

## LOGISTICS INTERPRETATION OF PRODUCT CHARACTERISTICS OF LIQUEFIED AND COMPRESSED NATURAL GAS

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**Abstract:** This paper analyzes product characteristics as a factor that affects the activities performed in the logistic channel. The analysis has been conducted for a specific product - natural gas and, in particular its two forms: liquefied and compressed. The features of these two forms are outlined in the context of fuel distribution to end-users. This study aims to structure and expand the existing knowledge about alternative distribution of natural gas to the end users based on an analysis of literary sources and regulations on its carriage by road and rail transport. A comparative analysis of the product characteristics of liquefied and compressed natural gas has been carried out and some basic features concerning logistics activities and logistics costs have been outlined.

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## 1. INTRODUCTION

Demand for natural gas has been on the increase over the past few decades. Analysis shows that only between 1977 and 2016 global consumption increased 2.7607 times, which is by 176.07% (according to data provided by: BP Statistical Review of World Energy, June 2017). The steady growth rate observed during this period shows a sustainable growth trend in natural gas consumption which is based not only on stronger energy demand, but also on recognizing its ecological, technological and economic advantages. Alongside these trends from the start of the century we have witnessed increasingly more dynamic development of carriage and storage technologies and technical standards for fuel utilization. Against this backdrop a number of countries have developed the natural gas distribution channel to end users whose energy facilities are not part of the gas distribution network. Thanks to this type of distribution system, which we will refer to as alternative, end users will have access to fuel before a gas pipeline is being built in their area. To make this possible a mobile compressed and liquefied gas storage equipment is used and the mode of transport is land transport – road and railway. This is what provoked the author to address the issue discussed in this paper. The key limitations can be grouped as follows:

First, the logistics systems which belong only to the third phase of the logistics process – distribution – are discussed; Second, the focus is on the physical activities carried out in the logistics channel; Third, only the issues related to alternative distribution of gas in its two forms – liquefied and compressed – are addressed; Fourth, only the carriage of small amounts of fuel to the end consumers by road and rail transport are included in the paper.

The subject of this research does not include the carriage of liquefied natural gas in large and small scales by water transport, as well as the alternative distribution systems built to provide the distribution of gas in the above mentioned forms to natural gas vehicle stations (NGV stations).

## 2. GENERAL OUTLINE OF THE STUDY

The paper is intended for the scientific community, as well as for energy distributors planning to diversify their portfolio of natural gas products. The study claims that the specific nature of natural gas product characteristics requires that specialized distribution systems be designed. The paper includes analyses of literary sources and regulations. The comparative analysis method has also been applied.

Literary sources related to logistics have been used, standards, data from BP Statistical Review of World Energy and the following regulations: European Agreement Concerning The International Carriage of Dangerous Goods by Road

(ADR 2017) and COTIF, Appendix C – Regulations concerning the International Carriage of Dangerous Goods by Rail (RID 2017).

The first stage of the research is based on the analysis of the key concept of product characteristics which discloses the main regularities related to logistics costs and the physical distribution activities carried out in the logistics channel.

The second stage of this study refers to the analysis of natural gas characteristics and the requirements for carrying out logistics activities based on the regulations on road and rail transport – (ADR 2017) and (RID 2017). They are used for the logistics interpretation of its product characteristics and for outlining regularities concerning the organization of the activities in the logistics channel and logistics costs.

### 3. LOGISTICS CHARACTERISTICS OF THE PRODUCTS

Logistics is of growing importance in the contemporary dynamic business environment because it contributes to the increase of competitiveness through the effective and efficient management of product and information flows (Rakovska, 2016, p. 63). The characteristics of the product disclose its inherent distinctive features and properties. They are a key factor in the adequate development of any logistics strategy (Ballou & Srivastava, 2008, p. 74) and its identification in the respective phase of the movement of the material flow. Product characteristics predetermine some of the requirements for providing additional elements of consumer services – before, during and after sales as well as the logistics activities carried out. This is why they play a key role in the strategic decisions involved in designing and re-engineering of every single logistics system. For example, during the third stage of the material flow the characteristics of the distributed product influence the activities related to the physical distribution and the value adding during the distribution process. Product characteristics predetermine the requirements for carriage, storage, packaging, handling and labelling and outline the necessity of clarifying the following interrelated questions:

- Are additional product processing operations needed? For example, the use of compressed natural gas requires lowering the pressure before letting gas run in the combustion installation, while liquefied gas requires regasification. These operations call for consulting consumers beforehand, providing specialized equipment and its maintenance, including spare parts, training working teams etc. and providing some additional extras for servicing consumers.
- What modes of transport can be used? These largely depend on the product durability and the limitations related to the delivery terms, the likelihood of

cargo damage and loss as well as product packaging which affects the possibility for using certain types of combined transport.

- What is the required technology for product warehousing and storage? It is predetermined by the acceptable storage methods which are supposed to preserve the product characteristics, the packaging of the product and affect the choice of handling equipment.
- How should the product be packaged? The packaging should guarantee the preservation of the product characteristics and provide safety during all technological operations in the logistics channel. Therefore, the choice of packaging depends not only on the physical and chemical properties of the product but also on the choice of appropriate modes of transport, warehousing and handling.
- What is the required product handling technology? The acceptable product handling methods determine the requirements for using handling equipment and the degree of its specific nature. They depend on the packaging used and the storage methods.
- Is special product marking and labelling necessary? Some hazardous products need special marking both on the packages and on the documentation required during their transport.

What matters most to logistics are the physical characteristics of the product such as: weight, bulk, perishability, flammability, substitutability (Ballou & Srivastava, 2008, p. 74), the risks of pollution, explosion, radiation to the environment and people and the degree of uniqueness.

Some authors add other characteristics like fragility (Coyle, Langley, Gibson, Novack & Bardi, 2008, p. 57; Rushton, Croucher & Baker, 2017, p. 111), contamination potential and extreme value (Rushton, Croucher & Baker, 2017, p. 111), as well as the possibility to be easily stolen (Ballou & Srivastava, 2008, p. 78), seen in the context of various degrees of risk potential. All mentioned characteristics have impact on the product movement in the logistics channel.

A traditional approach to the classification of product characteristics exists in literature, which groups them in four main categories: weight-bulk ratio; value-weight ratio; substitutability and risk characteristics (Ballou & Srivastava, 2008, p. 74; Rushton, Croucher & Baker, 2017, p. 109). Other authors determine the product-related factors as the most important groups: dollar value; density; susceptibility to damage and need for a special handling (Coyle, Langley, Gibson, Novack & Bardi, 2008, p. 55). Essentially, the last classification includes need for special handling rather than the substitutability group. All factors included in the product categories affect the logistics costs related to carrying out the physical distribution activities in the channel which makes them of high importance to logistics. The present paper will use the traditional approach to classification of product characteristics.

### **3.1. Weight-bulk ratio**

The main regularity observed for products with high weight-bulk ratio is the lower logistics cost per unit. The reason for that is the good utilization of the loading capacity and the loading facilities of the vehicles. A similar situation can be observed in using the storage capacity.

As a result of the better use of transport vehicles and storage units, transport and storage costs are spread over a larger base which results in lower logistics costs per unit. The reverse situation occurs with products with lower weight-bulk ratio where the logistics costs per unit are higher since they are spread over a smaller base of carried and stored product (Ballou & Srivastava, 2008, p. 74; Coyle, Langley, Gibson, Novack & Bardi, 2008, pp. 56-57).

### **3.2. Value-weight ratio**

It illustrates the ratio between the product price and its weight. Products with low value-weight ratio have high carriage costs, but with lower storage and stock maintenance costs in comparison to products with higher value-weight ratio (Rushton, Croucher & Baker, 2017, p. 110), since the tied working capital is lower. The opposite regularity can be observed for products with high value-weight ratio. (Ballou & Srivastava, 2008, p. 77).

### **3.3. Product substitutability**

This characteristic feature affects consumer behavior in the context of existing opportunities for alternative product or brand selection. It is important for distributors to determine the degree of product substitutability – low or high, and whether they will be offering its substitutes. These issues should be considered as soon as the distribution system is being designed since the product substitutability is a factor for securing the necessary service level and affect the possibilities for allowing/disallowing a deficit. Considering these peculiarities product substitutability affects carriage and warehousing costs, especially when alternative products have other characteristics and a different degree of equipment security in the logistics channel is needed. According to Ballou and Srivastava “distribution managers try to provide product availability at a level so that consumers will not have to consider a substitute product” (Ballou & Srivastava, 2008, p. 77) since this can lead to incurring further costs.

### **3.4. Risk characteristics**

They reflect the specific characteristics of the product and the threats involved in its movement in the logistics channel. As a rule, the higher the risk a particular product faces, the higher the logistics costs (Ballou & Srivastava, 2008, p. 78), because specific measures are taken for its protection: providing specialized transport; using special warehouses and packaging; designing special handling and labelling procedures; insuring against specific risks, security etc. It also calls for the need for designing special distribution systems (Rushton, Croucher & Baker, 2017, p. 111).

## **4. LOGISTICS INTERPRETATION OF PRODUCT CHARACTERISTICS OF NATURAL GAS**

Natural gas is a multicomponent mixture which consists primarily of methane and hydrocarbons from its homologous series  $C_nH_{2n+2}$  and non-hydrocarbons components - CO<sub>2</sub>, N<sub>2</sub>, H<sub>2</sub>S, inert gases, water vapour etc. (Speight, 2007, p. 5 and ICS 75.060). It is a primary energy source formed in natural underground accumulations during the anaerobic decomposition of organic material from living organisms and plant species.

The physical characteristics of natural gas are a prerequisite for its physical state to change via two technological operations – liquefaction and compression. They are of exceptional importance to the activities related to transport, storage, packaging, handling and labelling of fuel, which are carried out in the logistics channel. The liquefaction process takes place at temperatures below zero during which natural gas turns from gas into liquid while its volume shrinks considerably in the process. During compression, on the other hand, pressure is increased, therefore the volume of natural gas in one package goes up while its physical state remains unchanged.

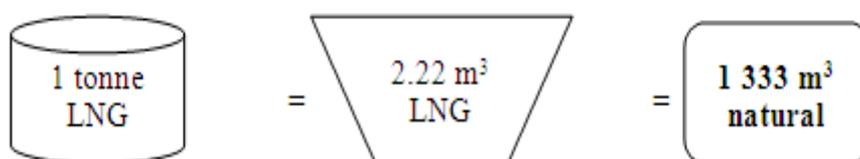
The product characteristics of natural gas are determined primarily by its physical and chemical properties which are given below.

### **4.1. Weight-bulk ratio**

According to the physical state in which it is being transported, warehoused and stored, natural gas is divided into two types: liquefied and compressed.

Liquefied natural gas (LNG). According to U.S. Energy Information Administration LNG is “natural gas (primarily methane) that has been liquefied by reducing its temperature to -260 degrees Fahrenheit (around -163°C) at atmospheric pressure” (Glossary, Natural Gas Annual, U.S. Energy Information

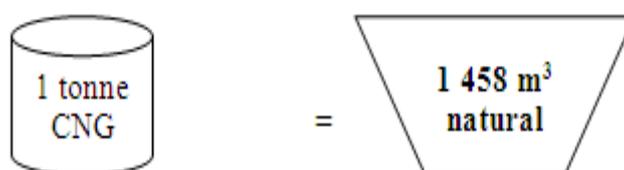
Administration, Washington 2015, p. 201). The volume of liquefied gas is more than 600 times smaller than the volume of natural gas in regular conditions (Mokhatab, Mak, Valappil & Wood, 2014, p. 2; Speight, 2007, p. 79, p. 100), i.e. when 1 m<sup>3</sup> of liquefied natural gas evaporates the result is around 600 m<sup>3</sup> of natural gas. The density of the liquefied natural gas varies from 430 to 470 kg/m<sup>3</sup> (Mokhatab, Mak, Valappil & Wood, 2014, p. 4). In the present paper we assume that the average density of LNG is 450 kg/m<sup>3</sup>, which we will be using in Figure 1 to illustrate the following example.



**Fig. 1.** Actual volume of natural gas from one unit LNG expressed in different units of measurement

Compressed natural gas (CNG) – “natural gas that has been compressed under high pressures typically between 3,000 and 3,600 psi (200-250 bar in EU) and held in a container” (LNG: A Glossary Of Terms, 3rd edition, The Petroleum Economist, London, 2006, p. 16). U.S. Energy Information Administration adds that it is „...stored in special high-pressure containers” (Glossary, Natural Gas Annual, U.S. Energy Information Administration, Washington 2015, p. 199). These characteristics make it possible for the volume of natural gas to be from 200 to 250 times higher than the volume of the used container/packaging.

The density of the compressed natural gas varies due to the gas composition which depends on the natural gas fields. We assume in the present paper that the average density of compressed natural gas is 0.686 kg/m<sup>3</sup>. In fact, 1 tonne of compressed natural gas equals around 1 458 m<sup>3</sup> natural gas – Fig. 2.



**Fig. 2.** Actual volume of natural gas resulting from one unit CNG expressed in different units of measurement

Table 1 presents a comparative analysis of the product characteristics of liquefied and compressed natural gas in some of the most commonly used packages.

**Table 1.** Comparative analysis of some product characteristics of liquefied and compressed natural gas

Indicators	Liquefied natural gas	Compressed natural gas
Technological process	Liquefaction	Compression
Volume of the product transported during 1 journey	Up to 600 times bigger than natural gas used under regular conditions	Up to 200 – 250 times bigger than the gas transported under regular conditions
Maximum weight of the product transported during 1 journey with limitations on the total weight of the composition of 40 tonnes	One tank for transporting liquefied natural gas can carry maximum of 15,50 tonnes liquefied gas or the equivalent of 21 700 m <sup>3</sup> natural gas	One battery-vehicle for transporting compressed natural gas can carry maximum 4 tonnes of compressed natural gas or the equivalent of around 5 830 m <sup>3</sup> natural gas
Weight of package	14 500 kg	28 500 kg
Weight of payload	15 500 kg	4 000 kg

#### 4.2. Value–bulk ratio

The distribution of natural gas is impacted by the value concentration in terms of transport costs. For example, the data in Table 1 illustrates that one journey can transport around 4 times more liquefied natural gas than compressed natural gas. This means that when liquefied natural gas is transported the transportation costs per 1 000 m<sup>3</sup> natural gas are about 4 times lower than the transportation costs for carrying the same amount of compressed natural gas over the same distance. As far as storage and inventory holding costs are concerned, they are higher for liquefied natural gas because of the larger quantity of product kept in one package – about 4 times more, while for compressed natural gas they are lower.

#### 4.3. Product substitutability

Natural gas has a low degree of substitutability. Practice shows that the production of the necessary energy for the heating or technological process from other fuels (diesel, fuel oil) instead of natural gas incurs a number of further costs.

This is due to the high degree of specialized function of the used equipment both in the case of end users (combustion installations) and natural gas distributors (compression installations, reservoirs for storing liquefied gas, transport equipment, storing and handling goods) which ultimately make them specialize in the distribution of a particular type of energy carrier. Some of the more important additional costs incurred when replacing natural gas with other types of fuel are:

1. Costs for resetting the combustion installations – usually the process leads to direct losses for the enterprise since the energy efficiency indicators and the efficiency of the facility deteriorate.
2. Costs for running energy facilities for other type of fuel – these include labour costs, expenditure made for personnel involved in administering the orders and exploitation costs for securing technical reliability and readiness of the facility (for example reservoirs, installations for heating oil fuel buckets etc.)
3. Storage costs for storing various types of fuels – these are high because the low stock turnover does not provide for making economies of scale for storage.
4. Costs related to scrap and wastage in transport, handling and storing different fuels.
5. Lost profits resulting from the price of the other type of fuel – this type of costs should be broadly considered as direct losses from:
  - the higher price of the other fuel for the production of a particular quantity of energy calculated in universal unit of measurement in the area of energy supply, for example kWh or MWh;
  - unrealized price discounts due to the purchase of lower quantities of the other type of fuel, than if it was used as a main energy source;
  - direct losses from increased cost norms and decreased share of energy costs in the price of the ready product, calculated per unit.

From the above stated it can be concluded that the natural gas distribution system should be built and function in compliance with principles guaranteeing regular deliveries. The purpose is to avoid allowing the consumer to switch to using another type of fuel in order to be able to guarantee high level of service

#### **4.4. Risk characteristics**

Risk characteristics are an extremely important element in building natural gas distribution systems because this is a hazardous load, i.e. substance which if transported, handled and stored inadequately, can cause accidents with dangerous consequences for the people and the environment. The main hazard that natural gas poses results from its specific properties and is closely related to its flammability. This requires that when transported via road and rail and while stored and handled packages should be marked with labels indicating the risk of getting easily inflamed (ADR 2017, 2016 and RID 2017, 2016).

**Table 2.** Comparative characteristic of the conditions for transporting compressed and liquefied natural gas under the international regulations for carriage of hazardous loads via road and rail

<b>Transport regulation</b>	<b>ADR 2017</b>	<b>RID 2017</b>
<b>Compressed natural gas</b>		
<b>UN No.</b>	<b>UN 1971</b>	<b>UN 1971</b>
<b>Name and description</b>	Methane, compressed or Natural gas, compressed with high methane content	Methane, compressed or Natural gas, compressed with high methane content
<b>Class</b>	Class 2	Class 2
<b>Classification code</b>	<b>1 F, compressed gas, flammable</b>	<b>1 F, compressed gas, flammable</b>
<b>Package</b>	Transported in accordance with the provisions stipulated in packing instruction P 200, in cylinders, tubes, pressure drums and bundles of cylinders. The receptacles should be airtight	Transported in accordance with the provisions stipulated in packing instruction P 200, in cylinders, tubes, pressure drums and bundles of cylinders, in closed and leak-proof gas containers
<b>Liquefied natural gas</b>		
<b>UN No.</b>	<b>UN 1972</b>	<b>UN 1972</b>
<b>Name and description</b>	Methane, refrigerated or Natural gas, refrigerated liquid with high methane content	Methane, refrigerated or Natural gas, refrigerated liquid with high methane content
<b>Class</b>	Class 2	Class 2
<b>Classification code</b>	<b>3 F, refrigerated liquefied gas, flammable</b>	<b>3 F, refrigerated liquefied gas, flammable</b>
<b>Package</b>	Transported in accordance with the provisions of packing instruction P 203, in closed, cryogenic containers equipped with a pressure-relief device for letting off surplus pressure	Transported in accordance with the provisions of packing instruction P 203, in closed, cryogenic containers with safety valves

Other accompanying dangers during the distribution of natural gas to the end user are related to the potential for explosion hazard, high pressure during transportation, warehousing and storage in compressed state as well as the possibility for burning the uncovered parts of the body resulting from careless

handling and not using personal protection equipment while working with liquefied natural gas. This is why the activities in the logistics channel for delivering fuel to the end users comply with a number of special directives, regulations, rules, procedures.

In international and inland transport compressed and liquefied natural gas carriage should have a unique identification number of the load in accordance with the classification of UN (ADR 2017, 2016 and RID 2017, 2016):

- UN 1971, Methane, compressed or Natural gas, compressed with high methane content;
- UN 1972, Methane, refrigerated or Natural gas, refrigerated liquid with high methane content.

Table 2 presents a comparative characteristic of the conditions for the transportation of natural gas in different physical states via land transport under the provisions of the regulations of ADR 2017 and RID 2017 (ADR 2017, 2016, vol. I, pp. 380–381, vol. II, pp. 64–87, pp. 88–89, RID 2017, 2016, part 3, p. 87, part 4, pp. 56–71, pp. 73–74).

Apart from the special conditions listed in Table 2, ADR 2017 and RID 2017 also stipulate specific requirements for loading, unloading, handling and labelling of natural gas and its two forms.

Storage time depends of the physical state and the packages used. For the products under consideration it varies widely – Table 3.

**Table 3.** Comparative description of storage time of natural gas depending on its physical state and the packages used

Types of natural gas	Package	Storage time
<b>Compressed natural gas</b>	Storage pressure containers	Until the next check for airtightness of the vessel, i.e. up to 60 months
<b>Liquefied natural gas</b>	Cryogenic vessels with double walls for providing the necessary degree of thermal insulation	Depending on the materials used no longer than 120 – 130 days

Risk characteristics of natural gas predetermine the higher logistics costs incurred during its transportation, handling and storing in comparison with those of loads with regular degree of risk. This regularity is influenced by several key reasons:

First, the transportation and storage of natural gas is done in special packages (ADR 2017, 2016 and RID 2017, 2016). They aim to minimize the hazards for the environment, the people and equipment which are manifested during the transportation, handling and storage of the product.

Second, the transportation is carried out by trained staff in accordance with the requirements for carriage of hazardous goods for the respective mode of transport. Every driver and engine driver involved in transporting natural gas should have a driver's licence permitting him to transport hazardous goods class 2 for the respective mode of transport. This permit guarantees that the person is familiar with the risks involved, is trained to carry out the procedure adequately and is capable of undertaking all necessary actions to minimize human and material damage in case of accident (ADR 2017, 2016 and RID 2017, 2016).

Third, transportation is possible only in specially certified vehicles. When transporting hazardous goods by road, for example, every traction engine should have a standard approval under ADR for the respective class (ADR 2017, 2016 and RID 2017, 2016).

Fourth, the transportation is done with specially designed equipment on board (ADR 2017, 2016 and RID 2017, 2016). Its purpose is to protect the life and health of the driver or the engine driver, to help him determine the danger zone and in case of accident to undertake all necessary steps to limit the harmful impact of the load on the environment.

Fifth, the insurance premiums for transporting hazardous cargo are higher. Premiums for insuring transport equipment are also higher because of its specialized purpose.

Natural gas has a lower degree of risk of theft than diesel fuel, for example, since its utilization requires specialized equipment for decompression and regasification. At the same time, however, due to the high degree of flammability and explosion hazard, the sites used for storing receptacles with compressed and/or liquefied natural gas require better operational supervision, protection measures and handling procedures.

## 5. CONCLUSION

The present study outlines the following key findings:

First, liquefied and compressed natural gas have different product characteristics and their specific nature calls for the need for developing various competences of distributors in the logistics channel.

Second, the specific characteristics of natural gas in its two different forms determine the necessity for specialized facilities for each of the two fuels both by the distributors and the end consumers.

Third, the transportation requirements for this product determine the specific features in the configuration of activities carried out in the logistics channel.

Fourth, the general manifestation of the regularities in the changes in the logistics costs, outlined in the concept about the product features is evidenced. The

conclusions stated justify the research thesis that the specifics of the product characteristics of natural gas require the design of specialized distribution systems.

Areas for future research can be formulated in terms of the features of the distribution of liquefied natural gas on small scale via river transport. Other research areas can be identified in relation to studying the specific features of the physical logistics activities in the alternative distribution systems of natural gas in its two forms – liquefied and compressed, to NGV stations and in the field of conducting relevant case studies.

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**Miroslav Stefanov** is an Assistant Professor in the Logistics Department at the University of National and World Economy, Sofia, Bulgaria. He holds a master's degree in Supply Chain Management and Human Resources Management as well as a PhD degree in Supply Chain Management from the same university. He teaches several subjects to undergraduate students: Design of Logistics Systems, Distribution policy, Business Logistics, Logistics Systems and Logistics in the

media environment and also Distribution Management to master's students. His research interests are related to design of logistics systems and logistics systems in energetics. He has a 10-year-long experience in Logistics gained at the largest company of natural gas distribution in Bulgaria, where he took part in design and operational management of compressed natural gas distribution system to end users and chain of filling stations as expert, senior expert and head of logistics department.