BENEFIT AND RESTRICTIONS RELATED TO THE APPLICATION OF NATURAL GAS AS ENGINE FUEL FOR CITY BUSES

Milojevic Sasa and Pesic Radivoje*
Assistant research*; Full Professor
Faculty of Engineering, Department for Motor Vehicles and IC Engines
University of Kragujevac, Kragujevac 34000, Republic of Serbia
E-mails: mismil01@gmail.com*; pesicr@kg.ac.rs

ABSTRACT

Human activities, in particular transport, are partially responsible for the problem associated with the greenhouse effect, and therefore global warming. The transport sector is responsible for around of 25% of Carbon Dioxide emissions and consumes almost 50% of global oil production. Natural Gas as an alternative fuel has many advantages: lower costs, lower emissions because of more complete combustion, lower noise and longer engine life. The goal of the European Union is that alternative sources of energy represent 20% of total consumption by 2020. In many countries around the world, intensively growing consumption of energy produced from fossil fuels. The similar situation is related to the European Union, where the demand for energy is constantly increasing too. Because the resources are limited, the consequences are the dependence of the oil product which comes from politically unstable regions with increased costs. According to the global strategy we are seeking to solve these problems through a series of initiatives and innovations including the introduction of Natural Gas buses in city transport. If we take into account the existing situation in city transport, our strategic proposal is to begin by retrofitting diesel buses into bi-fuel or dedicated Natural Gas Vehicles. This paper analyzed some benefits, which summarized according to the authors' experiences about the introduction of the Compressed Natural Gas buses in urban transport in Kragujevac city. Regarding to the future, for us this is first step before starting new project related to the introduction of Hydrogen buses in city transport.

Keywords: CNG buses, Alternative fuels, Emission, City transport.

1. INTRODUCTION

In the last 50 years, transport systems have been characterized by a serious increase in the use of the private car and the parallel development of road infrastructure and parking space to accommodate it. The following are some of the most adverse effects of this form of dispersed development based on a high use of the private car:

- congestion, and the related losses in travel time and competitiveness,
- higher transport costs for the community,
- loss of valuable green spaces,
- higher consumption of energy for passenger transport,
- pollution, and related health problems,
- contribution to climate change,
- decreased quality of urban life,
- health problems due to the lack of physical exercise,
- social exclusion for those who can't afford to live close to the city center and do not have access to a private car

In April 2010, the European Commission (EC) released a Communication on a European strategy on clean and energy efficient vehicles and fuels. EC set out several policy measures to support the creation of a clean and energy efficient transport system that will contribute to achieving the Europe 2020 objectives with respect to reduction of Carbon Dioxide (CO_2) emissions and increase the share of alternative fuels and renewable sources in transport (UN ECE 2012).

Generally, transport is responsible for about 32% of the EU´s final energy use and 21% of CO_2 emissions. Public urban and sub-urban transport systems with buses are only responsible to a very low degree for local environmental pollution. As example, their energy consumption per travelled passenger/kilometer is one-third of that of a car, specifically as the number of such vehicles involved is extremely low. As consequence, regarding to the total CO_2 emissions, only 5% is generated by buses and coaches. Therefore, bus transport is not, in principle, an essential target in the fight against CO_2 (UN ECE 2012).

But because of the public nature of their activity, usually in close relation with or even regulated or funded by public bodies or authorities, bus operators have an extended responsibility in environmental matters. This means that the operators and the relevant authorities in this sector have to step up their commitment.

Looking in the long term, new form of advanced propulsion systems (hybrid drive, fuel cells, etc.) will become widely accepted due to their low toxicity of exhaust gasses, specifically because of low noise emissions level. But while these advanced propulsion systems in vehicles do not reach the real price and the level of technical efficiency, there will be a strategic dilemma regarding the choice of powertrain and fuel. The ultimate goal is to meet increasingly strict environmental regulations and reduce fuel consumption.

Second option is the use of numerous alternative fuels existing as available for vehicles. EC action plan provides for a 20% substitution of conventional fuels such as petrol and diesel with alternative fuels by 2020. The Commission aims at dramatically reducing Europe's dependence on imported oil and cut carbon emissions in transport by 60% based on 1990 levels by 2050. Methane (Natural Gas/Biogas) is mentioned as one of the alternatives and can play an important role to help achieving the 2050 key goals. Methane will make an important contribution to achieve the predominant target to have no more conventionally fuelled cars in cities, in order to improve local air quality and reduce noise exposure. It will have to be complemented by the development of an appropriate refueling infrastructure for new vehicles. Regarding to the global strategy, the large fleets of urban buses, taxis and delivery vans are particularly suitable for the introduction of alternative propulsion systems and fuels (UN ECE, 2012).

Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG), both as the alternative fuels, have many advantages: lower cost, more complete combustion, lower emissions, lower noise and longer engine life. CNG technology has been developed for decades and now is available for commercial use in motor vehicles. Natural gas causing about 25% lower CO_2 emissions compared to the same amount of energy diesel fuel, due to the lower carbon content (H/C = 4), and thus contributes significantly to reducing global warming. This enables bus body builders as example, to make natural gas buses comply with the challenging and voluntary emission standards, without using extensive filter technology as it is selective catalytic reduction system with AdBlue or expensive additives (Milojevic and Pesic, 2012).

The introduction of natural gas powered vehicles is basically caused by very high investment costs that are required for the build-up of the needed refueling infrastructure (CNG compressor's stations or LNG pumps). EU member states have decided to put a different strategy focus on national level, in terms of type of vehicles. As example, some states like France or Spain are so far mostly going for urban Heavy Duty Vehicles (urban buses and trucks) using CNG, but hardly have any Light Duty Vehicles on their roads (UN ECE, 2012).

The diversity of national strategies has led to a very fragmented development of natural gas refueling (public filling stations or private flee depot stations). According to previous, there are the needs for a harmonized strategy to develop natural gas refueling across the EU. The following two concepts of natural gas refueling stations apply:

- CNG station using a compressor connected to the pipeline and
- LNG station with CNG and LNG dispenser where LNG is stored in a cryogenic tank.

In total there are only 4.623 refueling points (public and private) in Europe, and more than 1.9 million NGVs (more than 280.000 buses) (*Journal:* Gas Vehicle Report, 2014).

The Republic of Serbia has initiated a number of pilot projects at the local level in order to promote the ecological advantages of buses powered by CNG for the transport of passengers. The first example is the reconstruction of a diesel bus to drive on CNG in the city of Kragujevac, which is used for further development of lobbying in order to replace the entire diesel fleet with CNG buses (Milojevic and Pesic, 2010).

2. INTRODUCTION OF CNG PROPULSION SYSTEM DEMONSTRATED ON CITY BUS

At the end of the nineties in the Republic of Serbia was attempting the production of city buses with CNG drive, where they used steel gas cylinders and natural gas engine complied with old technologies. Bearing in mind the experience of leading manufacturers of buses, the design engineers in domestics Production Company from Kragujevac city have successfully implemented a prototype of fully low floor city bus with CNG propulsion system. The prototype bus is implemented with the original gas engine complied with Euro IV legislations, while the serial production continued with engines to meet the EEV+ norm. Engine is designed for operation exclusively on CNG, so that their structural characteristics and projected operating cycle, ensures maximum dynamism and efficiency. In combination with the automatic gearbox are achieved good performances of driving and maximum use of engine output parameters, which have a positive effect on the comfort of passengers.

Fig.1, shows parts of the installation for CNG supply from bus roof mounted gas cylinders to the engine that is applied to prototype version of CNG bus. All parts inside of the CNG installations are designed and approved according to the regulation UN ECE R 110 (Milojevic and Pesic, 2012; United Nations, 2008; Rasche, 2009).

The retrofit of the diesel bus into a dedicated natural gas vehicle begins with the joining of the CNG cylinders with the original rack, Fig.1, to the bus roof. We selected CNG storage system that includes type 3 cylinders composed of an aluminum 6061 liner reinforced by carbon fiber in epoxy resin (brand Dyne-cell®), with a favorable ratio between weight and volume (0.3 kg/L to 0.4 kg/L) (Rasche, 2009).

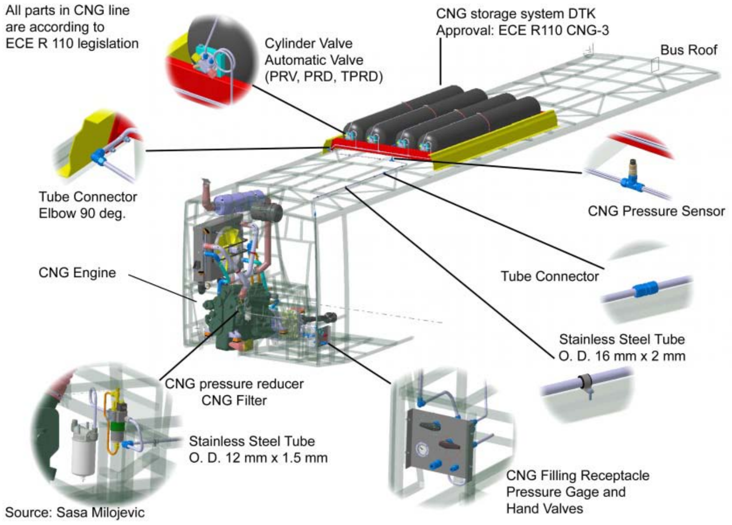


Fig. 1. Sketch of the CNG fuel line equipment installed on the bus (Milojevic and Pesic, 2010).

During the retrofit, we have considered the existing regulations regarding the dimensions and gross vehicle weight. Specifically, we took into account the requirements relating to the correct joining of the main parts of the CNG fuel line and gas cylinders, all legislated by regulation ECE R 110 (Milojevic and Pesic, 2010; United Nations, 2008). The position of the new center of gravity is calculated, taking into account the added weight of the CNG cylinders with the rack on the bus roof.

According to requirements for vehicles of categories M3 and N3, (resistance to destruction of the roof structure during deceleration of 6.6·*g* in the longitudinal and 5·*g* in transverse direction), we calculated and accepted the mounting of CNG cylinders assembly to carry through the auxiliary "U" profiles, Fig. 2, (United Nations, 2008; *Journal:* Intellectual Property Gazette, Milojevic et al., 2012).

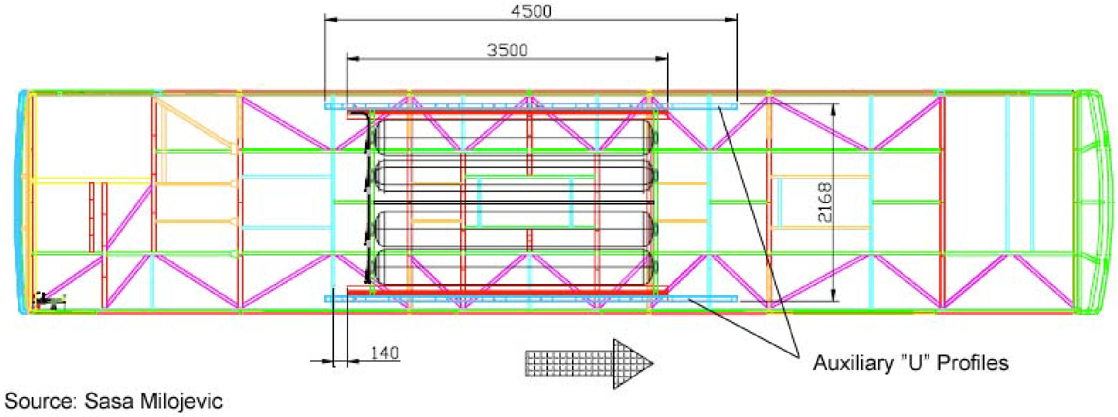


Fig. 2. CNG cylinders rack position on the bus roof.

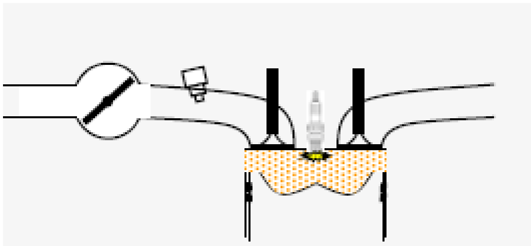
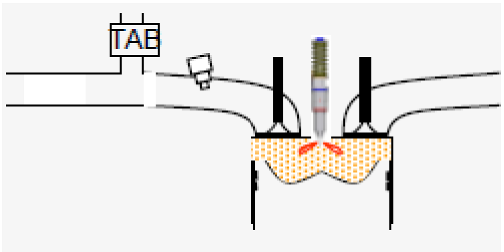
Combustion Concepts Applicable to CNG Engines – Main Benefits

Substituting conventional fuels (gasoline and diesel) by natural gas in road transport can be achieved by introducing to the market new vehicles ex-factory equipped with CNG engines, or as a first step, by converting engines of existing vehicles to CNG. To introduce natural gas as a fuel for road transport through the conversion of vehicles to CNG, the following options are possible (United Nations, 1993; Milojević and Pešić, 2011):

a) Modification of a gasoline (Otto cycle) engine to CNG combustion (conversion to a dedicated fuel);
b) Modification of a gasoline engine to either CNG or gasoline (two way/bi-fuel) combustion;
c) Conversion of a diesel engine to dedicated CNG (spark ignition) combustion; and
d) Conversion of a diesel engine to dual fuel (gas and diesel combined) combustion.

For conversion of existing diesel buses as it is our situations, only two options are applicable, Table 1 (UN ECE, 2012):

Table 1. Natural Gas Engine Combustion Concepts – (Modification of Diesel Engine)

Combustion Concept	Dedicated Spark-Ignited (used in our case)	Dual Fuel (DF)
		
Operation	Gas and air pre-mixed at low pressure Air flow is metered using a throttle Ignition from spark plug Uses either an oxidation catalyst or three-way catalyst (lean burn or stoichiometric mixture) Otto cycle	Gas and air pre-mixed at low pressure Air may be partially metered using a turbo air bypass or a throttle Ignition from diesel pilot injection (existing injector or specific pilot injector) Otto cycle / Diesel cycle
Fuel System	100% Natural Gas CNG or LNG No run on Diesel Capability	Typical substitution of 50 up to 60% over duty cycle 100% run on diesel capable

As example, for the retrofit, we are used spark ignited natural gas engine designed to meet 2010 U.S. Environmental Protection Agency (EPA) and California Air Resources Board (CARB) emission standards, Fig. 3. The engine works on the base of stoichiometric combustion with Cooled Exhaust Gas Recirculation (CEGR) technology to enable a three way catalyst after treatment method, leveraging EGR technology to create a high-performance. With this engine/combustion concept, we are replaced the lean-burn technology used for our first prototype bus engine. The cooled EGR system takes a measured quantity of exhaust gas and passes it through a cooler to reduce temperatures before mixing it with fuel and fresh air to charge the cylinder. Cooled EGR, in combination with stoichiometric 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 (Milojevic and Pesic, 2010).

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 used lean burn natural gas engines, in this case, torque at idle is improved over 30% and fuel economy is improved by up to 5% (Milojevic and Pesic, 2010).

If we look from the point of using the buses in public transport, it is very important fact that selected stoichiometric engine type is capable of operating on CNG or LNG. The used engine can also operate on up to 100% bio-methane, renewable natural gas made from biogas or landfill gas that has been upgraded to pipeline and vehicle fuel quality.

The noise incurred and generated by city traffic has a negative impact to a large extent to life quality, too. In the Republic of Serbia as well as in other parts worldwide, the traffic generated noise is becoming a very serious issue, especially in large industrial cities.

Another advantage of our and similar projects is the fact that reconstructing buses from diesel fuel drive to CNG applications, we contribute to noise decline to a large extent. It was also proved during the conveyed tests and noise measuring according to methods defined by adequate and referential standards.

When at idle, the outside bus noise with CNG drive is lower for 7 up to 13 dB(A) compared to the alternative with diesel engine, whereas at 1800 min^{-1} at high idle, decline of 22 dB(A) was registered. The outside noise of CNG drive buses in motion, at speed limit of 30 $km \cdot h^{-1}$, 40 $km \cdot h^{-1}$, and 50 $km \cdot h^{-1}$ is lower for 1 up to 6 dB(A) compared to the same type bus version with diesel fuel drive (Milojevic at al., 2013).

In public transportation of passengers in the city of Kragujevac there are 50 buses which daily make about 250 km as an average, for 315 working days per year, by applying the CNG buses instead of the existing with diesel engines, a considerable decline in noise emission would be achieved.

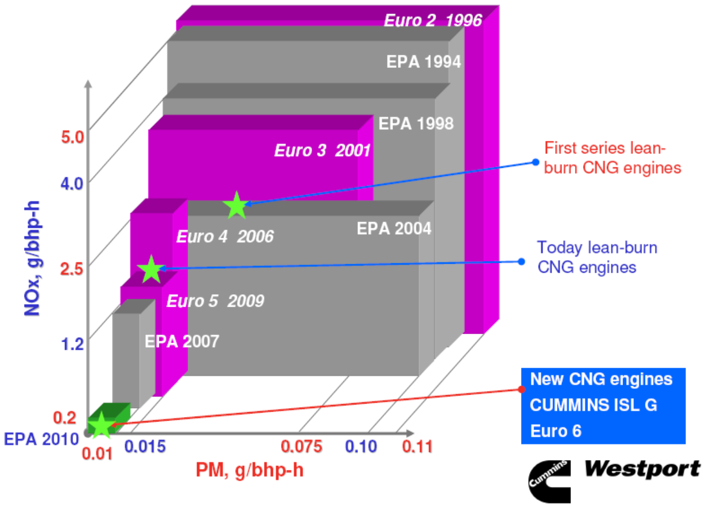


Fig. 3. Exhaust gas emission standards and used engines position.

CNG Bus Safety Guidelines

We selected the relevant properties of natural gas which are important to know when used as vehicle fuel (Milojevic and Pesic, 2010):

- 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 is lighter than air and in gaseous form at atmospheric conditions. This property allows to quickly rise and disperse in the unlikely event of leak,
- CNG has an ignition temperature of around 480 °C to 650 °C, whereas gasoline is approximately 260 °C to 430 °C and diesel is less than 260 °C. This relatively high ignition temperature for CNG is an additional safety feature of this fuel. 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 °C, 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, while outside of this range will not support combustion).

The main safety concern regarding CNG buses 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 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.

We insist on the obligatory equipment of the buses with system for fire-extinguishing with water mist in engine compartment and other enclosed spaces.

3. BENEFITS OF CNG BUSES IN THE CITY OF KRAGUJEVAC

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 (Website: http://www.worldwatch.org/node/5461).

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 environmental benefits (*Website:* http://www.dieselnet.com; Milojevic and Pesic, 2010):

- Meets Regulated 2010 EPA/CARB and Euro VI (09.2014) limits for emissions,
- Lower greenhouse gas emissions, (up to 25% less),
- Improved Reliability and Efficiency,
- Reduced reliance on crude oil,
- Bio-methane capable and pathway to hydrogen,
- Natural Gas is safer than existing liquid fuels,
- CNG costs up to 50% less than gasoline or diesel fuel,
- It can be transported anywhere

Fig. 4 shows a diagram of changes in prices of oil and gas. Natural gas is significantly less expensive than crude oil and the gap is growing. Price of gas is significantly lower than the price of a litre of diesel fuel, specifically if the transportation company has its own CNG refuelling station (*Journal:* Gas Vehicle Report, 2014).

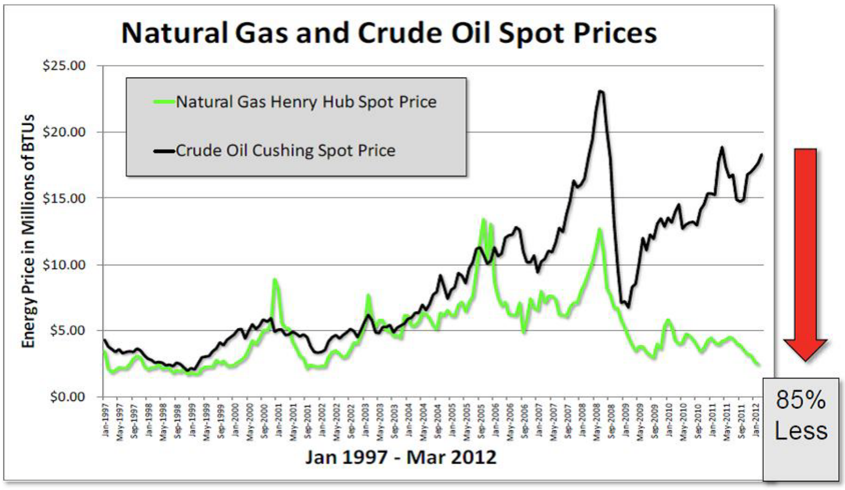


Fig.4. Natural gas and crude oil spot prices.

Cost-Benefit analysis regarding to the public transportation of passengers with buses in the city of Kragujevac for 315 working days per year is presented inside of Table 2 (Milojevic and Pesic, 2010).

Table 2. Costs analysis regarding to the situation with Diesel or CNG propulsion system.

	Diesel	CNG	Saving
Price of fuel	1.3 €/L	0.45 €/kg* 0.8 €/kg**	
Average fuel consumption (Measured per one bus)	40 L/100 km	33 kg/100 km	
Fuel consumption per year	1,764,000 L	1,455,300 kg	
Fuel cost per year (for 50 buses in operate)	2,293,200 €	645,885 €* 1,164,240 €**	1,647,315 €* 1,267,8755 €** (Saving of min. 50%)

*The case with proper refuelling station; **The case with public refuelling station

Investments for replacing diesel engine with new power pack including CNG Engine, Automatic Gearbox and CNG fuel line with storage system on the bus are about 55,000 €/bus. The new Euro VI CNG bus costs about 180,000 €/bus. Costs for a new CNG refueling station, including two compressors with total capacity of 1,800 $m^3 \cdot h^{-1}$, and additional infrastructure are about 450,000 € (profitable for only one year). Return of total investments is for 3 to 4 years (Milojević and Pešić, 2011).

4. GAS MARKET SUPPLY AND CNG BUSES FILLING – ONE OF RESTRICTIONS

The security of the CNG supply is very important requirement to continue the introductions of natural gas vehicles in city transport. The South Stream project is aimed at strengthening the European energy security. The new gas pipeline will significantly raise the energy supply security of the EU`s countries, and the Republic of Serbia, too.

The project provides for the offshore South Stream pipeline to run under the Black Sea from the Russkaya compressor station on the Russian coast to the Bulgarian coast. The total length of the offshore section will be around 900 kilometers and the design capacity of 63 billion cubic meters (Milojevic and Pesic, 2010).

According to previous, to secure natural gas supply to the transporters and another, like the bridge before gas networking (applicable for any territories), is better to use the Containers for CNG Bulk transport with trailers, as it is demonstrated on the Fig. 5, (Milojevic and Pesic, 2011; Rasche, 2009).

(a) (b)

Fig. 5. The 250 bar modules (a) ISO 20 ft. Container (b) 10 ft. cube for bulk transport.

Analyzed containers for gas transport are approved according to ADR as MEGC, with the next main characteristics (Rasche, 2009):

- Extremely High Storage Capacity due to Light-Weight Composite Cylinders,
- Low Weight, Less Wear and Friction resulting in Lower Costs for Maintenance and Repair,
- Handling by Crane or Forklift,
- Lifetime up to 40 years,

- Standard 250 bar Service Pressure,
- Vertical or Horizontal Assembly with Neck or Belly Mounting Cylinders

The comparison between composite type-3 cylinders and steel cylinders with dimensions and filling characteristics and capacities, are presented in Table 3 (Rasche, 2009).

Table 3. ISO 20 ft. and 40 ft. CNG container options compared to semitrailer case.

TYPE OF CNG CONTAINER	20 ft. Container	40 ft. Container	Jumbo Vessels 40 ft. Semitrailer
Cylinder material	Composite Type-3 Al 6061 liner with Carbon Fiber in Epoxy Resin		Steel 34CrMo4
Standard	TPED / ADR		
Number of Cylinders	76	152	9
Cylinder outside diameter	406 mm		559 mm
Weight / volume ratio (per one cylinder)	84 kg / 234 L		2660 kg / 2385 L
CNG capacity* / Cylinder Volume ratio (total)	4222 kg / 17784 L	8444 kg / 35568 L	4471 kg / 21400 L
Cylinders weight / Container weight ratio (for full system)	6384 kg / 15.0 t	12768 kg / 29.4 t	23940 kg / 40 t
Working / Test pressure	250 / 375 bar		250 / 300 bar

*depending on actual density of CNG and filling conditions!

TPED -Transportable Pressure Equipment Directive, ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road, MEGC –Multi Element Gas Container.

5. CONCLUSIONS

Use of CNG as an alternative fuel is an effective, currently available way to help solve environmental and fuel resource problems. In fact, natural gas has safety advantages compared to gasoline and diesel: it is non-toxic, neither carcinogenic nor corrosive gas, and has no potential for ground or water contamination in the event of fuel release.

Substituting existing fuels by natural gas in road transport can be achieved by introducing new vehicles equipped with CNG engines, or as a first step, by converting engines of existing vehicles to CNG drive. The better variant for buses is the using of the completely new engine with dedicated CNG combustion, which is paired with automatic gearbox and driven axle. To secure natural gas supply to the transporters and another, like the bridge before gas networking is better to use the Containers for CNG Bulk transport with trucks and trailers.

The introduction or expansion of natural gas vehicles use will require investment in new refueling infrastructure. Regarding from second side, the introduction of advanced diesel buses meeting U.S. 2010, or upcoming Euro VI emission standard will require diesel fuel sulfur reductions and more commercial availability of AdBlue (as example for selective catalytic reduction system functionality, applied in the after treatment line).

When deciding to introduce or expand the use of CNG buses, one must evaluate the appropriate CNG engine technology to use relative to the desired emissions performance. Current lean-burn CNG engine technology can only achieve Euro V emissions levels with the addition of oxidation catalyst. To achieve U.S. 2010/Euro VI emissions performance stoichiometric CNG engines with three-way catalyst will be required. By installing the Gas Rack with CNG Cylinders Type 3 and with projecting the installation of CNG equipment of the bus according to the UN ECE Regulation No. 110, was achieved great progress from the aspect of vehicle safety in traffic.

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

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