydrogen refuelling stations is shown in the Table 8.1.

The drawings illustrate areas of penetration of cars with fuel cells (within 300 km of areas of hydrogen refueling stations), proposed for construction by 2020, 2025 and 2030.

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Table 8.1. Directional temporal sequence of the proposed construction of hydrogen refuelling stations in Poland

Listing	Number of hydrogen refuelling stations (locations)	Number of hydrogen powered vehicles		Number of hydrogen powered vehicles driving to Poland or transiting
		buses	passenger cars	
Rok **2020**	**1** (Poznań)	**3**	**10**	**1000**
Rok **2025**	**4** (Poznań, Warszawa, Białystok, Szczecin)	**10**	**1000**	**10000**
Rok **2030**	**30** (Poznań, Warszawa,Białystok, Szczecin, rejon Łodzi, rejon Trójmiasta i inne)	**100**	**15000**	**60000**
Rok **2040**	**200** (Poznań, Warszawa, Białystok, Szczecin, rejon Łodzi, rejon Trójmiasta, Wrocław, rejon Katowic, Kraków, inne)	**500**	**600000**	**100000**
Rok **2050**	**600** (Poznań, Warszawa, Białystok, Szczecin, rejon Łodzi, rejon Trójmiasta, Wrocław, rejon Katowic, Kraków, inne)	**1000**	**2000000**	**300000**

Source: ITS own assumptions and estimates

The proposed numbers of hydrogen refuelling stations, regions of locations and periods of their launching, will enable future operation of the registered in Poland electric vehicles with fuel cells and will enable the development of hydrogen cars movement of foreign registrations, for which Poland would be a country of destination or cars transiting through Poland.

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Fig.8.2. Penetration areas of cars with fuel cells (within 300 km of areas of hydrogen refueling stations), of the stations proposed to be build by 2020

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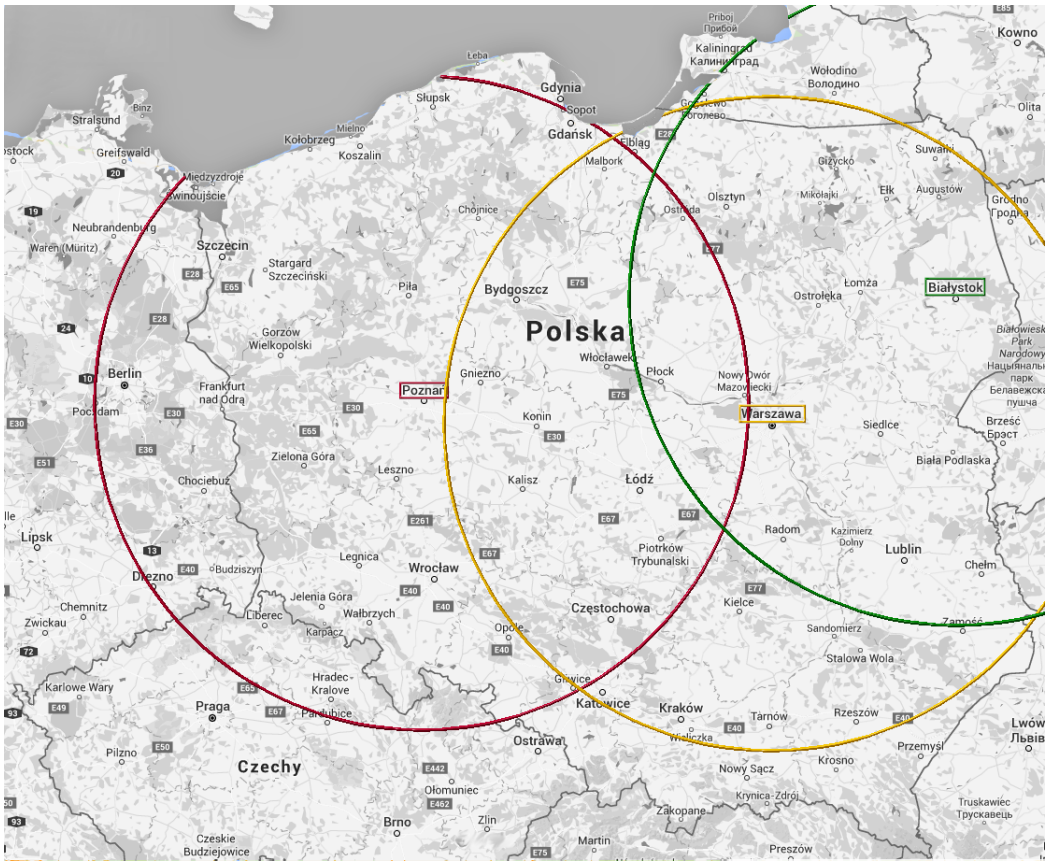

Fig. 8.3. Penetration areas of cars with fuel cells (within 300 km of areas of hydrogen refueling stations), of the stations proposed to be build by 2025

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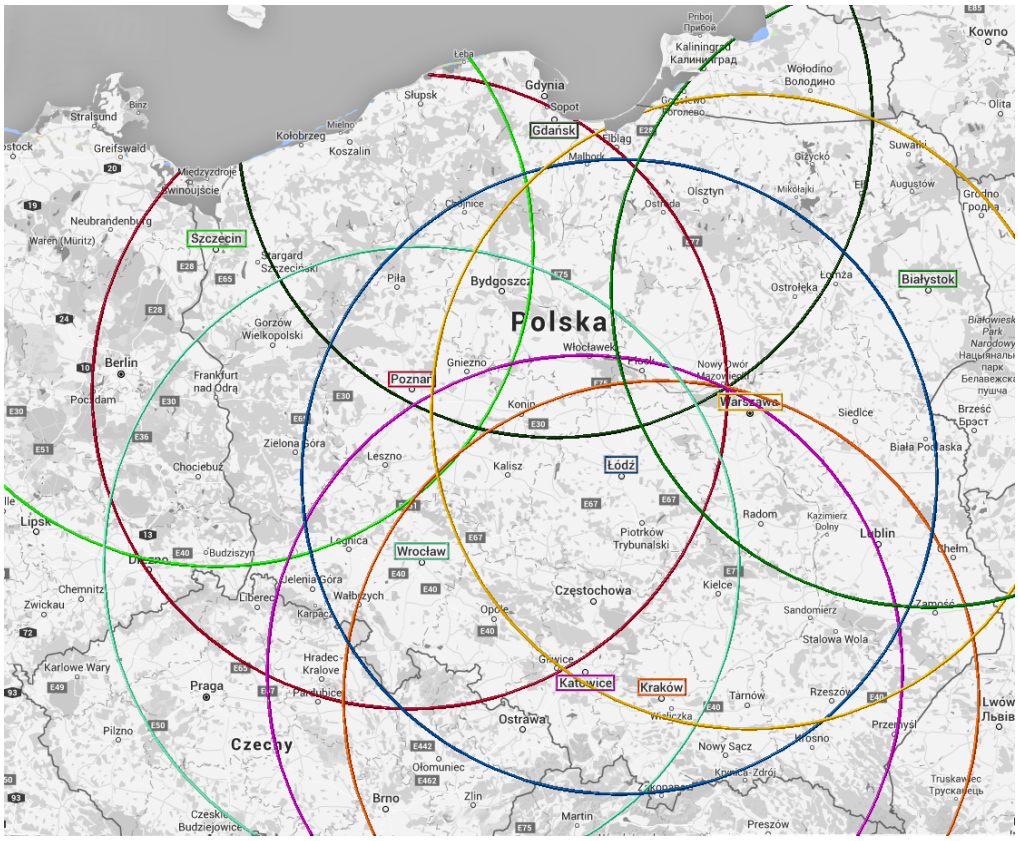

Fig. 8.4. Penetration areas of cars with fuel cells (within 300 km of areas of hydrogen refueling stations), of the stations proposed to be build by 2030

Assuming a predetermined sequence of construction of hydrogen refuelling stations (with an average distribution yield of 200 kg of hydrogen per 24 hours) in Poland (according to Tab. 8.1.) and currently average cost to build a hydrogen station in order of 680 - 830 thousand Euro and 388 - 473 thousand Euro in the 2030 [14] the costs of building infrastructure of hydrogen filling stations in Poland by the 2030 were estimated at:

- by the 2020: construction of one station - 0.68 - 0.83 thousand Euro,
- in the years 2021 - 2025: construction of four stations - 1.6 - 2.0 million Euro,
- in the years 2026 - 2030: construction of 25 stations - 9.7 - 11.8 million Euros

In total, building by the 2030, in Poland of 30 hydrogen refuelling stations would cost 12–15 million Euros.

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The forecast, at the adopted assumptions, of the number of electric cars in Poland, including those with fuel cells, by the 2050 is illustrated in Figure 8.5.

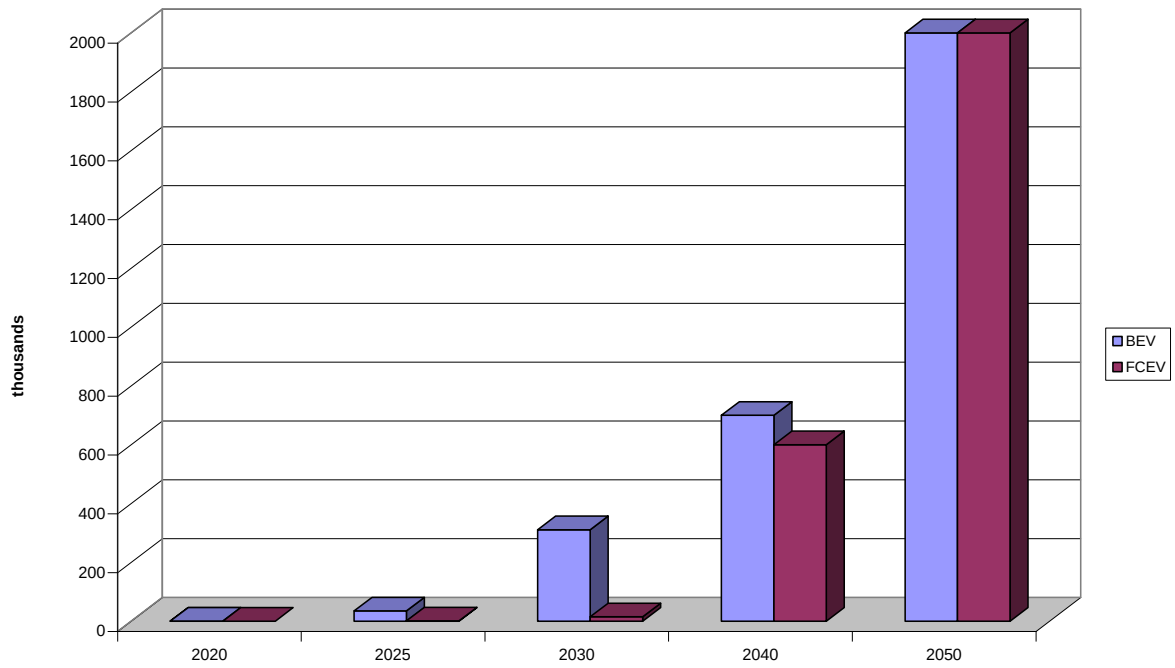

Fig. 8.5. Projected number of BEV and FCEV electric passenger cars in Poland [in thousands]

The forecast number of hydrogen-powered passenger cars operated in Poland in 2030 should be about 15 thousand and in 2050 about 2 million cars.

The projected demand for hydrogen fuel in the road transport in Poland till the 2050 is illustrated in Fig. 8.6.

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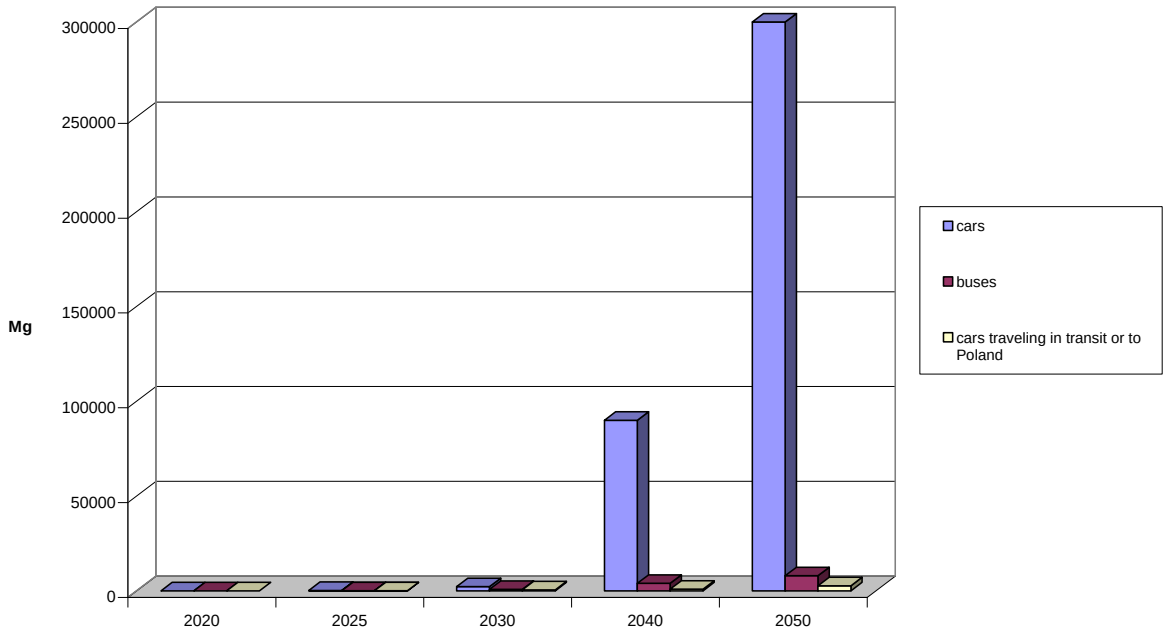

Fig. 8.6. Forecast demand for hydrogen by the vehicles equipped with fuel cells in Poland till the 2050 [Mg]

In 2050 the hydrogen consumption structure will be dominated by operated in Poland passenger cars (96%).

9. Policies for supporting the development of hydrogen propulsion infrastructure in Poland

The development of new technologies in transport, including hydrogen technologies, due to innovativeness and the lack of economic efficiency (especially in the initial phase) is, in the countries implementing them in the current period, strongly promoted. Among the promoted instruments for the strategy of introducing hydrogen in the transport sector in Sweden [79] were found, for example, the following tools:

- With respect to the vehicles:
  - public procurement,
  - joint procurement of vehicles,
  - expanding the zones of the limited access for cars with conventional propulsion in the cities,

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  - introduction of fees relating to pollutants emission from motor vehicles with internal combustion engines,
  - introduction of the tax on vehicles, differentiated depending on the size of carbon dioxide emissions.
- With regard to the infrastructure:
  - subsidies or loan guarantees for investing in the hydrogen refuelling infrastructure development,
  - public - private partnership,
  - tax exemptions for those running the hydrogen infrastructure,
  - tax exemptions for raw materials used in production of hydrogen

The provisions of the number of EU laws refer to the potential financing of hydrogen projects.

One of the key elements of the policy supporting the development of the use of hydrogen in transport is the Implementing Decision of the Commission of 19 March 2014 on the adoption of the multiannual work program for the years 2014-2017 for the LIFE program (2014/203 / EU).

Subject of the support of the cited Decision represent projects for the mobility in line with the sustainable development rules regarding those elements which are necessary to meet air quality standards, taking into account the actual cleaner driving conditions, the use of electric and low-emission vehicles, as is defined in the "Horizon 2020"Work Programme, the use of clean alternative fuels, innovative programs for modernizing the civil service vehicles, alternative propulsion technology for trains such as electromobility and mobility based on hydrogen fuel, developing and implementing low emission zones having a major impact and charging systems for the use of roads based on advanced access criteria and product labels for consumers (the main metropolitan centres) and the use of innovative logistics platforms in the final stage of delivery of goods.

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In Poland these documents also apply, so formally there are a number of possibilities for financing the development of hydrogenization in transport, but in actual practice there is no support in this respect.

For the record, it should be noted that in Poland there are following operational programs providing funding opportunities for investments related to the development of road transport based on hydrogen propulsion:

1. Operational Programme Infrastructure and Environment (OPIE); Priority axis VI - Development of a low-emission public transport in the cities

Projects financed by the Priority VI are eventually to contribute to the greater use of low-emission urban transport and the development of public transport system in the cities.

The 4.v investment priority "Promoting low-emission strategies" is dedicated to all types of territories, in particular urban areas, including the promotion of sustainable multimodal urban mobility and adaptation measures to mitigate the impact of climate change. Support for public transport will be one of the elements of the implementation of the activities as part of the investment priority 4.v, arising from low-emission economy plans prepared by the local authorities, including in their scope issues related to sustainable urban mobility. The support will include projects for the development of public transport. It is expected to implement projects, that will include elements to reduce / minimize the impact of noise / vibrations / and air pollution. The projects will be implemented according to the environmentally best rational option investigated. Treated as priority will however be the purchase of vehicles with alternative propulsion systems (electric, hybrid, biofuel, hydrogen, etc.). Investments will be both of infrastructural and rolling stock character, as well as comprehensive, covering both types of projects. Investments in the national program will be complementary to other enterprises implemented in the regional programs concerning the reconstruction of urban infrastructure eliminating, from the city centres, individual car traffic in favour of the public transport and supporting the spatial and functional integration of the different transport subsystems.

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Within the OPIE, in the case of urban transport, financed will be projects stemming from the Integrated Territorial Investments Strategy for the 13 regional cities (with the exception of Eastern Poland cities).

In the area of urban transport the beneficiaries will be local territorial governments (including their unions and agreements) - the regional capitals and their functional areas and organizational units acting on their behalf and special purpose companies, as well as managers of infrastructure for urban transport and public transport operators.

Selecting the projects for funding under the investment priority will be on the non-competition basis that will be applied to 13 regional cities and their functional areas with Integrated Territorial Investments Strategies (ITI). The selection of projects will be aimed at selecting investments that as much as possible contribute to better functioning of transport on the metropolitan area, reducing traffic congestion in urban areas and improving the accessibility and urban mobility, also characterized by the economic efficiency.

2. Operational Programme Eastern Poland 2014-2020 is a national program funded by the European Regional Development Fund (ERDF)

The priority axis II covers with its investment scope the priorities 4e, promoting low-emission strategies for all types of territories, in particular urban areas, including the promotion of sustainable multimodal urban mobility and adaptation measures to mitigate the impact of the climate changes.

The implementation of the investments supporting the development of modern transport infrastructure contributes to improving the environment, in particular to reduce pollutants emissions, and thus improves the life of the inhabitants of five regional cities: Białystok, Kielce, Lublin, Olsztyn and Rzeszów together with their functional areas or the ITI implementation areas of the above-mentioned regional cities.

In order to create a sustainable transport system it is essential to promote alternative forms of transport compared to private transport, and therefore preferred will be projects,

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thanks to which there will be, among the others, promotion of sustainable environmentally friendly public transport system, by purchasing low-emission bus fleet, among the others.

As part of the PI 4e, subject for funding, will be projects selected on the non-competition basis included in the Strategy ITI (Integrated Territorial Investments) and investments in the urban transport as part of the PI 4e, which will contribute to, among the others, implementation of new patterns of use or the promotion of clean and energy efficient vehicles (clean fuels and vehicles). The purchase of low-emission fleet should be accompanied by investments in the necessary infrastructure for the proper functioning of sustainable mobility. As priority will be treated the purchase of vehicles with alternative propulsion systems (electric, hybrid, biofuel, hydrogen, etc.).

3. "Connecting Europe Facility"

"Connecting Europe Facility" - CEF is a fund established by the European Parliament Regulation No. 1316/2013 of 11 December 2013, intended for projects relating to the development, construction or modernization of the existing infrastructure, in the field of transport, energy and Telecommunications (now TEN-T networks).

The fund is to contribute to the achievement by the EU of 20-20-20 targets, set out in the Strategy Europe 2020, i.e. reducing CO_2 emissions by at least 20 percent as compared with 1990 levels, increasing the share of renewable energy sources in the total energy consumption by 20 per cent, increasing energy efficiency by 20 percent.

The objective defined in the "Transport" sector is, first of all, ensuring sustainable and efficient transport in the long term through completion of the trans-European transport network (TEN-T) and its corridors by the 2030 and enabling the decarbonisation of all modes of transport through transition to innovative, low-emission and energy-efficient transport technologies. To achieve the implementation of the objective are to contribute, among the others, the actions implementing alternative fuels on the TEN-T network. The entities eligible to apply for funding are the Member States, international organizations, public or private organizations based in the Member States. The funds will be allocated mainly in the

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form of grants reserved for projects, which are difficult to implement due to their cross-border nature and very long-term return on the investment.

4. Horizon 2020 (EU Framework Programmes)

In the EU Framework Programmes the funds have been earmarked for the following area: „Smart green and integrated transport".

4.a. Mobility for Growth

Funding concerns, among the others, the research projects aimed at the implementation of environmentally friendly transport solutions, including vehicles that do not require the use of fossil fuels, and innovative infrastructure.

4.b Green Vehicles

Funding concerns, among the others, research projects aimed at improving energy usage efficiency, the use of unconventional energy sources to power vehicles.

5. Operational Programme Eastern Poland

(for 2015 - co-financing by the Polish Agency for Enterprise Development - PARP).

Priority axis II Modern Transport Infrastructure; Measure 2.2 Road infrastructure

The financing will encompass the infrastructure projects on: the national and regional roads within the regional cities and along the regional roads in the functional areas of regional cities or areas of the Integrated Territorial Investment (ITI) implementation of the regional capital, ensuring their connection to the national road network, including the TEN-T.

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6. Intelligent Development Operational Programme (2015 - co-financing by NCBiR)

Priority 1. Support for conducting R & D work by the enterprises

Sub-measure 1.1.2 R & D work related to creating the pilot installation (demo).

Funding will support experimental development work - the verification of new solutions under conditions close to realistic and operational ones.

Priority 4. Research and development work

Action 4.1 Research and development work

Sub-measure 4.1.4 Application Projects

The financing will cover application projects (projects involving industrial research or experimental development work carried out by consortia).

7. Regional Operational Programme of Mazowieckie Region for the years 2014-2020, as part of the EFRR

Priority IV transition to a low-emission economy

The financing will cover application projects aimed at, among the others, reducing emissions of air pollutants, including the development of low-emission urban mobility.

8. Regional Operational Programmes

Financial support refers to conducting research - development (R & D) work by enterprises producing demonstration installations (pilot). Funding granted for the projects implementation includes only development work, taking into account production of the demonstration installation. The beneficiary may entrust the implementation of some R & D work in the project to the subcontractor. Commercialization of the results of R & D work is the prerequisite to receive funding, understood as the implementation of the project results in the entrepreneur's own business or licensing or selling the results in order to introduce it to the business of another entrepreneur.

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In the case of other programs intended to fund research work of innovative character, such as:

- National Fund for Environmental Protection
- Norwegian Financial Mechanism
- Financial Mechanism of the European Economic Area
- National Green Investment Scheme (GIS)
- Swiss Financial Mechanism

it is not expected to finance the development of transport infrastructure, including hydrogen refuelling infrastructure.

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Recapitulation

- The advancement of hydrogen supplied fuel cells technology producing electrical energy used by automobile engines offers a real opportunity for the global automotive industry.
- 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 centres 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.
- 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 [29] of 22 October 2014. Under the provisions of the said Directive, it is recommended to EU countries to progressively ensure

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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): 1 - Poznań 2 - Warsaw, 3 - Białystok, 4 - Szczecin, 5 –Lódź region, 6 - Tri-City area, 7 - Wrocław, 8 - Katowice region, 9 - Kraków.
- Under the adopted assumptions, taking into account both the progressive development of the hydrogen car fleet in Poland (15 thou. cars, vans and 1,000 buses) and transit traffic (60 thou. cars), the construction by the 2030 of thirty refuelling hydrogen stations, Gould require a financial outlay of 12 - 15 million Euro.
- Tin 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 - 1 000 buses and 100 - 300 thousand cars transiting Poland.

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- 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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