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Swedish Urban Transport Model Powered by Biomethane

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In the recent years, the European Community has been implementing a plan to increase the share of renewable fuels used for energy production and powering vehicles. It aims to partially reduce the dependence on crude oil imports and reduce CO_2 emission. Particularly interesting are the achievements of Sweden against this background, for which the European Commission has set the highest value of the indicator, and to implement which Sweden adopted unconventional solutions across Europe. One of them is the plan to eliminate by the 2030 fossil fuels from the urban transport, and one of the fuels that is to replace today still widely used diesel oil, would be biomethane. The article describes the reasons and circumstances which made Sweden use biomethane to power buses used in urban transport on a very large scale, in comparison with other European countries. The article shows the characteristics of this fuel, the method of its production and application prospects.

Keywords: urban transport, alternative fuels, biomethane

1. INTRODUCTION

One of the greatest achievements of the European Community is to make a coordinated effort by the Member States to improve the environment and fight the sources of pollutant emissions causing danger to the environment. The long-term EU policy in this field assumes significant reduction in pollutant emissions in the future, compared to today's level. Assumptions of the overall plan to reduce pollutant emissions at the scale of individual countries and those distributed among the individual industries differ between each other. In the case of the road transport sector, the main sources of pollutant emissions are combustion engines and their noise.

The improved for many years system to limit the pollutant emission from the exhaust systems of vehicles has been based on the type-approval tests of a vehicle or an engine, in which the tested object had to be characterized by the emission lower than required. This adopted model of admitting the vehicle to the commercial circulation was convenient for the manufacturer because it allowed to introduce to the market every vehicle meeting the requirements of the regulations. This system ignores however the situation in which the accumulation of too many sources of pollutant emissions in one place (even meeting the applicable regulations) may lead to the occurrence of the areas with dangerous concentrations of toxic components of exhaust gases around transport routes and pose a threat to human health in the immediate vicinity to the streets of heavy traffic.

The problem came to prominence at the turn of the century, when on the one hand, the number of vehicles in traffic continuously increased, on the other hand, the development of toxicology and medical sciences allowed to link the incidences of some civilization diseases with pollutant emissions from the exhaust systems of vehicles. In particular, this concerned the emission of particulates and nitrogen oxides. Both of these components are formed in diesel engines and till the introduction of the EURO VI limits constituted a major problem in the development of the automotive industry. Reports of the World Health Organization clearly evaluate the relationship between particulate matter emissions and the increased risk of incidences of cancer.

In the spark-ignition engines a technology of purifying exhaust gases was mastered quite early through the use of triple action catalytic converters and supplying the engine with the air-fuel mixture of stoichiometric composition. In the diesel engines, for many years, it was impossible to find an effective way that would result in a significant reduction of NO_x emissions in the exhausts. A similar case concerned the particulate matter emissions, where for many years the decision was delayed to reduce the allowed emissions of this exhaust component to such a level that would require the use of particulate filters. This state of affairs meant that in the countries really cared about the environment there has been an increased interest in urban transport technologies used in spark-ignition engines. As an alternative to the diesel engine powered city bus they begun to see a bus powered by spark-ignition engine running on compressed natural gas.

2. BIOMETHANE - IDEAL FUEL FOR URBAN TRANSPORT

Natural gas mainly consisting of methane is a very environmentally friendly fuel. It can be used to power the engine as an alternative to the diesel engine and allows - compared with diesel engines - to virtually eliminate emissions of particulate matter from the exhaust gases, reducing NO_x emissions and eliminate toxic non-methane hydrocarbons (NMHC) from the exhausts. In the engine powered by methane the hydrocarbons contained in the exhaust gases are largely also methane, and thus the exhausts contain only traces of hydrocarbons considered toxic. Among the hydrocarbons emitted by compression ignition engines there are benzopyrenes or cyclic hydrocarbons considered to be carcinogenic.

With a larger mass fraction of hydrogen in the methane molecule than in the molecule of diesel oil, among the oxidation products of this fuel the greater part takes water vapour in relation to the concentration of CO_2. That means that among the products of incomplete combustion of methane, concentration of CO will be less than in the combustion of diesel fuel. Also, in the diesel engine, thanks to lower pressure in the cylinder, the noise emission intensity is reduced by several dB.

The only drawback to the petrol engine is its efficiency. This engine is inherently less efficient than the diesel engine. This is a factor which, on the one hand, affects the increase of CO_2 emissions. On the other hand, a larger share of hydrogen in methane is a factor contributing to reducing CO_2 emissions. In practice, both of these phenomena usually compensate each other and we have to deal with minor differences in CO_2 emissions between CNG powered buses and the diesel ones. Of the two possible concepts of supplying the engine with natural gas: the engine burning fuel-air mixture of stoichiometric composition and the engine burning a lean mixture, the latter has a slightly lower fuel consumption.

The problem of CO_2 emissions takes on a new dimension when we try to substitute the CNG and diesel with renewable fuels. In the case of CNG its renewable substitute will be bio-methane, which can be mixed and which can substitute CNG in any proportion. Bio-methane can be obtained by the anaerobic fermentation of organic compounds. Then biogas is obtained, containing approx. 60% methane, which for the purpose of becoming a motor fuel is then purified in the so-called upgrading process to the methane content above 96%. On an industrial scale biogas can be obtained in the fermentation chambers or, for example by degassing landfills.

In the case of diesel oil its renewable substitute are mostly methyl esters of rapeseed oil. However, this is a fuel different from diesel oil and because of its properties should be added to the diesel fuel in the amount of a few percent. The use of RME in particular reduces the durability of exhaust aftertreatment systems.

Biomethane is an attractive fuel for urban transport. In addition to the above properties, it alone has this feature, that for its production is used primarily organic waste likely to come from households, sewage treatment plants, food processing, dining, agriculture and husbandry, waste from green areas, etc. Its production does not require adequate acreage prepared for agriculture or relevant climatic conditions, such as in the case of rape. It is therefore a strategically good fuel and in terms of environment, as it allows, at least partly, to make the domestic fuel market independent of fuel imports especially from politically unstable regions. An important part of this puzzle, in line with the strategic character of urban transport, is the local nature of the fuel. In its distribution costs, the distance of the bio-methane producing source from the fuel station distributing it, plays an important role. Swedish examples show that a city of 100 000-200 000 (Lingkoeping [1], Oerebro) can, from its own organic waste, produce so much biogas that it is enough to power the entire city bus fleet.

The Directive of the European Parliament and of the Council - 2009/28/EC of 23 April 2009. *On the promotion of the use of energy from renewable sources* [3] established, for all the Member States, the national indicative targets by the 2020, setting the percentage of biofuels and bio-components in the fuel market of the country concerned (Table 1). On average in the 2005-2020 period the share of renewable energy and the use of biofuels are expected to increase by several percent in each of the Member States. While analysing the data contained in the Table 1, our attention is drawn by the fact that on the day of the entry into force of this Directive, the Member States were marked by significant disparities in the share of renewable energy in their economies and different biofuels use. Scandinavian countries have special position in the field of energy production from renewable sources. If the Table 1 contained also Norway, then with its energy industry producing mainly electricity in the hydroelectric plants it would take a high position in the clean energy production ranking.

Among the European Community countries the absolute leader in the field of renewable energy use is Sweden.

Table 1. National targets for the share of renewable energy

	The share of energy from renewable sources in gross energy consumption in 2005	**Target share of the energy from renewable sources in gross energy consumption in 2020**
Belgium	2.2 %	13 %
Bulgaria	9.4 %	16 %
The Czech Republic	6.1 %	13 %
Denmark	17.0 %	30 %
Germany	5.8 %	18 %
Estonia	18.0 %	25 %
Ireland	3.1 %	16 %
Greece	6.9 %	18 %
Spain	8.7 %	20 %
France	10.3 %	23 %
Italy	5.2 %	17 %
Cyprus	2.9 %	13 %
Latvia	32.6 %	40 %
Lithuania	15.0 %	23 %
Luxembourg	0.9 %	11 %
Hungary	4.3 %	13 %
Malta	0.0 %	10 %
The Netherlands	2.4 %	14 %
Austria	23.3 %	34 %
Poland	7.2 %	15 %
Portugal	20.5 %	31 %
Romania	17.8 %	24 %
Slovenia	16.0 %	25 %
The Slovak Republic	6.7 %	14 %
Finland	28.5 %	38 %
Sweden	39.8 %	49 %
The United Kingdom	1.3 %	15 %

3. SWEDEN - EUROPEAN LEADER IN THE USE OF RENEWABLE FUELS

The fact that Sweden has become the European leader in the use of renewable fuels was influenced by many factors. First of all, for many years successive governments of Sweden have pursued policies to reduce the economy's dependence on fuel imports, significantly ahead of the policy guidelines of the Union in this regard. This resulted in multi-annual programs to reduce imports of fossil fuels.

According to the Swedish Energy Agency [4, 5], the structure of energy consumption in Sweden (Tab. 2) includes a 22% share of renewable fuels in the energy balance of the country. Coal and its derivatives cover only 4% of the demand for energy. Even smaller share in the energy balance falls on natural gas (1.6%). This is due, among the other things to the underdeveloped gas network in Sweden, the lack of own sources of natural gas and the lack of cross-border gas network connections allowing easy transportation of gas. With 368 TWh of energy consumed per year in Sweden, 85 TWh (23%) falls on transport. The structure of energy used in transport is presented in the Table. 3.

The Swedish plans, in addition to complying with the EU provisions for the use of nearly 50% of energy from renewable sources in Sweden, additionally by the year 2030, have set an ambitious goal of eliminating fossil fuels used by public transport and the introduction in 2050 of zero-emission vehicles. This follows forcing limiting, to 50%, of the NOx and PM emissions for the fleet of vehicles in the years 2008-2020 [2]. According to the so-defined lines, the urban transport operators in Sweden begun to implement these tasks. It was relatively easer to decide on the use of biomethane, bioethanol and biodiesel as motor fuels for the urban buses. However, under Swedish conditions, bioethanol and biodiesel were still largely imported fuels, and thereby unreachable for the domestic market in the required amount. Biomethane did not have these disadvantages.

In Sweden in 2012, there were 233 biogas plants producing biogas [6], which is nearly three times more than in Poland. The biogas production program began there in the fifties of the twentieth century and it was guided by the desire to utilize municipal waste. A characteristic feature of the Swedish program in a European context is that the biogas produced in majority, as purified biomethane, is used to power internal combustion engines. In Poland, the entire produced biogas, which could be sold on the market as an energy carrier, is earmarked to produce electricity in a cogeneration process. This is the result of old-fashioned Polish energy industry based on fossil fuels, which in order to meet EU regulations on the use of renewable fuels, needs large quantities of these fuels. In Sweden, where fossil

Table 2. Structure of the energy consumption in Sweden in 2014

Type of energy carrier	Energy consumption [TWh]
Biomass	81
Coal and coke	15
Crude oil products	92
Natural gas and coke oven gas	6
Other fuels	5
Central heating	49
Electrical energy (nuclear, hydro, wind)	120
In total	368

Out of the 13-percent share of biofuels in the transport sector, 16% accounted for bioethanol, 73% for biodiesel, and only 1% for biomethane. Statistically, it looks that biomethane is a marginal fuel for transportation purposes. But this is not the case, as in fact, due to the location of the biomethane filling stations its use is restricted to the southern part of the country, and also it was used especially in urban transport.

Table 3. The share of different fuels in the Swedish transport in 2014

Type of fuel	Share in transport [%]
Biofuels	13
Fuel derived from crude oil processing	83
Natural gas	1
Electric power	3

fuels are not used for the production of electricity, the biogas produced can be allocated to power vehicles in greater quantities, and an additional financial incentive scheme favours this type of fuel, due to, among the others, lower CO_2 emissions. Fig. 1 shows that 57% of the biogas produced in Sweden is destined for the fuel market for transport means, and only 4% for the electricity production. On the motor fuels market the compressed biomethane slowly begins to replace CNG. For several years now Swedish market recorded stagnation of the CNG consumption level while the biomethane consumption is constantly increasing.

Poland has good conditions for biogas production on a much broader scale than it is in Sweden. In particular, great potential lies dormant in the domestic agriculture, which could contribute to the intensification of the production of biomethane.

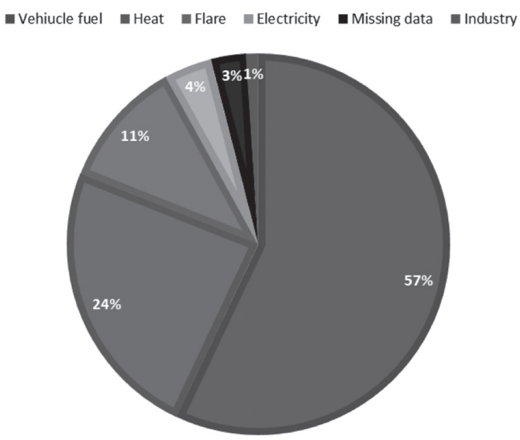

Fig. 1. Purpose of the biogas produced in Sweden in 2014.

County	
Skåne:	464
Västa Götaland:	178
Stockholm:	129
Östergötland:	120
Örebro:	61
Uppsala:	40
Västmanland:	40
Halland:	37
Södermanland:	20
Kalmar:	16
Jönköping:	9
Kronoberg:	9
Gävleborg:	5
Gotland:	4
Norrbotten:	4
Västerbotten:	4
Total:	**1.140**

Fig. 2. Number of biomethane powered buses operated in Sweden in 2010 [2]

In 2010 among 9,283 urban transport buses running in Sweden, there were 12% of buses adapted to run on methane (biomethane or natural gas) [2]. In 2013, this percentage increased to 17% [7] and it is the highest such indicator among European countries. Buses adapted to run on biomethane operate in 30 Swedish cities. Fig. 2 shows the regions in Sweden where one can find buses powered by biomethane.

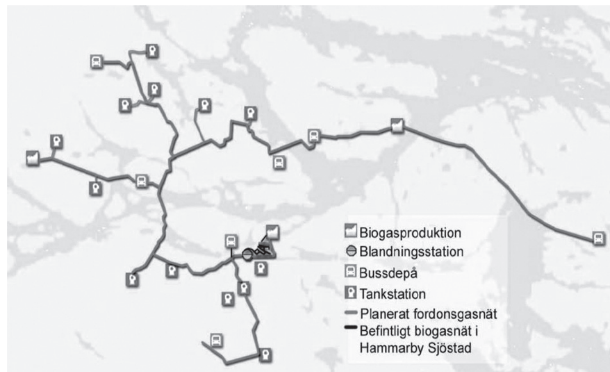

Fig. 3. The planned biomethane network in Stockholm [9]

The specificity of the Swedish model of the development of urban transport powered by methane lies in the fact that the Swedish authorities came to the conclusion that in the next few years this is, for a series of reasons, the best fuel for this type of transport: ecological, satisfactory in terms of engine performance, renewable, produced on site, enabling to resolve the problems of accumulation of waste, and possible to be used in standard buses adapted to run on CNG. Due to the lack of the developed gas network in Sweden [8], which - as in Germany - would allow the biomethane producers to inject it into the national network of natural gas, in Sweden there were consortia created in the cities, coordinated by the municipal authorities, and consisting of urban transport operators on the one hand, and the biogas producers (urban sewage treatment plants, landfills, biogas plants using a substrate of agricultural origin) on the other. These entities have joined their facilities with the pipelines, often several kilometres long, and made the biomethane produced to be delivered to the local bus depot and used for refuelling buses. This way, the bus transport has developed, among the others, in Stockholm, Vesteras and Oerebro.

Plans for the Stockholm SL operator envisaged for 2016 a fleet of 385 buses powered by biomethane from three interconnected pipeline plants. Adjacent to the planned pipeline there were to be located 7 bus depots and 13 public biomethane filling stations [9]. These plans (Fig. 3) have already been partly realized, because they were divided into three steps involved in the construction of each of the biogas plants and the first two stages have already been completed.

Fig. 4. Distribution of CNG and biomethane filling stations in southern Sweden

In Sweden in 2012 there were 136 CNG/ biomethane filling stations operating (Fig. 4) located in the overwhelming majority in the south of this country. This number is several times greater than the number of CNG stations existing in Poland. One can observe a certain convergence between the location of gas infrastructure (Fig. 4) and the number of biomethane powered buses operated (Fig. 2). The specificity of Sweden is that these stations distribute CNG or bio-methane, or both fuels at the same time.

In Poland, the Motor Transport Institute intends to launch soon the country's first public biomethane fuel filling station located at the landfill in Niepołomice. Currently there are last arrangements being made before opening it. Poland has great potential to intensify the production of biomethane [10-19] and should make an effort to expand the production of this fuel.

4. CONCLUSIONS

Years of Swedish experience have shown that the purified biogas to biomethane quality is a good renewable fuel, suitable for use in public transport buses. Biomethane has both good environmental properties and the possibility of being produced, in the first place, from waste and raw materials of non-agricultural origin.

REFERENCES:

[1] 100% Biogas for Urban Transport. Linköping, Sweden. http://www.seai.ie/Renewables/Bioenergy/100_biogas_for_urban_transport_in_Linkoeping_IEA_Bio_Task_37.pdf

[2] Methane owered urban Transport in Sweden Public Transport Busse, https://eu-smartcities.eu/sites/all/files/docs/best-practice/CS-0410-Methane-urban-transport-in-Sweden.pdf

[3] Dyrektywa Parlamentu Europejskiego i Rady 2009/28/WE z dnia 23 kwietnia. 2009 r

[4] Israilava A.: *Biofuels in Sweden: national verification system for sustainability*. Swedish Energy Agency, 2013.

[5] Raport Swedish Energy Agency z 2016 r. http://www.energimyndigheten.se/en/news/2016/energy-in-sweden---facts-and-figures-2016-available-now/

[6] Biernat K., Dziołak P. L., Gis W., Żółtowski A.: *Summary elaboration on the production and potential of biogas production in the Baltic Sea Region countries today and in the perspective of the next years*, 2012.

[7] Biogas buses – A cost estimate http://www.biofuelregion.se/UserFiles/file/Biogas%20buses%20PM%20Goldmann%20121220.pdf

[8] Biernat K., Dziołak P. L., Gis W., Wójcik, M. Żółtowski A.: *Baltic Sea Region biogas infrastructure overview — existing and planned*, 2012.

[9] Hallgren L.: *Towards a sustainable public transport system in Stockholm*, http://www.balticbiogasbus.eu/web/Upload/doc/Kaunas_201009/4%20SL%20Lennart%20Hallgren.pdf

[10] Gis W., Grzelak P., Żółtowski A.: *Czynniki rozwoju transportu miejskiego zasilanego biometanem,* Prace Naukowe Politechniki Warszawskiej „Transport", zeszyt 98, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2013, pp. 175-182.

[11] Merkisz J., Gis W., Grzelak P., Żółtowski A., *The possibilities of reducing emission pollutants of exhaust from city buses by the use of biomethane. Combustion Engines*. 2013, 154(3), pp. 562-569.

[12] Gis W., Rudkowski, M., Żółtowski, A. *Feasibility study for the pilot biomethane refueling station for city buses in Rzeszow*. Combustion Engines. 2013, 154(3), pp. 581-586.

[13] Gis W., Żółtowski A., Grzelak P., L.: *Biomethane as a fuel for city transport.* Journal of Kones / Vol. 19, No. 2 / European Science Society of Powertrain and Transport Publication / Warsaw. 2012. pp. 175-179.

[14] Biernat K., Dziołak P. L., Gis W., Żółtowski A.: *Potential of biomethane production In Baltic Sea Region.* 5. Rostocker Bioenergieforum, 2. und 3. November 2011 an der Universität Rostock. Schriftenreihe Umweltingenieurwesen Agrar- und Umweltwissenschaftliche Fakultät, Band 30, Tagungsband, pp. 405-415.

[15] Biernat K,. Dziołak P. L, Gis W., Żółtowski A.: *Analysis of the Biomethane Potential in the Selected Countries of the Baltic Sea Region*. Międzynarodowa Naukowo-Techniczna Konferencja pn. Biogas as Vehicle Fuel. Rzeszów, 19-20.10.2011. Silniki Spalinowe nr 1/2012(148), p. 95.

[16] Biernat K, Dziołak P. L., Gis W., Żółtowski A.:: *Analysis of the Biomethane Distribution Possibilities In the Selected Countries of the Baltic Sea Region*. Międzynarodowa Naukowo-Techniczna Konferencja pn. Biogas as Vehicle Fuel. Rzeszów, 19-20.10.2011. Silniki Spalinowe nr 1/2012(148), p. 98.

[17] Gis W., Menes E., Waśkiewicz J., Żółtowski A.: *Evaluation of the Biomethane Production Potential From Municipal Sources and its Use in Urban Bus – The Example of Warsaw*. Międzynarodowa Naukowo-Techniczna Konferencja pn. Biogas as Vehicle Fuel. Rzeszów, 19-20.10.2011. Silniki Spalinowe nr 1/2012(148), p. 100, PL ISSN 0138-0346.

[18] Biernat K, Dziołak P. L., Gis W., Żółtowski A.: *Analysis of the Biomethane Distribution Possibilities in Poland.* Międzynarodowa Naukowo-Techniczna Konferencja pn. Biogas as Vehicle Fuel. Rzeszów, 19-20.10.2011. Silniki Spalinowe nr 1/2012(148), p. 99, PL ISSN 0138-0346.

[19] Gis W., Jakóbiec J., Żółtowski A.: *Biogas As Engine Fuel*. Międzynarodowa Naukowo-Techniczna Konferencja pn. Biogas as Vehicle Fuel. Rzeszów, 19-20.10.2011. Silniki Spalinowe nr 1/2012(148), p. 97.

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