

EXPLOITATION AND ENVIRONMENTALLY ASPECTS OF HYBRID BUSES IN EUROPEAN CITIES

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1. INTRODUCTION

The energy and environmental problems at the moment are the major problems that the world faces today. The intensive development of the automotive industry has been one of the hallmarks 20th century. At the beginning of 70-ies of the last century due to the oil crisis in the developed countries of the world, all leading vehicle manufacturers are headed in research of alternative fuels in order to partially mitigate the dependence on fossil fuels. In addition, it is known that fossil fuels as an energy resource will have a limited service life of up to 100 next years (Figure 1).

World Energy Outlook 2100

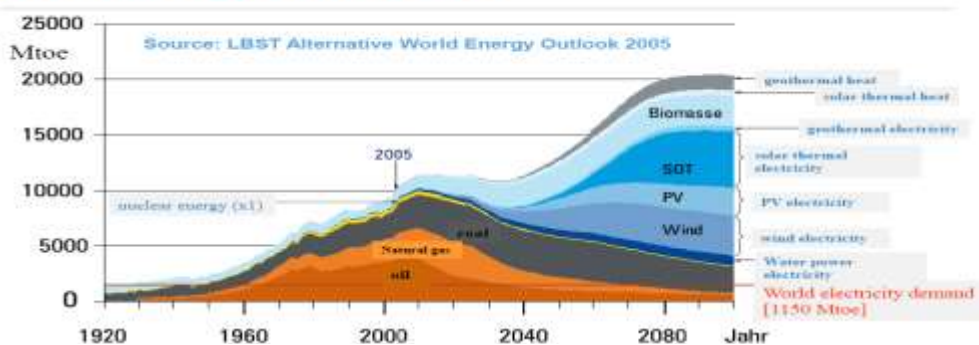


Figure 1 The use of energy resources in the world to 2100. [4]

Trend of production, available reserves, volatility of fuel prices (Figure 2), in the past 40 years have accelerated on the experiments with various alternative fuels from which we will mention electric vehicles, solar cells, methanol, vegetable fuel, hydrogen, natural gas, etc.

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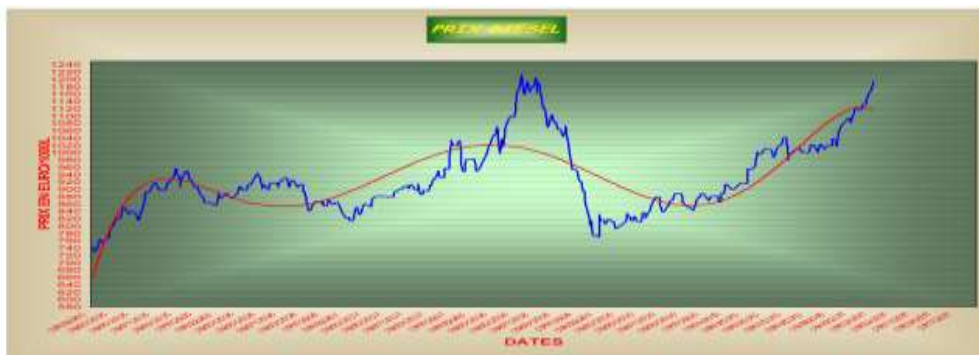


Figure 2 The trend of change in the price of diesel fuel in the EU (2005-2011) Euro/1000 [4]

But the key question that came to the fore and that required an immediate solution has become a matter of ecology, and the rapid increase in environmental pollution as a direct result of burning fossil fuels. The enormous release of carbon dioxide CO₂, primarily from automobile engines and industrial plants has led to global warming (Figure 3) and causing the greenhouse effect, acid rain and the formation of damaging the upper layers of the atmosphere.



Figure 3 Global warming, melting ice at the North Pole 1973-2003 year

2. PLACE AND ROLE OF BUS SUBSYSTEM TRANSPORTATION IN THE EU

In the cities of the EU, the bus subsystem of public transport is one of the most important segments of the urban life of the city, which has a direct impact on meeting the socio-economic and other needs of the population.

Thanks to its techno-exploitation advantages and flexibility, its role in the distribution of passengers with highly capacitive lines of public transport such as metro or LRT and urban parts, is irreplaceable. According to the data of UITP's, today in the 100 largest cities in EU operational use is around 54,700 buses urban type, which achieve about 80% of the transport of labour-expressed in km. The EU is the world leader in the production of city buses. Annually produces about 12,000 new buses which are 60% of world production [9].

Most buses use conventionally energy but fossil fuels are one of the main causes of urban pollution and emissions in cities. For these reasons bus subsystem has become important as a major promoter of new technologies in the implementation of sustainable

development strategies. The above facts have initiated the adoption of a series of strict standards relating to limit emissions from conventional vehicles to drive, from ECR 49 of 1982, over Euro emission standards (Euro 1 to Euro 6) (Figure 4) in the period 1992 to 2013, the introduction of buses powered by CNG, LPG and bio fuels, has led to significant progress in reducing emissions of gases (CO, NOx, CxHy, PM10). The problem is that the buses and vehicles on conventionally fuels are remaining high emitters of carbon dioxide CO2, as a direct result of burning fossil fuels.

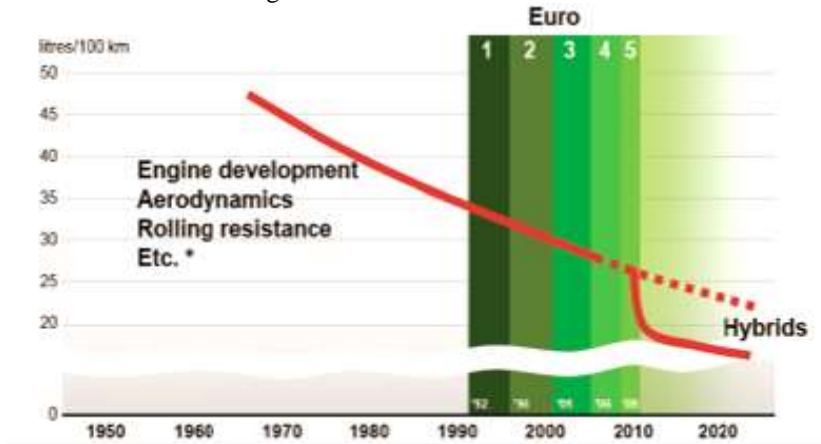


Figure 4 The evolution of development in terms of bus emissions [11]

Since December 2010, the EU countries have been applied the EC Directive 33/2009 concerning the promotion of energy efficient and environmentally clean vehicles in road transport, which are used in the public sector such as buses for public transport, utility vehicles, etc. The directive defines a strategy to reduce CO2 emissions by 20% by 2020 year compared to the base year 1990 year [6]. Significantly, the directive regulates the energy and environmental criteria for tendering for procurement of new vehicles, which will be an integral part of the tender documents. This directive defines the price of emission, expressed in Euro / kg for each product: CO2 (0.03 to 0.04 Euro / kg), NOx (0.0044 Euro / g), Non-Methane Hydrocarbons - NMCH (0.001 Euro / g), Particular matter - PM (0.087 Euro / g) [6]. The Directive specifies that the basis for all calculations in terms of calculating the value of the issue or the cost of emissions is g / km, not g / KWh.

3. EU-WHITE PAPER OF TRANSPORT

The introduction of hybrid buses (diesel-electric) in the system of public transports passengers in the period 2010-2020 years, is the first step in the implementation of the strategy defined by the EU which is the ultimate goal that by 2050, in cities of the EU , will be only vehicles with pure electric drive or "zero emissions" (CO2) [7].

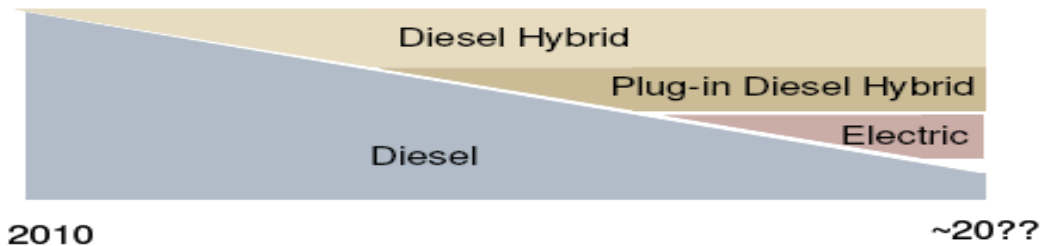


Figure 5 Forecast uses of buses for public transport in the EU for the period 2010-2050.

It is observed that the trend of using diesel-powered buses have a constant tendency of reduce everything to its complete abolition of the 2050 year. (Figure 5) Enhanced Hybrid concept "plug in" will be present after 2015. Introducing the bus with pure electric drive will depend primarily on battery technology, battery capacity; need to provide autonomy of day operation, without charge. The widespread use of this type of drive is expected after the 2020. It should be noted that there are now buses with full electric drive, but their application is limited only to the mini and midi versions, with the range of movement of about 120 km, which is not enough for a regular exploitation. Currently they are developing electric-powered buses with standard lengths of 12 m and articulated 18 m, with different recharge batteries. This concept was presented in 2009, on the one line in Shanghai (China). In Geneva (Switzerland) is currently in the implementation of the project Trolleybus Optimisation System Alimentation - TOSA the introduction of the first buses to electric drive, whose start-up is planned for May 2013. For the period after 2025, provides for the growing use technology of fuel cells (Fuel-Cell), which is used as fuel, hydrogen (H₂).

HYBRID CONCEPT OF CITY BUSES

The concept of buses with hybrid drive is based on the use of two types of drive. Buses have the two engines: diesel engine displacement about 5 litres and the electric motor-generator. Depending of concept in use are serial and parallel types, (Figure 6)

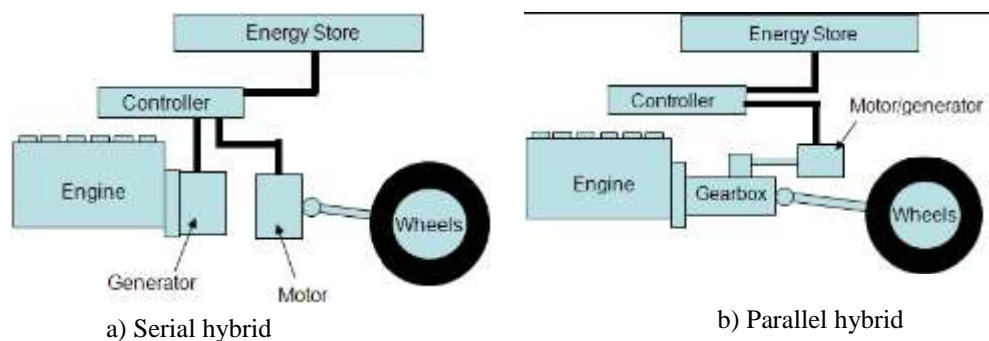


Figure 6 The working principle of the serial and parallel types of hybrid buses

In a serial-type hybrid (Figure 6a), the diesel engine drives a generator to produce electricity, which accumulates in high capacity battery (ultra cap, Ni MH, Li-ion). The vehicle is powered by electric motor located on the drive shaft. Diesel engine is turned on, when the battery needs to be supplemented, the control unit regulates it. The cooling system prevents overheating and keeps the operating temperature of electrical components. Recovery system uses for electricity to charge the battery during braking mode. Block inverter converts direct current from the battery into AC to drive asynchronous traction motors.

In the parallel-hybrid concept (Figure 6b) can be to power electric motor or diesel engine directly. Buses are powered with electric traction. When the vehicle reaches a certain speed of 20-25 (km/h) includes a diesel engine that powers the vehicle through the transmission. Depending on the mode and the load can be turned on simultaneously diesel

and electric motor. The main components of the hybrid buses: Hybrid unit, diesel engine, inverter module, cooling unit, brake resistor, battery, battery cooling system (Figure 7).

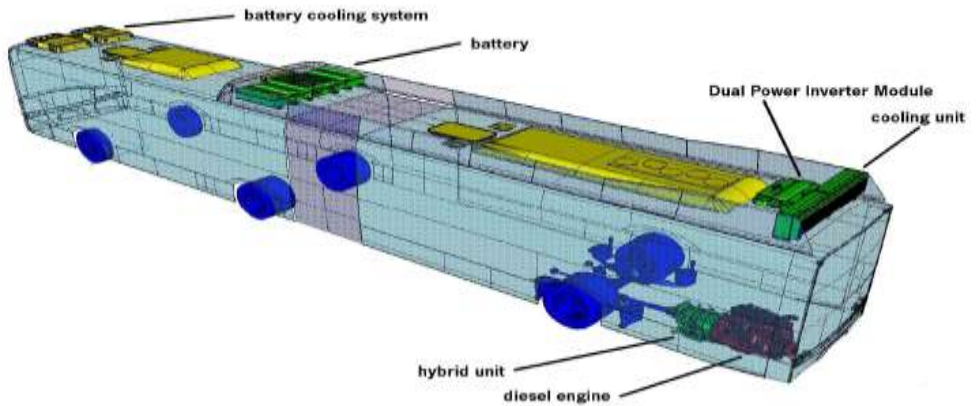


Figure 7 The main components of the hybrid buses

Main advantages of the concept of hybrid system in comparison to buses for urban transport with a conventional drive are reflected in:

- Lower consumption of diesel fuel (20 to 40%),
- Reduced CO₂ emissions,
- Lower emissions of harmful substances: CO, NO_x, C_xH_y, PM₁₀,
- Lower level of external noise (10-12 dB(A)), and
- Good driving performance (acceleration-deceleration) [3].

4. OPERATIONS HYBRID BUSES IN THE EU AND WORLD

The concept of the hybrid buses for public transport has been known since the 1969 year, when the Mercedes-Benz was shown the application of these buses. Their increased utilization in urban public transport is recorded in the early 21st century only. At first it was just a demonstration and observation opportunities primarily techno-exploitation elements, leading bus manufacturers: Mercedes, MAN, Volvo in some EU capitals. Putting into operation of buses with hybrid drive in the EU has begun since 2006 year. The period 2006-2010 was marked by a relatively small number of buses with hybrid drive, which has been involved in regular exploitation. It was the pilot testing a hybrid concept in cities: Paris, Barcelona, Dresden, Strasbourg, Nuremberg, Wallonia and Flanders region in Belgium, Luxemburg. London was exception where from 2006 in regular exploitation included 56 "double-decker" Wright-bus, which can be considered the beginning of the "mass" of introducing this kind of buses in Europe. In the period 2010-2011/12 years there is a steady upward trend in hybrid buses in regular operation, on the end of 2010. The EU has been in service 178 buses with hybrid drive but the mid-2012, in service is 1191 buses with hybrid drive. In the following Figure 8, is shown the numbers of hybrid buses by EU countries in 2012.

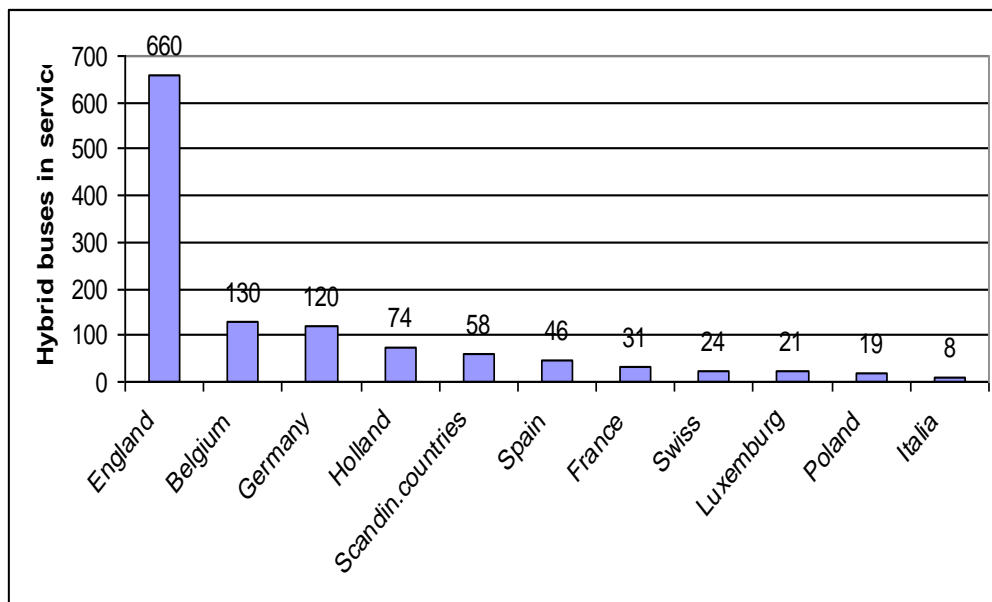


Figure 8 EU number of hybrid buses in service 2012 year

Cities and regions with the highest number of hybrid buses currently in service are: London (260), Manchester (162); Flanders Region-Belgium (136), Dresden (57), Oxford (43); Birmingham (33), Dordrecht (27), Barcelona (25), Region South Holland (24), Luxembourg (21), Hamburg (20), Oslo (18), Bochum (13) [5].

In 2012 expected to continue increase the number of buses in use. City of Dijon (F) has published a procurement of 100 new hybrid buses, which will become the city with the largest percentage share of hybrid buses.

Also, should be emphasized that the exploitation of hybrid buses have presented in North America, starting since 1990. According to the data available at end of 2010 in the United States and Canada were in service 6300 buses with hybrid drive. Observed by cities: New York (1812), Toronto (950), Washington (550); Philadelphia (510), Seattle (520), Chicago (228) [5].

Of the types of buses that are used the most common models are: Daimler Orion and New Flyer bus-Xcelsior. At this time all leading bus manufacturers in the EU in its commercial offer are given city buses with hybrid drive. The following Table 1 presents all types of hybrid buses by manufacturers in the EU [5].

The following Figure 9 shows the Volvo 7700 Hybrid with basic technical data [8].

5. AN EXAMPLE OF THE EXPLOITATION OF HYBRID BUSES IN LONDON

The Bus transport in London is one of the largest systems of its kind in Europe and the world.

With approximately 8500 buses in service, working on a network of 700 lines, transports around 6.4 million passengers a day [1]. The structure of the fleet consists of: 33% of single vehicle, 62% double-decker and 5% of the articulated. Buses are spent about 240 million litres of diesel fuel per year, which releases exceeding 610 000 tons of carbon dioxide CO₂, which represents about 5% of the total emission. Responsibility than bus

emissions of gases is 6% for coal hydrogen (Cx Hy), 7.7% for micro particles (PM10), and 8% for carbon monoxide (CO) and 9% for oxides of nitrogen (NOx). [1] This high level of emissions, give rise to adopting a series of measures in London, which began to be implemented from 2000. Its aim is to reduce the level of emissions.

Table 1 Manufacturers and types of hybrid buses in the EU

Manufacturers	Type of drive	Energy storage	Size
Evobus	Serial	Li-ion	18 m
MAN	Serial	Ultra capacity	12 m
Volvo	Parallel	Li-ion	12 m
Scania	Serial	Li-ion	15 m
Irisbus	Serial	Li-ion	12-18 m
Solaris	Serial/Parallel	Ultra capacity	12-18 m
Van Hool	Serial	Li-ion	9-10-18-24 m
VDL	Parallel	Li-ion	12 m
Hess	Serial	Ultra capacity	18-24 m
Aleks. Dennis	Serial	Li-ion	10 m (DD)
Tata-Hyspano	Serial	Li-ion	12 m
Castrosua	Serial	Li-ion	9,6-11 m
Wright	Serial	Li-ion	12 m (DD)

Technical Data VOLVO 7700 Hybrid

- Length: 12 000 mm,
- Width: 2 555 mm,
- Height: 3 200 mm,
- Vehicle weight: 18 000 kg,
- Number of doors: 3,
- Number of passengers: 95,
- Hybrid system: parallel Volvo-I-SAM,
- Diesel engine : Volvo D5E, 5 L,
- Power output / torque: 210 hp, 800 Nm,
- Electric motor power output: 160 hp/800 Nm,
- Batteries: Li-ion, and
- Transmission: Volvo-I-Shift automatic.



Figure 9 Volvo 7700 H, AVL- Luxemburg

6. THE MOST IMPORTANT MEASURES

1) Substitution of old buses with diesel-powered, buses with lower emissions that meet Euro 3, Euro 4, and Euro 5. This phase was particularly pronounced during the period 2001-2006 years, according to data from 2010 year, over 76% of buses meet these emission norms. The most significant reduction was achieved in the micro emissions of PM10 [2]. The following Figure 10 presents annual bus trends of emissions (CO₂, NO_x, PM₁₀) for period 2001-2011 and forecasts for period 2012-2018.

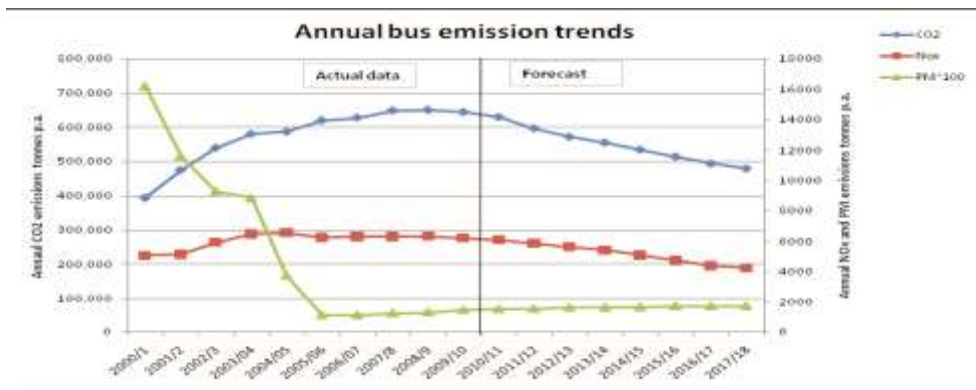


Figure 10 Annual bus emission trends in London (2001-2018 year)

2) The introduction of hybrid buses

Putting into operation of hybrid buses has been a strategically decision that started with the implementation of the 2006 year. Currently, 260 hybrid buses are run every day and London is planning introduction of this type bus, total of 600 buses until 2016 year [2].

The following Table 2, presents the results of comparative testing of 3 different types of buses with diesel-powered buses and equivalent to the hybrid [1] on the central line route 159 (Figure11).

Table 2 Results of tests on the line route 159 (6th February – 5th March 2011 year)

Type of buses	Type of drive	Euro norm	Consumption L/100 km	CO2 (g/km)	NOx (g/km)	PM (g/km)
ADL Enviro 400	Diesel SCR	Euro 4	47.6	1253	6.146	0.035
ADL Enviro 400 H	Hybrid Serial-BAE	Euro 4	32.3	856	4.170	0.024
Wright Gemini 2	Diesel SCR	Euro 5	47.3	1250	3.490	0.025
Wright Gemini 2 H	Hybrid Serial-Siemens	Euro 4	27.7	734	2.04	0.020
Volvo B9TL	Diesel SCR	Euro 4	63.0	1670	4.648	0.046
Volvo B5L	Hybrid Parallel-ISAM	EEV	35.4	937	2.612	0.026

From the table 2 it can be observed that for all three types of buses with hybrid drive have had decline in fuel consumption compared to the same bus with diesel propulsion. As a result of less consumption of diesel fuel is lower emissions of CO₂, NO_x and PM is shown in Table 2.

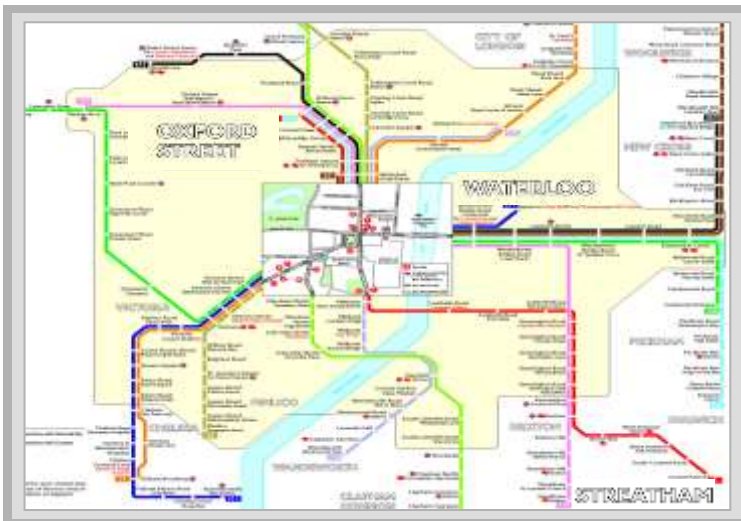


Figure 11 Pink line-Route 159 (Marble Arch - Streatham Station)



Figure 12 ADL Enviro 400 Hybrid

The effect of using hybrid buses from the point of emission reductions are: 76% less emissions C_xH_y, 98% lower CO emissions, 12% lower NO_x emissions, 31% reduction in fuel consumption and emissions of CO₂, 4 dB(A) lower level of external noise. [10]

In addition to the large scale introduction of hybrid buses on the streets of London as the most important measures to reduce emissions and CO₂, coming from the bus subsystems [2]:

- Driver training in fuel-efficient driving,
- Use of bio-fuels,

- Introduction of "shut-down" which excludes diesel engine when the vehicle is in the column, traffic lights, stop location,
- "Retrofit" buses with Euro 3 norm of the CRT to reduced NOx emissions (the period 2012-2015),
- Purchase of new buses with Euro 6 emissions standard (from 2015 to 2018),
- Experimental exploitation buses are driven by fuel cells currently has 8 buses in service.

7. AN EXAMPLE OF THE EXPLOITATION OF HYBRID BUSES IN THE FLANDERS REGION (BELGIUM)

The company "De Lijn" is the largest operator in the Flanders region (Belgium). Performing public transport in the cities of Bruges, Ghent, Antwerpen. Exploitation of buses with hybrid drive were begun since 2008 years and is currently 130 buses " Van Hool " in regular operation. According to the results of the test on bus line No 3, (Table 3), Van Hool AG 300 D for diesel-powered vehicles and identical with hybrid operation in the winter period, the hybrid bus was had the lower fuel consumption from 12.85 to 16.05% [12].

Table 3 *Comparative results of fuel consumption on buses Van Hool AG 300 H and AG 300D*

Period	Van Hool AG 300H L/100 Km	Van Hool AG 300D L/100 Km	%
22/10/-22/11/2010	47.63	55.3	13.8 6
1/1-31/1/2011	49.2	58.6	16.0 5
1/2-28/2/2011	49.81	57.15	12.8 5

The noise level measured on station while bus departure is 82.5 dB(A) for buses with diesel-powered and 72.4 dB(A) with hybrid drive [11].

8. AN EXAMPLE OF THE EXPLOITATION OF HYBRID BUSES IN BARCELONA

Company-TMB-has 25 solo buses with hybrid drive, a serial-type by producer Castrosua-MAN. Trial period was begun in 2008/9 on the two hybrid buses. Since 2010 the fleet of hybrids was increasing. Experiences show that the use of hybrids in city driving conditions generate savings of 20-25% compared to an equivalent diesel bus, while the suburban mode, the difference is 10-15%, table 4 [13].

Table 4 *Effects of reducing fuel consumption in different modes*

MAN - Castrosua	Stop time %	Average speed km/h	Energy saving %
City driving conditions	44	12.1	20-25
Suburban driving conditions	32	25	10-15

Interestingly, note that TMB has in service 370 buses powered by CNG. They are planning that some of CNG buses should be reconstructed, installation of equipment Generator-Electric motors and other components and will become buses with Hybrid CNG-powered.

9. FURTHER DEVELOPMENT OF THE CONCEPT OF HYBRID BUSES FOR PUBLIC TRANSPORT

Buses with hybrid drive have been gaining increasing importance in many EU companies and cities, thanks to its advantages in energy efficiency and emissions of CO₂, compared to a conventional bus. However, the hybrid concept has certain shortcoming which slows massive use especially in less developed countries and cities. The perceived disadvantages are:

- High cost of hybrid buses (higher by 50% compared to the same bus with a diesel-powered),
- Battery life and their price (at present battery technology limits their lifespan to 6-7 years, after which it is necessary to replace the battery, which increases the costs),
- The greater weight of buses,
- Specific maintenance (two engines, highly sophisticated technology, precautions 600 V),
- Additional training for drivers and maintenance workers.

Power, Torque and Fuel consumption

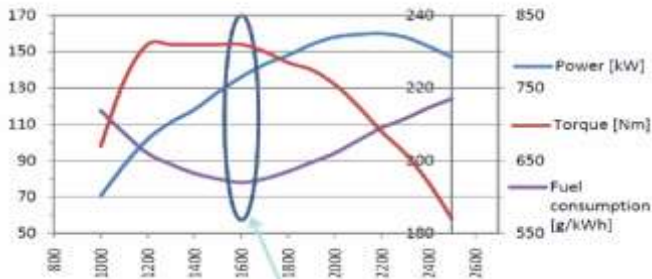


Figure 13 Optimal mode of serial hybrid "Citaro" [14]

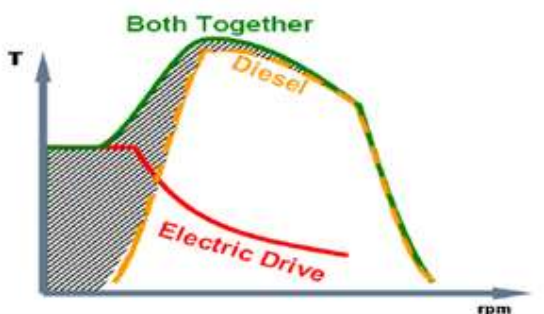


Figure 14 Parallel hybrid concept "Volvo" [8]

For most of the hybrid buses depending on the system drive (serial or a parallel) in real operating conditions, it is necessary to review all the influential weights (speed,

intensity of passenger flows, terrain ...) on routes where vehicles with hybrid drive working. From that very much depends on the choice of the most suitable vehicle and therefore the effects of use. Figure 13 shows an example of the optimal mode serial-type hybrid Citaro G BlueTec. Figure 14 shows the characteristics of torque for parallel hybrid concept Volvo 7700 H.

In the next period, hybrid buses will have permanent development and improvement as an alternative of diesel buses.

- Improving battery technology that will allow to keep the battery life of 10-12 years, which is approximately the service life of the vehicle,
- Increasing the capacity of the battery which will allow greater autonomy in electric mode, the vehicle,
- At the moment capacity Li-ion battery is 85 Wh / kg. It is expected that in 3-4 years capacity will be about 170 Wh / kg,
- Optimize components of the hybrid propulsion and auxiliary equipment on the vehicle,
- Higher capacity batteries enable supplementing " plug in" while the vehicle is stationary at the station or terminus and thus reduce to a minimum the use of diesel engine, and
- Reducing vehicle weight. By using lighter composite materials, tends to reduce vehicle weight by 1000 kg. This would have the effect of a 7% increase in the efficiency of hybrid buses.

10. CONCLUSIONS

Exploitation of hybrid buses in many EU cities is a significant improvement of the transport system of the city, especially in terms of environmental protection, energy efficiency and quality of transport. Experiences in EU cities that use this concept were contributed to identify possible specifics compared to diesel buses, especially in terms of reducing fuel consumption, environmental benefits as well as future trends in the development and promotion of the hybrid concept.

In the period 2011 - 2020 years hybrid buses will significantly contribute to the sustainable development of cities, as the first phase in the use of electric drive, which will be primary in all vehicles for road transport, in a future.

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