LNG: A Viable Alternative Transport Fuel for Heavy Goods Vehicles

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Summary

This paper evaluates the benefits of Liquefied Natural Gas (LNG) as an alternative road transport fuel for the Heavy Good Vehicles (HGV's) sector using real results obtained from the ongoing GARneT (Gas as an Alternative for Road Transport) project. This project is led by Gas Natural Fenosa and has the aim to identify what are the future key developments that will enable LNG to become a credible alternative to diesel as a road transport fuel for the HGV's sector.

The GARneT project is co-financed by the Trans European Transport Network (TEN-T) and has put into operation seven different LNG refuelling stations during 2013 located on major Spanish transport corridors to supply liquefied natural gas (LNG) as a transport fuel to both private and public fleets. Monitoring trials have been started, which will continue until the end of 2014 in order to demonstrate both the benefits of LNG as a transport fuel and that the LNG refuelling infrastructure can be run effectively and safely. The project should finally identify any future development needs.

The lessons learnt from the construction and early operation of the public LNG refuelling stations has been considerable and positive, It has been demonstrated that fixed LNG refuelling stations can both be built and operated safely and offer a very high availability. Also the project is testing mobile LNG refuelling stations, a viable option to quickly put infrastructure at required locations. Furthermore, the experience gained within the GARneT Project will provide a basis for launching a framework context for the design and operation of the next generation LNG refuelling stations. From the initial monitoring programme, we can state that the LNG refuelling stations are operating safely and provide a reliable service of LNG. On the HGVs, we are observing improvements in the CO_2 emissions of the trucks, a saving of 15% for the dual fuel HGV and potential fuel cost savings of the order of 22 and 23% for dedicated gas fired HGVs and 13 to 15% for the dual fuel HGVs. However, further results are required to confirm these indications and determine the reliability of the LNG fuel systems. The results obtained throughout 2014 will lead to many lessons learnt for LNG as a transport fuel.

Introduction

Environmental issues and security of supply related to the use of petroleum products in the transport sector are well known and have been presented many times before[1]. The European Union (EU) transport sector faces the challenge to reduce its large dependence on oil, which today accounts for 96% of energy use in transport, of which, 84% of this oil is imported, equivalent to an approximate cost of 1 billion Euros every day, around 2.5% of the EU Gross Domestic Product (GDP). CO_2 emissions from road transport accounted for 20.4% of the total Green House Gas emissions in 2011 and these emissions have increased by 27% in the period of 1990 to 2011. In January

2013, the European Commission adopted the Clean Power for Transport package that sets out a comprehensive alternative fuels strategy for all modes of transport. The package highlighted that there is no single fuel solution for the future of mobility and all principal alternatives should be pursued, with a focus on the needs of each transport mode. The package did, however, establish that Natural Gas is part of the EU mix of alternative fuels that could substitute oil as an energy transport fuel in the medium to long term. Natural Gas offers a significant potential to contribute to the diversification of transport fuels and can potentially benefit from the synergies with the production of biomethane, a renewable fuel. Natural gas offers important environmental benefits in terms of reduction of CO_2 and other pollutant emissions.

Liquefied Natural Gas (LNG) is an attractive option for HGVs and maritime transport due to its high energy density. Currently, the HGV trucks in the EU run mainly on diesel and LNG is seen as the only current option that can substitute diesel for this sector. The biggest advantage of LNG over Compressed Natural Gas (CNG) is space requirements. LNG requires only 36% of the space of CNG to store the same quantity of energy and, therefore, is more suitable to the heavy transport sectors, which requires a large quantity of energy to be stored on a vehicle. However, LNG still requires 1.8 times the space of liquid petroleum-derived fuels to store the same amount of energy, a slight disadvantage. Although LNG is stored as a liquid in the fuel tank, it is supplied to the engine as a gas and LNG technology for trucks is a mature technology with considerable experience available from other continents, where good performance has been observed.

The downside is that the LNG market in Europe for trucks is almost inexistent; only a very few trucks fleets are operating in the EU and there are only a very small number of refuelling stations, which tend to be private stations. The main barriers for market development are the lack of infrastructure, common standards and vehicle homologation. There is a clear need to develop refuelling infrastructure and demonstrate the technical environmental and economic benefits of this option.

Within this panorama, Gas Natural Fenosa (GNF) is leading the GARneT project (Gas as an Alternative for Road Transport), which is co-financed by the Trans European Transport Network (TEN-T). This project aims to undertake a study to determine the required steps to integrate state of the art LNG refuelling technologies into the transport system to demonstrate, promote and accelerate the wide scale use of LNG as an alternative environmentally friendly and cost effective transport fuel for HGVs in Europe. As part of this action, during 2013 seven different public LNG refuelling stations were constructed along the principal transport corridors in Spain to supply LNG to both private fleets, the only current market, and future public fleets. Monitoring trials are now being performed to demonstrate the benefits of LNG and to identify future development needs. This will subsequently lead to the development of business models to show how LNG as a transport fuel can be expanded both in Spain and to the rest of Europe. In this paper the progress of the project is discussed along with the preliminary results of the on-going monitoring trials.

GARneT Project

Gas Natural Fenosa and Ham Criogénica launched the GARneT project on the 15th of April 2012. The specific objectives of the project were:

- Implement seven LNG refuelling stations trials on some of the prioritised trans-European transport network routes.
- Investigate the logistics of supplying LNG to the stations.

- Define business models based on the experience of this project to supply LNG across Europe at an economic price.
- Identify requirements for regulatory standards across the Member States and to propose actions to achieve harmonisation.

As stated previously the project is co-financed by the Trans European Transport Network (TEN-T) and such an action should contribute to the goal of achieving future 'low carbon' transport solutions, a goal of the European Union. The total project budget was estimated as 3.87M€ and the project is due to be completed by the end of December 2014.

<u>LNG Refuelling Station's Technologies</u>

The GARneT action set out to evaluate four different configurations of LNG refuelling technologies. Each LNG refuelling station is a public station and incorporates bespoke communication technologies installed at the stations to permit the required monitoring trials of the project to be undertaken. Additionally some bespoke monitoring equipment has been installed in some LNG fuelled HGVs to obtain data on the performance of these vehicles.

At the time of project launch, the LNG HGV market was immature in Europe without the existence of specific standards for the vehicle technologies. In Europe, there was and still is a requirement from the existing vehicles for two different refuelling LNG supply conditions, one being saturated LNG (equilibrium pressure of 7 bar o less) and the other being super saturated LNG (equilibrium pressure of 15 bar).

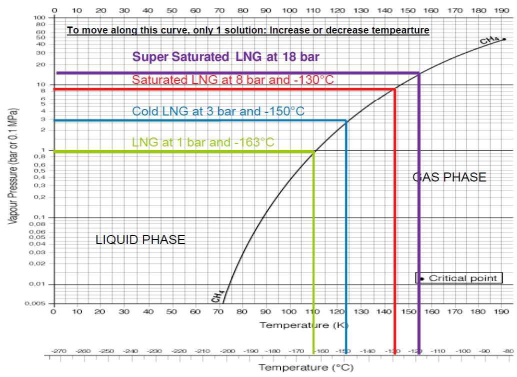

Figure 1: Temperature vs. Pressure Diagram for Methane (CH_4)[2]

Although further developments and standardisation of the truck market are expected and over the next years, at the time of project launch it was not clear which one of the two technologies would prevail, if any, in the European market.

Due to this uncertainty, it was decided to implement two designs of LNG refuelling stations in order to obtain the maximum experience so that the business models and costs could be determined for each type installation. The types of LNG refuelling station chosen were:

1. Type 1: A lower cost option that supplies LNG only at Saturated Conditions
2. Type 2: A more complicated design that can supply LNG at both saturated and supersaturated conditions.

It was also decided to implement both fixed and mobile designs of the LNG refuelling stations. A mobile station allows for a rapid roll out of infrastructure enabling LNG to be served at key locations whilst the fixed infrastructure is being constructed.

As there are a greater number of potential Compressed Natural gas (CNG) vehicles circulating in Spain, it was decided that the stations would also be designed to supply CNG as well as LNG. The other aspect considered for the fixed refuelling stations was the demand of the potential clients. Currently as there are very few fleets operating LNG fuelled vehicles, the first stations are small stations consisting of one fuel dispenser and one LNG cryogenic storage tank of $60m^3$, equivalent to that of a road tanker, which delivers LNG to the refuelling station from the LNG entry points. If more demand is required in the future, a second storage tank and further fuel dispensers can be added in the future.

Description of Type 1 Station:

The design of this refuelling station enable that natural gas can be supplied in the following forms:

- LNG at approximately 8 barg (saturated).
- CNG at 200 barg an ambient temperature.

Natural gas is stored as LNG at cryogenic temperature (between -130°C and -163 °C). The LNG storage tank pressure can be increased by means of a Pressure Build-Up Unit (PBU). The PBU takes LNG from the bottom of the tank and returns it as vapour, so that the pressure is increased up to the desired value within the tank. LNG is simply transferred to the vehicle due to the pressure difference between the station storage tank and the on-board vehicle tank. The LNG dispenser meters and delivers the fuel. For the CNG supply, the LNG is transferred to ambient vaporizers again by pressure difference. After vaporization the natural gas is odorized, a legal requirement for leak detection and sent to the CNG dispenser, a combined unit which consists of: compressor; storage cylinders and dispenser. The CNG supply has a maximum capacity is 300 $(N)m^3/h$ at 200 barg.

Vehicle filling information, such as the quantity of LNG loaded (in kg), date and time, is stored by the data system of the station that provides information to the monitoring programme.

The advantages of this type of station are:

- Medium-Low capital costs
- Low space requirements
- High reliably
- Possibility to supply CNG
- Possibility to manage the Boil of Gas (BOG).

The disadvantages of this type of stations are:

- Not able to supply “super-saturated” LNG
- LNG Dispenser cannot be allocated far away from tank
- Moderate operational costs, due to the NG compressor energy consumption

Description of Type 2 Station:

The design of this refuelling station is more complex than the Type 1 refuelling station, due to the fact that it can supply natural gas in the following forms:

- LNG at different saturation conditions (between 8-18 barg)
- CNG at 200 barg an ambient temperature.

As with the Type 1 design, natural gas is stored as LNG at cryogenic temperature (between -130℃ and -163 ℃). The LNG storage tank pressure can be also increased by means of a Pressure Build-Up Unit (PBU) again as in the Type 1 design. However, in this design, for the supply of LNG, LNG is transferred from the storage tank to the dispenser by means of the centrifugal pump and, therefore, can be delivered at the required saturation conditions. For the CNG supply, the LNG is pressurized up to 350 barg and transfer to the ambient vaporizers by means of the piston pump. After vaporization the natural gas is odorized for leak detection and the CNG is stored in cylinders at 250 barg. This can then be delivered by means of the dispenser at 200 barg. Boil-Off Gas (BOG) from the main LNG storage tank is managed by means of an ambient heater and one BOG tank. When required, natural gas from this tank is compressed and injected to the CNG supply line.

The advantages of this type of refuelling station are:

- Possibility to supply “saturated” and “super-saturated” LNG.
- The LNG dispenser does not need to be nearby to the storage tank.
- High LNG refuelling capacity (several dispensers can operate at same time).
- High CNG refuelling capacity.
- The BOG is consumed as CNG.

The disadvantages of this type of refuelling stations are:

- High investment cost.
- High operational cost.

Description of Mobile Stations:

This project also includes the operation of three mobile LNG refuelling stations. These stations do not have a specific location and can be located according to the trial needs where there are potential customers. Two designs of mobile stations have been developed. The first design can only supply LNG at approximately 8 barg (saturated). LNG is stored in an ISO intermodal cryogenic container (ICC) with a payload of 7,995kg of LNG, which is mounted is a truck trailer. The ICC can be pressurized by means of an ambient vaporizer (PBU) and the LNG is transferred from the ICC to the on-board vehicle tank by pressure difference.

The second design of mobile station is capable of supplying LNG at both saturation and super-saturation conditions (between 8 and 18 barg) and can deliver CNG at 200 barg. Basically the station is a LNG Tank Truck equipped with a centrifugal pump to supply LNG and with a piston pump to supply CNG. The storage tank is a vacuum-perlite insulated tank with 8.000 litres of capacity. High Pressure vaporizers are located around the tank.

Figure 2: The Two Types of Mobile Stations constructed in the Project

Locations of the LNG Refuelling Stations in the GARneT project

The location decided for the LNG refuelling stations of this project took into consideration the following criteria:

- Proximity to the LNG supply terminal situated on the coast in order to simplify the logistic of LNG supply to the refuelling station and to minimise costs.
- Local to major industrial areas where potential clients are located.
- Close to or on one of the National and International transport corridors to allow drivers to refuel without having to make a major deviation for fuel.

Taking into consideration the above factors the stations were constructed in the locations shown below:

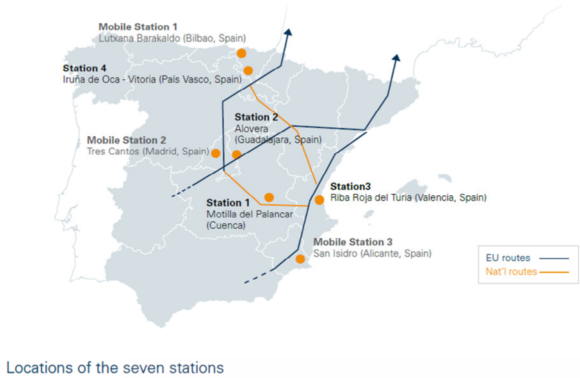

Figure 3: Location of the LNG Refuelling Stations of the GARneT project

Of the four fixed stations:

- Motilla de Palanca and Ribarroja are Type 1 stations that supply LNG at 8 barg (saturated) and CNG.
- Alovera and Iruña de Oca are Type 2 stations that can supply LNG at different saturation conditions (between 8-18 barg) and CNG.

All the fixed refuelling stations entered into operation by August 2013 according to the original project plan.

Figure 4: Iruña de Oca, Ribarroja, Alovera & Motilla del Palancar LCNG Refuelling Stations

Preliminary outcome of the Monitoring Programme

The monitoring programme has the final objective to evaluate the reliability and operability of the LNG refuelling stations as well as to evaluate the performance of the vehicles using the LNG either in dedicated or dual fuel form. The monitoring programme started in August 2013 and will continue until the end of December 2014. The results obtained will then feed into future deployment and business models for the expansion of LNG as a transport fuel in Europe.

Key Performance indicators (KPI) were established to determine the following:

- Refuelling Stations:
  a. Operational availability and reliability of the LNG refuelling system
  b. Safety Issues
  c. Loading time for a typical truck tank of 120 kg
  d. Percentage of successful Loads
  e. LNG logistic costs
  f. Annual Operational Costs of the Refuelling Stations

- LNG Vehicles
  a. LNG Fuel Consumption
  b. Diesel Fuel Substitution in a Dual fuel vehicle
  c. Engine Efficiency
  d. Fuel cost differences for LNG vs. Diesel
  e. Operational and Maintenance costs for LNG and Diesel vehicles. vs. Diesel
  f. Emissions levels (CO2, NOx, & Particles & Noise levels)

Although the results to date are very preliminary, in the following text we discuss some of the initial findings obtained up to December 2013.

LNG Refuelling Stations

With respect to safety, we have not registered a single incidence in the construction and operation of the LNG refuelling stations. The following KPIs were defined:

$$A_{Co}\left[\frac{accidents}{station}\right]=\frac{No.of.Accidents.during.Construction}{No.of.Fuelling.Stations.Constructed}$$

$$A_{O}\left[\frac{accidents}{15.000MWh}\right]=\frac{No.of.Accidents.during.Operation}{Total.Energy.Dispensed}*15.000$$

In both cases “Accident” is defined as an undesirable or unfortunate happening that occurs unintentionally and results in risk of damage to persons and/or installations.

The current value is zero and although the results are preliminary, to date we can confirm that the LNG refuelling stations can be constructed and operated safely without incidence.

With respect to the refuelling stations reliability, we created the following KPI:

$$R_{St}\left[\frac{incidents}{15.000MWh}\right]=\frac{Number.of.Incidents.during.Operation}{Total.Energy.Dispensed}*15.000$$

Whereby for this KPI, an incident is defined as an event causing unavailability of the refuelling station. The values measured to date are in the range of 0.02 to 0.19 incidents/15.000MWh of energy dispensed. This results in a very high availability of the LNG refuelling stations. Most of the stations have had 100% availability and in the poorest case the measured availability is 99%. This means that the LNG refuelling stations are available when the customer needs them.

The refuelling stations are not manned, so we have monitored the refuelling time in minutes for a typical truck tank of 120kg of LNG. The results show that the refuelling time is in the range of 4 to 8 minutes depending on the type of the refuelling station. Also we monitor the number successful refuelling events with the following KPI,

$$N = \frac{No.of.Successful.Fillings}{No.Total.of.Fillings} * 100\%$$

A successful refuel is one when the user has not had any issue in the complete operation from refuelling to payment. In some cases, the initial value to date has been considerable lower than our objective of 99% for a fixed refuelling station and 97% for the mobile refuelling stations. We believe that the principal causes for this are that the users are not fully familiar with the use of LNG technology and that the number of refuelling events is still fairly modest, which means that one incident has a considerable impact on the result, We believe this value will improve over time when the users are more familiar and the training process is optimised. A key issue to the success of this process is the commitment and acceptance of the truck drivers.

It is still early days to make definite conclusions on the performance of both the fixed and mobile LNG refuelling stations, but both technically and economically they are aligned with our expectations. More concrete conclusions will be determined by the end of the trial in December 2014 when we will publish the definite results.

LNG Vehicles

There are currently three types of LNG fuelled HGVs available:

- Dedicated Spark Ignited Natural Gas (SING)
- Port Injection Dual-Fuel (PIDF)
- High Pressure Direct Injection (HPDI)

At the project launch, the HPDI engines were not commercialised in Europe, so that trials have simply focussed on the SING and PIDF vehicles.

Safety of the LNG fuel system in the truck is a key issue and we have established the following KPI to measure this value:

$$A_T = \frac{Number\_of\_Accidents}{100.000km}$$

Whereby an “accident” is defined as an undesirable or unfortunate happening that occurs unintentionally and results in risk or damage to persons and/or installations. To date this value is zero, and we have not incurred any incident. This underlines the safety of these LNG installations.

With respect to the reliability of the LNG fuel system installed on the truck, the following KPI is being monitored:

$$R_T = \frac{Number.of.Incidents}{100.000km}$$

Whereby an “incident” in this case is defined as any truck failure caused by the LNG fuel system that requires repair. We established a target value of less than 0.10 Incidents/100,000km. Over the first few months of the trials, the values measured have been 1.17 for the dual fuel PIDF vehicles and 2.48 for the dedicated SING vehicles. These results exceed our target, suggesting that there are possible reliability issues with the LNG system in the trucks. However, currently we consider that this result is not totally representative, due to the fact that the trucks have covered very few kilometres, the installations tend to be bespoke and the installation issues are overwhelming the measured value at this moment. More kilometres have to be incurred before we can obtain a robust answer on the reliability of the LNG injection system.

For the dual fuel PIDF vehicles we have established KPIs to measure the quantity of substitution of LNG, calculated on an energy basis and are an indication of the overall efficiency of the engines. The KPIs for LNG fuel substitution is:

$$Su_{PIDF} = \left(\frac{E_{LNG}}{E_{PIDF}} \right) * 100\%$$

Where E_{LNG} is the LNG energy consumption and E_{PIDF} is the total fuel energy consumption of the vehicle. We are measuring values shown in the following table:

Table 1: Diesel fuel substitution (S_u PIDF)

		August	September	October	Average
Su_{PIDF}	%	54,98	55,37	55,39	55,37

The measured values are slightly lower than our target values. The reason could be that the degree of substitution in a truck depends heavily on the torque of the engine, so it is related to the load of the engine and may vary in a wide range depending on the driving conditions, payload, etc. Or it could be that the kit is not fully optimised for the diesel motor and more developments are required in this area.

With respect to energy efficiency of the LNG fuelled motors; we are currently observing that the dual fuel vehicles are some 6 to 9% less efficient than a diesel fired truck. Our target value for the efficiency loss is less than 5%. However, on a month by month basis, the efficiency loss value is reducing and approaching the target value. The reason for this could be that the required driving style is different for a dual fuel vehicle and that the drivers have a learning curve to optimise the efficiency of these vehicles. We need to have more running time before any firm conclusion can be made.

On a positive side, we are observing fuel cost savings for the LNG fuelled vehicles when employing the following fuel costs:

- Diesel: 1.062 €/l
- LNG: 0.902 €/kg

the costs obtained over a 3 month trial period between August 2013 and October 2013 were:

Table 2: Fuel Costs over the period August to December 2013

		August	September	October	Average
C_{diesel}	€/100 Km	34.93	34.93	34.93	34.93
C_{SING}	€/100 Km	27.39	26.95	26.77	26.95
C_{PIDF}	€/100 Km	30.13	29.64	29.41	29.64

The savings on the dedicated SING trucks were between 22 and 23% and for the dual fuel PIDF trucks were 13 to 15%. These figures will be firmed up over the remainder of the trial period, and additional maintenance costs if any will be determined to allow for the final business case to be developed.

With respect to the environmental performance of the trucks, KPIs were developed for CO_2, particulate, NOx and noise emissions for both the dedicated SING and dual fuel PIDF trucks. To measure these values dedicated measuring equipment has had to be fitted to the trucks for specific back to back tests with a diesel fuelled vehicle. The equipment has two important parts: a gas analyser measurement system and a flow meter measurement system incorporating a GPS system and data logger. The equipment measures the concentration of the pollutant gases and exhaust flow rate. Using this data, it is possible to calculate the quantity of grams that the vehicle emits during the different cycles.

Figure 5: Equipment for measuring emissions

These measurements have just begun, but we have already observed reductions in the emissions of CO_2 of the order of 15% for the dual fuel PIDF trucks. The tests will continue until the end of the monitoring period.

<u>Conclusions</u>

The GARnet project has advanced according to it's planning, resulting in four fixed LNG refuelling stations and three mobile LNG refuelling stations being put into operation before August 2103. A monitoring trial has commenced that will run until the end of December 2014.

The lessons learnt from the construction and early operation of the public LNG refuelling stations has been considerable, we have demonstrated that these stations can be built and operated safely and have a very high availability. Furthermore, the experience gained within the Garnet Project will provides a basis for optimising the design, layout, operation and maintenance of the next generation refuelling stations. At the end of the monitoring trial we will have good operational and economic data for the different types of LNG refuelling stations tested. For the HGVs, we are observing improvements in the CO_2 emissions of the trucks and potential fuel cost savings. However, further results are required to confirm these indications and determined the reliability of the LNG fuel systems.

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