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Tangible benefits of using liquefied natural gas fuel in the urban transport of Szczecin

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Abstract

Being the cleanest mine fuel due to the release of low exhaust emissions into the atmosphere, natural gas has been utilised by many fields of transport. A rapidly growing world market of liquefied natural gas (LNG) fuel has enabled to implement this fuel in urban transport. This article concentrates on presenting an alternative solution for the use of LNG fuel in urban buses to reduce exhaust emission using the example of Szczecin. On the basis of a significantly growing segment of the engines for the gas driven market, the article also shows the possible costs arising from the use of LNG fuel in urban buses of Szczecin. The impact to the natural environmental from the use of diesel fuel from vehicles was analysed. Based on the exhaust emission analysis this article shows the difference between using a fuel which emits less noise and is a cleaner energy source with high energy efficiency and the fuel used by carriers.

Introduction

The steadily increasing trend in prices of fuel oil, the imposition of increasingly stringent emission regulations by the European Commission, the continuous growth of traffic and environmental aspirations pose serious problems with the use of conventional fuels such as diesel fuel or gasoline. These problems, are not of an economic nature, but relate to the continuous deterioration of air quality – a phenomenon mainly occurring in cities. One possible remedy is the use of liquefied natural gas (LNG) in the form of LNG fuel, which has a calorific value comparable to diesel fuel and gasoline, as well as better composition combustion, a lower price and in contrast to the CNG is easier to transport (Śliżak, 2013).

In the current situation of the petroleum fuel market, the technology has become increasingly common to allow vehicles to be powered with natural gas. Since the fifties, there has been about 2000 cars in Poland which used natural gas (PGNiG, 2014). The world's interest in natural gas as a motor fuel intensified in the 70s during the oil crisis. It was caused by the scarcity of raw materials and the rapidly growing sector of transport vehicles. Currently, the use of natural gas has both economic and environmental dimensions.

LNG is one alternative fuel which has a limited impact on the environment. In contrast to gasoline or diesel fuel, in the event of a spill, LNG does not cause contamination of the environment, nor does it pollute waters or poison animals due to its quick evaporation into the atmosphere. Additionally, it does not compound with water. However, the main component – methane, is a strong greenhouse gas, 72 times stronger than carbon dioxide (on a 20 year scale) (Ramaswamy, 2001). The following table (Table 1) shows the components of LNG fuel.

An important argument for the use of LNG is that simultaneously to the condensation process, the gas is cleaned from water vapour, helium, nitrogen, carbon dioxide, propane-butane and partly from oxides of sulphur. Because of differences in condensing temperature of the natural gas components,

Table 1. Composition of LNG (based on data (PGNiG, 2014))

No.	Component	Content mass [%]
1	Nitrogen	≥ 4
2	The sum of combustible ingredients	≥ 96
3	Methane	≤ 93.83
4	Ethane	≤ 1.72
5	Propane	≤ 0.4
6	I-butane	≤ 0.03
7	N-butane	≤ 0.015
8	Pentane	≤ 0.005
9	Carbon dioxide	≤ 0.005
10	Water	≤ 0.0002
11	Sulphur compounds	≤ 0.0006
12	Mercury	≤ 0.001

the combustion products of LNG are mainly carbon oxides, water and small amounts of nitrogen oxides with very low particulate emission. For comparison, the combustion products of diesel fuel in internal combustion engines are compounds such as oxides of sulphur, carbon dioxide, carbon monoxide, nitrogen oxides, particulate matter and hydrocarbons, like aldehydes.

Another advantage of LNG fuel is its competitive price relative to diesel fuel and the fact that natural gas in a liquefied form occupies about 600 times less volume compared to normal conditions. Due to this feature, LNG can be transported over long ranges easily – with the only condition being the need to use special cryogenic tanks or cylinders, whose main feature is the ability to maintain a constant low temperature gas.

Calorific values of diesel fuel and natural gas are at a similar level. Given the differences in the combustion process and the generated heat (loss), fuel consumption in the case of LNG is higher. However, the current downward trends in prices of LNG – (with an average decrease in world prices of about 30% in the period from March 2014 to March 2015) (CIRE, 2016), it is a more economically profitable fuel.

Economic and ecological benefits arising from the use of LNG fuel in public transport in Szczecin

Roads and Transport Authority in its subordinate companies SPA "Dąbie" SPA "Klonowica" PKS Szczecin and SPPK have 77 bus routes and operate a total of 230 vehicles. The average age of rolling stock is different for each company, but the average age of a Szczecin bus is nearly 11 years. The average number of kilometres travelled by bus is 235 km/day, thus every month gives about 7000 km and the annual result is 84,000 km/year. Taking the average value of combustion of 43 l/100 km, the average daily bus burns approx. 100 litres of diesel fuel per month giving a figure of around 3,000 litres. For a total bus fleet, over 1.6 million vehicle-kilometres will be covered while more than 692,000 gallons of diesel fuel will be burnt per month (ZDiTM, 2016).

From an economic point of view, the choice of LNG for urban transport is a profitable decision (Table 2). The cost per 100 kilometres for an urban bus in Szczecin, taking an average of combustion at 43 litres per 100 km is less than 170 PLN (diesel at a price equal to 3.94 PLN/l). To compare, declared fuel combustion of bus Solbus Solcity 12 powered by LNG is 51.6 Nm (36 kg) per 100 km (Krone, 2006), which shapes the cost at less than 108 PLN (the price of 3 PLN/kg). The difference in the cost of driving per hundred kilometres is as high as 36%. Continuing this line, ZDiTM buses annually overcome approx. 19.35 million vehicle-kilometres consuming 8.32 million litres of diesel fuel worth close to 32.8 million. LNG consumption amounts to around 7.3 million kg worth 21.9 million. This results in the formation of savings equal to about 10.9 million during the year.

Table 2. Properties and data spreadsheets for fuel for city buses

	LNG	Diesel
The calorific value	50 MJ/kg	42–44 MJ/kg
Equivalent energy	1 kg	1.23 kg
1 m^3	430 kg	820–845 kg
Listed price	6.9 $/MMBtu*	355 $/t**
Market price	3 PLN/kg	3.94 PLN/l***
Density	450 kg/m^3	840 kg/m^3
CO_2 emissions	1 kg LNG is burned, creating 2.79 kg of CO_2	1 kg diesel is burned, creating 2.64 kg of CO_2

* The average trading price of LNG in Japan and in the UK in February 2016; equal 0.93.PLN/Nm³, 536 PLN/m³, 1.31 PLN/kg by the US dollar 3.74 PLN dated. 31.03.2016

** On the day 31.03.2016. For 1.13 PLN/l, acc. US dollar exchange rate 3.74 PLN.

*** Diesel price on the Polish market dated. 31.03.2016.

The use of LNG, unfortunately, brings some inconvenience. One example is the higher cost of the purchase of rolling stock. For vehicles with a length of 12 m, these costs are increased to about 200,000 PLN and for 18 m length can be as high as 430 thousand PLN (Table 3).

Table 3. List of the costs of buses in the basic version and runs on LNG/CNG (CBA, 2016)

Brand and model	Price + VAT [PLN] (basic version)	Price + VAT [PLN] (LNG/CNG)
Iribus Citelis 12	640,000	CNG/LNG 730,000
Iribus Citelis 18	820,000	CNG/LNG 950,000
MAN Lion's City	720,000	CNG/LNG 920,000
Mercedes-Benz Citaro	820,000	CNG 940,000
Mercedes-Benz Citaro G	1,300,000	CNG 1,700,000
Solaris Urbino 12	720,000	CNG 830,000
Solaris Urbino 15	800,000	CNG 870,000
Solaris Urbino 18	910,000	CNG 1,350,000

Assuming that an additional contribution to the purchase of a vehicle will reach 200 thousand PLN, after less than 4 years of use, it begins to generate additional profits (Table 4, Figure 1). Differential equation of fuel expenses with mileage 85,000 km/year (Śliżak, 2013):

$$\frac{s}{100}\left(p_1 \cdot q_2 - p_2 \cdot q_2\right) = x \qquad (1)$$

where:

- s – the average annual mileage;
- p_1 – price of a litre of diesel fuel;
- q_1 – average fuel consumption of diesel fuel per 100 kilometres;
- p_2 – price per kilogram LNG;
- q_2 – average fuel consumption of LNG;
- x – the difference in operating costs.

$$\frac{85{,}000}{100}[\text{km}] \cdot \left(3.94\left[\frac{\text{PLN}}{1}\right] \cdot 43\left[\frac{1}{100\text{ km}}\right] - \right.$$
$$\left. + 3\left[\frac{\text{PLN}}{\text{kg}}\right] \cdot 36\left[\frac{\text{kg}}{100\text{ km}}\right]\right) \approx 52{,}200\ [\text{PLN}]$$

Data calculation:

- mileage: 85,000 km/year;
- burning diesel: 43 l/100 km;
- burning LNG 36 kg/100 m;
- Diesel price: 3.94 PLN/l;
- LNG price: 3 PLN/kg.

One barrier preventing investment in liquefied natural gas power systems is the lack of infrastructure for refuelling. There are tanker trucks with the capability of refuelling other vehicles, but it is a cost-effective solution for only a small number of customers. Assuming, that Szczecin public transport companies do invest and develop an LNG-powered fleet, a solution would be needed in the form of stationary fuel station. This involves the filling station having in its offer traditional fuels, and additional fuels LNG and CNG. The occurrence of such stations would be a positive asset for Szczecin because of the inclusion of the city to the Blue Route (ang. *Blue Corridor*). Blue Trail is the idea of creating a network of routes with LNG/CNG stations in Europe, mainly for trucks. The cost of building LNG stations with a capacity of 12 vehicles per hour is approx. 750 thousand € (Śliżak, 2013).

Table 4. The balance of costs incurred and obtained with the introduction of LNG

Year of exploitation	Surcharge when buying bus [PLN]	The balance of costs [PLN]
	–200,000	
1	52,200	–147,800
2	52,200	–95,600
3	52,200	–43,400
4	52,200	8,800
5	52,200	61,000
6	52,200	113,200
7	52,200	165,400
8	52,200	217,600
9	52,200	269,800
10	52,200	322,000

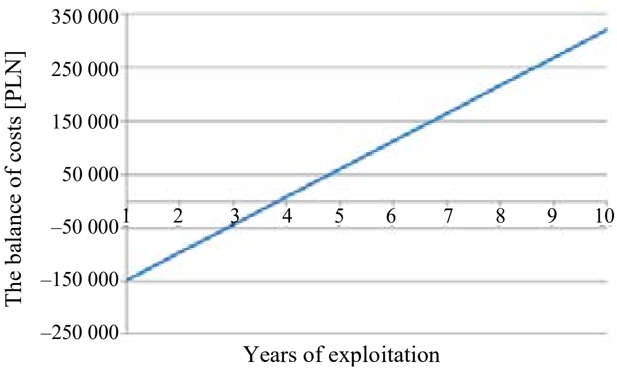

Figure 1. The period of reimbursement of additional expenditure on the purchase of LNG bus (based on data from Table 4)

Buses have a standard LNG tank with a capacity of 330 dm^3, which can contain about 130 kg of fuel. This does not mean that they are the only possible capacity to install. This volume is comparable to the volume of the standard diesel tank. Buses burning 36 kg/100 km of LNG are able to travel about 350 km on a single tank. Taking into account the characteristics of connections, most buses on Szczecin bus lines, where the average daily length of the route is 235 km, could complete their route on a single tank.

From an environmental point of view, the use of LNG as a fuel is much more advantageous than the use of oil. The reason for this is much smaller and less harmful emissions of fuel combustion products (Table 5).

Table 5. European emission standards for diesel engines of trucks and emissions LNG [g/kWh] (based on Michałowski, 2007; DieselNet, 2016)

Level	CO	HC	NO_x	PM
Euro I	4.5	1.1	8	0.612
	4.5	1.1	8	0.36
Euro II	4	1.1	7	0.25
Euro III	2.1	0.66	5	0.1
Euro IV	1.5	0.46	3.5	0.02
Euro V	1.5	0.46	2	0.02
Euro VI	1.5	0.13	0.4	0.01
Natural gas	0.12	0	0.36	0.007

For LNG fuel, lower rates per kilowatt hour of fuel burned is observed compared to the most restrictive standard Euro VI for diesel. For carbon monoxide it is lower by 92%, and the emission of hydrocarbons has been almost completely eliminated. Emissions of nitrogen oxides and particulate matter is smaller by 10% and 30% respectively. For the Euro IV standard, which is used by most of Szczecin buses, the situation is as follows: 92%, 100% (a small part), 90% and 65%. Current CO_2 emissions from Szczecin bus is around 21,900 tonnes, while with the use of LNG, it would be reduced by 7.5% to 20.3 thousand tonnes.

Often overlooked a kind of "pollution" of the environment is noise. It also adversely affects physical and mental health, however by using LNG fuel, noise is significantly reduced compared to a conventional diesel engine (Table 6).

Table 6. Noise reduction in Scania trucks (Wodołażski, Rejman-Burzyńska & Jędrysik, 2013)

Distance	Diesel fuel	Methane	Difference
		dB(A)	
7.5 m forward	71.7	60.6	–10.5
7.5 m from left side	69.6	59.8	–9.8
7.5 m from right side	69.6	60	–9.6
Cabin (driver's ear)	60.6	54.7	–5.7

The differences in noise levels range from 5.7 to 10.5 dB (A), and it should be noted that decibels are on a logarithmic scale. This means that a difference of 10.5 dB in the human mind is considerable and the difference between LNG engines and diesel may be as high as 50%.

Installation of LNG fuel in vehicles and security

Technology in the construction of LNG vehicles guarantees safety. In addition to the specific multi-layer construction of the cylinder for liquefied natural gas (Figure 2), it has many different types of safety valves which function to regulate the transmission of gas inside the installation and the adjustment of pressure (Figure 3).

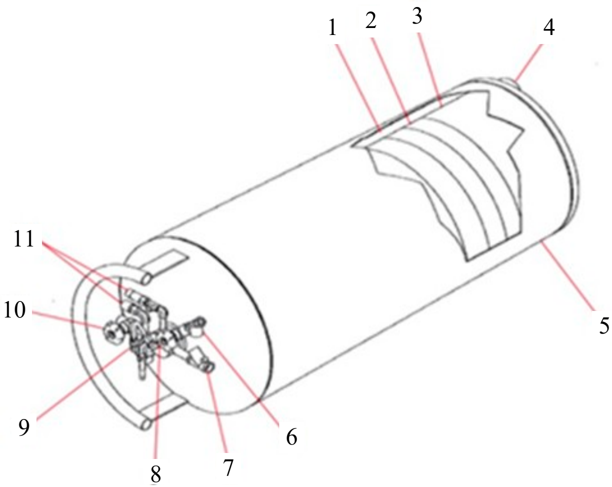

Figure 2. Schematic diagram of the LNG tank (Przegląd pożarniczy, 2016); 1 – vacuum space, 2 – isolating material, 3 – inner tank, 4 – underpressure valve, 5 – outer cover, 6 – outflow securing valve, 7 – bunkering securing valve, 8 – cutting off the fuel valve, 9 – tank pressure regulator, 10 – ventilation valve, 11 – safety valves

Tanks for the storage of LNG vary significantly from those used for CNG or LPG. The most important difference that distinguishes this type of tank is its thermal insulation, which is placed between the outer layer and inner vacuum tank. This is the best known radiant heat insulator so far. A good thermal isolation tank is needed to maintain the low temperature inside the tanks for as long as possible, which should be held at about –162°C. This ensures maintenance of the natural gas in liquid form and consequently, a reduced pressure ranging between 3 and 8.5 bar, for up to seven days.

Except for the vacuum space, the tank is composed from additional isolating material and an inner and outer tank. The inner tank is designed to keep the liquefied natural gas in a hermetically sealed environment, while the external tank with its thick,

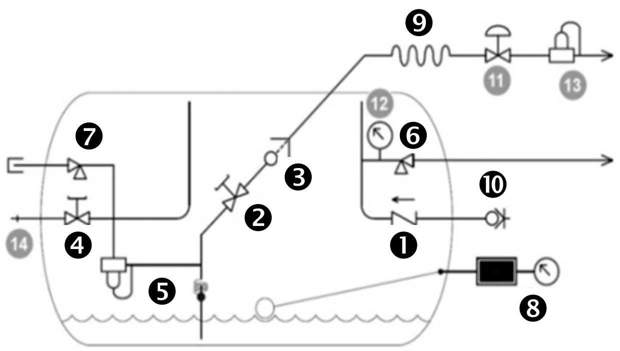

Figure 3. Scheme of the LNG fuel system (Przegląd pożarniczy, 2016)

reinforced walls protects the interior of the cylinder, mainly from mechanical shock and high temperatures (e.g. due. fire).

At the entrance to the tank, the installation is composed mainly of pressure regulators and valves. They ensure safe refuelling of LNG.

Safety valve refuelling (1), aims to prevent gas reversing to the power cylinder; the manual fuel shut off valve (2) is closed during repair and renovation work on the vehicle; the unduly valve (3) shuts off the flow of gas from the tank to the heat exchanger for excessive, uncontrolled discharge thereof; i.e. the ventilation valve (4) is used to drain the tank and for aeration during the first filling or when the tank has too large an amount of gas in the form of volatile a pressure regulator (5) in the vessel allows the vapour to be sent to an installation supplying gas to run the engine in the case where the pressure within the tank rises above the nominal allowable pressure (0.85 MPa); the main safety valve (6) vents gas at the moment when the pressure inside the tank exceeds 1.5 MPa to a special wire led out beyond the contour of the vehicle; the additional safety valve (7) is turned after exceeding a pressure of 2.25 MPa to quickly reduce high pressure in the tank; a heat exchanger to heat the LNG has this purpose so that the resulting vapour, can then go to the engine of the vehicle. Heat is obtained mainly by the engine refrigerating fluid. In order to fill the tank, the filling adapter (10) is needed. The automatic fuel shut off valve (11) blocks the flow of gas to the engine when the engine is switched off or when its turnover falls dangerously low. The supply pressure regulator regulates the pressure of the gas, where its value in the engine should be 0.67 MPa (Przegląd pożarniczy, 2016).

An important aspect for the safety of the LNG compared to other fuels (in particular diesel fuel) is its very low carcinogenicity. Virtually no solid particles result from the combustion of natural gas and hydrocarbon NMHC, providing a cleaner exhaust gas (without soot and smoke emanating from the exhaust of the vehicle) and also a reduction in the incidence of cancer. Particulates generated during combustion of petroleum fuels have such a small size, that they are able to not only get to the human respiratory system, but also into the bloodstream (where they are impossible to remove from the body, allowing them to accumulate).

According to the World Health Organization (WHO) particulate matter (PM) shortens the life of the average person by about 8 months and specifically in Poland by 10.7 months.

Hydrocarbons are able to react with oxygen to form nitrogen peroxide, and various kinds of aldehydes and peroxides. Some of these have a narcotic effect, and are even fatal in high concentrations, while others combine with fats and accumulate in the human body acting as a carcinogen.

Other products of combustion are nitrogen oxides for example. Eliminated by the combustion of LNG are the more toxic products exhaust elements of diesel fuel. Nitric oxide is bound to haemoglobin, and is oxidized to nitrogen dioxide. The effects of poisoning are numbness of the limbs and the general weakness of the body. Carbon monoxide combines with haemoglobin much more simply than oxygen, which displaces it from the body. This results in body hypoxia, pulmonary enema and brain lesions, and at higher doses, can lead to death.

Conclusions

Implementation of an LNG power supply system in Szczecin transport would bring considerable economic benefits in the form of savings when buying fuel at 10.9 million dollars per year. This represents 36% of current expenditure on the purchase of diesel fuel. In addition, it would allow a reduction of noise and emissions in Szczecin; furthermore the construction of LNG filling stations would raise the prestige of the Szczecin city and include it into the Blue Corridors programme.

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