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ELECTROMOBILITY AND HYDROGENIZATION OF THE MOTOR TRANSPORT IN POLAND NOW AND IN THE FUTURE

Wojciech Gis

Motor Transport Institute
Jagiellonska Street 80, 03-301 Warsaw, Poland
tel.: +48 22 4385400, fax: +48 22 4385401
e-mail: wojciech.gis@its.waw.pl

Abstract

The article analyses activities within the world, EU and Poland in aspect electromobility and hydrogenization now and in the future. Will be presented estimates cars park of global hybrid (HEV), hybrid plug-in (PHEV) and fully electric (BEV). Changes in production volumes and number of registered types of vehicles as abovementioned are presented in a breakdown into world.

The overall number of HEVs produced thus far is estimated at approx. 12.5 million and over 1.3 million in Europe. There are roughly 38 thousand HEVs registered in Poland. There were about 800.000 hybrid plug-in vehicles registered in the world in 2016. Of 3.2 million electric plug-in vehicles and BEVs used in the world in 2017 more than 1.2 million were used in China, approx. 750 thousand in the USA, 850 thousand in Europe, including c.a. 650 thousand in the EU countries.

Yet, electric plug-in vehicles (BEVs and PHEVs) globally accounted for just 0.3% of the worldwide fleet of passenger cars in 2017. The article also addresses the development of the electric vehicles market and the annual new vehicle registrations.

The existing situation in the field of hydrogenization motor transport in the world, in the EU and in Poland will also be analysed. This will be analysed in terms of the number of hydrogen vehicles and hydrogen refuelling stations.

Keywords: *road transport, hydrogenization, combustion engines, electromobility, environmental protection*

1. Introduction

The size of the worldwide vehicle fleet estimated in 2017 to total 1.3 billion vehicles (of which 95% accounted for passenger cars), combined with its pace of growth (the fleet came to 250 million vehicles in 1970, 500 million in 1986 and a billion in 2010) [1, 13, 16] raises the issue of exhaustibility of liquid fuels consumed by the automotive industry on one side and on the other – the problem of greenhouse gases and other pollutants generated by internal-combustion engines.

One of the prospective directions of development in the automotive industry over the forthcoming decades is electrification. A great deal of programmed and legal initiatives was undertaken in this area in the first and second decade of the 21st century, both by public administrations in most developed countries and by various international organizations, which resulted in concrete actions of automobile producers and their business milieus [7, 8, 19].

Initiatives nowadays in the area of electrification in motor transport (vehicles with electric drive that dominated in the initial period of development of the automotive industry were overtaken completely by vehicles equipped with internal combustion engines) focus on three different technical solutions.

The first solution both in terms of time sequence and the scale of development involves hybrid electric vehicles (HEV) equipped with classic internal combustion engines and supporting electric engines powered with electric energy generated by batteries charged during car driving.

The second solution relates to plug-in hybrid electric vehicles (PHEV) that apply an internal-combustion engine with an electric engine, in which the electric energy may be generated also by batteries charged by external sources.

The third solution (considered by many experts as the only true electric vehicles) comprises vehicles that use only electric power from batteries charged with energy from external sources (Battery Electric Vehicle – BEV). Because of the external power source, those cars are also categorized as plug-in vehicles.

2. Electromobility

2.1. Hybrid cars

The overall number of HEVs produced thus far is estimated at approx. 12.5 million, of which to year 2017 more than 6 million cars were sold in Japan, approx. 3 million in the US and over 1.3 million in Europe. More than 90% of produced HEVs are hybrid petrol electric vehicles [17]. The above proportions are confirmed by data from several countries reporting to Eurostat according to which among 700,000 HEVs registered in those countries only 72 thousand were hybrid electric vehicles equipped with diesel engines.

The largest HEV fleet in Europe is located in France (300,000 vehicles), the UK and Germany (200,000 vehicles each) and the Netherlands (approx. 150 thousand vehicles).

The worldwide HEV fleet accounting for 1% of the world fleet of passenger cars, with the continually growing production coming to approx. 2 million vehicles annually, is going to grow but still at a pace that does not guarantee the accomplishment of levels assumed by most projections and forecasts (Tab. 1).

In 2016, the largest share in the market of newly registered passenger cars HEVs enjoyed in Japan (38%), Norway (36.9%), the Netherlands (3.7%), France and Sweden (2.3% each).

In Poland hybrid vehicles such as HEV recorded in annual reports of the Main Statistical Office since 2015 account for more than 90% of electric vehicles reported in such publications. Few had been recorded at the beginning of 2000s (from 48 vehicles sold in 2004 to approx. 300 newly registered vehicles in 2009) [4, 18].

The overall number of registered hybrid vehicles in Poland by year 2010 is estimated at approx. 1000 vehicles. Year 2013 turned as a break-through when 1864 hybrid electric vehicles were sold and registered in Poland. In the next years the following was recorded: over 2500 hybrid vehicles in 2014, 5539 in 2015, 9849 in 2016 and over 17 thousand hybrid vehicles in 2017 [3, 15]. At the end of 2017, roughly an overall of 38 thousand HEVs had been registered in Poland. While there are 26 models of various hybrid vehicles of 12 brands available on the Polish market, the market is practically dominated by Toyota (69% of sales) and its affiliated company Lexus (27% of sales).

Tab. 1. Sales of hybrid-electric passenger cars in years 2010 – 2017, in thousands [10]

Description	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Poland	0	0	0	1	2	5	10	7
UE/28	80	132	137	166	166	191	279	431
Europe	-	-	-	183	182	208	303	459
USA	274	269	401	459	452	384	347	364
Japan	392	316	678	679	1000	1100	1000	1000
World	746	717	1200	1336	1635	1692	1650	1823

2.2. Hybrid plug-in cars

In Europe where the sales of PHEV approximated 150 thousand in 2017 (Tab. 2), hybrid vehicles enjoyed the greatest popularity in Germany (c.a. 30 thousand vehicles) and in the UK (slightly over 30 thousand cars). Globally the greatest number of PHEVs had been sold in 2017 in China (111 thousand vehicles) and in the US (roughly 90 thousand vehicles) [14].

The overall registered fleet of plug-in hybrid electric vehicles in 2016 worldwide only slightly exceeded 500 thousand (Tab. 3) of vehicles and accounted for merely 0.07% of the global fleet of passenger cars. The greatest number of PHEVs was noted in the US (approx. 300 thousand), China (165 thousand), Japan (65 thousand) and the Netherlands (100 thousand). Significant numbers of PHEV were also noted in the UK (55 thousand), Germany (c.a. 32 thousand) and Norway (approx. 35 thousand).

Tab. 2. Newly registered plug-in hybrid passenger cars (PHEV) in years 2011-2015, in thousands [10]

Description	2011	2012	2013	2014	2015	2016	2017
EU28	0.6	9.0	15.1	35.7	86.9	89.5	115.4
Europe	0.6	9.3	16.4	35.7	96.7	113.0	144.0
Norway	-	0.3	0.3	1.7	7.8	20.7	25.2
Japan	0	11	14.1	16.2	14.2	9.4	31.5
USA	8.0	38.6	49.0	55.4	42.8	72.9	89.9
In total	9.0	60.7	91.6	133.7	221.7	286.7	385.1

Available data regarding years 2016 – 2017 prove that a relatively moderate pace of development is noted in this segment of the automotive industry and even that is being limited – e.g. in the Netherlands the sales of PHEVs in 2016 dropped by almost 50% (from 41 thousand to 21 thousand and in 2017 to 1.200 vehicles). A spectacular though less rapid than as assumed at the turn of the first and second decade of the 21st century development was recorded by BEVs.

Tab. 3. Registered fleet of plug-in hybrid passenger cars (PHEV) in years 2011- 2016, in thousands [10]

Description	2011	2012	2013	2014	2015	2016
EU28	0.9	9.6	36.5	69.2	158.6	-
Norway	0.0	0.3	0.7	2.4	12.4	34.4
Europe	0.9	9.9	37.2	71.8	171.4	-
Canada	0.3	1.7	3.2	5.4	8.0	14.4
China	0.7	0.9	1.6	25.9	86.6	165.6
Japan	0.0	11.0	25.1	41.3	55.5	64.9
USA	8.0	46.4	95.6	150.9	193.8	266.6
In total	9.4	69.7	161.3	295.0	517.0	805.3

2.3. Fully electric cars

In 2010, there were just 16 thousand BEVs registered worldwide (Tab. 5). Only 6 thousand were registered that year (Tab. 4). The registration of newly purchased electric passenger cars began to grow rapidly from that moment to come to 39 thousand in 2011, 58 thousand in 2012, 112 thousand in 2013, 191 thousand in 2014, 325 thousand in 2015, 466 thousand in 2016, and 759 thousand in 2017.

The increased sales had been generated mostly by China with a production of more than 60% of BEVs manufactured globally. The world fleet of such vehicles was respectively 16 thousand vehicles in 2010, 55 thousand in 2011, 113 thousand in 2012, 227 thousand in 2013, 420 thousand in 2014, 740 thousand in 2015 and over 1.2 million in 2016, of which 255 thousand in Europe (including approx. 160 thousand vehicles in the EU).

The largest fleet of BEV passenger cars was noted in China (over 480 thousand vehicles), the US (almost 300 thousand vehicles), Japan (86 thousand vehicles), Norway (100 thousand vehicles), France (67 thousand vehicles) and Germany (approx. 41 thousand vehicles). Poland with its fleet of several hundred BEVs has been outpaced significantly by countries such as Italy or Portugal.

Despite an over 70-fold increase of the world fleet of BEVs in years 2016-2017 electric passenger cars still account for just 0.1% of the total number of passenger cars registered in the world.

Tab. 4. Newly registered electric passenger cars (BEV) in years 2010-2017, in thousands [10]

Description	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Poland	-	0	0	0	0.1	0.2	0.1	0.4
EU28	0.5	7.9	12.4	22.1	35.2	54.2	63.5	97.5
Norway	0.4	1.8	4.2	8.2	18.1	27.8	29.5	44.9
Switzerland	-	-	1.0	1.0	1.0	3.3	3.3	4.8
Europe	0.9	9.9	17.4	31.0	54.2	85.3	96.3	147.2
Canada	-	0.2	0.6	1.6	2.8	4.4	5.2	14.9
China	1.0	4.7	9.6	14.6	48.9	146.7	257.0	468.0
Japan	2.4	12.6	13.5	14.8	16.1	10.5	15.5	24.5
USA	1.2	9.7	14.6	47.7	63.4	71.0	86.7	104.5
In total	6.4	38.5	57.8	112.1	190.8	325.4	466.4	759.1

Electric vehicles (plug-in and battery electric) comprised 1.48% of all new car registrations in EU-28 in 2017 [6]. There is a significant variation across the EU countries for example, in Sweden electric vehicle registrations are 5.5% of all new cars [6]. Outside of the EU, Norway is a clear leader with 39.2% of new car registration being electric vehicles [5, 11].

Tab. 5. Registered fleet of passenger BEVs in years 2010-2016, in thousands [10]

Description	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
EU28	1.9	9.3	21.2	44.3	74.2	121.8	161.3
Norway	3.3	5.3	9.5	19.7	41.8	72.0	98.9
Europe	2.7	12.1	28.1	59.0	107.0	182.4	251.4
Canada	0	0.2	0.9	2.5	5.3	9.7	14.9
China	1.5	6.3	15.9	30.6	79.5	226.2	483.2
India	0.9	1.3	2.8	2.9	3.3	4.3	4.8
Japan	3.5	16.1	29.6	44.3	60.5	70.9	86.4
South Korea	0	0.3	0.8	1.4	2.8	5.7	10.8
USA	3.8	13.5	28.2	75.9	139.3	210.3	297.0
In total	16.4	55.1	112.9	226.8	420.3	745.6	1208.9

In [11] is suggested that by 2030 battery electric vehicles sales could be between 13% and 21% of total new car sales in climate goal and regulation scenarios. Including range extended electric vehicles increase is 34% and 51%. According to one of the scenarios aims to achieve is 10 g per v km [11].

If Europe were to move to a zero – emission car fleet the share of new car sales, which would have to be zero emission (battery electric and fuel cell) would need to be around 20% in 2030, 40% in 2040 and 50% under a medium forecast [11].

In terms of total vehicles, there could be around 24 million electric cars on the road in Europe in 2030, around 10% of Europe's car fleet. This is based on there being 18 million new cars sold in Europe [2] and assuming a 7% market share of new cars in 2020, a 17% market share in 2030 and linear growth between the years [11].

The majority of life cycle analyses suggest that well-to-well (WTW) GHG emissions per km driven of BEVs in Europe lower than ICEVs and hybrid vehicles. Based on the carbon-intensity of the EU electricity mix in 2015, the WTW emissions of a mid-sized BEV were between 60 and 76 g CO_2 – eq/km. This is between 47% and 58% lower than the emissions of an average mid-sized ICEV passenger car in 2015, at 143 g CO_2 – eq/km [11].

3. Hydrogenization

Hydrogen molecules are a critical complement to electrons in the challenge of far-reaching decarbonisation. Vision of Hydrogen Council is sees hydrogen powering more than 400 million cars, 15 to 20 million trucks, and around 5 million buses in 2050, which constitute on average 20 to 25% of their respective transportation segments. Since hydrogen plays a stronger role in heavier and long-range segments, these 20% of the total fleet could contribute more than one-third of the total CO_2 abatement required for the road transportation sector [12].

Area for practical use of hydrogen as a fuel carrier is transport, including in particular road transport. In recent years 2 motor companies (Hyundai, Toyota) have launched the serial production of fuel cell vehicles (hereinafter referred to also as hydrogen-fuelled or hydrogen vehicles) and others such as Volkswagen, Mercedes Benz, BMW, General Motors also produce such vehicles. The start of serial production by those companies depends on the availability of expanded hydrogen refuelling network of HRS (Hydrogen Refuelling Stations). In 2016, there were only c.a. 200 such stations available in the world. It is expected that by 2020 the number of HRS should come to approx. 1000 and by 2025 – to c.a. 3500 (Tab. 6).

Tab. 6. Number of public HRS worldwide in 2016 and their projected number in 2020-2025 [9]

Year	USA	Europe	Asia	Total
2016	60	100	103	263
2020	130	520	340	990
2025	600	2000	830	3430
Source: H2 Mobility, US DOE, Hydrogen Europe, Air Liquid – cited from: How hydrogen empowers the energy transition, Hydrogen Council 2017, p. 9.				

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

Currently approx., several thousand vehicles fuelled with hydrogen are used in the world, including more than 1000 in the US and 2000 in Japan and several hundred in Western Europe. A dynamic growth of fleets of hydrogen vehicles is planned – for example, China expects to have 50 thousand hydrogen vehicles in 2025, to eventually exceed one million in 2030, whereas Japan will have a fleet of 40 thousand hydrogen vehicles in 2020 and approx. 300 thousand in 2030. According to projections of 2014 – the European fleet of hydrogen vehicles is expected to have 350 thousand vehicles in 2020, the fleet in Japan – 100 thousand, in Korea – 50 thousand and in the US – 20 thousand [9].

In addition, the fleet of hydrogen-fuelled buses is to be developed – in Europe, it will have 1000 buses in 2020, while for instance in South Korea – almost 30 thousand buses by 2030.

In Poland, there are practically no vehicles equipped with fuel cells. However, it was developed by Motor Transport Institute "Circumstances of the national plan for hydrogenization of road transport in Poland". In the first place taken into account were [9]:

- already existing refuelling opportunities in the neighbouring countries,
- the expected future HRS locations in the Baltic countries,
- gradually increasing the area available for hydrogen-powered cars as a result of the subsequent location of new stations at distances up to 300 km from the existing or sequentially from the newly-opened ones.

In addition, while pre-indicating another HRS location taken into account was:

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

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

4. Summary

Decarbonizing of the transport segments is possible with range of technologies that offer different energy efficiency (the energy required as input) and their energy density in terms of weight and volume [12]:

- BEVs have the highest well-to-wheel energy efficiency (60% when powered by electricity from renewables, 30 to 35% when powered by gas- or coal-based electricity; compared to roughly 25 to 30% for ICEs), while batteries have the lowest energy density per weight (0.6 MJ per kg), making them well suited for lighter vehicles and shorter ranges,
- Hydrogen, when stored aboard a vehicle, has a much higher energy density per weight than batteries (currently around 2.3 MJ per kg), allowing FCEVs to travel longer distances and perform better for heavier vehicles for which batteries become impractical and inefficient.

While the requirements of range and weight is related to transport segments. It is specific pattern of usage, which determines the attractiveness of technology. While same consumers drive only locally, for example, others regularly drive their cars long distances, making FCEVs more attractive. Trucks for local distribution may be able to run on batteries, while those for long-haul freight will profit much more from the longer range of hydrogen [12].

Although FCEVs and BEVs are sometimes represented as competing technologies, they are actually complementary [12].

Improvements in fuel cell efficiency will likely reduce fuel consumption by 20 to 35% until 2030. In addition, fuel cost per hydrogen is expected to fall as distribution and retail infrastructure scale up. These improvements could give FCEVs an advantage over diesel in all transport segments, even if oil prices remain near today's low levels. This is particularly relevant for consumers who drive long distances and commercial vehicles used extensively [12].

The cost of hydrogen refuelling infrastructure are less than often though. Hydrogen Council shows that building the required refuelling infrastructure would cost $1,500 to 2000 per FCEV until 2030. This is the same order of magnitude as the cost for the recharging infrastructure for a BEV, as a home charger currently costs around $ 2000. By 2030, costs of refuelling infrastructure could decrease to less than $1,000 per FCE. A study comparing infrastructure costs for 20 million FCEVs and 20 million BEVs in Germany found that, when required grid investments are considered, the total cost per FCEV might even be lower than for BEVs [12].

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