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Natural Gas Buses in Serbia Public Transport - Some Operational Experiences

The state of development and application of compressed natural gas (CNG) buses in Serbia is presented, together with a review of their number in some European countries and cities. After several years of operation of these buses in the largest fleets in Serbia (Belgrade and Novi Sad), an analysis of their economic benefits and ecological characteristics has been carried out. Special attention is paid to the operational costs and possible savings achievable by CNG buses compared to diesel buses. Ecological characteristics of these buses are presented through the measurements of exhaust emissions on one type of these buses and through presentation and analysis of data from the literature on emissions of the buses of identical or similar engines. The preformed investigations show that application of CNG buses brings significant savings as regards total costs during their operational lifecycle compared to diesel buses. On the other hand, CNG buses have a significant ecological potential as regards fulfilling stringent requirements for exhaust emissions standards.

Keywords: CNG buses, domestic development, fuel consumption, total costs, fuel cost savings.

1. INTRODUCTION

Since 2010 more than a third of the primary energy is derived from oil, and around 62% of the final energy consumption originating from oil is associated with the transportation sector. In Europe, in the European Union member countries (EU-27) in particular, the transport sector represented approximately 33% of the total energy consumption and was responsible for about 24% of carbon dioxide (CO_2) emissions in 2011 [1]. Given that, governments have been introducing a large number of policies and measures across all modes in an effort to improve efficiency of energy use.

According to a UITP (International Association of Public Transport) report published in 2011, buses account for 50-60% of the total public transport offer in Europe, and 95% use diesel fuels. However, a wide range of alternative fuels and technologies, at different levels of technical and market maturity are now available for bus operators [2].

A wide range of non oil-based options for road transport has been developed in the last decade, and some technologies are already commercialized. Five technological mainstreams are discussed today [3]: Biofuels, Natural gas and Liquid petroleum gas, Hybrids, Hydrogen and Fuel cells, and Battery electric technologies.

Alternative fuels [4] intended for application in motor vehicles could to a significant degree reduce air pollution thanks to some of their characteristics making them cleaner than petrol or diesel fuels. Generally speaking, these fuels while burning emit less hydro carbonates which are less reactive and less toxic and emission of CO_2 is also reduced thus less contributing to the process of global warming.

The hardest obstacle for massive implementation of alternative fuels and technologies in motor vehicles are their excessively high prices.

Natural gas has been considered as one of the most potential alternative fuels. This clean-burning alternative fuel can be used in vehicles as either compressed natural gas (CNG) or liquefied natural gas (LNG). According to the experiences and expectations for the future implementations of urban sustainable transport policies, CNG and hybrid electric are the two technologies to be addressed for a joined procurement of clean buses.

Development of CNG bus started in Serbia in 1996 and over this period several prototypes have been realized followed by a very modest series production. Since 2011 the fleet of city buses has been enriched by several buses of foreign production.

Positive experiences gained by the operation in real driving conditions of CNG buses realized so far and an accelerated development of the network of refuelling stations contributed towards an increased interest of transportation companies for procurement of this type of buses.

The purpose of this work is to support further enlargement of the fleet of CNG buses in Serbia, which are more energy efficient and ecologically acceptable and, in this way, make a contribution towards reducing consumption of fuels originating from oil and reducing influence of bus traffic on air pollution in urban environments.

2. SOME SPECIFIC OF CNG BUS TECHNOLOGIES

Most CNG buses of today are based on diesel engines [5] converted to spark-ignition engines. Spark-ignited engines are quite common in city bus applications all over the world.

Two main combustion schemes are applied in gas engines, either lean-burn combustion in which NOx formation is controlled in the combustion process by excess air, or stoichiometric combustion in combination with a three-way catalyst (TWC). Three-way Catalysts are also known as oxidation-reduction catalysts. They are designed to oxidize both carbon oxide (CO) and hydrocarbon (HC) and reduce nitrogen oxide (NOx). This results in the production of CO_2, nitrogen, and water [6].

The lean-burn engines are equipped with catalysts, namely oxidation catalysts (OC) to control HC, CO and methane emissions. Oxidation Catalysts are designed to oxidize both CO and HC, resulting in the production of CO_2 [6]. The ignition energy required for lean methane-air mixture is high, and thus misfiring and lifetime of the spark plugs are challenges for lean-burn engines. Keeping the air-fuel mixture stable especially with changing gas quality requires sophisticated engine management, e.g., closed loop control with lambda sensor [7].

Today many manufacturers have switched to stoichiometric combustion, as this technology in combination with TWC, in fact, provides lower emissions especially under transient running conditions. Closed-loop controlled stoichiometric engines are also less sensitive to changes in gas quality than simple lean-burn engines. The thermal load is high in stoichiometric engines [7].

Some manufacturers offer both naturally aspirated stoichiometric engines and turbocharged lean-burn/mix engines for CNG buses. At moderate load and speed, the turbocharged lean-mix engine operates with stoichiometric mixture. In the high torque and/or high engine speed range the engine operates with lean mixture to reduce the thermal loads of the engine. The engine is equipped with a three-way catalyst. In lean conditions, the catalyst operates as an oxidation catalyst [7].

New engine technologies like variable valve timing, exhaust gas recirculation (EGR), skip-fire, direct injection etc. can help to enhance the efficiency of spark ignited gas engines, but not to the level of compression ignition engines [7].

CNG engines present an attractive alternative to diesel engines for urban buses because they have been shown to emit lower particulate matter (PM) and NOx emissions in terms of grams per kilometre travelled and in terms of grams per unit energy produced. Although in theory CO_2 emissions per unit of energy produced are also lower compared to diesel fuel due to a higher ratio of hydrogen to carbon, the emission studies show a different trends [8].

On the basis of extensive investigations carried out by International Association for Natural Gas Vehicles (IANVG) [9], evidence is gained of certain peculiarities characteristic for application of CNG technologies in buses, like:
- CNG buses typically cost between 10 and 25% more than their diesel equivalents;
- On-board fuel storage capacity will add about 17% to the vehicle weight;
- CNG buses have a range of about 400km, compared with 700km for diesels;
- The fuel efficiency of CNG is not as good as diesel, with a 10-15% penalty being observed;
- Maintenance costs may be more expensive, due to lower production volumes of parts;
- Reliability of CNG buses may not equal diesel;
- Refuelling infrastructure costs are high;
- The most successful fleets have had a third or more of their fleet converted to CNG.

3. OVERVIEW OF CNG BUSES IN EUROPE

The use of natural gas in transportation is growing very rapidly in many countries. Worldwide there are about 21 million NGVs (Natural Gas Vehicles) supported by a network of 25,650 fuelling stations [10].

In Europe there are 4,684 fuelling stations and 1,734,385 NGVs, of which the number of buses is 154,068 or 8.9 %. From European countries the largest number of CNG buses has Ukraine (102,216), Armenia (17,300), Russia (12,000) and Georgia (6,000) [10].

In EU member countries the number of CNG buses is considerably lower compared to the above countries. Figure 1 shows 10 EU member countries having the largest fleets of these buses (including medium duty buses) [10].
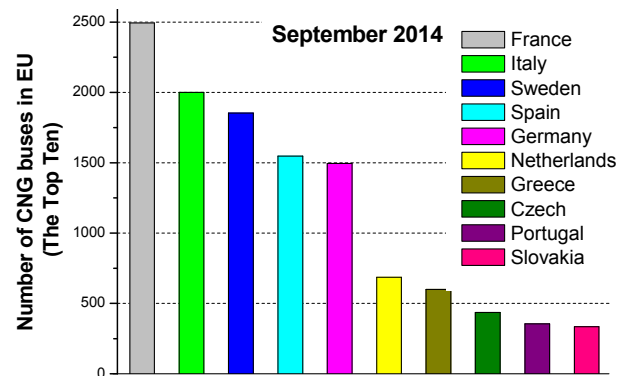

Figure 1. The EU countries with the largest number of CNG buses

European cities having the largest fleets of CNG buses are: Madrid (800), Rome (400), Barcelona (330), Lille (290) Bordeaux (289), Torino (286) The Hague (265), Porto (259), Nantes (251), Bologna (206), Malmö (160), Seville (156), Florence (153), Bremen (125), Nuremberg (99), Zagreb (60), Skopje (50 with dual fuel), Ljubljana (20) [11].

The study by IANVG found that only those operators that have been committed to a large enough number of CNG buses have had the greatest success.

The number of CNG buses in Europe has grown significantly over the last five years, and continuation of this trend is expected in the near future bearing in mind EU policies on alternative/renewable fuels and emissions of green house gases.

Many EU member countries applied various stimulating measures to enlarge their CNG vehicles fleets including buses [12], such as: Sweden (Investment support (~ 30%) for filling stations); Germany (Reduced tax rates for CNG vehicles up to 2018 and CNG fuel vouchers between €500 & €1,500, and subsidies for fleets); France (Set targets for number of CNG vehicles including 3,000 CNG urban buses and subsidy with €7,500/bus); Spain (Filling station grants from €25,000 up to €60,000 dependent on station type and size), and Netherlands (€600,000 subsidy for installing filling station).

As far as predicting future development of CNG vehicles it should be emphasized that many analyses and assumptions exist. According to one of the analyses [13], by taking into account current trends and the expected level of crude oil prices at the world market, the accomplished level of development of CNG vehicles and other factors, the corresponding mathematical modelling showed that by the year 2030, number of CNG vehicles in the world would reach 100 million. Compared to the number of these vehicles in 2014 this would result in an enlargement by a factor of 5.

4. STATUS OF DEVELOPMENT AND APPLICATION OF CNG BUSES IN SERBIA

In Serbia the program of development of CNG buses started in 1996 by making a study on possible application of natural gas in the transportation system in Serbia [14]; by 1998 bus manufacturer IKARBUS from Belgrade made the first prototype of CNG bus, marked IK-104 CNG, Table 1 [15]. The choice of engine and specific equipment for this prototype was based on commercially available solutions at that moment. The results of the tests of this bus showed all advantages of the natural gas as a cheaper fuel compared to diesel. This project ended by making one prototype which was not included in regular service.

In 2005 IKARBUS produced a new CNG bus, marked IK-103 CNG, Table 1, based on a somewhat more modern engine compared to the previous one. The bus has been included in regular service in the Public Transport Company "Novi Sad" where it is still running. Unfortunately, series production of this new bus has not been launched.

Appreciating the significance and necessity of introducing ecologically cleaner and economically more acceptable buses in the fleets of the major cities in Serbia, Institute of Nuclear Sciences VINČA, Centre for Engines and Vehicles, revived in 2005 the initiative for continuing the domestic development of a CNG bus. The initiative grew into a project, supported financially by the Ministry for Science and Technological Development of the Republic of Serbia, which was ended in 2008 by completion of a new prototype of the bus by the manufacturer FAP, Priboj. The bus, marked FAP A537.4 CNG, Table 1, was presented to the public at the Belgrade Fair of Commercial Vehicles "BEOTRUCK 2008". Two of these buses have been produced and included over the

AUTOKODEKS Company in the public transport in Belgrade where they are still running.

In February 2009 the firm "Vulović transport" ltd. from Kragujevac, in cooperation with the Belorussian firm MAZ, presented to the public a CNG low-floor bus marked MAZ-BIK-203 CNG, Table 1. The bus has been included in the public transport in Kragujevac and two years later several tens of these buses have been incorporated into the public transport of Belgrade.

After that, the fleet of CNG buses in Serbia was increased by 11 new buses manufactured by SOLARIS and IVECO, Table 1, procured for the Public Transport Company of "Novi Sad" in 2011.

The number of CNG buses included in regular service in Serbia by the end of 2014 reached 35. This is not a large number, but could be considered satisfactory having in mind this number several years ago. Table 2 shows structure of the fleet of CNG buses in Serbia in terms of locations, numbers, and models.

A reason for Serbia's lagging in the development and application of CNG vehicles, in general, is lack of the corresponding infrastructure, i.e. of refuelling stations despite a relatively well developed pipeline network. Investment costs of building a refuelling station are several hundred thousand Euros. Nevertheless, there were 9 refuelling stations in Serbia by the end of 2014: two in both Belgrade and Pančevo and one in Čačak, Kruševac, Kragujevac, Niš, and Zrenjanin. In Novi Sad there are two refuelling stations for internal use. One is in the Public Company „Srbijagas" and the other in the Public Transport Company „Novi Sad". Opening of several more refuelling stations has been announced, creating conditions for further significant increase of the number of CNG vehicles.

5. COMPARISON OF CNG AND DIESEL BUS FUEL CONSUMPTION

Introduction of CNG buses in the public transport in several cities in Serbia set the question of their economy as regards fuel consumption compared to their diesel counterparts. The initial period of exploitation indicated considerably lower costs of fuel of CNG buses. In order to obtain a more realistic picture of fuel consumption, a comparative testing of the CNG and diesel buses was carried out. This investigation was realised in cooperation of the Institute of Nuclear Sciences "VINČA", City Public Transport Company "Belgrade", and City Public Transport Company "Novi Sad". The tests were conducted for the selected bus models operated in the public transport in Belgrade and Novi Sad. Buses of the most common types were included. All buses were 12m of length, 2-axles, and of total gross weight 18.000 kg.

Two CNG buses by domestic manufacturers, FAP and VULOVIĆ TRANSPORT, and one by foreign manufacturers, SOLARIS, were included. The bus models subjected to the tests were: MAZ-BIK-203 CNG (CNG 1), SOLARIS Urbino 12 CNG (CNG 2), and FAP A537.4 CNG (CNG 3). Their basic technical data are presented in Table 1.

Models of the diesel buses subjected to the tests were selected at random from the buses operated at the selected locations. The consumption was measured for the bases: MAN SL 283 (**DIESEL 1**), IRISBUS IVECO CROSSWAY LE (**DIESEL 2**), and FAP A537.3 (**DIESEL 3**), and their basic technical data presented in Table 3.

Lines of the public transport determined for the measurement of consumption have been selected to represent different driving cycles at the selected locations. In locations in Belgrade and Novi Sad the selected lines were characterized by urban operating conditions (Lines 26 and 9, respectively) and a line in Belgrade was selected to represent urban-suburban operating conditions (Line 704). Table 4 presents pairs of the tested buses.

Line 26 (Dorćol - Braće Jerković) is a line with complex configuration of the terrain having many up hills and down hills, and accommodating 23 stops and 20 traffic lights.

Line 704 (Zemun polje - Zeleni venac) is a line containing segments of an urban line and mainly straight and flat terrain outside the city core, including 17 stops and 15 traffic lights.

Line 9 (Novo naselje - Petrovaradin) having relatively straight and flat terrain with 25 stops and 25 traffic lights.

The comparative testing at Line 26 included 5 CNG and 8 diesel buses, whereas at Lines 704 and 9 the testing included one CNG and one diesel bus. It should be mentioned that all tests have been carried out at similar daily hours and similar weather conditions, and that qualities of the CNG and diesel fuels were within the prescribed quality limits at all locations.

The results of the measurement of fuel consumptions, including basic data on driving bus cycles are presented in Table 5. When calculating energy consumption of the buses, the applied data for diesel fuel were energy content 36 MJ/litre and density 840 kg/m^3 and for CNG fuel energy content 34.4 MJ/m^3 (48,8 MJ/kg) and density 0.705 kg/m^3.

From the presented results, one may conclude that fuel consumptions are different for the analyzed bus models. It is also noticeable that fuel consumption is proportional to the average bus speed, its load, and characteristics of the driving bus cycles. It should also be taken into account that the tested buses had different mileages, several times higher for diesel compared to CNG bus (except for the buses of Line 9 which were of the same production year and of approximately the same mileages).

When the consumption data, per each pair of buses, are recalculated at the annual level and assuming that within this period the buses make 50.000 to 100.000 km, one obtains the potential fuel cost savings in favour of CNG buses.

Figure 2 shows possible savings (in Euros) per each CNG bus compared to its diesel counterpart as functions of the realized mileage (at annual level). The parameter in these calculations is the average fuel price in Belgrade and Novi Sad in November 2014. CNG price was 0.60 Euro/kg and diesel fuel 1.09 Euro/litre. The recalculated price of CNG per litre of the diesel

equivalent is 0.44 Euro/litre, thus the ratio of gas and diesel prices is 0.404 (referenced to the energy content).
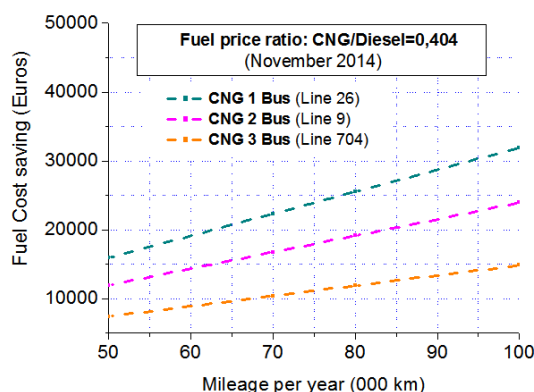

Figure 2. Fuel cost saving with the current fuel prices

Analysis of the presented results leads to the following conclusions:

- At Line 26, where the operating conditions were the hardest, the saving effect in terms of fuel was the highest. In this one should bear in mind that the mileages of diesel buses were significant which could have influenced their consumptions.
- On the other hand, at the easiest Line 704, the saving effect was the lowest, but one should bear in mind that engine of the corresponding diesel bus was in a very good state and known by its economy.
- Line 9 is possibly the most representative since the tested buses were of the same production year and of the same mileage level, where the saving by the CNG buses was between the above two cases.
- Savings on fuel costs (at the annual level of 80.000 km) for the tested CNG buses were:
  - with CNG 1 bus: 25,528 Euros,
  - with CNG 2 bus: 19,144 Euros, and
  - with CNG 3 bus: 11,888 Euros.

If price of the CNG was 20% lower (0.48 Euro/kg) than the current price (with government subsidies), ratio of the equivalent gas price and diesel fuel price (in terms of energy content) would be 0.325. With this ratio of the prices of CNG and diesel, even greater savings would have been accomplished, as illustrated by Figure 3.
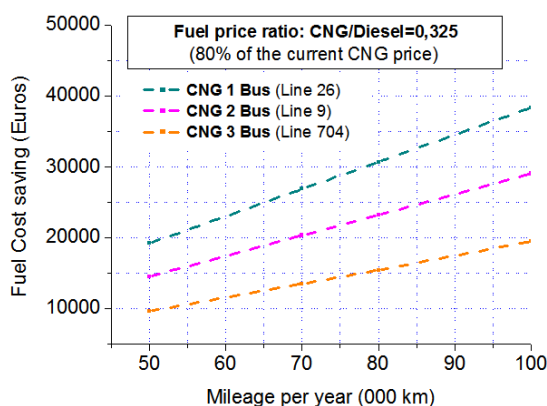

Figure 3. Fuel cost saving with decreased gas price by about 20%

In this case, for an average mileage of 80.000 km at annual level, the savings would be:

- with CNG 1 bus: 30,712 Euros,
- with CNG 2 bus: 23,234 Euros, and
- with CNG 3 bus: 15,440 Euros.

The presented results undoubtedly show advantage of CNG buses over diesel buses as regards economy effects. Under the assumption that lifecycle of a bus is 10 years, it can be concluded that, on the basis of fuel costs, for the given period of operation one bus can make savings sufficient for purchasing one new CNG bus, whose single price is from 180,000 to 250,000 Euro.

6. COMPARISON OF TOTAL BUS OPERATION COSTS

One of the goals of this work is establishing the main elements of cost during exploitation of CNG buses compared to diesel buses, for the assumed lifecycle of a bus and total lifetime mileage. In accordance with Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles total lifetime mileage for buses is 800,000 km [16].

Total costs of buses, in this paper, implies the costs during service life, including bus procurement costs and operational costs. The operational costs include costs of fuel and maintenance costs (the costs of the scheduled services, operating fluids, and spare parts).

The fuel costs are calculated on the basis of the consumption measurements and the maintenance costs are calculated on the basis of the costs realized in the operation period until now. In doing so, a care has been taken that maintenance of the buses is carried out in accordance with the procedures prescribed by the manufacturer. The costs of labour, as well as the external costs concerning the additional infrastructure – refuelling stations, have not been taken into account.

The CNG buses are more demanding as regards maintenance, since their engine are much more sensitive to the lengths of service intervals, owing to their specific components, such as spark plugs, wires, filters for fuel, etc. In addition, periodic inspections of the complete fuel installations are required for these buses, including CNG storage tanks.

In this analysis are included 6 CNG buses (Solaris Urbino 12 CNG) and 15 diesel buses (IRISBUS IVECO Crossway LE) over the exploitation period 2011-2014. The CNG buses have done over 1.4 million kilometres in the mentioned exploitation period, while the diesel buses have done over 3.5 million of kilometres.

When calculating total costs within the assumed service lifetime of a bus, the following elements are included:

- price of diesel buses: (imported 160,000 €, domestic 125,000€),
- price of CNG buses: (imported 240,000 €, domestic 170,000€),
- total lifetime mileage: 800,000 km,
- diesel price: 1.09 €/litre,
- CNG price: 0.60 €/kg,
- fuel consumption for diesel buses: 45.4 litres/100 km and

- fuel consumption for CNG buses: 42.6 kg/100 km.

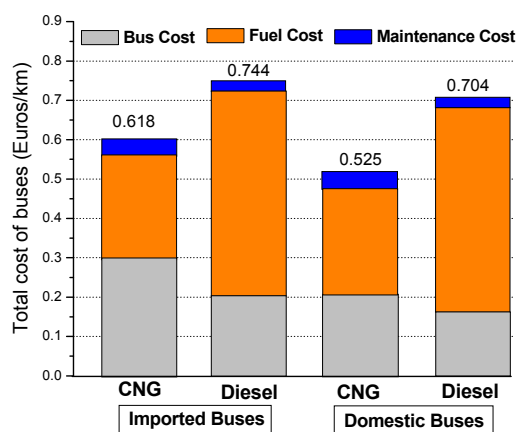Figure 4 shows total costs for both imported and domestic considered buses.

Figure 4. Total costs of different bus technologies

The comparative analysis of costs imported buses shows that dominant costs are the purchase cost of buses and fuel costs. Despite a considerably higher cost of a CNG buses compared to the corresponding diesel buses (about 50%), but a considerably lower fuel cost (48%), total costs of a CNG buses over the considered period of operation are lower by 17%. Positive effects in favour of CNG buses would have been certainly higher if the purchase price of buses and CNG fuel costs were lower than the calculated. Both of these items can be highly influenced by the government through the corresponding subventions. In that sense, the Republic of Serbia adopted the Regulation on subsidized purchase of CNG vehicles of domestic production by 30% at the beginning of 2010.

Immediately after introduction of this Regulation, some effects were visible through an increased number of CNG buses in the public transport of the city of Belgrade. Even though the price of domestic buses was lower compared to the imported buses by as much as 40%, the relatively modest production capabilities of domestic manufacturers and underdeveloped network of CNG refuelling stations turned out to be the limiting factors for any significant enlargement of the fleet of domestic CNG buses.

If one takes into account a relatively favourable price of domestic CNG buses accompanied by the fact that the prices of domestic diesel buses compared to the imported diesel buses are lower by 30%, then, assuming that the share of other costs (fuel and maintenance) is the one presented in the above analysis, Figure 4, one comes to the following conclusion: Total costs of domestic CNG buses, after 800,000 km of operation, would be by 25% lower compared to those of domestic diesel buses and by 14.6% lower compared to the imported CNG buses.

7. EMMISSON CHARACTERISTICS OF CNG BUSES

It is well known that CNG engines produce considerably lower emissions of PM and NOx compared to diesel engines. However, they produce more CO and HC than diesel engines. Special

oxidation catalysts have been developed for CNG engines to reduce CO and HC emissions, as well as additional PM reductions.

From the presentation of the basic technical characteristics of CNG buses that are in use in Serbian public transport, Tables 1 and 2, it can be observed that the prevailing buses with Euro V/EEV emission and stoichiometric combustion engines, and that there are only three buses with lean-burn spark-ignited combustion engine.

After introduction of bus FAP A537.4 CNG (CNG 3) having engine CUMMINS CGe 280 into regular service, Institute of Nuclear Sciences "VINČA", Center for Engines and Vehicles, initiated measurement of its emission performance under real driving conditions. The measurements included determination of the concentrations of CO, HC (including methane), NOx, and CO2 in exhaust system on Line 704. Engine CUMMINS CGe 280 is turbocharged, lean-burn engine with an oxidation catalyst and makes use of a closed loop control, with an Air/Fuel ratio sensor and backpressure sensor [17].

For performing these measurements, the following equipment has been used:

-A comprehensive data logging system, AX22 [18] (measurement of bus speed and mileage),

-Air-mass meter with hot-film, BOSCH HFM5 [19] (measurement of air flow at the engine intake), and

-Gas analyzer, GLOBALPRO EGA-688 [20] (measurement of concentrations of gases in the exhaust system).

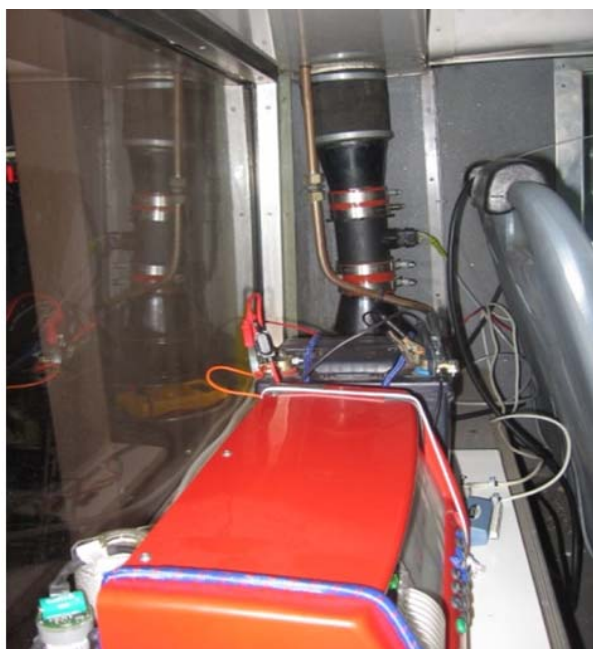Parts of the measurement equipments (gas analyzer, air-mass meter) are shown in Figure 5.

Figure 5. A view at the measurement equipment

Having in mind that emissions of vehicles under real operating conditions are usually expressed as functions of the distance travelled (g/km) it was required to apply the corresponding calculations and transforms to convert the measured volumetric concentration of the component emissions into above form. For performing these calculations the use is

made of the data on travelled distance, total measured volume of exhaust gases during tests, and data on reference densities of the components. It should be mentioned that the obtained data are tentative and of an informative character.
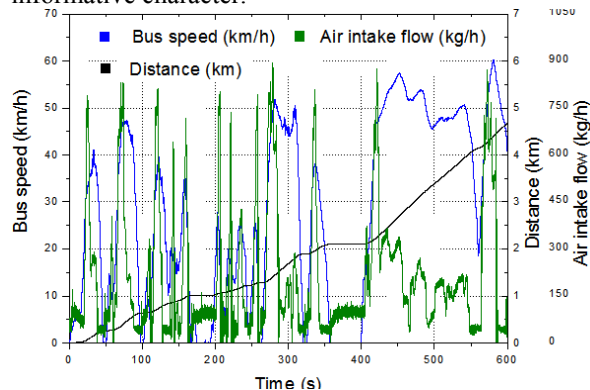

Figure 6. Record of the driving cycle elements of CNG 3 bus

Figures 6 and Figure 7 show partial records of the measured parameters, at one segment of Line 704, without load of the bus.
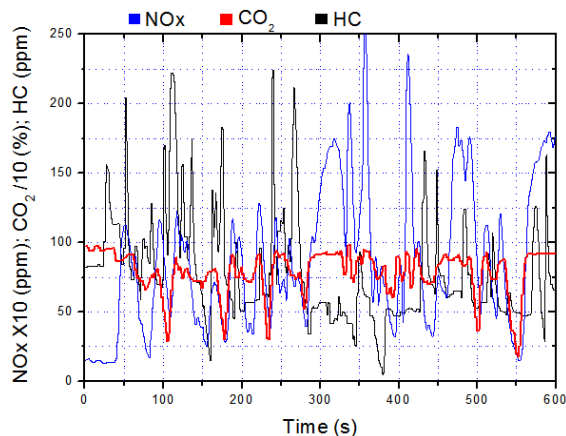

Figure 7. Record of the parameters of the exhaust emission of CNG 3 bus

Table 6 presents average values (from several measurements) of the exhaust emission components for no load and half loaded bus and entire Line 704. Relatively low level of HC emission (including mainly methane) is certainly due to the built in oxidation catalyst. All emission components are increased with increasing load.

Table 6. Exhaust emission of FAP A537.4 CNG Bus

Engine	Cummins CGe 280 CNG lean burn engine, **Euro IV**		
Real driving cycle–Line 704 (Distance: 15,1 km; Average speed: 27,5 km/h, Share of idle: 15%, Stops/km: 1,6)			
Emission (g/km)	NOx	HC	CO	CO$_2$
No load	9.97	0.28	n/a	872
Half load	10.92	0.33	n/a	1006

However, a shortcoming of lean-burn engines, in general, is that the oxidation catalyst cannot reduce NOx emission under lean-burn conditions therefore this emission is relatively high. The measured CO$_2$ is at the level of the corresponding diesel engine because CNG buses do not give a significant benefit in terms of

CO₂ reductions (can even lead to a small increase). The reason is that CNG engines, owing to their lower energy efficiency (by about 25%), annul the effect of lower CO_2 emissions, which has natural gas compared to diesel fuel.

For informative comparison, Table 7 shows the measurement results of emissions by Daimler Orion V with Cummins CG-280 CNG engine, without OC, carried out in laboratory conditions, according to Braunschweig bus cycle [21]. As can be noted, the same engine, but without OC, is in question and emission of HC is quite higher. The other components of the exhaust emissions are approximately at the same levels. It is observable that NOx emissions increased with increasing load, but the increase was very moderate. CO and CO_2 emissions tend to increase with increasing load [22].

Table 7. Exhaust emission of Daimler Orion V CNG bus

Engine	Cummins CG-280 CNG lean burn engine, **Euro III**			
Braunschweig bus cycle (Distance: 11,0 km; Average speed: 22,5 km/h, Share of idle: 26%, Stops/km: 2,65)				
Emission (g/km)	NOx	HC	CO	CO₂
No load	10.0	17.5	0.17	1180
Half load	11.0	20.0	0.32	1300

After the city transport companies in Belgrade and Novi Sad purchased certain number of CNG buses having the newest stoichiometric combustion gas engine (Cummins Westport ISL-G and Iveco Cursor 8 F2G), it was interesting to establish how their emissions compared to those of the lean-burn engines. Unfortunately, the lack of adequate measuring equipment turned further activities to collecting and analysis of data taken from the literature.

Cummins Westport ISL-G 8.9 liter engine [23] (built in CNG 1 bus) is a stoichiometric CNG engine that employs cooled EGR, turbo-charging and after-treatment through a TWC to achieve Euro V emission levels [17]. For analyzing emission performance of this engine the use is made of the data collected at the Altoona Bus Research & Testing Center (ABRTC), in Altoona PA [24]. This Centre conducts required testing for all new transit bus models under the Federal Transit Administration's new model bus testing program. The test is performed on chassis dynamometers in laboratories according to Orange Country Bus cycle [25]. This driving cycle was developed by West Virginia University based on real bus operating data. Altoona measured emissions for Daimler Orion VII CNG bus with Cummins ISL G280 CNG engine are given in Table 8.

Table 8. Exhaust emission of Daimler Orion VII CNG bus

Engine	Cummins ISL G280 CNG stoichiometric combustion engine, **Euro V**			
Orange Country Bus cycle (Distance: 10,46 km; Average speed: 19,31 km/h)				
Emission (g/km)	NOx	HC	CO	CO₂
Half seated load	0.16	0.18	4.03	1177

IVECO Cursor 8 F2G CNG engine (built in the buses by IVECO IRISBUS and SOLARIS) is stoichiometric combustion CNG engine, with a TWC to achieve Euro V emission levels. Exhaust emission of Citelis 12 CNG bus, with Cursor 8 F2G engine, measured by the University of Graz in Austria on chassis dynamometers in laboratories according to Brauschweig bus cycle [26] are presented in Table 9.

Table 9. Exhaust emission of Citelis 12 CNG bus

Engine	Cursor 8 F2G, stoichiometric combustion CNG engine, **Euro V**			
Braunschweig bus cycle (Distance: 11,0 km; Average speed: 22,5 km/h, Idle: 26%, Stops/km: 2,65)				
Emission (g/km)	NOx	HC	CO	CO₂
Half load	1.45	0.15	0.45	1063

The listed data on emissions of different engine technologies are of informative character and are aimed at indicating technological solutions of CNG engines capable of fulfilling the current emission standards.

Analysis of the presented results indicates that engine technology has an important influence on exhaust emissions. It is noticeable that stoichiometric engine with EGR and using a three-way catalyst can significantly reduce the emissions of NOx and HC compared to the lean–burn engine. However, stoichiometric combustion with EGR includes significantly higher CO emissions compared to the lean-burn strategy. Regulated emissions depend on the sophistication of the engine and the exhaust control system.

To meet the most stringent Euro VI emission standards, natural gas engine manufacturers have found it necessary to switch to stoichiometric combustion combined with EGR and TWC after-treatment.

8. CONCLUDING REMARKS

The experience acquired so far from the operation of CNG buses in Serbia indicates some positive economic effects coming from the use of natural gas as a cheaper fuel compared to diesel. In all tests carried out with CNG buses, significant savings have been accomplished on fuel costs, reaching up to 50% compared to diesel buses.

Despite higher purchase price of CNG buses and higher maintenance costs compared to diesel buses, total costs of these buses are lower. Depending upon purchase price of a bus, these costs could be lower by up to 25%.

CNG buses have good ecological characteristics, since modern CNG engines fulfil the most stringent standards on harmful emissions. From the above data on emissions of certain CNG engines one can conclude that stoichiometric operation with EGR and three-way catalyst as the preferred strategy in the future.

The results presented in this paper indicate the importance of domestic bus production and natural gas as an alternative fuel. Without help from the government through the corresponding subsidies and incentives, domestic manufacturers cannot cope with the increasing international competition. In that sense, a clear strategy concerning further development of the bus sector inclusive of the strategy of development of alternative fuels and technologies is needed.

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АУТОБУСИ НА КОМПРИМОВАНИ ПРИРОДНИ ГАС У ЈАВНОМ ПРЕВОЗУ У СРБИЈИ - НЕКА ИСКУСТВА ИЗ ЕКСПЛОАТАЦИЈЕ

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У овом раду приказано је стање развоја и примене аутобуса са погоном на природни гас, односно компримовани природни гас (КПГ) у Републици Србији, са освртом на њихову заступљеност у неким европским земљама, па и шире. После неколико година експлоатације ових аутобуса у највећим возним парковима у Србији (Београду и Новом Саду), спроведена је анализа њихових економских предности и еколошких карактеристика. Посебна пажња посвећена је трошковима експлоатације и могућим уштедама аутобуса на КПГ у поређењу са дизел аутобусима. Еколошке карактеристике ових аутобуса представљене су кроз мерење издувне емисије на једном од аутобуса и кроз приказ и анализу података из литературе о емисији аутобуса са сличним или истим моторима. Спроведена истраживања указују да примена аутобуса на КПГ доноси значајне уштеде у погледу укупних трошкова током експлоатације у поређењу са дизел аутобусима. С друге стране, аутобуси на КПГ имају висок еколошки потенцијал у погледу могућности да испуне строге захтеве у области издувне емисије.

Table 1. Models of CNG buses in the Serbian fleet (excluding IKARBUS IK-104 CNG)

Bus	IKARBUS IK-104 CNG	IKARBUS IK-103 CNG	FAP A537.4 CNG
Engine	RABA DELTEC G10 DE 190	RABA G10 DEUTSLL 190	CUMMINS –CGe4-280
Engine Power	190 kW (260 KS)	190 kW (260 KS)	209 kW (280 KS)
After treatment	-	-	Oxidation Catalyst
Transmission	ZF 6S-85	VOITH D854 3E automatic	Allison T 325R/TC 421i automatic
Emission Standard	n/a	Euro 3	Euro 4
Passenger Capacity	100	100	100
Year	1998	2005	2008
Bus	**MAZ-BIK 203 CNG**	**SOLARIS Urbino 12 CNG**	**IVECO IRISBUS Citelis CNG**
Engine	CUMMINS ISL Ge EV 250	Iveco Cursor 8 CNG	Iveco Cursor 8 CNG
Engine Power	192 kW (261HP)	200kW (272 HP)	200kW (272 HP)
After treatment	TWC for CNG	TWC for CNG	TWC for CNG
Transmission	Allison T280 (R) automatic	Automatic Voith Diwa 854.5	Automatic Voith Diwa 854.5
Emission Standard	Euro 5/EEV	Euro 5/EEV	Euro 5/EEV
Passenger Capacity	103	91	100
Year	2011	2011	2012

Table 2. The structure of CNG buses in Serbia

City	Total units	Manufacturer	Type of Bus	Units	Year
Belgrade	22	FAP Serbia	FAP A537.4 CNG	2	2008
		VULOVIĆ TRANSPORT Serbia	MAZ-BIK-203 CNG	20	2010, 2011
Novi Sad	12	SOLARIS Poland	SOLARIS Urbino 12 CNG	6	2011
		IVECO IRISBUS Italy	IVECO Bus Citelis CNG	5	2012
		IKARBUS Serbia	IK-103 CNG	1	2005
Kragujevac	1	VULOVIĆ TRANSPORT Serbia	MAZ-BIK-203CNG	1	2009

Table 3. Models of diesel buses tested comparatively with CNG buses

Bus	MAN SL 283 (DIESEL 1)	IVECO IRISBUS CROSSWAY LE (DIESEL 2)	FAP A 537.3 (DIESEL 3)
Engine	D 0836 LOH 02	Iveco Cursor 8	OM 457 hLA
Engine Power	206 kW (280 HP)	243 kW (330 HP)	185 kW (250 HP)
Transmission	VOITH 864.3E automatic	VOITH D 864.5 automatic	VOITH D864.5 automatic
Emission Standard	Euro 3	Euro 5	Euro 3
Passenger Capacity	105	101	101
Year	2003	2012	2005

Table 4. Pairs of the tested buses at the selected locations

Belgrade		Novi Sad
Line 26	Line 704	Line 9
CNG 1 (79,500 km)	CNG 3 (620,000 km)	CNG 2 (239,081 km)
DIESEL 1 (508,000 km)	DIESEL 3 (800,000 km)	DIESEL 2 (243,987 km)

Table 5. Relevant properties of drive cycles and fuel consumptions of all tested buses

Bus	CNG 1	DIESEL 1	CNG 2	DIESEL 2	CNG 3	DIESEL 3
City Line	26		9		704	
Type of bus cycle	Heavy urban		Easy urban		Suburban	
Distance	9.7 (km)		10.9 (km)		15.1 (km)	
Stops/km	3.4		3.4		1.6	
Average speed	12.9 (km/h)		17.7 (km/h)		22.7 (km/h)	
Stop time	45 (%)		25 (%)		15 (%)	
Average load	55-60 (%)		25-30%		35-40 (%)	
Fuel consumption	54 (kg/100 km)	59 (lit/100 km)	42.6 kg/100km	45.4 lit/100km	37 (kg/100 km)	34 (lit/100 km)
Energy consumption	26,3 MJ/km	21.24 MJ/km	20.8 MJ/km	16.34 MJ/km	18.06 MJ/km	12.24 MJ/km
Period of testing	October 2013		November 2014		October 2013	