NATURAL GAS AS A SAFE TECHNOLOGY FOR CLEAN URBAN VEHICLES

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1. INTRODUCTION

Natural gas is a fossil fuel of choice for Europe. It is clean, safe, and available fuel with a acceptable price for the region's residential, industrial, and commercial customers [2,5,8].

Today the natural gas consumption shows an increase after the global economic crisis. World natural gas consumption grew by 7.4% in 2010, with above-average growth in all regions. The US had the world's largest 2010 increase in consumption, rising by 5.6% to a new record high. Russia and China also registered large increases – the largest volumetric increases in the country's history in each case. Consumption in other Asian countries also grew rapidly in 2010 (+10.7%), led by a 21.5% increase in India. EU27 countries also show an increase of 7.2% in 2010 in total natural gas consumption, compared to 2009 [11,14].

Natural gas production in North Sea and other EU countries will continue providing significant amounts of gas for Europe's needs. According to the latest estimates by the International Energy Agency, natural gas consumptions in the EU will be increased from 536 billion cubic meters (bcm) in 2008 to 636 bcm in 2035 – an increase of 19%. By 2035, EU domestic gas production will have dropped up to about 50%. In that situations, the Russian Federation has the choice to fill a significant proportion of the EU import gap of 113 to 155 bcm by the year 2030 [11].

The South Stream Offshore Gas Pipeline is important in terms of efficiency and stable supply of the gas market. The project will contribute to EU energy security, like in the Republic of Serbia too, and will help to meet their Carbon Dioxide (CO_2) reduction targets.

The projected 63 bcm of natural gas per year transported via pipeline is equivalent to [11]:

- The same energy as 50.000 wind turbines,
- The energy of 38 nuclear power plants,
- Provides the energy needed for about 30 million European households,
- Accounts for approximately 10% of the total EU gas consumption,
- Delivers the same amount of energy as 420 Liquefied Natural Gas tankers, and
- Delivers the same amount of energy like approximately 550 oil tankers that could be challenging crude oil transportation exercise given the intense maritime traffic in the Black Sea and in the Bosporus Strait.

The transport sector, which relies heavily on cars and trucks, is responsible for about a quarter of the world's energy use and has the fastest rising of carbon emission

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regarding to any economic sector. Road transport currently accounts for 74% of the world's total transport-related (CO_2) emissions [8,13].

The world's fleet of vehicles is passed number of one billion (1.015 billion in 2010, 752 million in 2000 and a mere 127 million in 1960), while the production capacities of the world's auto companies was estimated to grow to 97 million units per year by 2015 (the estimations are before the global economic crisis in 2009) [13].

Natural gas as fuel for motor vehicles has more and more share. The consequences to this fact are that today world has approx. 15.1 million of NGVs (half million of the CNG buses and 14.1 million of cars and light duty vehicles), and over 20.500 filling stations [1].

According to this trend, the policy developments will also influence on the future gas demands, including the EU's adoption to the future emission targets. These cannot be achieved without using of natural gas as a substitute for fuels that creating more pollution in the vehicles. Natural gas is essential for maximizing the reduction of carbon and rest exhaust emissions rapidly at a relatively small cost of the substitution process.

Regarding to the rise of natural gas application like engine fuel and importance of the topic, in the paper is preferred to find a replay on the question: (How Safe is NGV?). The analyses in the paper are confirmed on the examples of the vehicles converted for CNG drive.

2. NATURAL GAS AS FUEL FOR MOTOR VEHICLES

All gases are good fuels for Otto engines: a mixture with air is high quality and ready for complete combustion, the work of engine is economical, with lower exhaust emissions and extended oil and engine life.

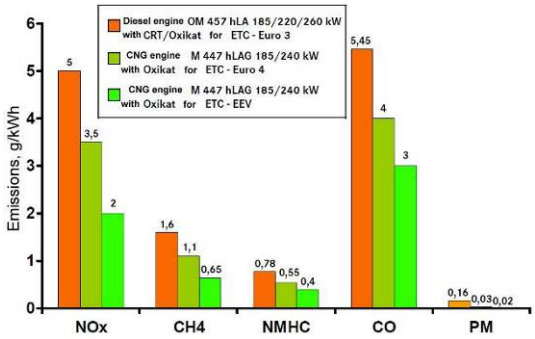
Natural gas is a naturally occurring fuel which requires little processing before use. Chemically it consists of 90% methane with smaller amounts of ethane, propane, butane, CO_2, and other trace gases. The high methane content gives natural gas its high octane rating (120-130) and clean-burning characteristics, allowing high engine efficiency and low emissions. The environmental benefit of using CNG, as fuel is the reduction of exhaust gases in articulated bus for example, Figure 1. Compared to the equivalent Turbo Diesel Engine, carbon monoxide (CO) emissions are over 50% lower, nitrogen oxide (NO_x) emissions are 80% lower, and there are around zero particulates [4].

Lean-burn heavy-duty CNG engines were initially popular due to their lower engine-out NO_x emissions and higher fuel efficiency compared to stoichiometric engines. A modern, closed-loop electronically controlled lean-burn CNG engine can achieve Euro V or lower emission levels for both NO_x and PM. For optimal emission performances, these engines should be also equipped with natural gas-optimized oxidation catalyst after-treatment.

To meet the most stringent Euro VI emission standard for NO_x, it is necessary to switch to stoichiometric combustion combined with exhaust gas recirculation and three-way catalyst after-treatment.

From the other side, it is notable that natural gas in normal conditions has a low density of energy per unit volume. To meet all requirements needed to become engine fuel, it shall be a subject to appropriate treatment. The easiest way is to use CNG stored under high pressure into cylinders on the vehicle (working pressure of 200 bar). Another possibility for increasing the energy density of natural gas in the fuel tank is its conversion

into liquid form through the cooling up to -162 °C, and storing it into cryogenic cylinders like Liquefied Natural Gas (LNG).



CRT®- (Continuously Regenerating Technology) particulate filter
ETC-European Transient Cycle, EEV- Enhanced environmentally friendly vehicle

Figure 1: *Exhaust emissions reduction of 12 liters engine in EvoBus*

Before discussing the NGV design, it is very important to understand some relevant properties of natural gas like vehicle fuel what makes this fuel different from gasoline or diesel. The items below summarize the basic differences between the properties of gaseous and liquid fuels that influence the NGV design changes:

- It is non-toxic, neither carcinogenic nor corrosive gas, but it is the stuffy,
- Natural gas is invisible but must been odorized so its presence can be detected,
- Unlike gasoline vapors, natural gas is lighter than air (methane has density of 0.68 kg/m^3 at 15 ^{o}C) and it is in the gaseous form at atmospheric conditions. In an event of a leak, this property allows to quickly rise in the atmosphere, while the propane (1,87 kg/m^3) and butane (2,44 kg/m^3) are heavy than air, and lower to floor,
- Natural gas has an auto ignition temperature of around 480 to 650 ^{o}C whereas gasoline is approximately 260 to 430 ^{o}C and diesel less than 260 ^{o}C. This relatively high auto ignition temperature for CNG is an additional safety feature of this fuel, and
- Methane has a very selective range of flammability. The mixture of gas in air by volume that will support combustion is between 4.4 and 15%. In other words, with less than 4.4%, of the methane in air, the mixture will not burn because it is too lean, and with greater than 15%, the mixture is too rich and will not burn. Ignitable range for gasoline is between 1.4 and 7.6% and around 0.6 to 7.5% for diesel.

Modification of the vehicle and engine to natural gas drive can affect:

- Emissions/air quality, and
- Performance, durability, and safety of engine /turbine/ generator / and other systems.

Quality can be described in two ways:

- Composition – chemical breakdown of components, and
- Performance – how the gas behaves in various circumstances. Some common measures of gas performance include heating value (Btu), Wobbe number, and methane number (MN). Gas performance can be managed by alteration of its content.

There are tree national and only one international standard for natural gas vehicle fuel:

- SAE J1616: Recommended Practice for Compressed Natural Gas Vehicle Fuel,
- DIN 51624: Automotive Fuels - Compressed Natural Gas - Requirements And Test Methods,
- 13 CCR § 2292.5 (California Code of Regulations) Specifications for Compressed Natural Gas, and
- ISO/TR 15403-2:2006 addresses the specifications of natural gas as a compressed fuel for vehicles as an addendum to ISO 15403-1. Specifically, ISO/TR 15403-2:2006 is intended to satisfy requests for quantitative data.

3. EXISTING TECHNICAL SOLUTIONS FOR NGV

Substitution of existing fuels by natural gas in road transport can be realized by introducing of new vehicles equipped with original CNG engines, or as a first step, by converting engines of existing vehicles to CNG drive. To introduce natural gas as a fuel for road transport, the following options are possible:

- Modification of a gasoline engine to CNG combustion (so called conversion to a dedicated fuel),
- Modification of a gasoline engine to either CNG or gasoline (two way/bi-fuel) combustion,
- Conversion of a diesel engine to dedicated CNG (spark ignition) combustion, and
- Conversion of a diesel engine to dual fuel (gas and diesel combined) combustion.

Figure 2 shows typical components associated with a CNG vehicle fuel system for sequential injection. These are basic elements and some system manufacturers may add other components.

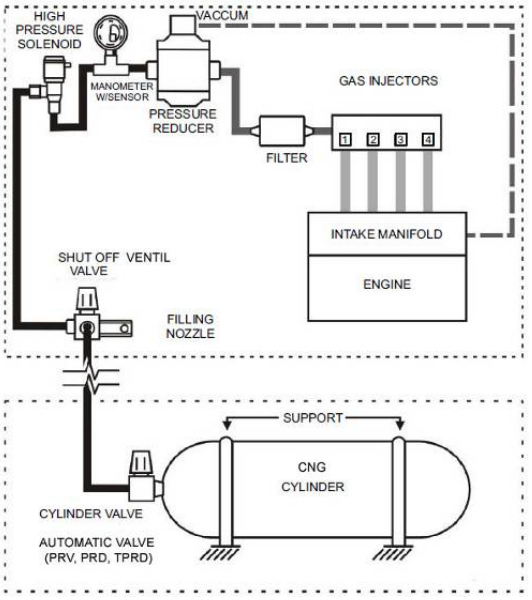


Figure 2: *Typical CNG Vehicle Fuel System*

3. 1 EXAMPLE OF PASSENGER CAR WITH CNG DRIVE

Conversion of gasoline vehicles has been successfully carried out for decades in many countries worldwide, mostly stimulated due to a price advantage of CNG over gasoline.

Strength construction in combination with the optimum use of interior space is a basic demand for NGV. Like example on the Figure 3 is presented a concept of the vehicle type Zafira 1.6 CNG [7], where are mounted CNG cylinders (two in front and two behind of the rear axle). For the reserve drive, between is mounted a gasoline tank.

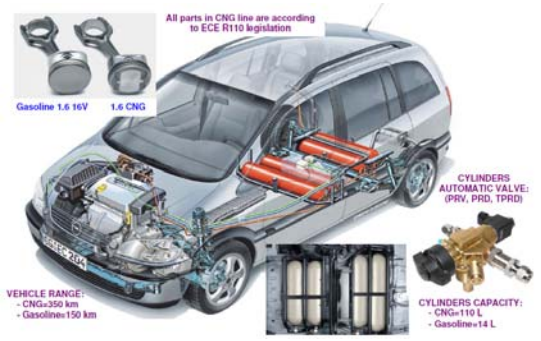


Figure 3: *Bi-fuel vehicle*

The mounted CNG cylinders are made of special steel, designed for working gas pressure of 200 bar. Prior to installation, each cylinder is separately checked under a pressure of 300 bar [7]. For additional protection in the event of an accident, the cylinders are mounted in safety cover made of steel used for racing vehicles.

Each of the cylinders is fitted with an automatic valve with the following safety features:

- The electrically controlled solenoid valve releases the flow of gas only when the ignition is switched on. In the case of an accident, or if the engine stops, all four solenoid valves will be closed,
- An integrated check valve automatically switches-off the flow of gas in the event of the pressure drop in the gas cylinders, caused by a leaking connection,
- In the event of a vehicle fire, an integrated melt fuse ensures a controlled release of natural gas if the temperature exceeds 110 °C,
- If pressure rises over a defined limit, an additional burst valve also ensures controlled release of gas, and
- Each gas flow from the cylinder is possible to stop by using a manual cut-off valve.

Because natural gas has an octane, value of up to 130, it is significantly less liable to cause engine knocking than gasoline. This means that the efficiency of vehicle is rising correspondingly by increasing the compression ratio. The Zafira 1.6 CNG has special pistons designed for natural gas operation. With the raised areas on the piston, heads increased the compression ratio to (12.5:1). This makes it possible to exploit the higher-octane content of natural gas, and consequently to boost operating efficiency. In addition to

the pistons, the valves, valve guides and valve sets of the Zafira 1.6 CNG were configuring specifically for natural gas operation [7].

The Zafira 1.6 CNG has unlike other natural gas vehicles a dual injection bank with four injection nozzles for natural gas and gasoline.

As a result, in conjunction with a special injection system and engine management in dedicated fuel operations, achieved nearly the same performances as in the case of the drive with the gasoline engine type 1.6 16V ECOTEC®.

According to the information received in the vehicle's exploitations, four capacious CNG cylinders ensure a drive range of approximately 350 km in natural gas operation. An additional reserve gasoline tank with the capacity of 14 liters mounted between the gas cylinders below the floor [7]. If need be, however, the reserve gasoline tank ensures an additional range of approximately 150 km, enough to bridge all gaps in the CNG supply network.

3. 2 PROJECT PROPOSITION FOR THE CONVERSION OF ARTICULATED BUS TO CNG DRIVE

For buses, driven by diesel engine, there are two options for conversion on CNG drive: conversion for dedicated or dual fuel combustion. The option can be selected, depending on the engine characteristics and the working conditions (routes, working time, available refueling network etc.).

City buses circulate from a garage to the destination places on unchangeable routes. Those are favorable conditions regarding to the needs of the transport logistics, specifically regarding to the paining of the refueling time and place. That is very important for territories with the limited gas network.

According to the mentioned and any other facts, the city buses are suitable for drive with engines on dedicated CNG combustion. Like first example, in existing diesel buses, the diesel engine must be modified to a spark ignition engine in order to burn natural gas instead of diesel. The major modification is a reduction of the compression ratio to approximately 14:1, while the cooling system of the engine has to be improved. Diesel injectors must be replaced with spark plugs and according to this; the high-pressure pump for diesel fuel needs to be replaced with the spark ignition coil(s), too. Additionally, a voltage converter from the standard 24 V system used on vehicles equipped with diesel engines to a 12 V system is required. For this reconstruction can be used a set of parts and instructions for the diesel engine reconstruction of the company Omnitek Engineering Corp. (OEC).

Secondly, from our side the best variant is the using of the completely new engine with dedicated CNG combustion, which is paired with automatic gearbox and driven axle. It is accepted the propositions for the bus drive unit with original engine and gearbox. The natural gas engine type is M 447 hLAG spark ignited, Figure 4. That engine is designed to meet the EEV emission standards, by applications of a single point injection of fuel, in combinations with lean burn combustion and oxidation catalysts. The engine is based on the 12 liters diesel automotive OM 457-hLA platform and shares many installation options with the diesel counterpart. In combination with the automatic gearbox DC, achieved good performance of movement and maximum use of engine output parameters, which have a positive effect on passengers comfort and fuel economy.

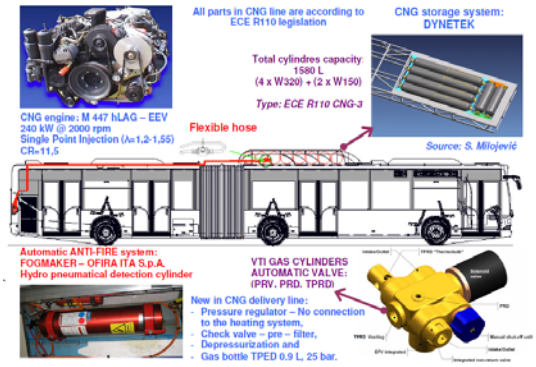


Figure 4: *The design of CNG line applied on the articulated bus*

In the bus, body can be integrated modern automatic anti fire system mark Fogmaker – Ofira, with hydro pneumatically activated detection cylinder.

The retrofit of the diesel bus into a dedicated NGV begins with the joining of the CNG cylinders with the original rack to the bus roof, Figure 4. For prototype vehicle, we are mounted four cylinders DYNETEK type "W320" and two of type "W150", with a total water capacity of 1.580 L. The selected CNG storage system includes type 3 cylinders composed of an aluminum liner (brand Dynecell®), with a favorable ratio between weight and volume (0.3 kg/L to 0.4 kg/L), [5,6,10]. During the conversion, 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 [6,12].

4. GAS MARKET SUPPLY AND CNG VEHICLES FILLING

The South Stream project has a goal to ensure the EU energy security. This project is required to continue the introductions of NGVs in our country too [11].

To secure natural gas supply, like the bridge before gas networking (applicable for any territories), is better to use the Containers for CNG Bulk transport with trailers Figure 5. Analyzed Containers for Gas Transport are approved by TÜV according to ADR as MEGC, with the next main characteristics, Table 1 [3,9,10]:

- Extremely High Storage Capacity due to Light-Weight Composite Cylinders,
- Low Weight, Less Wear and Friction = Lower Costs for Maintenance and Repair,
- Handling by Crane/Forklift, and attaching to the trailer by ISO corner castings,
- Lifetime up to 40 years,
- Standard 250 bar Service Pressure,
- Vertical or Horizontal Assembly with Neck or Belly Mounting,
- Leak test at service pressure N_2, helium leak test at 2 bar,
- Higher filling level during rapid filing at high gas temperature (Al 6061 liner high heat-conductivity), and
- Cylinders type-3 (Al 6061 liner) is Corrosion Free with respect to Steel cylinder or Jumbo Vessel Trailer.

(a) ISO 20 ft Container

(b) 10 ft Cube for Bulk Transport

Figure 5: *The 250 bar Modules*

Table 1: *ISO 20 ft and 40 ft Container Options DYNETEK*

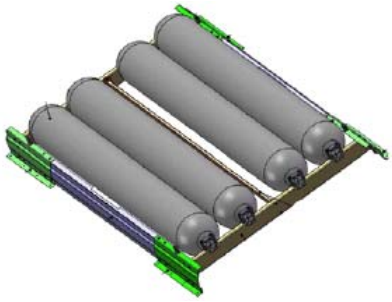
TYPE OF CYLINDERS	Composite Type-3 20 ft Container 1CC 250 bar	Composite Type-3 40 ft Container 1CC 250 bar	Jumbo Vessels 40 ft Semi trailer 250 bar
A. Cylinder Material	Al 6061 liner + Carbon Fiber in Epoxy Resin		Steel 34CrMo4
Standard	TPED / ADR		
No. of Cylinders	76	152	9
Outside diameter	406 mm		559 mm
Cylinder capacity	234 L		2385 L
Cylinder Weight	82 kg		2660 kg
Test pressure	375 bar		300 bar
Total Cylinder Volume	17784 L	35568 L	21400 L
B. Weights			
Total Cylinder weight	6232 kg	12464 kg	23940 kg
Total gas weight *	4222 kg	8444 kg	4471 kg
Total Trailer Weight Full Container	Approx. 14.5 t	Approx. 29.4 t	Max. 40 t

*depending on actual density of CNG used and filling conditions!
TPED - Transportable Pressure Equipment Directive,
ADR - European Agreement concerning the International Carriage of Dangerous Goods by Road, and
MEGC - Multi Elements Gas Container.

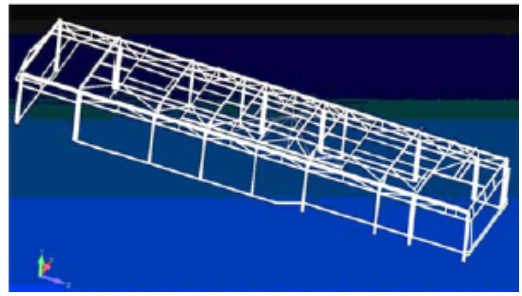
5. INSPECTION OF THE NATURAL GAS VEHICLES AND CYLINDERS

The principal requirement for NGV of the M3 and N3 categories is the strength at destruction of the joint assembly between the CNG cylinders and the chassis during a deceleration of 6.6·g in the longitudinal direction and 5·g in the transverse direction (UN ECE No. 110. 2008; ISO/DIS 11439, 2000). The standard ECE R 110 legislates the proofing of these requirements using calculations rather than experimental testing [12].

Like example, on the Figure 6 are presented standard CNG cylinders rack and a generic model of bus, which includes the supporting structures to a level below the windows [6].



(a) CNG cylinders rack DYNETEK V294



(b) Model of the supporting bus structure

Figure 6: *The standard CNG cylinders rack and a generic model of bus*

6. REGULATIONS RELATING ON THE INSPECTION OF NGV

6. 1 INTERNATIONAL REGULATIONS

Regulation and standards for natural gas vehicles are shown on Figure 7.

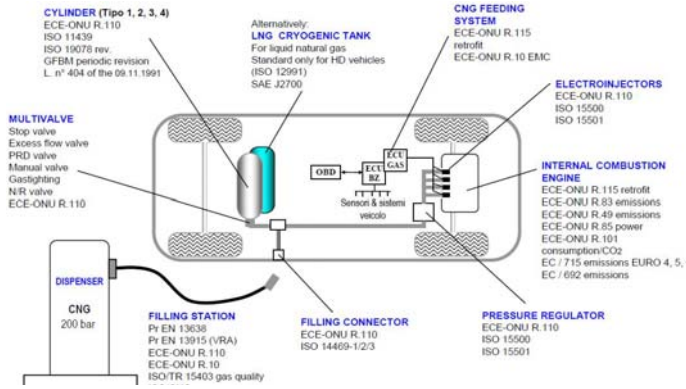


Figure 7: *Regulations and standards for natural gas vehicles*

Ecological demands relating on CNG truck and buses are defined in ECE Regulation No. 49. For passenger cars, those demands are defined in ECE Regulation No. 83.

Safety and demands regarding to mounting propriety of CNG equipments, also relating on gas driven vehicles are defined in the next two Regulations [12]:

1. UN ECE Regulation No. 110 – uniform homologation provisions concerning the approval of:
   - Specific components of motor vehicles using CNG in their propulsion system, and

- Vehicles with regard to installation of specific components of an approved type for the use of CNG in their propulsion system.

2. UN ECE Regulation No. 115 – uniform homologation provisions concerning the approval of:
   - Specific LPG (liquefied petroleum gases) retrofit systems to be installed in motor vehicles for the use of LPG in their propulsion system, and
   - Specific CNG (compressed natural gas) retrofit systems to be installed in motor vehicles for the use of CNG in their propulsion system.

6. 2 NATIONAL REGULATIONS

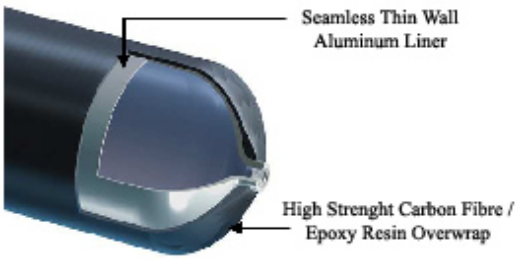
In the Republic of Serbia for gas driven vehicles are applicable the next Regulation and under Regulation acts:

- Law about traffic safety on the roads (Republic of Serbia, Official carrier No. 41/09 and 53/10),
- Rulebook about partition of motor vehicles and trailers and technical demands for the vehicles in the traffic on roads (Republic of Serbia, Official carrier No. 64/10. and 69/10), and
- Rulebook about vehicles testing (Republic of Serbia, Official carrier No. 8/12).

7. INSPECTION AND MAINTENANCE OF CYLINDERS AND CONNECTING ELEMENTS

7. 1 CYLINDER DESCRIPTION

DyneCell® cylinders, which here analyzed are type-3 fully wrapped. Those cylinders consist of a seamless 6061 aluminum liner, which is fully wrapped with a carbon fiber, and epoxy reinforced laminate, Figure 8 (a) [10]. Figure 8 (b) illustrates the cross section of cylinder with reinforced neck, checked in vibrations. Comparing with type-4 cylinders of plastic liner, those type-3 cylinders after strong and vibration tests have not the problems like as the leakage because of cracks under thermal and mechanical stresses [10].



(a) Design of the DyneCell® Cylinder

(b) Reinforced neck – cross section after testing

Figure 8: *DyneCell® cylinder cross section before and after testing*

DyneCell® cylinders are designed to work under the nominal service pressure of 20 MPa (200 bar) at an ambient temperature of 15 °C. In the real situations, at filling, the pressure to be dispensed shall be calculated giving consideration to gas temperature in order to prevent pressures exceeding the maximum allowable filling condition. The following approximation calculations, represented with equation 1 may be helpful here [3,10]:

$$\text{Pressure of CNG bar} = 176 + 1.6 \text{ x (Temperature of CNG °C)} \quad (1)$$

The actual pressure of CNG in cylinder also depends, however, on the relevant gas composition.

The maximum filling pressure may not exceed 26 MPa (260 bar) at any temperature. Cylinders shall not be connected to compressors at filling stations with maximum output pressures greater 1.5 times of nominal value.

Settled temperature of gases in cylinders may vary from a low of -40 °C to a high of 65 °C. The temperature of the cylinder materials may vary from -40 °C to 82 °C. Temperatures over 65 °C shall be sufficiently y local, or of short enough duration, that the temperature of gas in the cylinder never exceeds 65 °C [3,10].

CNG shall comply with gas compositions specified in ISO 11439 respective UN ECE Regulation No. 110 [12].

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

When 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 be removed from service [3,10].

7. 2 INSTALLATION REQUIREMENTS

The Neck Mount Brackets securely fasten the DyneCell® cylinders Figure 9 for cylinder rack like on Figure 6 (a) on board automotive vehicles Figure 4 in a horizontal position. Cylinders are mounted using the two different neck-mounting brackets that secure the extended necks. One end of the cylinder is held secure while the other end is allowed to slide as the cylinder expands, adjusting for temperature and pressure variations.

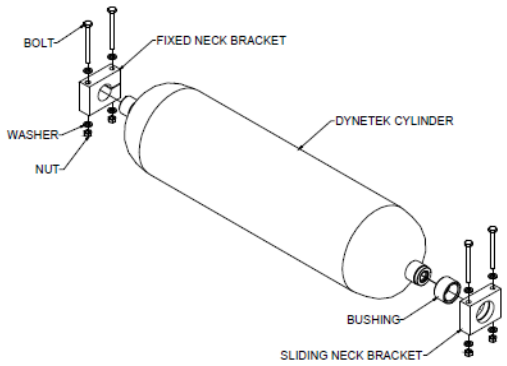


Figure 9: *Cylinders with Neck Mount Assembly*

When the brackets are installed, the fixed neck mount bracket locks the cylinders neck against sliding in the bracket up to a longitudinal load of 17 kN. This is equal to the following weights of a filled cylinder, Table 2 [3,10,]:

Table 2: *Allowed total weight of cylinders according to UN ECE R110*

Vehicle category	M1 or N1	M2 or N2	M3 or N3
Acceleration	20·g	10·g	6,6·g
Max. allowed total cylinder weight *	86 kg	173 kg	262 kg

* *Max. total cylinder weight* = 17 kN / (9,81 m/s² *x acceleration)*

7. 3 INSPECTION AND RETESTING REQUIREMENTS

Cylinders require an external visual re-inspection for defects in the composite wrap at certain intervals after installation or upon reinstallation. Inspection shall always be in accordance with the relevant standards and regulations of the country where the cylinder is operated.

According to UN ECE R110, for natural gas cylinders this inspection shall be performed at least every 48 months after the date the vehicle enters into service [12]. Other cylinders may have shorter inspection intervals depending on the relevant standard. Also any requirements due to the type approval need to be respected.

Inspection shall 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 [3]. If a hydraulic pressure test is to be performed for retesting, this may only be done using specially treated water (use of inhibitors, removal of chloride etc.). Also, recommended to use shortest possible time of exposure and never fill the cylinders with ordinary water since there is a risk of damaging the aluminum liner material due to tap Water corrosion.

An inspection is an important safety measure to detect whether the cylinder or mounting system is damaged, and to ensure that it is not suffering from a harmful environment during operation. Inspections should be conducted with the proper tools, which may include measuring tools to measure flaw length and depth, a flashlight etc. There are two types of inspections, General Inspection and Certification Inspection as summarized by Table 3, [3].

Table 3: *Summary of Inspection Categories*

Inspection Type	Inspection Description	Inspection Frequency
General Inspection	Performed by the driver, maintenance personnel, or other service technician. It is primarily a visual inspection to ensure that the cylinder, mounting and piping are in good condition and secure.	Recommended every 3 months
Certification Inspection	Performed by trained personnel who are certified in accordance with the local regulations and authorities. It is a more detailed examination of the cylinder, mounting and piping.	According to local authority, customarily performed when the cylinder or vehicle is put into service, and then every 3 or 4 Years.

The general inspection is not a mandatory inspection, however the manufacturer of cylinders recommends this inspection every 3 months to ensure that the fuel storage system is in good condition. The extent of this inspection includes an examination of the following [3]:

1. Mounting System, and
2. Cylinder(s).

Inspection which relating to the installation of the CNG system is aimed at control the connection of the cylinders and equipment on the vehicle's chassis. In the case when is loosen connections of the CNG system parts it should be re-implemented process of fixing. If there is damage to the parts, make sure is it the vehicle been involved in an accident. If so, then it should be required a new certification. The inspection of the CNG cylinders is with goal to determine if there are damages. Some indicators of damage are presented in the Table 4, [3].

Table 4: *Indicators of the damage on the cylinders*

Cylinder Damage Type	Signs of Cylinder damage	Potential Causes of Damage
Impact	Dents, scratches, cracked or peeling laminate, crazing (hairline cracking of the laminate)	Consequent of the impact with a blunt object, or from damage when the cylinder is dropped
Cutting	Cut, scratch, gouge, peeling laminate	From a sharp or pointed object
Abrasion	Scuffs, dull or whitish appearance, flat spots	Friction between the laminate and an object in contact with the cylinder
Fire or Excessive Heat	Charred laminate, discoloration, soft spots, blistering, swelling	Direct flame, excessive heat source in contact with cylinder, excessive heat source near cylinder
Weathering	Cloudy appearance/ discoloration, soft spots	UV radiation or water impregnation through a crack in

		the laminate
Chemical Attack	Discoloration, soft spots, blistering …	Brake fluid, any corrosive fluid

First recommendation is to regard that the cylinder is covered with an outer layer of pure epoxy resin. Due to manufacturing, thickness may vary. Cutting damage or abrasion, which is limited to this layer of pure resin, are not critical and require no damage assessment.

The Certification Inspection is a detailed examination of the mounting system and cylinder. Inspection shall be performed by trained personnel licensed in accordance with national regulations. The frequency of this inspection is designated by the local authority and is customarily performed when the cylinders or the vehicle is put into service and then at certain intervals. CNG cylinders according to UN ECE R110 have to be inspected at least every 4 years, for other cylinders; usually intervals of 3 years apply [3,12].

7. 4 GENERAL RULES FOR WORKING ON CYLINDERS AND COMPONENTS

Listed below are a few important safety guidelines to follow when filling and defueling cylinders and components with pressurized natural gas [3,10].

1. Wear protective gear:
   - Safety glasses & safety boots.
2. Use correct tools:
   - Use the special tools specified by the manufacturer, if applicable, and
   - Obtain relevant documentation from the manufacturer before commencing.
3. Understand the system:
   - Only trained personnel shall perform maintenance and inspection tasks, and
   - A clear understanding of the fuel system functions is mandatory.
4. Eliminate potential ignition sources:
   - No open flame or other heat sources, and
   - Disconnect all electrical wires and ground the system to prevent sparks.
5. Assume system / component is pressurized:
   - Open fittings and ports slowly and stop immediately if gas starts to leak or if excessive torque is required to open the connection.
6. Take necessary precautions with a potentially flammable mixture:
   - Natural Gas is flammable in air at concentrations from 5% to 15%,
   - Do not operate, store or ship a system with a potentially flammable mixture. Purge the system according to relevant documentation from the manufacturer, and
   - Do not connect any electrical line to a system that contains a flammable mixture.

8. CONCLUSIONS

Use of CNG as an alternative fuel is an effective, 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. An odorant is added to provide a distinctive and intentionally disagreeable smell which is easy to recognize.

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 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 truck-trailers.

CNG cylinders require an external visual re-inspection for defects in the composite wrap at certain intervals after installation or upon reinstallation. Inspection shall be in accordance with the relevant standards and regulations of the country where the cylinder is operated. According to UN ECE Regulation No. 110, the certificated inspection shall be performed at least every 48 months after the date the vehicle enters into service. General inspection performed by the driver or other service technician, is recommended every 3 months.

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