CNG BUSES FOR CLEAN AND ECONOMICAL CITY TRANSPORT

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INTRODUCTION

The goal of the European Union is that alternative sources of energy will represent 20% of total consumption by 2020, confirming the strong political will amongst European countries to reduce global pollution and improve living standards. The use of alternative sources of energy can significantly increase a country's energy independence from international political and economic issues, since they need not fear the threat of energy supply interruption. Geographical features of the country affect the final decision as to the type of alternative source of energy to use.

Whatever climate policies are introduced, natural gas – a special focus in WEO-2009 *(*The World Energy Outlook 2009) – is also set to continue to play a bridging role in meeting the world's sustainable energy needs. In the Reference Scenario, gas demand rises by 41% from 3.0 **t**rillion **c**ubic **m**etres (tcm) in 2007 to 4.3 tcm in 2030. Gas demand also continues to expand in the "450 Scenario" but is 17% lower in 2030 than in the Reference Scenario thanks to more efficient use, lower electricity demand and increased switching to non-fossil energy sources [1].

WEO-2009 demonstrates that containing climate change is possible but will require a profound transformation of the energy sector. The "450 Scenario" sets out an aggressive timetable of actions needed to limit the long-term concentration of greenhouse gases in the atmosphere to 450 parts per million of carbon-dioxide equivalent and keep the global temperature rise to around 2 ^{o}C above pre-industrial levels. To achieve this scenario, fossil-fuel demand would need to peak by 2020 and energy-related carbon dioxide emissions to fall to 26.4 gigatonne (Gt) in 2030 from 28.8 Gt in 2007 [1].

Today, there are two key benefits of operating a Compressed Natural Gas (CNG) powered vehicle:

- Lower harmful emissions, and
- Reduced fuel costs (CNG fuel cost is approximately 50% less than diesel).

The greatest environmental benefit of using CNG as fuel is the dramatic reduction of exhaust gases; for example, compared to the equivalent Turbo Diesel Engine carbon

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monoxide (CO) emissions are over 50% lower, nitrogen oxide (NO_x) emissions are 97% lower, and there are zero particulates.

The engine also can operate on biofuels, a sustainable fuel that is now becoming commercially available from renewable sources, or CNG, which is the same gas we use for our heating and cooking at home.

As concern road transport vehicles featuring following properties seems to be good candidate for shift from consumption of liquid hydrocarbons to use of natural gas as a fuel:

- Fleet vehicles whose are able to be supplied by fuel from one refuelling station,
- Vehicles performing limited amount of kilometres per day not demanding storage of high amount of fuel in vehicle tank,
- Vehicles which do not fully utilize their loading capacity during typical operations. Weight penalty due to high mass of fuel storage tank does not influence payload capacity of vehicle in this case, and
- Vehicles, whose makes possible by proper design and arrangement of their power unit to exploit the environmental advantages of natural gas use. In this way the still more strict environmental regulation demands can be fulfilled or even lower emission of pollutants can be obtained.

Usually the daily performance of city bus is about 350 km for our city conditions. Nevertheless the city bus is many times favourite subject for use of natural gas as a fuel.

Natural Gas is pressurized to 22 MPa in vehicular storage tanks, so that it has about 1/3 of the volumetric energy density of gasoline. The storage pressure is about 20 times that of propane. Combustion of methane is different from that of liquid hydrocarbon combustion since only carbon-hydrogen bonds are involved and no carbon-carbon bond, so the combustion process is more likely to be complete, producing less non-methane hydrocarbons. Operations under lean conditions will also lower the peak combustion temperatures. The lower combustion temperatures lower the NO_x formation rate and produce less engine-out NO_x.

Natural gas (from the chemical point of view mainly methane CH_4) contains 75% of carbon and 25% of hydrogen by mass. Diesel oil, which is composed from heavy hydrocarbons, contains about 87% of carbon and 12% of hydrogen by mass. Complete oxidization of 1 kg methane produces approx. 2.75 kg of CO_2, while complete oxidization of 1 kg diesel oil produces about 3.15 kg of CO_2. At the same time heating value of methane is higher than those of diesel oil in ratio about 50/43 (MJ/kg). Even if slightly lower efficiency of gas engine (compared to diesel one) is taken into account the production of CO_2 from natural gas powered vehicle is significantly lower than those from vehicle equipped with diesel engine. Natural gas fuelled engine practically does not produce any particles. Premixed combustion which takes place in combustion chamber of gas engine avoid the reactions which caused in diesel engine combustion chamber to fuel thermal decomposition and formation of soot [2,3,4,5,6].

THE ECO-CNG POWERED CITY BUS PROJECT

Take in mind the experience of leading manufacturers of buses, we propose the technical specifications and new design for a prototype of fully low floor city bus with CNG drive. The prototype bus is implemented with the original gas engine mark CUMMINS according to Euro IV legislations, while the vehicle serial production continued with engines to meet the Enchanced Enviroment friendly Vehicle (EEV/EEV+) norm. Assembling the original engine is provided the maximum efficiency of the applied fuel, since the same is designed for operation exclusively on CNG, so that their structural characteristics and projected operating cycle, ensures maximum dynamics and efficiency. In combination with the automatic gearbox mark ALLISON, achieved good performance of movement and maximum use of engine output parameters, which have a positive effect on passengers comfort and fuel economy [3].

Figure 1 shows the parts of the CNG fuel line equipment from on the bus roof mounted gas cylinders trade mark DYNETEK to the engine that is applied to bus. All parts of the installations are designed according to regulation UN ECE R 110 and the same labels are printed on the material.

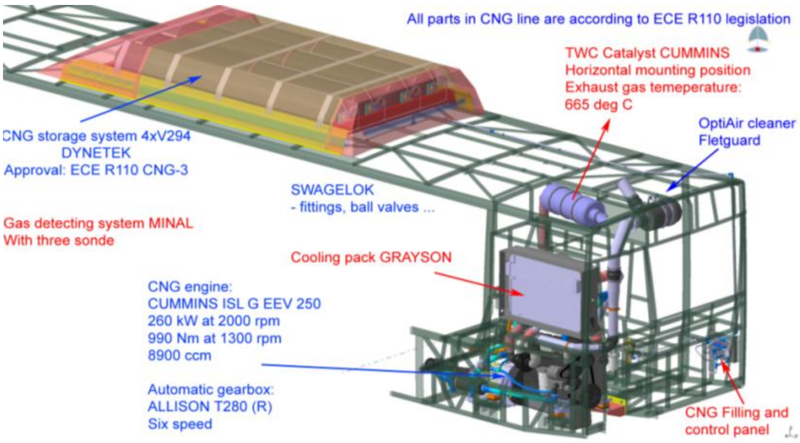

Figure 1: *The CNG fuel line equipment in the bus*

Implementation of CNG as fuel, first of all, request mounting of gas cylinders with the appropriate support. The mounting position on the bus roof has been selected according to the projected mass distribution on the front axle and rear – driving axle, all on the basis of primary diesel vehicle, in order to save vehicle performances and brake forces distribution [3].

On the vehicle roof are mounted four cylinders mark DYNETEK "V294", with a total water capacity of 1.176 l, diameter 386 mm and length 3128 mm. Weight of one tank was about 92.4 kg (0.308 kg/l). The composite DyneCell® cylinders are particularly lightweight cylinders for the storage of CNG. They consist of a thin-walled, seamless aluminium internal vessel whose entire surface is wrapped with a high-strength carbon fibre reinforcement (CNG Type III = “fully wrapped metal liner” in accordance with ECE R 110 and ISO 11439) [3].

By using tank-type CNG-3, achieved the better bus performance, lower weight, has up to 8 seats more for passengers, the lower number of failures and regular vehicle services, the friction on the wheels of the front axle is less for about 30%, and gas consumptions is lower for about 0.5 to 1 kg/100 km. As a comparison, for the same radius with one filling, if used gas tanks-type CNG-2, bus had about 40% more weight [7].

Low Emissions, Improved Performance, Lower Costs

This bus package contains the Cummins Westport 2007 ISL G spark ignited, natural gas engine. These engines are designed to meet the proposed 2010 U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) emission standards at launch in mid 2007, fig. 2. The engine is based on the 8.9 L diesel automotive (ISL) platform and shares many installation options with the diesel counterpart.

The 8.9 L 2007 ISL G engines will use stoichiometric combustion with Cooled Exhaust Gas Recirculation (CEGR) technology to enable a three way catalyst after treatment method, leveraging Cummins proven EGR technology to create a high-performance natural gas engine. This replaces the lean-burn technology of C Gas Plus and L Gas Plus engines. The cooled EGR system takes a measured quantity of exhaust gas and passes it trough a cooler to reduce temperatures before mixing it with fuel and the incoming air charge to the cylinder. Cooled EGR, in combination with stochiometric combustion (the theoretical or ideal combustion process in which fuel and oxygen are completely consumed, with no unburned fuel or free oxygen in the exhaust), provides significant benefits [3,4,8].

The use of cooled EGR (in place of large amounts of excess air used in lean burn technology) lowers combustion temperatures and knock tendency. Use stoichiometric combustion with CEGR technology also improves power density and fuel economy compared to lean and alone stoichiometric technologies. Compared to previous Cummins Westport Inc. (CWI) lean burn natural gas engines, ISL G torque at idle is improved over 30% and fuel economy is improved by up to 5% [8].

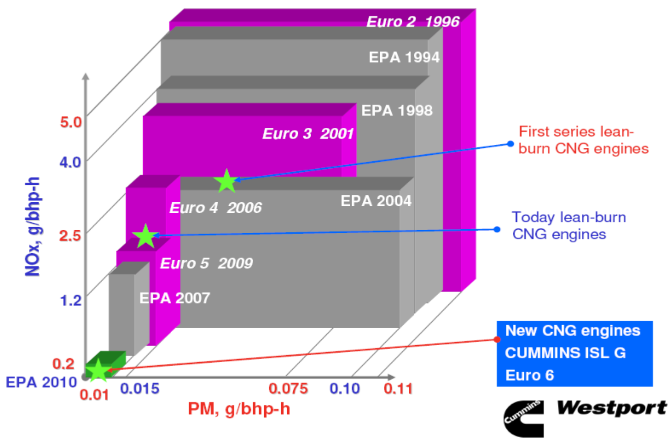

__Figure 2:__ Exhaust gas emission standards and ISL G position

Another benefit of the ISL G`s advanced combustion technology is CEGR combustion creates an oxygen-free exhaust, which in turn allows for the use of Three-Way Catalyst (TWC) after treatment. TWC-s is effective, simple passive devices packaged as part of the muffler that provide consistent performance and are maintenance-free. The ISL G does not require active after treatment such as a diesel particulate filter (DPF) or selective catalytic reduction (SCR).

Air/Fuel regulation in Cummins closed-loop electronic control system based on Cummins Interact^{TM} System. Sensors for engine parameters, including intake manifold pressure and temperature, fuel inlet pressure, knock detection, air/fuel ratio, and fuel mass flow. Electronically controlled waste gate turbocharger is also integrated. The ISL G engine is capable of operating on compressed or liquid natural gas (CNG, LNG). The ISL G can also operate on up to 100% biomethane – renewable natural gas made from biogas or landfill gas that has been upgraded to pipeline and vehicle fuel quality. Biomethane fuel is carbon dioxide (CO_2) neutral and using it as fuel reduces vehicle greenhouse gas emissions by up to 90% [8].

New CNG Powered Bus Safety Guidelines

Some relevant properties of natural gas like vehicle fuel include:

- Natural gas is invisible but odorized so its presence can be detected,
- CNG fuel systems store fuel at approximately 20 MPa, and as high as 26 MPa,
- Unlike gasoline vapors, natural gas and hydrogen are both lighter-than-air and in gaseous form at atmospheric conditions. This property allows these fuels to quickly rise and disperse in the unlikely event of leak,
- Both CNG and H_2 have an ignition temperature of around 480 ^oC to 650 ^oC – whereas gasoline is approximately 260 ^oC to 430 ^oC and diesel is less than 260 ^oC. This relatively high ignition temperature for CNG and H_2 is an additional safety feature of these fuels. To ensure a safe environment in the maintenance garage, the surface temperature of equipment that could contact a gas leak is usually limited to 400 ^oC [9], and
- Natural gas has a very selective and narrow range of flammability–that is, the mixture of gas in air that will support combustion (between 5% and 15% natural gas in air by volume–ratios outside of this range will not support combustion) [9].

The main safety concern regarding CNG vehicles in a repair facility is the possibility of fuel releases and their consequences. Natural gas leaks can be either fast or slow. A fast leak usually involves the release of a safety valve or complete severing of a fuel line. In the case of the safety valve, all the gas in the fuel tank will be vented to the atmosphere. Other major fuel releases can be controlled by closing appropriate valves. Slow releases are those caused by fuel escaping through a loose fitting or an abraded line or hose.

Both types of leaks can cause flammable mixtures to form in the work area. These flammable mixtures will disperse and over time will dissipate to safe levels. Workplace safety can be maintained by reducing fuel release volumes, keeping ignition sources away from areas where flammable mixtures may travel and using proper ventilation to control how long these flammable mixtures exist and where they will be present.

If a slow fuel release occurs, natural mixing of the released fuel with the surrounding air will cause **most** such mixtures to become too lean to support combustion. Methane's relatively narrow flammability range means that the diluting of the mixture occurs quickly and the only flammable mixture will be near the release site.

Fast releases have the potential to generate large clouds of fuel that can form flammable mixtures some distance from the release site. Since methane is lighter than air, released fuel will tend to rise from the release site. This contrasts with conventional fuels which puddle and form vapors that travel along the floor. In facilities where CNG vehicles are being serviced, ignition sources above the vehicles are of primary concern. These ignition sources can include electric equipment that generate sparks or high surface temperatures and open flame heaters. Ventilation systems should be designed to remove fuel from above vehicles or to promote mixing of the air in the space above the vehicles.

Figure 3 shows garage model for CNG vehicles with a flat roof and overhead lighting and infra-red heaters.

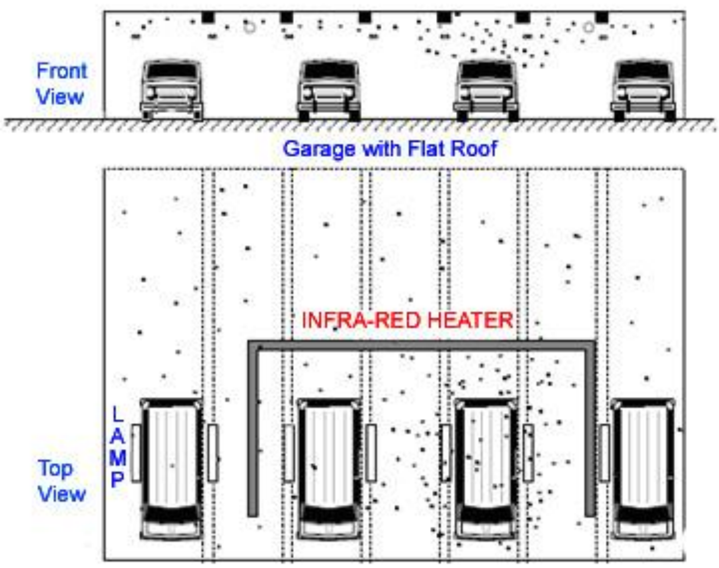

Figure 3: *Example of CNG Vehicle Fuel Release – Garage with Flat Roof*

A fast fuel release from one of the vehicles will cause a flammable cloud to travel across the ceiling. While the flammable cloud is rising it will pass over the lighting and the heating system. With the large flat ceiling, a flammable layer can form below the ceiling. Without proper ventilation removing fuel from near the ceiling, this layer can be ignited by a spark from the lighting or heating system.

According to previous analysis, lighter-than-air fuels have safety advantages, roofs and ceilings of these facilities must be designed without any unventilated “pockets” in the ceiling space that could trap gas. Ventilation systems for CNG – fuelled buses garages must be designed that typically provides between 5 and 6 Air Changes per Hour (ACH) (the requirement is for 425 L/min per 1 m^2 of ventilated area) [9]. There is no additional airflow requirement and cost, according to existing diesel facilities designed for a baseline ventilation rate of 4 to 6 ACH.

Used CNG tanks have been tested under a pressure of 30 MPa and for fire protection all cylinders fitted with Pressure Relief Devices (PRD), approved according to the relevant standard in connection with the cylinder type. Cylinders are equipped with electric shut-off valves to stop and open the CNG flow in fuel line. In the valve is integrated thermal switch that quickly respond to increasing temperatures (in 110 ^oC + - 3.5% according to ECE R 110). That is so called Temperature triggered Pressure Relief Device (TPRD) system that is integrated in the brass device, which are placed in the middle and at the end of the cylinders. Its working pressure is 26 MPa and this is also a protective device, pressure regulator that is thermal activated at the temperature of 110 ^oC in cylinders for CNG [3,7].

In figure 4 is shown one of the stickers on one of the mounted tanks. On the sticker there are useful data.

Figure 4: *The photo of gas tank sticker*

The cylinders have a maximum Service Life of 15 to 20 years [7] from the final manufacturing inspection date, depending on the number of cycles per year specified in the standard for the country where the cylinder is operated. The expiration date is specified on the label, fig. 4.

Than the Service Life is reached, the cylinders must be removed from service. If cylinders are filled more than [1000 x Service Life in years] before the expiration date is reached the cylinders must also be removed from service [7].

Cylinders require an external re-inspection for defects in the composite wrap at certain intervals after installation or upon reinstallation. Inspection shall always be in accordance with procedures outlined in ISO 19078, and/or also according to the relevant national standard of the country where the cylinder is operated. According to ECE R110 Rev. 2/Amend.4, for natural gas cylinders this inspection shall be performed at least every 48 months after the date the vehicle enters into service [7].

On the bus is also integrated system for measuring the concentration of methane with three sonde (placed in the engine compartment area, in the passengers saloon, and under the CNG tank cover on vehicle roof, (in accordance with the standard ECE R110), and central microprocessor with LCD display, which is placed in the driver working place [3].

ACTUAL TRENDS AND SECURITY OF GAS MARKET SUPPLY

Security of the natural gas market supply represents one of the major strategic and long term goals of a responsible energy policy in the gas field. Concerning gas, Serbia is one of the highly import depending countries of the region, which has suffered problems of a unilateral supply interruption several times in the past. In January 2009, during the gas crisis due to a well-known dispute between the Russian Federation and Ukraine, Serbian natural gas market supply has been totally deferred.

In order to prevent unforeseeable circumstances in terms of gas crisis or other accidental situations affecting the market supply, Public Enterprise Srbijagas has entered investments into construction of an underground storage near Banatski Dvor and intensified activities towards diversification of supply routes as well.

The prospect of the South Stream Project arouses interest in the European energy market. This project would make Serbia a transit country and could considerably contribute to the security of market supply not only in Serbia but also in the countries of South East and West Europe.

In the winter 2009/10 in the crisis time, with short-term measures was conducted follows [10]:

- Increase domestic production to 7 million cubic meters of gas per day,
- Increasing amounts of gas from underground storage Banatski Dvor on 1 million cubic meters gas per day,
- Security Storage 200 million cubic meters of gas in Hungary for Serbia, with delivery at the level of 2 million cubic meters of gas per day, in the winter period,
- Imports from Russia at the level of 10 million cubic meters of gas per day.

In this way, the first time provided the amount of natural gas from 13.7 million cubic meters a day, for the Serbian market and exports in transit for Bosnian Federation [10].

Long-term planning measures to ensure security of supply of natural gas market in Serbia, according to the Energy Development Strategy up to 2015 include the following objectives:

- Completion of construction of the second phase of the Banatski Dvor underground gas storage capacity to 5 million cubic meters of gas per day, and
- Connectivity infrastructure at the regional level, international project South Stream.

The first phase of Banatski Dvor underground gas storage is finalized, so it is with a capacity of 960,000 cubic meters. In the mid of december 2009, began gas production.

Based on the credit of the European Bank for Reconstruction and Development, plans to build underground gas storage in Itebej nearly Žitište, and connect with the regional gas network.

Potential project South Stream is a project of international gas pipeline from Russia that under the Black Sea to Bulgaria and further via two routes transported gas transit through several countries in Western Europe. For now, the supposed route through Serbia would be between Zaječar, Belgrade, and Subotica [10].

In addition to several signed protocols and agreements, 15 may 2009 in Sochi, in the presence of Prime Minister of the Russian Federation and Italy, representatives of gas companies from Russia, Italy, Bulgaria, Serbia, Greece signed an agreement to build an International Gas Pipeline South Stream. According to this decision, 17 November 2009 year, the Gazprom and Public Enterprise Srbijagas start joint venture company South Stream Serbia AD, with direction office in Bern, with previously defined main goals.

In the complete calculation Russian story is just special. Russian Federation produced 651 billion cubic meters of gas in 2007, which represents 41.3% of total produced energy of this state, of which for us interest Gazprom produced 549.6 billion cubic meters of gas in Russia. For 2010 year, the predicted 670, while for the 2030 year forecasts of gas production in Russia reached approximately 997 billion cubic meters [3,10].
The above strategy is in accordance with the assessment that in the period between 2020 and 2025 in the European market require an additional 200 billion cubic meters of gas per year.

REASONS FOR USE OF CNG BUSES IN KRAGUJEVAC

Today the world has about 9.56 million vehicles operated on natural gas (CNG bus total number is about 256,820) and over 14,500 filling stations. According to estimation, it comes up with lower CO_2 emissions by over 15 billion tons [11]. Since 1991 until today, the middle rate of growth of motor vehicles with CNG drive in the total fleet is 18% per year. If continue with this rate by 2020, in the world will be around 65 million gas vehicles, while natural gas as a fuel a day to change to 3.5 million barrels of oil [11].

By using buses with CNG drive, primarily to a large extent contribute to the preservation of health, as compared to conventional diesel vehicles have the following benefits [8,11]:

- For more than 50% lower emissions of Non Methane Hydrocarbons (NMHC),

- From 30% to 60% lower NO_X emissions,
- More than 80% of the less reactivity of the ozone layer,
- Reduced the emission of sulphur compounds in the products of combustion,
- Reduced the emission of fuel vapours during the fuel filling,
- For more than 90% reduction of Particulate Matter emissions,
- Eliminated black smoke from exhaust and carcinogenic particulate emissions, and
- For more than 15 dB below the level of external noise to the diesel vehicle.

Figure 5 shows a diagram of changes in prices of oil and gas. Price of gas is significantly lower than the price of a litre of diesel fuel, especially if the company has its own CNG fuel station [8].

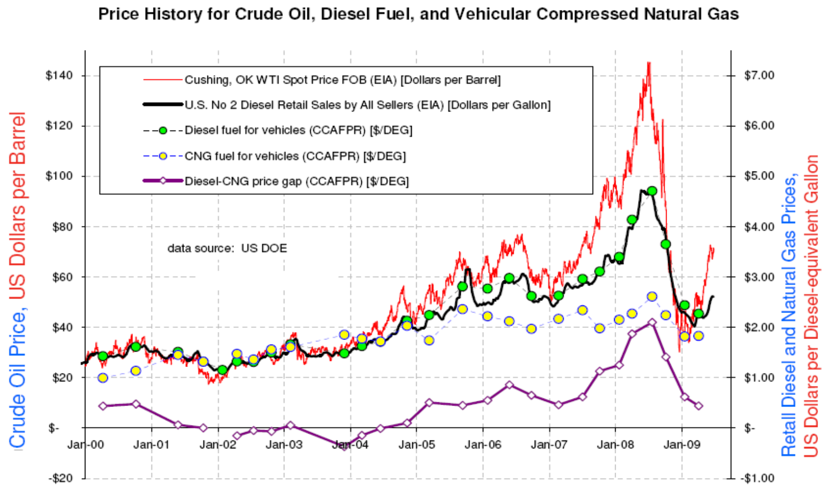

Figure 5: *Prices change for Crude Oil, Diesel and CNG*

Costs of bus fleet conversions to natural gas technologies are concentrated in the initial capital investment. The purchase cost of a CNG bus can range from $25,000 to $50,000 more than a diesel bus. This price differential is expected to grow narrower as production volumes of CNG buses increase. Also, investment in natural gas fuelling infrastructure usually requires construction of a new fuelling facility. These fuelling facilities can be an investment in future natural gas vehicle fleets that will demand public refuelling stations. The Federal Transit Administration has estimated the cost of a fuelling station for a fleet of 200 buses at approximately $1.7 million. Finally, National Fire Protection Association (NFPA) codes may require modification of bus storage depots to incorporate gaseous fuel detection systems. Despite these added costs, operational and maintenance expenses tend to be lower than those for diesel-powered buses, including newer "clean diesel" models fitted with after-treatment devices. Natural gas-powered buses save money because they do not require frequent oil changes and regular cleaning and eventual replacement of new filters. Since natural gas engines are inherently cleaner burning and experience less engine wear, normal maintenance costs tend to remain low, but these costs have varied among transit.

Public transport in Kragujevac city operates with 50 buses with average 280 km/per day, every 315 working days per year. In this moment, actual situations with diesel and CNG buses are in the next [3,12]:

- Average diesel fuel consumption is about 40 L/100 km. With range of 280 km per day, this is about 112 L of Diesel fuel daily, for one bus. With 50 buses for Public Transport in Kragujevac final average diesel fuel consumption is 5,600 L of diesel fuel daily
- Average CNG consumption is about 33 kg/100 km, and this is about 4,620 kg of CNG daily
- Price for Euro Diesel fuel in this moment is about 1 €/L, whereat for CNG is about 0.41 €/kg on proper CNG filling stations, or 0.65 €/kg on liberal sale

Taking into account these parameters, we obtain the following conclusions about a **year operation** with a 50 buses operated on diesel fuel and CNG especially in Kragujevac city in 315 working days [3,12]:

- Total consumption in case of diesel drive is 1,764,000 L of diesel fuel or 1,764,000 €
- Total CNG consumptions is 1,455,300 kg of CNG or 596,673 € *(proper fuel station)*
- If transporter uses the public station, then the annual CNG cost is about 946,000 €

If we replace complete diesel buses fleet in Kragujevac city with new CNG buses, (our proposal project “KRAGUJ”) total money savings is about 1,167,000 € yearly.

Costs for additional infrastructure and new CNG filling stations are about max 450,000 € for two stations with filling capacity of 1,800 m^3 of CNG an hour. Also should take into account the depreciation for buses.

Looking the complete calculation for the period from 5 to 10 years, according to contract validity for Passengers Public Transport, it is clear what the level of fuel savings is much major.

All this should add the second benefits, taking into account the reduction of vehicle noise at work on CNG, as well as reducing emissions of toxic and harmful combustion products in exhaust gases.

Another main purpose was to produce biogas for the city buses to reduce the local, regional and global emissions from the urban transport (some projects started in Kragujevac on this topic).

The city is located in the middle of an agricultural district on the plains central Serbia. The prerequisites for building a biogas plants were thus obvious. The manure from cattle and pigs in the area could be co-digested with abattoir waste and organic waste from other food industries.

The biogas plant has made it possible for the city of Kragujevac like example to decrease the CO_2 emissions from transport and also to decrease the local emissions of dust, sulphur and NO_X.

During the prototype bus exploitation was confirmed a better fuel economy with CNG, compared to diesel drive. Fuel cost per kilometre is lower for about two or three times with CNG, especially in situations than the transportation company has its properly CNG fuel station.

In the period from 26/05/2009 to 17/06/2009, during the exploitation in City Transportations Company Belgrade, CNG bus achieved an average gas consumption of 40.7 kg/100 km (on the city routes: 74, 94, 55 and 58). During the work on private line number 707 in Belgrade city, average gas consumption was 32.5 kg/100 km, while in the city of Kragujevac, during the exploitations on mixed regimes in all routes achieved an average gas consumptions of 33 kg/100 km. On the open road, while a drive at intercity conditions, average gas consumption measured was 22.4 kg/100 km. Also, it is important to note that the vehicle radius with one filling is around 560 km in the urban conditions [3,12].

According to possibilities of gearbox regime settings to work on economy mode, referred to the experience during the prototypes exploitations, was realised the vehicle adjustment-settings for further serial production. Also it`s very important that the CNG engine working temperature moving in the projected range, without deviations. Visual control of CNG fuel line is not significant changes, and all detectors are not registered methane presence in the measuring areas.

CONCLUSIONS

Use of Compressed Natural Gas – CNG as an alternative fuel is an effective, currently available way to help solve pressing environmental and fuel – resource problems.

The goal of the European Union is that alternative sources of energy will represent 20% of total consumption by 2020, confirming the strong political will amongst European countries to reduce global pollution and improve living standards.

Using the gas tanks composed of light material type 3 and projecting the CNG vehicle installations in accordance with regulations ECE R 110, on the buses achieved a remarkable progress in terms of safety, and also regarding to fuel economy and emissions lowering.

Mounting of original CNG engine reached the maximum effectiveness of the used fuel, the vehicle meets the environmental norms defunded with Enchanced Enviroment friendly Vehicle norm. Combination with automatic gearbox with six speeds have a positive effect on passengers and drive comfort, as well as on cost, because of effective using of engine power output.

By using buses with CNG drive, primarily to a large extent contribute to the preservation of health, as compared to conventional diesel vehicles have environmental benefits.

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