

Dalibor BARTA, Miloš BREZÁNI, Tomáš KALINA

## LNG AS ALTERNATIVE FUEL FOR RAILWAY TRANSPORT

*Despite the innovating transport technologies around the globe, transport sector is the fastest growing consumer of energy and producer of greenhouse gases in the European Union and this trend is expected to continue in next years. Energy security is the one of the key condition of smooth functioning of state. Nowadays only few European countries are energy self-sufficient. Denmark, Norway, the Netherlands, Russian Federation and United Kingdom produce more energy than they can consume. Countries in Central and Eastern Europe are absolutely dependent on imported oil and gas from other suppliers. This paper gives basic information about Liquefied Natural Gas as a greener alternative to other fossil fuels. It focuses on basic properties of LNG, which are fundamental to understanding LNG correctly and then possibly use it as a fuel for rail vehicles.*

### INTRODUCTION

Growing pressure to use more environmentally friendly alternative drives of public transport vehicles leads to finding possible applications of new or hitherto little utilized species of drives and fuels. These are most often tested and used in road vehicles, but they gradually find their application also in rail vehicles. It is increasingly talking about hybrid drives, use of hydrogen, CNG, bio-fuels in internal combustion engines, but each alternative variant has some advantages and some disadvantages compared to current solutions. CNG, for example, as well as electric vehicles allows a relatively small range, which is sufficient in the use in urban public transport but for normal public rail transport it is inadequate. LNG (liquefied natural gas) compared to CNG allows up to 3.5 times longer range. Therefore, the possibility of using LNG in rail transport is proving to be an interesting solution.



Fig. 1. LNG locomotive GE Evolution [9]

Proved reserves of natural gas represents high potential for the European transport sector. Globally, natural gas is the third largest source of energy after oil and coal. It accounts for 23.9% of primary energy consumption.

United States are the world's largest producer of natural gas. The next producers are Norway, Qatar, Saudi Arabia, Australia, Malaysia, Russia and others. While Russia had the world's largest decline in volumetric terms in 2012, Qatar remained the largest

world exporter with a share of over 32.1 per cent of global LNG exports, see Fig. 2.

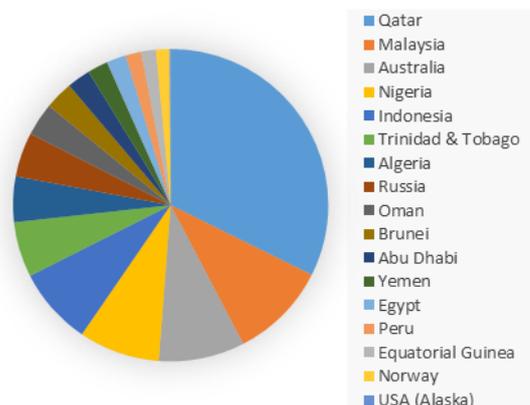


Fig. 2. LNG export in 2012 [3]

One study projects that by 2030 Norway and Russian Federation will be driving global exports of LNG, moreover they will lead the fourth wave of LNG export. The first wave is taking place now and is led by Qatar, the second wave is projected to occur in 2014 with Australia and the Asia Pacific. The third wave is expected to occur around 2020 and it will be driven by West Africa [5].

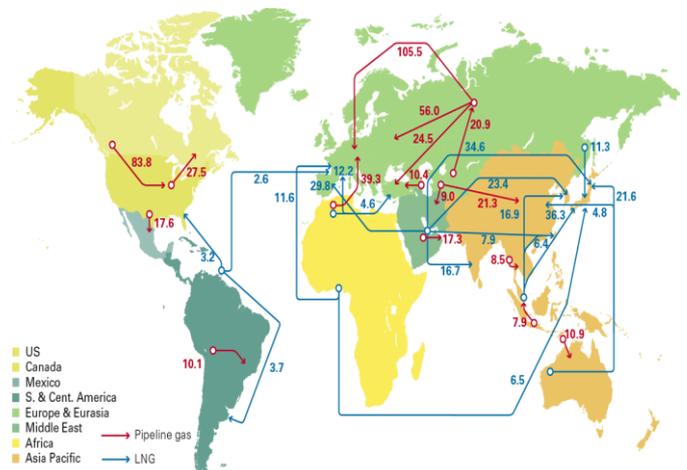


Fig. 3. Major gas trade movements of 2012 in billion cubic metres [1]

Now the LNG share of global gas trade represents 31.7%, [3], [4]. Figure 3 shows the major gas trade movements in 2012.

The outlook for LNG trade is positive in view of following facts:  
- the decline in nuclear power use, new gas finds worldwide (Cyprus, Israel and the United Republic of Tanzania), promotion of LNG in Asia region, attractiveness of gas as a greener alternative to other fossil fuels.

The world is enough of various studies on the use of LNG in the rail vehicles, but only Russian manufacturer began mass production of locomotives running on LNG. Although LNG reaches only 50 % of the energy density of diesel, Russia is keen to utilise its abundant supply of natural gas, which is significantly cheaper than diesel, as a fuel source (Fig. 4).



Fig. 4. Prototype LNG turbine locomotive [11]

First LNG-powered railway shunting locomotive TEM19 (Fig. 5) has been put into operation in Russia in november 2015. This locomotive was produced in the Bryansk Machine-building Plant and its LNG engines, will make it possible to reduce environmental burden and to save energy resources by 24% a year.



Fig. 5. LNG-powered railway shunting locomotive TEM19 [12]

## 1. BASIC PROPERTIES OF LNG

Physical and chemical are fundamental to understanding LNG as a fossil fuel. The properties of LNG make it a good source of energy but, on the other hand, they can also make LNG a hazardous material. These properties influence how we assess and manage safety risks. It is necessary to clearly distinguish LNG properties

as a liquid form, but also as a gas or vapour to accurately understand and predict its behaviour.

Natural gas cooled to approximately  $-162^{\circ}\text{C}$  at atmospheric pressure condenses to a liquid and become liquefied natural gas – LNG [6]. This low temperature makes LNG a cryogenic liquid and it requires to involve special technologies for handling. The cryogenic temperature means it will freeze any tissue (plant or animal) upon contact and can cause other materials to become brittle and lose their strength or functionality. This is why the selection of materials used to contain LNG is so important. To remain a liquid, LNG must be kept in specially designed containers, which function like thermos bottles – they keep the cold in and the heat out. Natural gas in liquid form takes up about 1/600th of the volume of natural gas in its gaseous equivalent so that is the economical reason to transport LNG.



Fig. 6. LNG tender [10]

Fuel tenders can be configured in two forms: a 10,000-gallon ISO tank, or a 20,000 to 30,000-gallon (approximate) tender that closely resembles a tank car.

In accordance to [13] an LNG-powered freight train using 25,000-gallon LNG fuel tenders could be able to operate, for example, between Los Angeles and Chicago one-way without a refueling stop, improving locomotive utilization, according to GE's Trillanes. The ISO LNG tank, though of lower capacity, offers more operational flexibility and potentially lower cost. At 40 feet in length and enclosed in a steel frame, the ISO tank can be mounted in a modified well (doublestack intermodal) car, and can be easily removed when empty and replaced with a full tank transported by truck, thus eliminating the cost and logistical constraints of a dedicated LNG fueling station.

LNG is odourless, colourless, non-corrosive, and non-toxic. Common smell of natural gas is caused by an odouring substance, which is added to natural gas before it is sent into the distribution grid due to detection of gas leaks [7]. Unlike household natural gas, the odorants (mercaptans) that assist in the detection of a leak cannot be used in a locomotive application. Instead, methane detectors must be in place to detect an LNG leak. The most vulnerable spots for a leak would be the connection from the fueling facility to the fuel tender and from the fuel tender to the locomotive.

### 1.1. Chemical Composition

Natural gas as a fossil fuel was created by organic material deposited and buried in the earth millions of years ago. It constitutes type of fossil fuel known as hydrocarbons, chemicals whose molecules consist exclusively of collections of hydrogen and carbon atoms. Natural gas is a mixture of methane, ethane, propane and

butane with small amounts of heavier hydrocarbons and some impurities, notably nitrogen and complex sulphur compounds and water, carbon dioxide and hydrogen sulphide which may exist in the feed gas but are removed before liquefaction [7]. The chemical composition of natural gas is a function of the gas source and type of processing. Methane is by far the major component, approximately over 85% of volume.

Table 1 displays the average chemical compositions of the LNG reported by the different receiving terminals.

**Tab. 1.** Average chemical composition of the LNG by selected countries

Origin	Nitrogen	Methane	Ethane	Propane	Butane +
	N2 %	C1 %	C2 %	C3 %	C4+ %
Algeria	0.65	90.15	7.9	0.4	0.5
Egypt	0.02	96.28	3.04	0.43	0.23
Libya	0.59	82.57	12.62	3.56	0.65
Nigeria	0.03	91.7	5.52	2.17	0.58
Norway	0.46	92.03	5.75	1.31	0.45
Qatar	0.27	90.91	6.43	1.66	0.74
Russia	0.07	92.53	4.47	1.97	0.95
USA	0.17	99.71	0.09	0.03	0.01
Yemen	0.02	93.17	5.93	0.77	0.12

(Source: GIIGNL - The LNG Industry) [3]

The chemical composition of the natural gas and the properties of its hydrocarbon components determine how LNG behaves, affect the predictions about its behaviours and influence how to assess and manage safety risks. LNG is often confused with liquefied petroleum gas (LPG), which in turn is often identified incorrectly as propane. In fact, LPG is a mixture of mainly propane and butane gases that exist in a liquid state at ambient temperatures when under moderate pressure. LPG's differing composition and physical properties compared to LNG make its behaviour different as well. The propane and butane in LPG have different chemical compositions from methane. Propane and butane can be stored and transported as a mixture, or separately. Both are gases at normal room temperature and atmospheric pressure, like methane, readily vaporising. Propane liquefies much more easily than LNG (at -43°C vs. -162°C) so it is substantially easier to compress and carry in a portable tank. In fact, LPG is stored as a liquid under pressure at room temperatures, whereas LNG is stored as a liquid only at very low temperatures and ambient pressure [14].

## 1.2. Boiling Point

Boiling point is the temperature at which a liquid boils or at which it converts rapidly from a liquid to a vapour or gas at atmospheric pressure. The boiling point of LNG varies with its basic composition, but typically is -162°C [6]. After transportation LNG is converted back into natural gas for distribution to industrial and residential consumers. The LNG regasification process warms the LNG and converts it back into its gaseous form [14].

## 1.3. Density and Specific Gravity

Density of LNG varies with its actual composition. It ranges between 430 kg/m<sup>3</sup> to 470 kg/m<sup>3</sup> [6]. It is less than a half of the density of water. The specific gravity of a liquid is the ratio of density of that liquid to density of water at 15.6°C. LNG specific gravity is one-half of water specific gravity. In case of spillage, LNG floats on water and vaporised very fast. Vapours at low temperatures are heavier than air and make visible white cloud. The cloud is white, because

cold vapours freeze the water in the air. The cloud disperses quite quickly, because vapour of methane is heated and at the temperature of about minus 100°C it has the same weight of air. At higher temperature vapour becomes lighter than air [14].

## 1.4. Flammability

The main hazard of LNG is flammability of liquid gas vapours, but it is the same property which makes natural gas desirable as an energy source. To be clear, natural gas is flammable but the liquid form of natural gas -LNG is not because of the lack of oxygen in the liquid. Several factors are required to start a fire from LNG vapours. In particular, the fuel and the oxygen have to be in a specific range of proportions to form a flammable mixture. This is called Flammable Range and it is the range of a concentration of a gas or vapour that will burn if an ignition source is introduced [8]. For LNG lower flammability limit (LFL) is 5% by volume and upper flammability limit (UFL) is 15% by volume. When vapour concentration exceeds its UFL, it cannot burn because too little oxygen is present. This situation exists in storage tanks or vessels, where the vapour concentration is approximately 100% methane. Any small leak of LNG vapour from a tank in a well-ventilated area is likely to rapidly mix and quickly dissipate to lower than 5% methane in air. Because of the rapid mixing, only a small area near the leak would have the necessary concentration to allow the fuel to ignite. All LNG terminals use several types of equipment on and around the storage tanks and piping throughout the facility to detect any unlikely leakages and combustible gas mixtures [6].

## 1.5. Ignition and Flame Temperatures

The auto-ignition temperature is the lowest temperature at which a gas or vapour will spontaneously ignite in a normal atmosphere without an external source of ignition, such as a flame or spark. In an air-fuel mixture of about 10% methane in air, the auto ignition temperature is approximately 540°C. The precise auto-ignition temperature of natural gas depends on its composition. If the concentration of heavier hydrocarbons in LNG increases, the auto ignition temperature decreases [14].

In addition to ignition from exposure to heat, the vapours from LNG can be ignited immediately from the energy in a spark, open flame, or static electricity when they are within the flammable limits. LNG burns quickly and is a better heat source than other fuels (e.g. gasoline). The methane in LNG has a flame temperature of 1330°C. As mentioned before, LNG burns quickly, at a rate of about 12.5 m<sup>2</sup>/minute, in comparison with gasoline's burn rate of 4 m<sup>2</sup>/minute. The combustion of LNG produces mainly carbon dioxide and water vapour. The radiant heat of an LNG fire is a frequent safety concern of government regulators and officials, and the public [6], [7].

Usually combustion engines running on natural gas are derived from diesel engines by some modifications, e.g. the camshaft and cylinder heads are usually modified and spark plugs and an electronic engine management are added. Another possibility is using the ignition doses of diesel, which ignites under high compression, to ignite the natural gas. This method provides some operational flexibility, depending upon the LNG/diesel ratio. According to the research results of GE Transportation the best ratio of LNG and diesel is the mixture of 20% diesel as a ignition doses and 80% LNG. This ratio allows the engine to revert to 100% diesel in the event of an LNG-related failure or the unavailability of an LNG stationary or mobile refueling station. At a 95% LNG/5% diesel ratio, reverting to 100% diesel is not possible. At a 100% LNG the engine would require a spark at the, since LNG does not ignite under compression.

## 1.6. Ecological aspects

Natural gas engines emit less noise than diesel engines.

Natural gas offers the lowest "carbon content" per energy unit of all mainstream fuels and about 25 % lower than diesel fuel. This advantage is however partly compromised by bad fuel economy (11 to 28 percent worse than diesel) which is known from test runs with CNG and diesel busses (urban driving cycle comparable to railways). Compression or liquefaction reduces the carbon dioxide advantage even more. Emissions of natural gas itself, e.g. from leakage and refilling losses, contribute to greenhouse effect.

According to a study by IFEU, the maximal carbon dioxide benefit can be achieved only if the fuel economy for natural gas is as good as for diesel traction. The toxic emissions from natural gas are much lower than for diesel propulsion. In contrast to the diesel engine, the combustion for the natural gas engine is soot-free, whereby the use of a three-way catalytic converter is possible.

**Tab. 2.** Comparison of relative emissions from natural gas and diesel engine [15]

	MAN diesel engine D 2866	MAN gas engine E 2866
Hydrocarbons	100 %	32 %
CO	100 %	16 %
NOX	100 %	3 %
Particulates	100 %	< 5 %

The comparison of relative emissions from natural gas and diesel engine is presented in Table 2.

## CONCLUSION

LNG appears to be an interesting alternative fuel with low price but the investment costs are still high. The problem is the need for an alternative supply system which can become costly, especially since there is no experience with natural gas infrastructure. Interoperability is problematic even on a national scale as long as natural gas infrastructure is confined to isolated parts of the network. Advantages of natural gas propulsion over diesel include reduced toxic emissions, higher resource reservoirs, in terms of CO<sub>2</sub> emission NG is about equal to diesel and from an energy efficiency point of view LNG propulsion is neutral. More generally, this technology lacks a striking advantage to justify the currently high transition costs. However, in some areas natural gas propulsion could offer an interesting alternative to diesel propulsion.

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Autorzy:

doc. Ing. **Dalibor Barta**, PhD. – University of Zilina, Faculty of Mechanical Engineering, Department of Transport and Handling Machines, Slovakia, e-mail: dalibor.barta@fstroj.uniza.sk  
Ing. **Miloš Brezáni**, PhD. – University of Zilina, Faculty of Mechanical Engineering, Department of Transport and Handling Machines, Slovakia, e-mail: milos.brezani@fstroj.uniza.sk  
Ing. **Tomáš Kalina**, PhD. – University of Zilina, Department of Water Transport, Faculty of Operation and Economics of Transport and Communications, Slovakia, e-mail: kalina@fpedas.uniza.sk