ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Liquefied natural gas: Could it be a reliable option for road freight transport in the EU?

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ARTICLE INFO

Keywords:
LNG
Freight transport
Heavy-duty vehicle
Alternative fuel

ABSTRACT

Approximately one-quarter of the total greenhouse gases (GHG) emissions in Europe can be attributed to the transport sector, with petroleum-derived fuels dominating road transport. In the current environmental and economic context, the use of less polluting alternative fuels simultaneously providing security of supply and optimal energy storage is encouraged. Natural gas (NG) technology for transportation is mature and extended through the use of the compressed form in urban and light vehicles. The introduction of liquefied natural gas (LNG) could broaden the use of natural gas for longer distances due to its higher energy density. In addition, the use of LNG in heavy-duty vehicles reduces the GHG emissions per kilometer by up to 20% and eliminates almost 100% of the sulfur oxides and particulate matter while also reducing the noise in inner cities compared with the use of diesel trucks. This paper reviews the key environmental, technical and socioeconomic aspects of LNG deployment as alternative fuel for road freight transport. Although it is necessary to continue research to develop a reliable database to estimate the actual environmental impact of LNG, the main difficulties for its deployment are market-related. From this market perspective, the prospects for LNG introduction in the European scenario have also been analyzed. Ensuring price stability and reducing uncertainty for investments are keys. Steps taken to date for developing an open and transparent international NG market are paving the way. In addition, the installation of new LNG terminals would significantly contribute to the security of supply and meeting diversification targets. Finally, some projections for the LNG implementation in the Spanish road freight transport are introduced, concluding that the fuel switch in long-haul trucks could reduce GHG emissions by 12% and diesel fuel consumption by 42% in the long term.

1. Introduction

In 2013, the European transport sector (EU-28) released 24.4% of the region's total greenhouse gases (GHG) emissions [1], with 94.6% of these emissions provided by road transport [2]. Within this transport mode, the use of gasoline and diesel yielded 98% of the GHG emissions [2].

These statistics are very similar to those of other Northern hemisphere countries, and many have recently intensified their search for economical and cleaner fuels for the transport sector. Hydrogen (H_2), biofuels, electricity, natural gas (NG), and synthetic fuels from coal, among others, have been identified as the most relevant for road vehicles [3–9], although some limitations have also been identified.

For example, even though H_2 can significantly reduce GHG emissions, its use in electric (with fuel cells) or internal combustion engines faces high production costs and low fuel density, requiring large investments to maintain the security and achieve acceptable energy storage [10]. In this context, the H_2 production costs, depending on the process, are expected to be reduced by 30–50% before 2050 [11]. In addition to the environmental impact of the use of electricity for transport being highly dependent on the power sources, battery electric vehicles show additional shortcomings related to the time for recharging, the low autonomy, and the high battery cost and mass. Although battery costs have decreased by 14% annually since 2007 [12], it is still necessary to continue investment in R & D to develop cost-effective and high energy density batteries to improve the competitiveness of electric

Abbreviations: CI, Compression ignition; CNG, Compressed natural gas; CO, Carbon monoxide; CO_2, Carbon dioxide; GHG, Greenhouse gases; H_2, Hydrogen; HD-UDDS, Heavy duty urban dynamometer driving schedule; HDV, Heavy-duty vehicle; HPDI, High-pressure direct injection; LNG, Liquefied natural gas; NG, Natural gas; NMVOC, Non-methane volatile organic compounds; NO_x, Mono-nitrogen oxides; PM, Particulate matter; SI, Spark ignition; SO_x, Sulfur oxides; SSL, Small scale liquefaction; TTW, Tank-to-wheels; WTT, Well-to-tank; WTW, Well-to-wheels

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http://dx.doi.org/10.1016/j.rser.2016.12.104
Received 1 December 2015; Received in revised form 7 December 2016; Accepted 25 December 2016
1364-0321/

Please cite this article as: Osorio-Tejada, J.L., Renewable and Sustainable Energy Reviews (2016), http://dx.doi.org/10.1016/j.rser.2016.12.104

vehicles with conventional ones. For these reasons, electric vehicles are generally suitable for only urban use or short distances [13]. In the case of biofuels, especially bioethanol and biodiesel, the main problem is their limited availability. Therefore, the EU recommended using other alternative fuels until advanced biofuels are commercially available on a large scale [14]. Advanced or next-generation biofuels include those generated from algae, waste or non-food biomass that do not affect arable land; *e.g.*, BTL (biomass-to-liquid) fuel, which has similar properties to diesel oil and is produced from lignocellulosic sources [15]. Currently, the biofuels outlook is uncertain, with some companies announcing new projects in 2014, but many others cancelling projects in recent years [12], mainly due to the low oil prices. Biogas produced from biomass or waste (biomethane) or synthetically (*e*-methane) [16], also is limited and large-scale production for competitive prices is needed. Synthetic fuels from coal have high availability, but the methods that allow a cleaner life cycle such as carbon dioxide (CO_2) capture increase the costs of the final product. In the long term, if more efficient production processes are developed, gaseous fuels from coal could be used if the number of gas-powered vehicles increases considerably [6]. The technical viability of the use of the NG in vehicles has long been demonstrated. The use of NG in vehicles was introduced in Italy in 1930, and New Zealand took accelerated steps years later [17]. In other world regions, the number of NG vehicles has increased since 1980, especially in Latin America and Asia, where the main motivation has been the cost savings achieved by the indigenous natural gas use. In some of these countries, up to 20% of the entire fleet works with natural gas, whereas in the pioneer Italy, they constitute only 1.1% of the entire registered fleet [18]. The main restricting factors for natural gas use in vehicles are related to the resource availability and the existence of pipelines and a distribution infrastructure [19].

In 2001, the European Commission proposed a 20% substitution of oil by alternative fuels in the road transport sector by 2020 to improve the security of the European energy supply and reduce the emissions of GHG [20]. At that time, the EU planned the introduction of biofuels in the short and medium term, natural gas in the medium and long term and hydrogen in the distant long term.

Although it was projected that biofuels would constitute at least 6% of the road transport fuels by 2010 [20], the value reached only 4.4% in that year, mainly due to the strong competition with agriculture and land use [14]. Currently, biofuels share approximately 5%. Due to difficulties faced in expanding their application, the EU aims to maintain this percentage while encouraging the use of other alternative sources [21].

The recent EU strategy for alternative fuels [11,14] is to prioritize mature technologies for each need. Based on its maturity and economic viability, NG is still reported by the European Union (EU) to be one of the best alternatives for road transport in the short to medium term to reduce the environmental impact and reach the objective of fuel diversification in road transport [14].

NG use has recently been extended by the compressed natural gas (CNG) application in light spark ignition engines for urban use. However, the limited autonomy of CNG vehicles would require the installation of a refueling station at least every 150 km, as was recommended in Directive 2014/94/EU on the deployment of an alternative fuels infrastructure [22], which has been difficult to implement due to the low demand for NG vehicles in the Member States. The European Parliament and the Council, with their Directive 2014/94/EU, regarding the Commission communication 'Clean Power for Transport', set deadlines for Member States to define regulations and ensure an appropriate number of refueling stations for road vehicles. Among these targets, the above Directive sets a deadline of the end of 2020 for the installation of electrical and CNG stations in urban and suburban densely populated areas. For the installation of liquefied natural gas (LNG) stations through roads and ports that connect the Trans-European Network for Transport (TEN-T Core Network) to supply heavy-duty vehicles (HDVs) and for H_2 stations, for those Member States that decide to include them, the deadline is the end of 2025. Likewise, the EU aims for these NG stations to receive biogas blends produced locally to decrease the carbon intensity in the fossil natural gas [22].

Due to its energy density, LNG is presented as the solution to the autonomy and infrastructure obstacles for long distance-road transport (a LNG vehicle with the same fuel tank size could travel up to 2.4 times the distance compared with one fueled by CNG [18,23]) and the only viable and mature alternative for diesel substitution [14].

This paper aims to analyze the key aspects for the introduction of LNG in the European transport sector, including both the technological and market aspects, and to highlight the benefits of the LNG trade in the NG market with respect to de-regionalization and energy security in the EU.

Some projections for LNG implementation in Spanish road freight transport are to obtain approximations related to the environmental impact and the diesel dependency reduction in the long term.

2. Analysis of LNG as fuel for road freight transport

As summarized below in Table 1, some studies have considered LNG introduction in road transport, taking into account technical, economic and/or environmental aspects. Most of these studies have been performed in countries outside of the EU, especially in North America.

2.1. Environmental aspects

The environmental advantages lie in the LNG production process itself. During the LNG production, the natural gas is dehydrated and cleaned of hydrocarbons, CO_2 and sulfur [36], obtaining high-purity methane (98%) that is then cooled to −162 °C, becoming a liquid and reducing its volume by approximately 600 times. Due to the high purity of the LNG, air pollutants, i.e. toxic engine emissions that can cause respiratory diseases in humans and animals as well as defoliation in plants [42,43], are lower than those of traditional fuels: approximately 80% for carbon monoxide (CO), 70% for mono-nitrogen oxides (NO_x) and 45% for non-methane volatile organic compounds (NMVOCs), whereas the reductions of sulfur oxides (SO_x) and particulate matter (PM) are greater than 97% [18,23]. Therefore, LNG trucks can seamlessly fulfill the Euro VI standard without requiring after-treatment exhaust equipment, as is required by diesel trucks.

However, there is no agreement about the environmental benefits of the LNG. The origin of these discrepancies is the stage of the whole LNG life cycle where the GHG emissions are measured. The life cycle assessment for fuels, which is known as well-to-wheels (WTW) analysis, comprises the well-to-tank (WTT) and the tank-to-wheels (TTW) analyses. The WTT analysis consists of the measurement of energy consumption and emissions during the fuel production, storage, transport and distribution, while the TTW analysis corresponds to such measurements during the fuel combustion in vehicles. In terms of energy consumption (g CO_2-eq/MJ), the LNG TTW analysis shows reductions in GHG emissions of up to 25%. However, as a result of the extra-energy needed for the liquefaction, transportation and distribution of LNG compared with diesel in the WTT analysis, the total GHG emissions reduction in the WTW analysis would be up to 16% [29,30,38,39].

Furthermore, LNG-fueled engines are less energy efficient than modern diesel-fueled compression ignition (CI) engines; in other words, LNG trucks consume more energy per kilometer. There are two types of LNG applications in vehicles. "Dual fuel" is a CI engine fueled by 90–95% LNG blended with a small quantity (5–10%) of diesel that acts as pilot whose efficiency is 5% lower than that of a diesel-fueled CI engine, whereas "dedicated" is a spark ignition (SI) engine fueled by 100% LNG, with an efficiency between 10% and 30%