

Tomas Kalina - Anezka Grobarcikova *

LNG AS ALTERNATIVE FUEL FOR EUROPEAN TRANSPORT SYSTEM

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 ships, trucks, etc. Furthermore, it focuses on essential parts of a process chain of LNG transport, which is liquefaction, transport of LNG itself and regasification. Closer look is given to the usage of far less preferred alternative for transport, which is inland navigation.

Keywords: Energy consumption, fossil fuels, liquefied natural gas, terminals, transport.

1. Introduction

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. Moreover, this trend is expected to continue in next years. Energy security is one of the key conditions of smooth functioning of state and 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 [1]. Countries in Central and Eastern Europe are absolutely dependent on imported oil and gas from other suppliers.

According to White Paper [2] (Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system) European Commission calls for breaking the oil dependence of transport and sets a target of 60% greenhouse gas emissions reduction from transport by 2050. Furthermore, it sets goals for the different modes of transport. In order to reach these goals a big share of alternative fuels is required. Alternative fuels can significantly contribute to improve European air quality and to reduce the existing oil dependency. As alternative fuels are generally considered any materials or substances that can be used as fuels other than conventional fuels. Well-known alternative fuels include natural gas and bio-methane, liquefied petroleum gas, biofuels, electricity and hydrogen. Proved reserves of natural gas made a very high potential for a significant contribution as an alternative fuel for the European transport sector. This opens the doors to LNG, common acronym for Liquefied Natural Gas as

the only way to transportation of this form of fossil fuel to distant destinations.

2. World demand of Natural gas and LNG trade

Globally, natural gas accounted for 23.9% of primary energy consumption in 2012. It is the third largest source of energy after oil and coal. To be precise, in 2012 the world consumed 3.0 billion tons of natural gas, compared to 4.1 billion tons of oil and 3.7 billion tons of coal [1]. Natural gas consumption increased by 2.2 per cent compared to previous year.

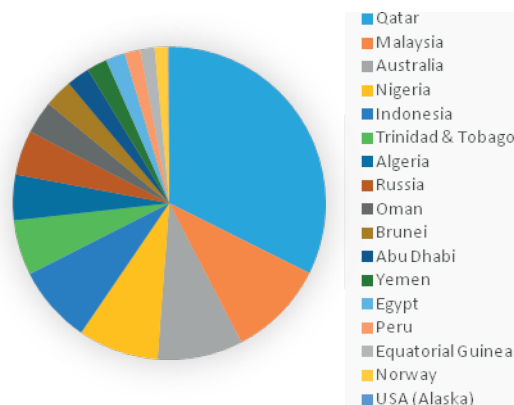


Fig. 1 LNG export [3]

During the same year, natural gas prices rose in Europe and Asia, but fell in North America, where rising US natural gas output

* Tomas Kalina, Anezka Grobarcikova

Department of Water Transport, Faculty of Operation and Economics of Transport and Communications, University of Zilina, Slovakia
Email: kalina@fpedas.uniza.sk

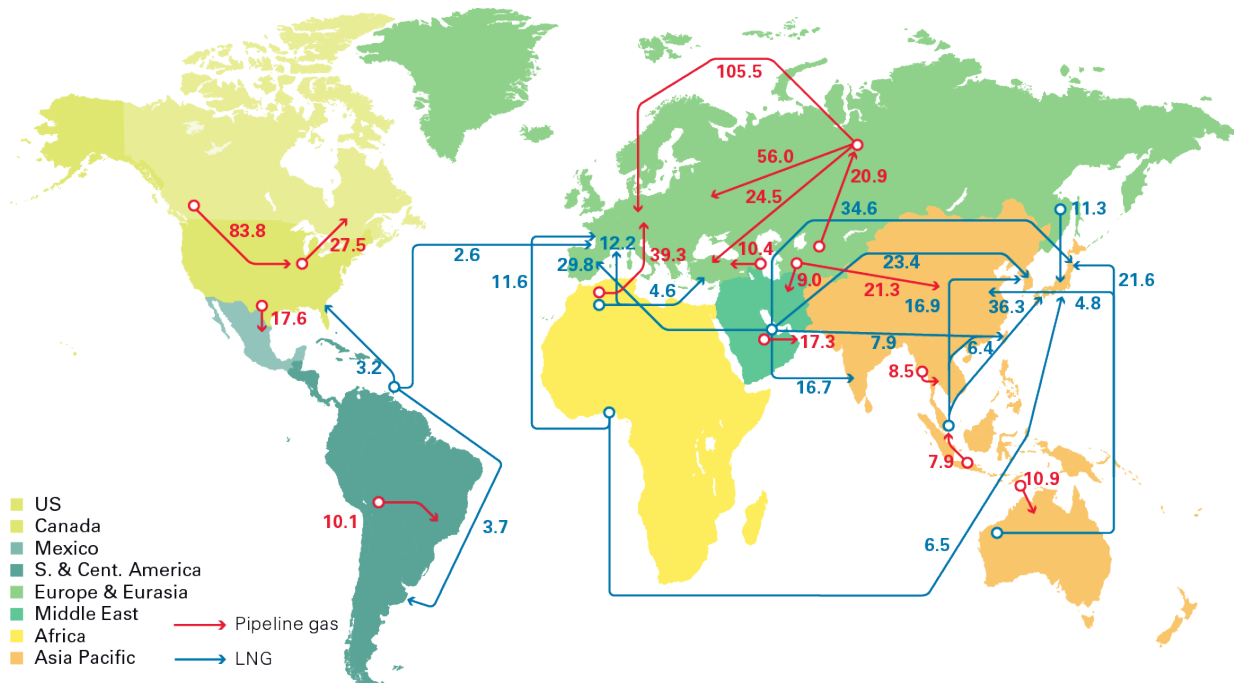


Fig. 2 Major gas trade movements of 2012 in billion cubic metres [1]

pushed gas prices to record discounts against both crude oil and international gas prices. Production grew by 1.9 per cent, with the United States remaining the world's largest producer. Norway, Qatar, and Saudi Arabia also saw significant production increases, while Russia had the world's largest decline in volumetric terms. Qatar remained the largest world exporter with a share of over 32.1 per cent of global LNG exports, see Fig. 1.

Increased export volumes were recorded also in Australia, Malaysia, Nigeria and the United Arab Emirates, while shipments from Algeria, Egypt and Indonesia contracted. LNG shipments fell for the first time, due to falling imports in Europe and the limited global liquefaction capacity expansion recorded during the year. Now LNG share of global gas trade represents 31.7%, [3] and [4]. Figure 2 shows major gas trade movements in 2012.

The outlook for LNG trade is positive in view of following facts: new gas finds worldwide (Cyprus, Israel and the United Republic of Tanzania), the decline in nuclear power use, promotion of LNG in Asia region, attractiveness of gas as a greener alternative to other fossil fuels. One study projects [5] 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 at the present time 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.

3. Basic properties of LNG

Chemical and physical properties are fundamental to understanding LNG and then safely use it as a fossil fuel. The presented properties made LNG 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. Moreover, to accurately understand and predict LNG behaviour, we must clearly distinguish its properties as a liquid from its properties as a gas or vapour.

When natural gas is cooled to approximately -162°C at atmospheric pressure, it condenses to a liquid and becomes liquefied natural gas - LNG [6]. This low temperature makes LNG a cryogenic liquid. Generally, substances which are -100°C are considered cryogenic and 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.

LNG is odourless, colourless, non-corrosive, and non-toxic. Common smell of natural gas is caused by an odorising substance

which is added to natural gas before it is sent into the distribution grid. This is due to detection of gas leaks [7].

There are five key liquid and gas properties for LNG, which are listed on Material Safety Data Sheets [6]: chemical composition, boiling point, density and specific gravity, flammability, ignition and flame temperatures. More about these properties is discussed below.

3.1 Chemical Composition

There are three major fossil fuels - coal, oil, and natural gas. Fossil fuels have been created by organic material deposited and buried in the earth millions of years ago. Crude oil and natural gas constitute types 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.

Average chemical composition of the LNG by selected countries Table 1

| 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 our predictions about its behaviours, and influence how we assess and manage safety risks. LNG is often confused with liquefied petroleum gas (LPG), which in turn is often incorrectly identified 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.

3.2 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 it is typically -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.

3.3 Density and Specific Gravity

Density of LNG varies with its actual composition. It ranges between 430 kg/m³ to 470 kg/m³ [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 vaporises very fast. Vapours at low temperatures are heavier than air and make visible white cloud. The cloud is white because the water in the air is frozen by cold vapours. 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 as air. At higher temperature vapour becomes lighter than air.

3.4 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].

3.5 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.

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 m³/minute, in comparison with gasoline's burn rate of 4 m³/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] and [7].

4. The LNG Process Chain

The global LNG business can be described as a process chain or value chain containing four main components [9]: Extraction, Liquefaction, LNG Transport and Regasification. Firstly, it is extraction and production. Plentiful source of gas is needed at a price competitive with other energy source, such as oil. Although there are plenty of reserves, they are in the wrong place and multi-billion dollar investment projects are needed to ship the gas to market. As consequence, investors are locked into a very inflexible long-term commitment, so political stability and future pricing worries weigh heavily on their minds, often leading to delays [10].

For this particular reason, the country must develop a sufficient market with a pipeline network capable of distributing the gas to domestic and commercial customers. The largest component of the total cost of the LNG value chain is usually the liquefaction plant while the production, shipping, and regasification components account for nearly equal portions of the remainder. In this paper we look closely to Liquefaction, LNG Transport and Regasification which are most significant for European transport system.

4.1 Liquefaction

Extraction of the natural gas from the earth's surface represents the first step along the process chain of LNG production. This is followed by liquefaction, which basically means the cleaning of the natural gas in the liquefaction plants (Fig. 3). A liquefaction plant represents one or more 'trains' which liquefy the gas. A train is a compressor, usually driven by a gas turbine [10].



Fig. 3 LNG Liquefaction Plant [3]

At the end of 2012 there were 89 liquefaction trains in operation in 18 exporting countries in the world [3]. The aggregate nominal capacity of all liquefaction plants reached 282 mmtpa (Million Metric Tonne Per Annum), to be compared with a worldwide LNG consumption of 236 mmtpa. Snohvit in Norway is the only liquefaction plant in Europe. Regrettably the plant owner decided to shelve their plans for a second train due to insufficient gas reserves. Nevertheless, in the Mediterranean region there are other possibilities for export of liquefied gas to Europe – in Egypt, Algeria and Libya and also another in Nigeria, Equatorial Guinea and Trinidad & Tobago. Feedgas supply for exports in Egypt has been reduced mainly because of rising domestic demand. On average, the liquefaction plants at Idku and Damietta operated at around 40% of the nameplate capacity. In Algeria, production was constrained mainly due to feedgas shortages. Due to civil war in Libya the plant remained shut down in 2012. Common situation happened also in Nigeria were various sabotage actions on feedgas pipelines led to force majeure

on deliveries at the end of 2012. From Middle East region there are potential imports through the Suez Canal from Abu Dhabi, Oman, Qatar and Yemen.

4.2 LNG Transportation

LNG transport involves four operations. Firstly, the natural gas is transported by pipeline from the gas field to the plant. Secondly, the LPG and condensates are separated out and the methane gas is liquefied and stored ready for sea transport. Thirdly, the liquid gas is loaded onto ships for transport to its destination. Finally, the receiving terminal unloads the cargo, stores it and regasifies it [10].

LNG transportation safety could be assessed from two views. On the one hand, there is danger of explosion and subsequent fire. On the other hand, it is the environmental aspect [8]. LNG is transported at low pressure. Because of its low temperature, the gas is transported in double-wall tanks with vacuum perlite insulation. Perfect insulation protects contents from heat and pressure, even if the container gets into fire and loses vacuum. There are known cases where cars transporting the LNG were burnt due to a malfunction of electrical installations, but the tank remained intact. Tanks are designed according to the regulations so they withstand even external fire. There had been no accident relative to explosion or fire in the content of LNG tankers.

In contrast to oil tankers, there are no recorded maritime disasters of LNG tankers. In the world there are currently about 378 tankers in the operation [3]. Compared with diesel and petrol, LNG is significantly safer, but it does not mean that LNG transport is completely safe. It may occur that large LNG amounts can escape from the ship into water. If the liquefied gas, which has a temperature of about -163°C , suddenly appears in a warmer ambient temperature, the liquefied natural gas will quickly change over to gas. A massive release of energy during this transition may cause an explosion.

Ignition of liquefied natural gas needs evaporation in a significant heat input and, consequently, it is possible to ignite its mixture with air, but only in a narrow range of concentrations from 5 to 15% at 280°C ignition, which is a considerably higher value than in the case of gasoline or diesel. Prevention of such cases is associated not only with designing ships for LPG transport but also employing skilled crews, trained specifically for such shipments [11].

Neither from the environmental considerations represents LNG transport an increased risk. In case of a tanker accident, gas does not accumulate in the water, therefore there is no direct damage to the water. Damage results from the possible leakage of chemicals or oils, which are necessary for the operation of the vessel, not directly from the cargo content of the LNG tanker. From the point of safety, LNG tankers are comparable with any other cargo ships.

The much worse problem in LNG transportation is lack of experienced crew to operate the complicated cargo handling system of LNG carriers. The estimations show that LNG ship owners need about 2300 deck officers, 1200 engineers, 1200 steam engineers and about 4500 ratings. Ships need experienced and well educated crew who can easily determine how LNG behaves in order to properly assess and manage safety risks [8].

4.3 Regasification

The last step in the LNG process chain involves the import terminals which are marine or floating facilities. LNG carriers deliver the LNG to a marine terminal (Fig. 4) where the LNG is stored before undergoing regasification which converts the LNG back into its gaseous form.



Fig. 4 Regasification terminal in Barcelona [3]

At the end of 2012 93 LNG regasification terminals were in operation worldwide [3], including 11 floating facilities. The combined nominal send-out capacity of the facilities reached 668 mmtpa, with 406 tanks, total storage capacity was close to 46 106 million m^3 of LNG. Based on an annual LNG consumption of 236.3 mmtpa, the global average utilization rate of receiving installations decreased to 36%. While the utilization rate of Asian terminals remained stable (around 46%), the European rate decreased to 31%. In the Americas, the average terminal utilization rate was around 10% but only 2% in U.S terminals. In Europe regasification plants are situated in Belgium, France, Greece, Italy, Netherlands, Portugal, Spain, Turkey and United Kingdom. Total storage capacity in liquid represents 8 644 500 m^3 . In May 2012 the construction of the new LNG terminal in Dunkirk (France) began, which, with 9.4 mmtpa regasification unit, is expected to be the largest terminal in Continental Europe. Under construction is another terminal in Poland, Swinoujscie, with expected start-up in the second half of 2014. Furthermore, in 2013 a new terminal in Livorno, Italy was expected to launch with 2.7 mmtpa regasification capacity.

5. Natural gas for European transport system

Nowadays many EU countries adapt to the general trend of replacing fossil fuels such as coal, lignite and oil well by environmentally more friendly natural gas. The majority share of the consumed gas in Europe comes from the United Kingdom, France, Germany and Italy [1].

The imports of Russian gas to Europe represent about 26% of the total consumption of EU countries. For Central and Eastern Europe, Russian gas is 87% of total imports. For example, Slovakia, Estonia, Latvia, Finland and Lithuania depend on 100% import from Russia. The primary effort of the EU is to maintain access to Algerian natural gas reserves, which could reduce dependence on Russia. Algeria's economy is heavily dependent on exports of hydrocarbons (oil and natural gas) – which make up 97% of exports, contributing 30% of GDP and finance 65% of the budget. EU imports 62.7% of Algerian exports, which is 58% of total EU natural gas imports [11].

The weakest link in the process chain of gas path from source to final consumer is a long haul. Current technology for natural gas transport allows long distances through pipelines or tankers in liquefied form. A wide branched European network of pipelines is preferred within the continental gas transport. In the recent past, it was annexed to the undersea pipeline connecting with the sites of customers in North Africa. Most gas from Algeria and Nigeria to Europe is transported in compressed form (CNG, PNG) by sea tankers into offshore terminals, followed by distribution pipelines, marine, rail and road tankers. Transshipment and storage capacity of most of these terminals is already at its limits. The solution is either construction of the new ones or substantial increase in inland traffic flows. An appropriate alternative also could be to carry LNG.

The use of inland waterways for LNG transportation is particularly relevant for landlocked countries of Central and Eastern Europe. The network of inland waterways of the European Union consists of approximately 37 000 km navigable rivers and canals. Interlinking the Danube to the Main and the Rhine by trans-European waterway connects the Black and North Sea with a direct connection to the network of waterways in western France, Luxembourg, Switzerland, Germany and the Netherlands. This waterway has become one of the infrastructural priorities of European transport projects taken within the European transport policy. The crucial goal of this priority is a full navigability of this important waterway so that the vessels could transport group of products from the North Sea to the Black Sea with the minimum weight of 3,000 tons during one turn. Overall, the EU has earmarked for this task the amount of 1,889 million € and from it 180 million € for the route Vienna – Bratislava. A significant amount is expected to use on the Lower Danube for removing ford sections with regard to the transport of heavy bulk items and also items containing dangerous cargo. An equally important activity for the Central European region

in this direction is the effort to link the Danube with the North and Baltic Sea by canals and the Elbe and Oder rivers. Czech, Slovak and Austrian investors promote the implementation of the Danube-Oder-Elbe Canal project in the trans-EU and the European Agreement on Main Inland Waterways of International Importance (AGN). The aim of this project is to connect the link in the waterway network which could lead to maximization of the gains from trade for countries of the region, including the extension of facilities for transportation of commodities, such as LNG.

Vessels for LNG transportation by inland waterways have a capacity of 2000 - 4000 m³, equivalent to 1.2 to 2.4 million m³ of natural gas. Restrictions in the transport are associated with a sufficient bridges clearance on the waterway. Given the low density of LNG (0.45 t/m³), draft of the vessel is negligible [11].

It opens the door to possible recovery of the recently neglected mixed river-sea technology. This system is based on the elimination of boundaries between the sea and river, which leads to elimination of transshipment from marine vessels onto river vessels and back. The removal of just one transshipment brings significant economic and time savings. In this case there is no need to build any pumping equipment and the ship can navigate from dispatch (liquefying terminal) to a port of destination.

Based on research results we can say that the river-sea transport technology can reduce transport costs by 10 - 15% in comparison with separate technologies – “inland” and “maritime navigation”. Positive effects of the formers technology appear in connection with the logistic technological scheme “door to door” [12].

6. Conclusion

The outlook for LNG is positive in view of new investments in building supporting infrastructure for LNG trade. In comparison with other fossil fuels, LNG is not as dangerous as people think and it becomes a significant energy source in European region. Therefore, one of the most recent contentious issues is to ensure its stable supply.

One of the options for Europe is an extensive network of inland waterways that offer relatively inexpensive, efficient, clean and reliable mode of transport. Countries with well-developed river and canal networks could envisage the development of LNG transportation to end users via inland waterways and, consequently, creating a virtual network of pipelines, which avoids congestion and allows the LNG supply to urban areas where geographical, demographic or environmental specificities are not suitable for the traditional laying of pipelines. One of the main problems nowadays is lack of experienced crew to operate the complicated cargo handling system. It is essential to educate not only officers, but also public about positive effects of usage of LNG as alternative fossil fuel.

References

- [1] BP. *BP Statistical Review of World Energy June 2011*. [online]. London: BP, 2013. Available on: <bp.com/statisticalreview>
- [2] EUROPEAN COMMISSION. *WHITE PAPER: Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system*. [online]. Brussels: European Commission, 2013.
- [3] GIIGNL. *The Lng Industry*. [online]. Paris: GIIGNL, 2013. 46 p. Available on: <http://www.giignl.org/sites/default/files/publication/giignl_the_lng_industry_2012.pdf>
- [4] UNCTAD. *Review of maritime transport 2013*. 2013. Geneva: UNCTAD, 2013. 204 p. ISBN: 978-9211128727.
- [5] UNCTAD. *Review of maritime transport 2012*. 2012. Geneva: UNCTAD, 2012. 196 p. ISBN: 978 - 9211128604.
- [6] GIIGNL. *Basic Properties of LNG*. [online]. Available on: <<http://www.giignl.org/about-lng/lng-basics>>
- [7] TABAK, J.: *Natural Gas and Hydrogen*. New York: Facts on File, 2009. ISBN-13: 978-0816070848.
- [8] STAROSTA, A.: Safety of Cargo Handling and Transport Liquefied Natural Gas by Sea. Dangerous Properties of LNG and Actual Situation of LNG Fleet. *TransNav, the Intern. J. on Marine Navigation and Safety of Sea Transportation*. vol. 1, No. 4, 2007, pp. 427-431. ISSN 2083-6473.
- [9] GIIGNL. *The LNG Process Chain*. [online]. Available on: <<http://www.giignl.org/about-lng/lng-basics>>
- [10] STOPFORD, M.: *Maritime Economics*. London: Routledge, 2009. 840 p. ISBN: 978-0415275583.
- [11] KLEPOCH, J., ZARNAY, P.: Vessels for River-Sea Shipping Technologies. *Communications - Scientific Letters of the University of Zilina*, vol. 3, No. 1, 2001, pp. 103-112. ISSN 1335-4205.
- [12] KALINA, T., PIALA, P.: River-Sea Technology in Transport of Energy Products. *TransNav, Intern. J. on Marine Navigation and Safety of Sea Transportation*, vol. 6, No. 4. 2012, pp. 469-473. ISSN 2083-6473.