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The possibilities of reducing emission pollutants of exhaust from city buses by the use of biomethane

Abstract: Depletion of fossil energy sources, and thus the prices increase of conventional fuels such as gasoline or diesel fuel, the energy security and dependence on imported fuels, as well as the deteriorating environment and global warming mean that there are more and more new technologies using renewable energy sources nowadays. In the medium- and long-term perspective a significant changes are needed regarding means of transport in ensuring "sustainable mobility". A solution is the implementation of biofuels, including biogas refined to form of biomethane, and renewable alternative fuels. Biomethane is produced from waste organic matter. Directive 2009/28/EC indicates the benefits of using waste for the production of transport fuels, to decarbonisation of the energy sector and requires Member States of UE to use renewable fuels. The paper presents possibilities of reducing contaminants in exhaust gases emitted by public transport buses as a result of the use of biomethane to power them. In view of the fact that biomethane is a chemical equivalent of compressed natural gas (CNG), there will be specify a condition of CNG infrastructure in Poland, the state of fleet of CNG buses, CNG filling stations and biomethane production potential from municipal resources in the case of Polish cities using bus public transport.

Keywords: CNG, biogas, biomethane, refueling station, city buses

Możliwości ograniczenia emisji zanieczyszczeń spalin z autobusów miejskich przez zastosowanie biometanu

Streszczenie: Wyczerpywanie się zasobów kopalnych źródeł energii, a co za tym idzie wzrost cen paliw konwencjonalnych takich jak benzyna czy olej napędowy, bezpieczeństwo energetyczne oraz uzależnienie od importu paliw, jak również pogarszający się stan środowiska i efekt cieplarniany powodują, że powstaje coraz więcej nowych technologii wykorzystujących odnawialne źródła energii. W perspektywie średnio- i długoterminowej niezbędne są istotne zmiany dotyczące środków transportu w zakresie zapewnienia „zrównoważonej mobilności". Rozwiązanie stanowi wdrażanie biopaliw, w tym biogazu oczyszczonego do postaci biometanu, oraz odnawialnych paliw alternatywnych. Biometan otrzymywany jest z odpadowej masy organicznej. Dyrektywa 2009/28/WE wskazuje na korzyści związane z wykorzystywaniem odpadów do produkcji paliw transportowych, celem dekarbonizacji sektora energetycznego i zobowiązuje państwa członkowskie UE do stosowania paliw odnawialnych. W zgłoszonym artykule została przeanalizowana możliwość ograniczania zanieczyszczeń w spalinach emitowanych przez autobusy komunikacji miejskiej w wyniku zastosowania biometanu do ich zasilania. W związku z tym, że biometan stanowi chemiczny odpowiednik sprężonego gazu ziemnego (CNG), określony zostanie stan infrastruktury CNG w Polsce, stan taboru autobusów zasilanych CNG, stacji tankowania CNG oraz potencjał produkcji biometanu z surowców komunalnych w przypadkach polskich miast wykorzystujących autobusową komunikację miejską.

Słowa kluczowe: CNG, biogaz, biometan, stacja tankowania, autobusy miejskie

1. Introduction

In the world there were 10 mln natural gas vehicles in exploitation in 2009. In 2012 there were more – abort 16 mln units, which accounted abort 1,2% of the fleet. Number of NGV buses in the world were almost 270 000 units, and in 2012 – almost 700 000 units [1].

Most NGV vehicles were registered in 2009 in Pakistan (over 2.1 mln units, and more than 2.9 mln in 2012), Argentina (nearly 1.8 mln, and more than 2.1 mln in 2012), Brazil (about 1.6 mln, and app. 1.7 mln in 2012) and Iran (1.5 mln, and about 2.9 mln in 2012) [1].

The leader in Europe is Italy, where there was registered almost 590 000 NGV vehicles in 2009 (in 2011 almost 750 000). In Germany were registered almost 84 000 (95 000 in 2012), and in Bulgaria more than 60 000 NGV cars (61 000 in 2012). In Poland the number of NGV vehicles amounted to 1.8 000 in 2009 (similar to 2012). [1]

Most of around 113 000 of NGV buses were registered at the end of 2008 in China (in 2012 already 229 000). In Colombia, about 14 000 NGV buses were in exploitation in 2012, in India about 12 000 (over 23 000 in 2012) in Armenia about 10 000 (over 17 000 in 2011). [1]

Among the European countries the most of NGV buses are operated in 2011 in Italy - about 2 300, followed by France - about 2 100 (about 2 400 in 2012), Germany about 1 500 in 2012. In Poland, at the end of 2009, the total on NGV buses was about 300 registered ones (288 in 2011). [1]

The numbers above indicate the changes in the CNG fleet in the world in the past few years. Without a doubt, the number of those vehicles steadily increasing.

According to the ENGVA forecast, in 2020 in Europe may be operated close to 70 000 of regional buses, about 23 000 city buses, about 150 000 trucks, 450 000 taxis, 7 600 lorry vehicles and more than 15 000 000 passenger cars powered by natural gas. [2]

In many countries there were implemented various financial incentives to stimulate investment in CNG vehicles.

In August 2010, in Poland there was 277 CNG buses handle passengers in 21 Polish cities, grouped in 23 companies (Dębica 6 units, Dzierżoniów 4 units, Elblag 11 units, Gdynia 14 units, Inowrocław 10 units, Komorniki 2 units, 5 units in Krakow, 2 units in Lublin, 7 units in Mielec, Mysłowice 8 units, Oława 1 unit, Przemyśl 15 units, 39 units in Radom, Rzeszow 40 units, Słupsk 5 units, Tarnow 32 units, Torun 3 units, Tychy 18 units, Wałbrzych 33 units, Wrocław 4 units, Zamość 18 units) [3]. Currently, there are changes in this respect exemplified by the number of CNG buses in Rzeszow (almost doubling their number) and the restructuring of the fleet in Wałbrzych, to some extent, limiting the number of such buses.

By the end of April 2009, there were 30 public CNG stations in Poland (at the end of November 2011, there was 32 [1]). In addition, compressed natural gas was available in several non-public refueling stations (at the end of November 2011 there were 14 CNG refueling stations [1]), that is service stations, only for the group of vehicles (fleets, public transport). Twenty-nine of the thirty public stations was owned by GK PGNiG, the only station outside the PGNiG Group is owned by NGV Autogas and it is located in Krakow, Siewna Street. There are private stations, among others in Przemyśl (MPK in Przemyśl), Krosno, Zgorzelec and in factories such as FIAT or Cersanit.

Distribution of CNG stations on Polish territory is uneven - they are heavily concentrated in south-east and south-west of Poland. Network of CNG refueling stations in the north and center of the country is relatively poorly developed. Distribution and the territorial coverage of the existing public CNG stations in Poland are presented in Figure 1 [4].

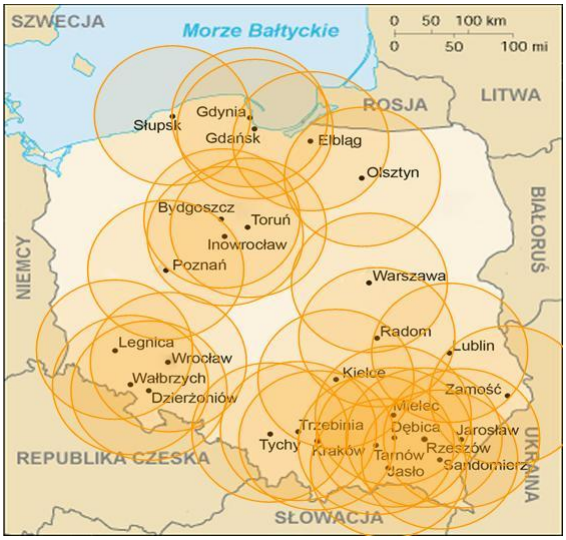

Fig.1. Territorial scope of public CNG refueling stations in Poland [4]

CNG refueling stations are located near roads, of which about 20% is located directly on the roads. Virtually none of the stations are located along the expressways or motorways.

The existing infrastructure in Poland in the field of CNG filling stations is insufficient and the lack of availability of fuel is one of the key barriers to NGV market development and demand for CNG. According to expert estimates, for a 10% share in the fuel market for passenger vehicles is necessary to provide opportunities for CNG filling up in every fourth refueling station in Poland. The increase in the availability of CNG fuel can be done by placing this fuel to offer in existing stations (such as in Germany, where the sale of CNG is on some stations belonging to the Polish Oil Concern Orlen). Chance to popularize CNG is raised by the adopted in 2010 "Strategy of the PGNiG Group in the development of the natural gas market for vehicles

(CNG)". The selected strategy option implied the company commitment to develop the CNG market in Poland, followed by activities for regulatory changes and promotions of CNG. In case of fail of the previous project to the above-mentioned project, PGNiG may begin to withdraw from the market or maintain its current state. The least profitable refueling stations will be closed. This solution is not too optimistic, but it gives a chance to use the biogas produced in the biogas plants and upgrading plants, where biogas is cleaned to the quality of natural gas (Biomethane). The condition of usefulness of biogas produced by the biogas plant after its purification as a motor fuel, will be its location. Installations that are near major cities and transportation routes will achieve the greatest success.

2. Biogas (biomethane) characteristics

The definition of biogas is provided by Directive of the European Parliament and of the Council 2009/28/WE [5] 23 April 2009 according to promotion the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/WE[6] and 2003/30/WE[7]. According to this document biogas is gas from landfills, sewage treatment plants and from biological sources. It is a gas produced from biomass and/or from the biodegradable part of waste that can be purified to a level corresponding to the quality of natural gas, for use as a biofuel or gas fuel.

Biogas is a mixture of methane (CH_4) and carbon dioxide (CO_2), in admixture with small quantities of hydrogen sulphide, nitrogen, oxygen, hydrogen and other substances. Biogas is a gas produced by microorganisms of the organic matter as a result of the methane fermentation in anaerobic conditions.

Biogas is produced in agricultural biogas plants, in the landfills and sewage treatment plants (Photo 1-3).

Photo 1. Agricultural biogas plant in Uniechówek, Poland
(Source: poldanor.com)

Photo 2. Farm based (crops) Örebro, Sweden
(Source: SL, Sweden**)**

Photo 3. Waste water treatment plant in Stockholm, Sweden
(Source: SL, Sweden)

Biogas can also be produced by a thermal-chemical gasification, which is a process where the biomass and organic waste, after heated with a limited amount of oxygen, the organic matter is resolved and gases such as carbon dioxide, hydrogen, water vapor, carbon monoxide and methane are formed. Biogas produced in this way is called a Bio-SNG (Bio- Synthetic Natural Gas.) This technology does not always among the technology of biogas production [8].

Biogas purification technologies allow for the removal of water, hydrogen sulfide, oxygen, nitrogen, ammonia and siloxane particles. It's resulting in the increase of biogas calorific value by the removal of carbon dioxide. It shall also include odorization and compression of biogas [9]. The current biogas purification technologies are as follows: water scrubbing (Pressurized Water Scrubbing - PWS); water flushing (or using certain technology Genosorb washing liquids); Pressure Swing Adsorption (PSA); Chemical adsorption (Amine Washing Technology), separation membrane; cryogenic fractionation [9]. As a result of these processes is obtained biomethane. Photos 4-6 show the purification of biogas installations in Sweden and Norway.

Fot. 4. Biogas upgrading installation in Oslo, Norway

Fot. 5. Upgrading in Örebro, Sweden (Source: SL, Sweden)

Fot. 6. Upgrading in Uppsala, Sweden (Source: SL, Sweden)

Biomethane can be directly used in spark-ignition engines as CBG (Compressed Biomethane Gas) and LBG (Liquid Biomethane Gas) obtained with the use of technologies such as teracastus [10], as is the case in Sweden, or can be directly injected into the natural gas network (Germany) Fig. 2.

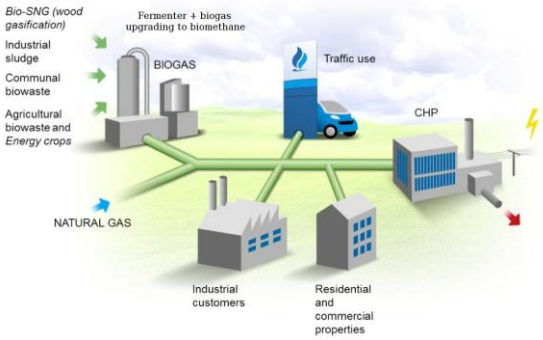

Fig. 2. Injection of biomethane into the natural gas network [9]
(Źródło: Gasum)

3. Production potential of biogas in Poland and Sweden

Table 1 provides a summary of the potential of biogas production in Poland and Sweden (European leader in the use of biomethane buses) under different scenarios. After analyzing the data presented in Table 1, the values that characterize the potential of biogas production for Poland and Sweden, the countries participating in the implementation of the European project Baltic Biogas Bus (BBB), the maximum values were accepted. Table 1 shows that in Poland there is significant potential for the production of biogas. It is significant even in the case of using only 20-25% of the potential for the transport bus, taking into account that in the country in 2009 (in enterprises and public transport facilities employing more than 9 persons) the inventory of buses for urban transport amounted to 11 755 vehicles and 100 buses for operation annually, the biogas production is at a level of about 6 mln Nm^3. In Sweden, already a significant number of city buses is powered by biogas (biomethane). For example, only in Stockholm in 2011 there was 230 buses powered by biomethane.

Table 1. Production potential of biogas in Poland and Sweden

Type of biogas		Country	
		Poland	Sweden
Biogas from agriculture	Percentage of total potential of biogas production	69%	76%
	Biogas production potential from agriculture [bn m^3/a]	2,0-5,5[1/]	1,75-2,13 *(7,04)*[3/] (4,56-5,01)[2/]
Biogas from landfills	Percentage of total potential of biogas production	27%	10%
	Biogas production potential from landfills [bn m^3/a]	0,796	0,23-0,28 *(2,3)*[3/] (0,60-0,66)[2/]
Biogas from sewage treatment plants	Percentage of total potential of biogas production	4%	14%
	Biogas production potential from sewage treatment plants [bn m^3/a]	0,0969	0,32-0,40 *(0,53)*[3/] (0,84-0,92)[2/]
TOTAL	Total production potential of biogas [%]	100%	100%
	[bn m^3/a] and [PJ/a or TWh/a	2,9-6,4 (22,8)[1/]; 52,3-115 PJ (410,4 PJ)[2/]	2,3-2,8 *(9,87)*[3/] [(14-17)[2/] TWh; (50,4-61,2)[2/] PJ] *(214,8 PJ*[3/] *(6,0-6,6)*[3/] [(35-40) TWh; (126-144) PJ)][2/]

[1/] wg [9]

[2/] wg Swedisch Association of Gas

[3/] in case of Sweden, the maximum values of biogas production potential resulting from the analysis was indicated by italics

4. Production potential of biogas (biomethane) from municipal sources for city transport needs in Polish cities

In Polish cities there is quite significant potential for production of biogas (biomethane) from sources such as municipal wastewater treatment plants and landfill. This amounts is nearly 0,9 bn m^3 of biogas [9].

So far in Poland, there are 76 wastewater treatment plants and 94 municipal landfills that have biogas plants, and sewage sludge as organic waste [9]

The largest biogas plants of this type exists in the bełchatowski county (3.3 MW), piaseczyński county (3.47 MW), człuchówski county (4.14 MW) and Siemianowice Slaskie (3.42 MW) [12].

Many Polish cities already uses buses powered by compressed natural gas (CNG), which can also be supplied with purified biogas (biomethane). These cities are listed in Table 2.

Table 2. Production potential of biomethane for city transport needs in Polish cities, based on existing infrastructure for biogas production [12]

City	Current number of buses [units]	The total capacity of the installation [MW]	Amount of biomethane possible to produce with the use of the existing infrastructure [mln m^3]	The maximum possible number of buses powered by produced biomethane [units]
Tychy	47	1,446	3,3	92
Rzeszów	40	1,010	2,3	64
Radom	39	0,64	1,5	41
Zamość	32	0,19	0,42	11
Tarnów	29	0,352	0,8	22
Wałbrzych	26	1,75	4	111
Przemyśl	19	0,34	1,3	21
Gdynia	14	4,167	9,5	265
Mielec	10	0,192	0,7	12
Inowrocław	10	0,320	0,72	20
Słupsk	10	1,233	2,8	78

Most buses are operated in Tychy (47 units), Rzeszow (40 units) and Radom (39 units). The greatest potential for the production of biogas (biomethane) has, however, Gdynia with the total power of biogas production about 4,167 MW in existing plants. In other cities, the potential for biogas production due to the existing infrastructure to produce biogas is the highest ain Wałbrzych and Tychy. Biogas production potential in these cities is sufficient respectively 111 and 92 buses powered only by biomethane from municipal sources [12].

5. Ecological aspekt of natural gas usage (biomethane) in bus city transport

The compressed biomethane is a fuel with parameters of compressed natural gas (CNG) fuel but in general is almost fully renewable. Previous results of studies of ecological properties of city buses run by VTT [11], among others in Braunschweig test indicates that currently:

- buses with spark-ignition engines powered with CNG-stoichiometric mixture, EEV emission level, characterized by the emission of NOx, as well as the PM, less than buses powered with diesel with self-ignition engines, EEV emission level (Fig. 3):
- buses with spark-ignition engines supplied by CNG, EEV emission level are additionally characterized by higher stability of emission during exploitation in comparison to the buses with self-ignition engines supplied by diesel,
- buses with spark-ignition engines powered with CNG, are characterized by very low emission of PM,
- use of CNG to power bus engines is making possible to achieves a small number of particles, low emissions of aldehydes and polycyclic aromatic hydrocarbons (PAH) Fig. 4-6, and low emission of NO_2,
- disadvantage of using CNG to power the spark-ignition engines of buses is higher energy consumption by the engines of these vehicles compared to the energy consumption of the self-ignition engines driving the bus.

CNG bus engines works much quieter than diesel powered engines. This is important

especially in the densely built-up cities with heavy traffic. Conducted studies confirm the reduction of the noise level for buses supplied by CNG in the range (1-3) dB.

Fig. 7 shows that the tested in the Braunschweig test, the best in terms of carbon dioxide emission buses powered by engines fueled with diesel as well as powered by engines supplied by CNG are characterized by the road emission of carbon dioxide at 1100 g/km [11]. However, we must remember that the biomethane fuel is almost fully renewable and in this respect, carbon dioxide emissions is almost zero.

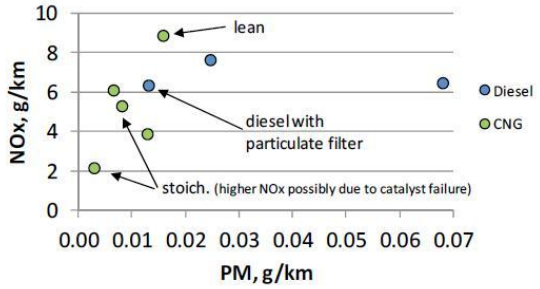

Fig.3. Road emission of particle matter and nitrogen oxides from city buses in Braunschweig cycle [11]

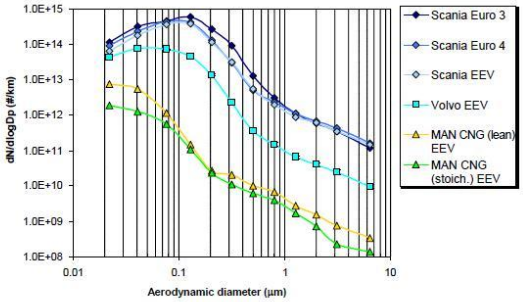

Fig.4. Road number of particulate matter from city buses in Braunschweig cycle [11]

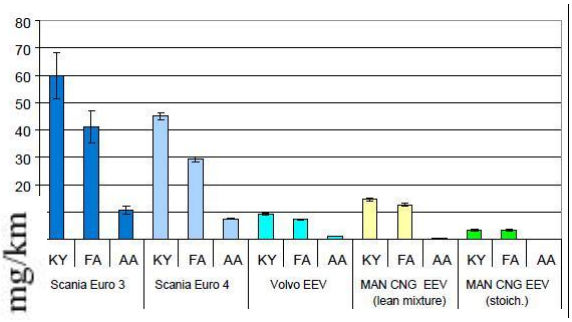

Fig.5. Emission of aldehydes from city buses in Braunschweig cycle [23]

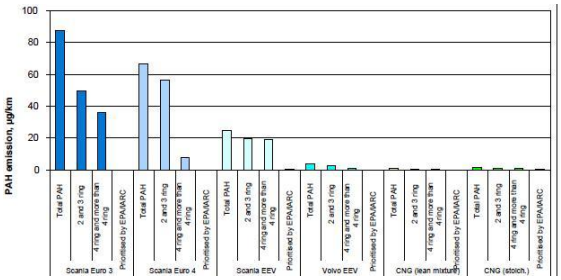

Fig.6. Emission of polycyclic aromatic hydrocarbons from city buses in Braunschweig cycle [11]

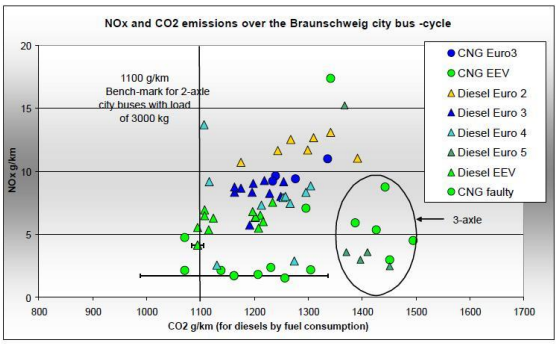

Fig.7. Emission of nitrogen oxides and carbon dioxide from city buses in Braunschweig cycle [11]

6. Summary

Presented data are indicate that the use of bio-methane, as a fuel being almost fully renewable, to power engines of city buses, is preferred for reducing the exhaust emissions of polluting substances, in comparison to the emission of pollutant gases in conventional diesel engines which power these buses. According to carbon dioxide emissions, in the case of biomethane, which is a renewable fuel, throughout the life cycle, i.e. from the source of its acquisition to the "wheels", is practically not present. Therefore, the authors of the article, carried out in cooperation with the European Baltic Biogas Bus project promotes the use of biomethane as a fuel for engines in bus city transport. Significant potential for biogas production in Poland will allow, after the upgrading, for the use of biomethane in principle to supply the engines of all public transport buses in the country.

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