THE USE OF NATURAL GAS IN MUNICIPAL TRANSPORT: CONSTRAINTS, POTENTIAL, PROSPECTS

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Summary

The paper presents multifaceted analysis of the possibilities of use of compressed natural gas (CNG) in the municipal transport in Poland.

Poland has enormous potential for the development of the transport based on natural gas. This is connected with such factors as price, low emission characteristics, and availability of this fuel (multiannual contracts with external suppliers, domestic production, and shale gas in view). Simultaneously, the current use of natural gas in transport is nearly 12 million m^3/a, which makes about 0.1% of the total natural gas consumption in Poland. At present, there are several dozen CNG filling stations, with 29 of them being open to the public; for comparison, the total number of vehicles fuelled with CNG varies around 2 500 and 310 of them are municipal transport buses.

The paper shows the benefits that may be gained from the introduction of natural gas as fuel for municipal transport. In particular, the environmental aspects (reduced pollutant emissions) and economic factors have been highlighted. Examples of the solutions implemented up to now in selected cities in Poland and of good practices in the development of CNG-fuelled motor vehicle fleets have been presented.

Moreover, a simplified financial analysis of making investments in city buses fuelled with compressed natural gas and in a company's own CNG filling station has been carried out. The analysis has revealed that investments of this kind may be profitable in the current situation.

In the recapitulation, the authors tried to answer a question what conditions should be met so that the sector of the application of natural gas as motor fuel could develop much more dynamically than hitherto.

Keywords: natural gas, CNG, emissions, municipal transport

1. Introduction

One of the Poland's most underestimated motor fuels is compressed natural gas (CNG). This is a quite surprising statement in consideration of the fact that Poland has relatively large

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own resources of natural gas. The evidenced resources of natural gas in Poland amount to, roughly, 98 billion m^3, according to data published by the PGNiG S.A. Capital Group [1], or even about 145 billion m^3 as reported by the Polish Geological Institute – National Research Institute (NRI) [2].

Simultaneously, apart from the gas extracted from existing sources, the resources of unconventional gas are being estimated. The most likely amount of the natural gas resources in the shale formations in Poland is between 346 and 768 billion m^3, according to the report published by the Polish Geological Institute NRI [2]. With the annual gas consumption assumed on the present level of about 14.5 billion m^3, this amount would be sufficient to cover Poland's total gas demand for 35 to 65 years. At the same time, it is noteworthy that "the report does not cover the hydrocarbon resources available from conventional deposits or from deposits present in other geological formations (e.g. tight gas or coal bed methane i.e. CBM)" [2]. Furthermore, the report covers only a part of the Poland's territory, i.e. the Baltic-Podlasie-Lublin basin, with disregarding such regions as e.g. Lower Silesia or Great Poland.

At present, Poland is an importer of natural gas. The domestic production covers about 30% of the demand (4 billion m^3/a). However, in view of the availability of the anticipated resources and of the growth in prices of traditional fuels, it seems obvious that natural gas should be used as motor fuel.

On the other hand, the present consumption of natural gas as motor fuel is actually negligible. In 2011, the consumption recorded at the filling stations belonging to the PGNiG S.A. Capital Group was about 11.8 million m^3, which made as little as about 0.1% of the total consumption of natural gas in Poland. In 2012, the consumption of natural gas for vehicle fuelling purposes is to be about 13.5 million m^3, according to PGNiG forecasts (based on the sales data recorded in the first half year).A rising trend at a rate of about 10% a year can be noticed; nevertheless, the share of natural gas in the entire motor fuel market in Poland is still rather marginal. The liquefied natural gas (LNG) is practically not used at all.

Therefore, a question should be answered whether good reasons exist for this market to develop much more dynamically in Poland.

2. Good points of compressed natural gas as motor fuel

The main component of natural gas is methane, which is the simplest of the hydrocarbon species and has a decisive impact on the physicochemical properties of compressed natural gas (CNG) used as fuel. This fuel is lighter than air; therefore, it goes up when leaking from a gasholder without causing a hazard of accumulation just above the ground surface. It has a high ignition point (about 600°C), which hampers the self-ignition of air-fuel mixture and thus improves the safety of vehicle operation. Other CNG characteristics include high octane number, which makes it possible to raise the engine compression ratio; wide range of ignitability of air-fuel mixture; and low burning rate of rich air-fuel mixtures [3]. The lower burning rate helps to reduce the engine noise (in the case of diesel

engines), which is one of good reasons for recommending the engines powered with this fuel as particularly suitable for being used in urban traffic [4].

The good points of CNG, emphasized in the context of increasingly restrictive European exhaust emission standards, include lower emissions (in comparison with those of conventional fuels) of the pollutants subject to the regulations, i.e. nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM). The research data available from literature confirm the significant reduction in particulate matter emission. As an example, this emission recorded for a city bus (meeting the EURO 2 standard requirements) was reduced by, roughly, 98% in comparison with that of a bus powered with diesel oil [5]. This is connected with differences in the chemical composition of the two fuels (diesel oil is a mixture of higher hydrocarbons, including aromatic hydrocarbons) and in the course of the combustion process. Moreover, the total hydrocarbon (THC), NO_x, and PM contents of the exhaust gases emitted by the same bus were radically lower when the bus was driven by a CNG engine as against those recorded for the bus with an engine fuelled with diesel oil, i.e. by 67%, 98%, and 96%, respectively. For CO, the differences observed were not so striking (the emission was reduced by about 10%).

It should be noted at the same time that inconsistencies occur in the literature data on the reductions in all the toxic pollutant emissions covered by the regulations, achieved by replacement of diesel oil with CNG. Tests carried out in urban traffic conditions on waste collection trucks meeting the EURO 5 standard requirements revealed that the emission reductions were significantly reduced for NO_x and PM, while the other pollutant emissions increased [6]. This might be related to the engine control methods or engine types (spark-ignition or diesel engines). Some authors explain the discrepancies in the results obtained by different test procedures and conditions, which not always were precisely described.

Some, although rare, literature data describing the exhaust pollutant contents that are not subject to legal regulations show that the total carcinogenic polycyclic aromatic hydrocarbons (PAH) and nitro-PAH content of exhaust gases is also significantly reduced in the case of CNG used instead of diesel oil (by up to 98%). The quantities of carbonyl compounds and light aromatic hydrocarbons contained in exhaust gasses are indicated to be negligible, too (only the formaldehyde content exceeded the detection limit; anyway, it was again observed as reduced by 95% when comparing the data obtained for CNG and diesel oil) [5].

The reduced pollutant emission characteristics of the CNG fuel may significantly help to cut down the health costs borne by the inhabitants of urban agglomerations and thus to really lower the social costs related to the increasing air pollution in cities [5, 7]. In WHO reports, motor traffic emissions are pointed out as the main reason for the air pollution in cities and the basic source of the particulate matter suspended in air and other toxic matter (e.g. PAH) harmful to human health [8].

3. Price policy

In addition to the undisputable good points related to the properties of natural gas, noteworthy is the attractive CNG price as against that of traditional fuels. From 14 July 2010 on, the owners of most of the CNG filling stations, being members of the PGNiG S.A.Capital Group, have been setting at their filling stations a variable CNG price determined with taking as a basis the parity of notations of the average wholesale net price of the Ekodiesel PKN Orlen diesel oil for the preceding period of four full weeks as published on the PKN Orlen S.A. website. The parity of the price of 1 m^3 of CNG to the wholesale net price of the diesel oil is 55%. It is worth of pointing out that the price thus determined does not correspond to the actual costs arising from the bare gas price, gas compression cost, tax (at present, CNG is exempted from the excise tax), and retailer's mark-up. The CNG prices charged at the filling stations that do not belong to the PGNiG S.A.Capital Group are more flexible. The time history of the prices of 1 Nm^3 of CNG recorded at the PGNiG S.A.Capital Group's filling stations from the date of introduction of the parity-based pricing has been shown in the graph below:

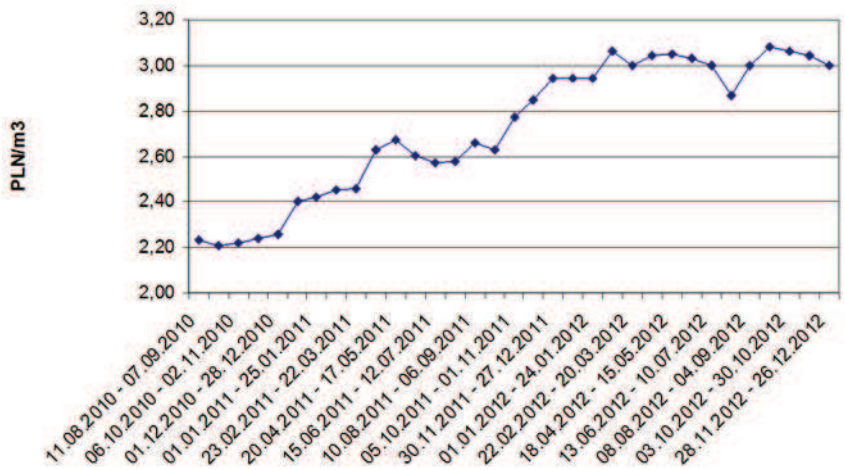

Fig. 1. Changes in the prices of 1 m^3 of CNG recorded at the PGNiG S.A. Capital Group's filling stations (Source: Authors' own study, based on data published by the PGNiG S.A. Capital Group)

The attractiveness of the CNG price is now connected with the zero excise tax rate on this fuel, to be maintained till 31 October 2013. Simultaneously, a proposal to change the fuel taxation system is now widely discussed on the EU level. The proposal is included in Directive 2003/96/EC being now revised and concerning the taxation of energy products and electricity. Initially, the excise tax rate on natural gas was to be drastically raised. However, in result of intensive information actions taken to show the effects of the changes on the European market and the inconsistency of the changes with the policy to reduce transport emissions, the European Parliament has approved, *inter alia*, the following amendment to the text of the Directive: "In the case of natural gas and biomethane used as motor fuel, higher minimum levels of general energy consumption taxation shall apply only

after an assessment, to be carried out by the Commission by 2023, of the implementation of the provisions of this Directive relating to the level of taxation applicable to natural gas in road transport. That assessment shall, *inter alia*, examine the progress in the availability of natural gas and biomethane, the growth of the refilling stations network in Union, the market share of natural gas vehicles in the Union, the innovation and technological developments in biomethane used as transport fuel and the real value of the minimum level of taxation." Until 1 January 2023, Member States may apply exemption or reduction in the level of taxation to "natural gas, biogas, and LPG used as propellants and LPG used as fuel." From that time "until 1 January 2030, Member States may apply a reduction of up to 50 % of the minimum levels of taxation for those fuels" [9]. At present, negotiations are in progress regarding the final form of the Directive because some member states (including Poland) refuse to accept the two-component taxation of fuels (according to energy content and CO_2 emission) and want the component related to the CO_2 emission to be voluntary.

4. The situation in Poland

In Poland, the number of CNG-powered automotive vehicles has recently remained on a level of about 2 200 to 2 500 units. As of 1 June 2011, there were 2 082 such vehicles [10]. Mostly they are passenger cars with factory-installed CNG fuelling systems. Among them, vehicles belonging to the PGNiG S.A. Capital Group make a significant part. In 2008, this company possessed 487 CNG vehicles. The market of municipal buses fuelled with CNG is also developing in Poland, with the number of such buses being now about 310. At present, 22 companies use vehicles of this type in 20 Polish cities [11]. In addition to this, the number of specialised, delivery, and goods vehicles is regularly increasing. An example may be the new range of vehicles offered by IVECO, which is introducing its Daily, Eurocargo, and Stralis CNG models into the Polish market.

5. Filling stations

At present, there are 29 CNG filling stations in Poland open to the public. In the largest number of cases, they are situated in the southern part of the country and some isolated stations are scattered in the central, northern, and western regions. In Podlaskie, Łódzkie, Lubuskie, and Opolskie Voivodships, there are no CNG filling stations at all at present. All the public stations are "quick-fill" facilities. Apart from them, there are several dozen stations unavailable to the public, which include the so-called "slow-fill" facilities serving large fleets, e.g. consisting of buses. Most of the public stations belong to PGNiG S.A. Capital Group.

6. Examples of solutions adopted for CNG fleets

A very good example of implementation of the program for replacing traditional fuels with CNG is Przedsiębiorstwo Komunikacji Miejskiej Sp. z o.o. in Gdynia (PKM Gdynia, a municipal transport company). It has 92 buses in total, with 14 of them being powered with CNG. The company began to introduce CNG vehicles in 2007, when the first 5 buses MAN LION'S CITY G CNG model were purchased. The replacement of buses fuelled with diesel oil with CNG units resulted in significant savings related to lower fuel costs and reduced charges paid for using the environment for business purposes and in reductions of pollutant emissions.

PKM Gdynia has estimated the amount of the savings made in result of changing the bus fuel. The averaged costs of the fuels (diesel oil and CNG) consumed during a many-year vehicle operation period (from September 2007 till December 2011) have been presented in the table below, which shows that the fuel costs were reduced by about 36%, although the consumption of CNG exceeded that of diesel oil.

Table 1. The benefits of using CNG at PKM Gdynia

Diesel oil [PLN/100 km]	168.60
CNG [PLN/100 km]	107.26
Savings [PLN/100 km]	61.34
Savings [%]	35.79

Source: Presentation "CNG w komunikacji miejskiej (CNG in municipal transport services)."PKM Gdynia, Międzyzdroje, 24 Jan. 2012

Any calculations of the cost-effectiveness of projects of this kind should be made with taking into account the fact that CNG vehicles are by about 20% more expensive than vehicles powered with diesel oil. However, if municipal transport buses annually travel about 100 000 km, the difference in purchase prices of buses of comparable performance will be paid back within about two years only. Thus, the buses will bring savings during the next years of service. For PKM Gdynia, we should note that the company has only been using its own refuelling station since 2010. At such a solution, the purchase cost of 1 Nm^3 of natural gas (the gas supply rate plus gas compression cost) is lower than the parity-based price.

Another example of using CNG as motor fuel is TOMAG of Pruszków, a small company providing transport services. It has 17 vehicles, with 6 of them being powered with CNG. The CNG fleet consists of 3 Fiats Ducato, 1 Citroen Jumper, and 2 Volkswagen Caddy vans. These vehicles are used for passenger transport within Warsaw and the surrounding areas. Each of them travels about 150 km a day (from Monday till Friday), consuming about 12 Nm^3 of CNG per 100 km. Thus, all these vehicles travel about 18 000 km in total and consume about 2 160 Nm^3 of CNG a month. To reduce the vehicle operation costs, TOMAG has installed on its premises a compressor model GAS200 made by NGV Autogas, of 8 ÷ 12 m^3/h output capacity. The CNG refuelling cost borne by the company is now 2.70 PLN/m^3 in gross terms, according to economic analyses. This cost includes the gas supply rate (with its constant and variable components), the gas compression charges, and the refuelling system depreciation allowance. A significant benefit of having a company's own

gas compressor results from drivers' work time and fuel cost savings, as the vehicles were previously refuelled at the nearest existing public filling station situated in Warsaw at Prądzyńskiego Street, 17 km away from company's premises.

7. Simplified cost-effectiveness analysis of the construction of a filling station and the purchase of a CNG bus

Within an EU project "GasHighWay – Promoting the Uptake of Gaseous Vehicle Fuels, Biogas and Natural Gas, in Europe" (www.gashighway.net), the authors of this paper carried out a cost-effectiveness analysis of the construction of a small public CNG filling station. For the analysis, an assumption was made that the compressor would serve at least 63 passenger cars a day. A gas compressor of 60 Nm^3/h output capacity complete with a gas storage tank of 500 Nm^3 capacity was selected. The gas purchase and CNG sale prices assumed were based on market data. The total project cost was estimated at about PLN 600 000 (without the land purchase cost being taken into account). The operating costs and the receipts were estimated at about PLN 770 000 and PLN 960 000 a year, respectively. For the above assumptions, the simple payback period was found to be shorter than 5 years.

A simplified cost-effectiveness analysis of the purchase and operation of Volvo 7000 CNG buses as against the Volvo 7000 model powered with diesel oil was also carried out within the GasHighWay project for one of the transport companies of the southern part of Poland. Both the bus models were compared with each other in respect of the costs of travelling a distance of 100 km, with the diesel oil and CNG prices being assumed as about 5.80 PLN/dm^3 and 3.00 PLN/m^3, respectively. The analysis results, inclusive of the purchase costs of both the bus models, have been summarised in Table 2.

Table 2. Comparison between bus purchase costs, fuel consumption, and travelling costs for Volvo buses powered with diesel oil and CNG

	Volvo 7000 (diesel oil)	**Volvo 7000 CNG**
Purchase cost	800 000 PLN	950 000 PLN
Fuel consumption per 100 km	42 dm^3	55 m^3
Cost of travelling a distance of 100 km	243.6 PLN	165 PLN

The simplified analysis has shown that the difference in purchase costs should be paid back when the distance travelled exceeds about 200 000 km.

8. Good practices in developing CNG vehicle fleets

Based on the experience gained to date in the field of developing CNG vehicle fleets, the following may be pointed out as conditions of the profitability of using CNG vehicles:

- The fleets should be based on new vehicles, factory-equipped for CNG fuel. This would make it possible to operate the vehicles without breakdowns and to achieve the planned economic and environmental objectives.
- It is recommendable that the fleets should consist of vehicles made by not more than one or two manufacturers. Thanks to this, the servicing and operation of the vehicles would be easier and the related costs would be lower in comparison with those to be borne in the case of having vehicles of many different makes.
- The construction of a filling station for one's own use should be carefully planned. It frequently happens in Poland that the stations are oversized and cause economic problems. Depending on the number and types of vehicles used and the frequency of refuelling operations, a decision should be made whether the station is to be designed as a quick-fill or slow-fill facility. The quick-fill stations are a cheaper solution in terms of investment costs; however, in the case that the fleets operated consist of larger numbers of vehicles and may be exclusively refuelled during specific periods (e.g. at night-time), the construction of slow-fill stations provided with an adequate number of fuel dispensers is more advisable.
- Preferably, the CNG filling station should be situated within the area of an existing conventional filling station. This would make it possible to reduce costs and to optimise the station functioning and the station personnel's work, especially in the situation that self-service at CNG refuelling has been forbidden by a Regulation of the Minister of Infrastructure of 15 July 2011.
- It is recommendable that the CNG filling station should be made available to all those who need refuelling of their vehicles (it should be open to the public). This would improve the economics of the whole project and contribute to development of the local market of private vehicles.

9. Conditions of development of the CNG market

The above examples and simplified analyses show that investments in CNG vehicles and infrastructure can be cost-effective solutions, provided that specific conditions are met. At the same time, stagnation in this market can be clearly seen in Poland. Without analysing the complex reasons for such a situation, we would like to point out the fact that the methods to make the development of this market in Poland more dynamic are worth being thought about.

Undoubtedly, a long-term strategy of development of the CNG market should be adopted, which should include solutions to be implemented on both nationwide and local levels. In consideration of particularly favourable properties of natural gas as fuel (the potential for reduction of emissions of greenhouse gases, other pollutants, and noise), such a strategy would be one of the elements of implementation of the long-term sustainable development policy. Poland is to fulfil specific obligations in this field, laid down in the EU climate and energy package and stemming from the Kyoto Protocol. The most important

areas of potential emission reductions include road transport, which accounts for 80% of the energy used by all the transport means and for about 23% of the CO2 emission, according to estimates. The potential of natural gas in this respect has been discerned by European institutions. Experts' reports prepared for the European Commission clearly show that natural gas plays the role of a bridge fuel between conventional fuels and technologically advanced fuels [13, 14]. The use of natural gas opens up wide vistas for the implementation of the use of biomethane and technologically advanced gaseous biofuels (bioSNG, HCNG), which will contribute to achieve the objectives related to the use of renewable energy sources in transport.

The development of a strategy for natural gas should be accompanied by comprehensive actions covering such areas as working out of favourable long-term legislative solutions to stabilise the market, preparation of instruments to support investment projects undertaken in the field of the refuelling infrastructure and the vehicles powered with such fuels, undertaking of pilot projects implemented on regional and local levels, conducting of widespread information campaigns, or support for research and development work.

For all these tasks to be carried out, cooperation is necessary between many entities and institutions interested in the development of this market in Poland, such as suppliers of vehicles and refuelling infrastructure, associations acting for the promotion of alternative gaseous fuels, scientific institutions, as well as local and national authorities. One of the most important enterprises related to the CNG market is certainly PGNiG S.A., which, as a gas supplier and owner of most refuelling stations, has created and shaped until now the development of local CNG markets. Simultaneously, the lack of a consistent development strategy for this segment of company's activity can be seen, which is very well reflected in the map of refuelling stations (uneven distribution of the stations, depending on decisions of district distribution companies; stations often situated on gasworks premises and only open during gasworks working hours; various infrastructure suppliers). This year, four stations belonging to PGNiG (located in Olsztyn, Bydgoszcz, Gdynia, and Kielce) have been closed.

Poland may implement good CNG promotion examples from other European countries, e.g. reduced vehicle registration costs, free parking of CNG vehicles in the paid parking zones, allowing CNG vehicles to enter central city parts, abolishing the recently introduced ban on self-service at CNG refuelling, and, which is most important, maintaining the preferential rate of the excise tax on CNG.

All these actions may help to develop the market of CNG vehicles and, in consequence, to introduce biogas as fuel to be used for transport purposes in the future, which will be consistent with the EU policy adopted to increase the share of biofuels in the total volume of transport fuels consumed and to reduce pollutant emissions. The issue of lowering the social costs related to the increased incidence of diseases and mortality rate among the inhabitants of urban agglomerations due to the presence of significant quantities of harmful substances generated by urban traffic cannot be considered as being unimportant, either. This aspect seems to attract insufficient attention and to be underestimated at discussions about the future shape of the road transport sector in Poland.

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