

## Case Study

# LIQUEFIED NATURAL GAS (Dual Fuel)



### TRIAL SUMMARY

The objective of this trial was to assess the fuel efficiency and GHG outcomes of dual-fuel LNG technology involving the assessment of a prime mover using LNG (throttle body injection) and operating a regional haul application in NSW.		Fuel benefit (DLE/100 km)	GHG benefit (g/km CO <sub>2</sub> -e)	Economic benefit (\$/100 km)
	LNG substituted for diesel: 48 %	14%↓ (8.2 DLE)	1.7%↓ (24 g/km)	4.1%↑ (\$2.96/100 km)

↑ performance better than conventional vehicle  
↓ performance worse than conventional vehicle

The *Green Truck Partnership* is designed to be a forum for the objective evaluation of the merits of clean vehicle technologies and fuels by heavy vehicle operators. This report discusses the results of a liquefied natural gas (LNG) dual-fuel trial conducted under the program in 2013.

## 1 DUAL FUEL LNG TECHNOLOGY

The LNG system in this trial was a dual-fuel system operating on a combination of natural gas and diesel. The system is available as an aftermarket kit and employs throttle body injection of natural gas prior to the inlet manifold of the diesel engine.

One benefit of dual-fuel technology is that it does not require a change to the basic diesel engine, apart from the addition of a new gas injection system and engine control unit fitted externally so as not to interfere with OEM engine equipment. In this system, an in-cab LCD display shows substitution rate, and can also be used to do system checks and diagnose faults.

Other claimed benefits from this technology include lower operating costs, lower tailpipe emissions, yet drivability similar to that of a pure diesel engine.

Unlike other natural gas engine technologies, dual-fuel systems also allow the engine to operate on pure diesel when the LNG supply runs out.

## 2 TRIAL OBJECTIVE

The system used in this trial was quoted by the manufacturer as providing an average fuel substitution rate between 40% and 60%. The purpose of this trial was to quantify the real-world fuel saving and GHG outcomes of a dual-fuel LNG system compared to a standard diesel engine.

## 3 METHODOLOGY

### DATA COLLECTION

The trial involved the in-field assessment of a regional linehaul prime mover fitted with an aftermarket dual-fuel LNG kit operating over a 4-month period. The same truck was tested with the LNG system activated and deactivated.

During the trial period, data loggers were used to collect drive cycle data relating to the operation of the trial vehicle. A comparison of the drive cycle data indicates whether the pre-trial and trial periods can be compared. The data collected by the loggers during the course of the trial included:

- **FUEL CONSUMPTION:** daily fuel consumed (L).
- **DISTANCE:** daily distance travelled (km).
- **FUEL ECONOMY:** daily fuel economy (km/L).
- **IDLE TIME:** time spent at idle (%).
- **ENGINE LOAD:** percentage of time spent at a given engine load.
- **AVERAGE SPEED:** average speed (km/h).
- **STOP FREQUENCY:** number of stops per kilometre travelled.

## DATA ANALYSIS

The main descriptors considered in this analysis included engine load, average speed and fuel economy. This data was used to assess the average performance of the vehicle throughout the trial and baseline periods, and to identify any periods where the operation of the vehicle was considered to be sufficiently different to warrant exclusion of related fuel consumption data.

Once the data validation was complete, the fuel efficiency of the LNG dual-fuel technology was compared with pure diesel operation. The results of this comparison are discussed in Section 4.

To ensure the fuel consumption comparison was valid, the duty cycles of the diesel and dual-fuel periods were compared over the course of the trial. Given that the vehicle was performing regional linehaul, parameters for engine load and average speed were considered sufficient for comparing vehicle operation.

Engine load is essentially a measure of how hard the engine is working based on a ratio of developed torque and theoretical torque (as a percentage) by the vehicle manufacturer. This parameter can be influenced by a number of factors including speed, driver technique, payload, terrain and transmission. Comparison of the engine load profiles for both periods revealed small differences in the engine load profile, as shown in Figure 1.

The analysis revealed an offset in the engine load profile for the LNG trial period (i.e. same shape, but a higher proportion of time at 10–20% engine load).

This shows the vehicle engine was ‘working harder’ during the LNG trial period and therefore likely to have consumed more fuel than if the engine load had been the same.

In order to ensure the difference was merely one of technology and not vehicle application, a second comparison was undertaken by considering the average speed profiles of the vehicle trial periods.

This analysis, presented in Figure 2, shows a good correlation between the vehicle speed profile during the LNG trial period and the speed profile during the diesel trial period.

Given the results of the vehicle speed profile comparison, the direct comparison of the fuel consumption results was deemed to be valid.

## ASSUMPTIONS

Conservative but reasonable Australian prices were used for LNG and diesel at the time of the trial, including:

- **DIESEL PRICE:** \$1.30/L  
(\$1.42 retail minus fuel tax credit of \$0.12)
- **LNG PRICE:** \$0.50/L.

In energy calculations, lower heating value was used for combustion of LNG and diesel:

- **DIESEL:** 35.6 MJ/L
- **LNG:** 48.8 MJ/kg.

Emissions intensity factors for diesel and LNG:

- **DIESEL:** 69.8 kg CO<sub>2</sub>-e/GJ
- **LNG:** 53.6 kg CO<sub>2</sub>-e/GJ.

## 4 RESULTS

Volumetric fuel efficiency (L/km) of the dual-fuel system is not directly comparable with a pure diesel engine because LNG and diesel have different characteristics, including energy density.

As a result, significantly more LNG is consumed than the diesel it replaces in the engine – in this case, 87 L of diesel and LNG combined for every 100 km of travel, compared with only 56 L per 100 km when operating on diesel alone.

However, representing the fuel energy of both fuels in a common unit (MJ), and subsequent conversion to a diesel litre equivalent (DLE) value, allows an indicative comparison of efficiency.

Figure 1  
Comparison of vehicle engine load  
across baseline and trial periods

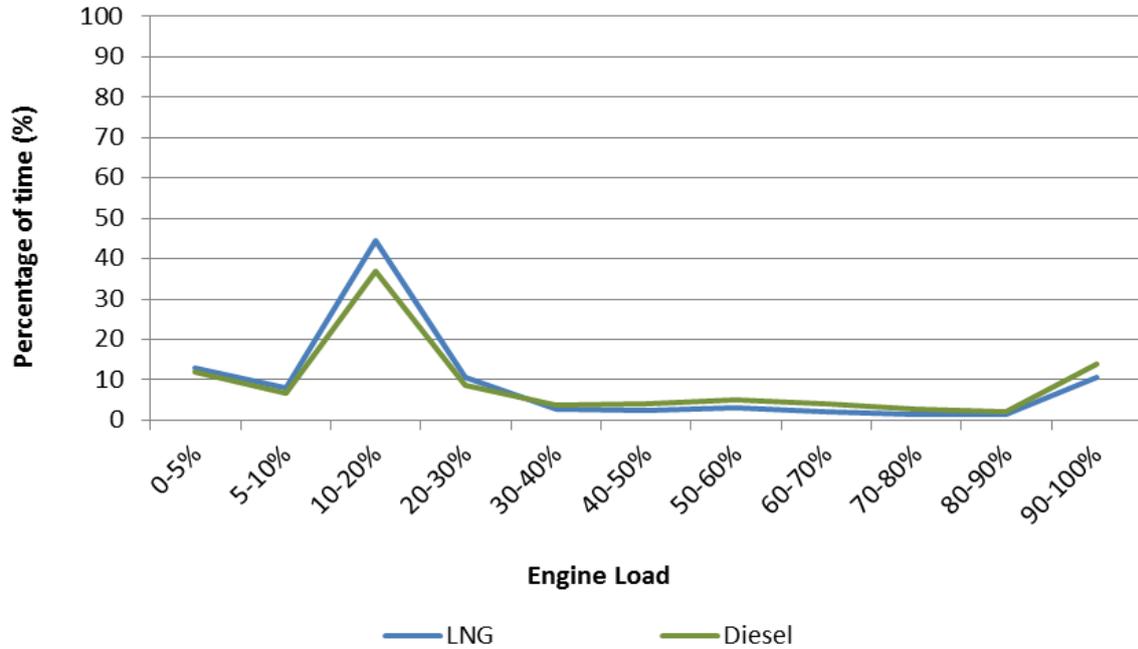
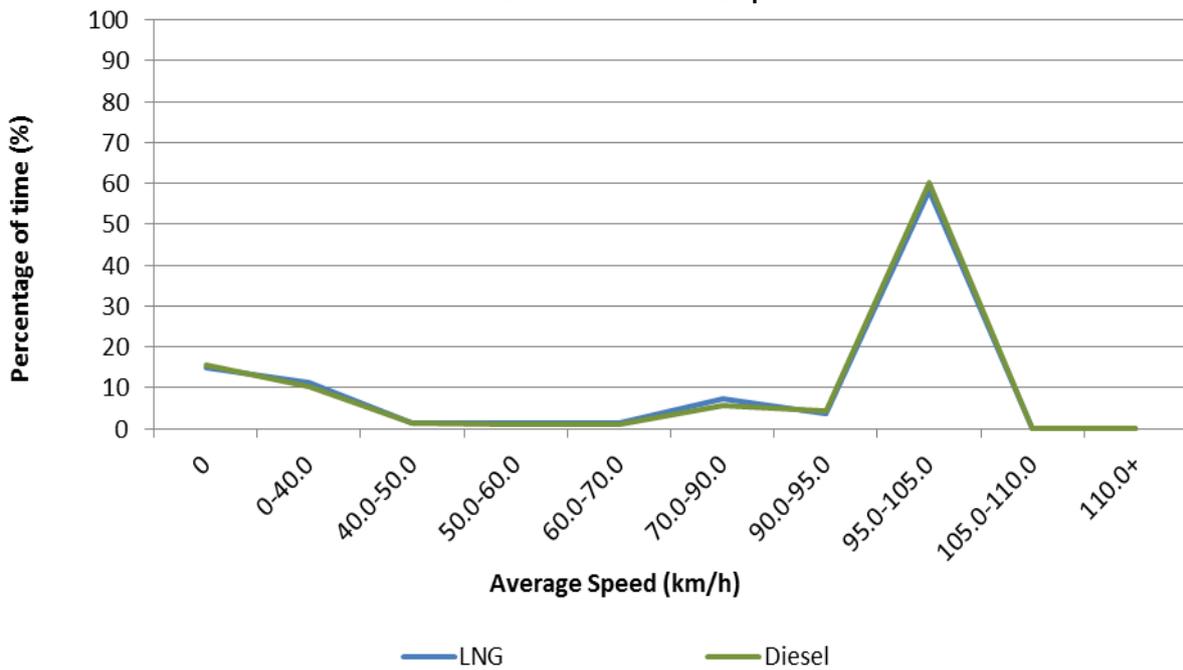


Figure 2  
Comparison of vehicle average speed  
across baseline and trial periods



On that basis, Figure 3 shows that the energy consumption when operating as a dual-fuel engine was around 14% higher than when operating on diesel alone (64.4 DLE per 100 km vs. 56.2).

Over the trial period, the average gas substitution rate was calculated as 48%. However, this figure should be interpreted with care, because it includes (a) periods when the engine could have used LNG and did, and (b) periods when the engine could have used LNG but did not (e.g. when the LNG tanks were empty and the truck reverted to diesel operation).

The calculated substitution rate is therefore specific to this application and route only. The same truck used in another application could show a higher value, especially if it carries sufficient LNG to never empty the tanks.

Applying the relevant emissions intensities for diesel and LNG produces the result shown in Figure 4. The period of diesel-only operation and the period of dual-fuel operation produced almost the same GHG emissions. In other words, there was no GHG benefit in using LNG in this case.

This result is at odds with the supplier's expectation of 12% GHG savings, but can be explained by the 14% higher energy consumption shown in Figure 3.

In cost terms, the dual-fuel system does provide a small but significant cost saving (more than 4%) over the duration of the trial, based on fairly conservative assumptions of LNG price and diesel cost. This result is shown in Figure 5. Note that the higher the diesel cost, or the lower the LNG price, the greater the saving would be. For example, at a (lower) 45 cpl LNG price and \$1.40/L diesel price, the fuel saving for using this system would be 14%.

Note that other costs should also be considered on a whole-of-vehicle-life basis, including maintenance, training, refuelling/infrastructure costs, and possibly some impact on resale value.

## 5 CONCLUSION

The results indicate that the type of dual-fuel LNG system used in this trial (throttle body injection) did not produce an emissions benefit in this specific application (route, duty cycle, refuelling frequency). If used in other applications where the gas substitution rate could be higher, the emissions savings could well be different.

Assuming the truck was doing the same kind of work with the same loads when operating as dual-fuel and during the diesel-only period – and the data validation seems to indicate this was the case – the truck appeared to be operating less efficiently (on an energy basis) during the dual-fuel period.

Despite these findings, the dual-fuel LNG system could provide fuel cost savings. Based on nominal price assumptions in this trial, the saving was calculated at greater than 4%. However, the magnitude of saving depends largely on the operator's supply prices for both diesel and LNG, and on the gas substitution rate. The higher the diesel price, the higher the substitution rate, or the lower the LNG price, the greater the saving.

Most importantly, the results are valid for one truck operating in one specific application only, and they may not be representative of the outcome in other applications. Prospective users of similar LNG systems may find greater or lesser savings and emissions reductions in their own circumstances. In addition, the economic outcomes over the life of the vehicle need to assess these fuel savings in light of the additional cost of technology and any variation in repair and maintenance costs.

Figure 3  
Comparison of diesel-litre equivalent (DLE) fuel efficiency during dual-fuel and diesel operation (L/100km)

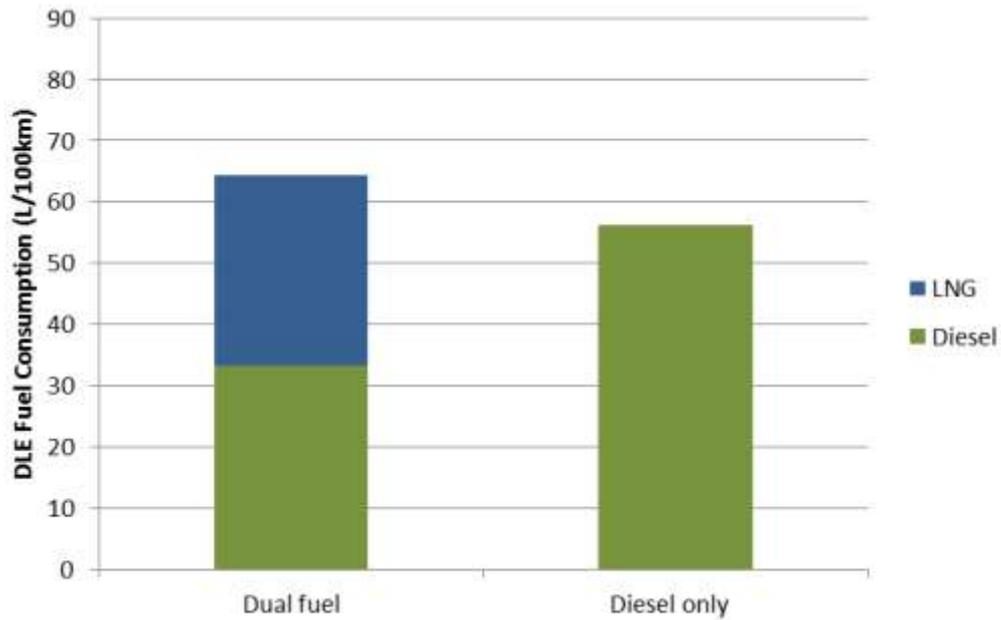


Figure 4  
GHG emissions of dual-fuel and diesel operation

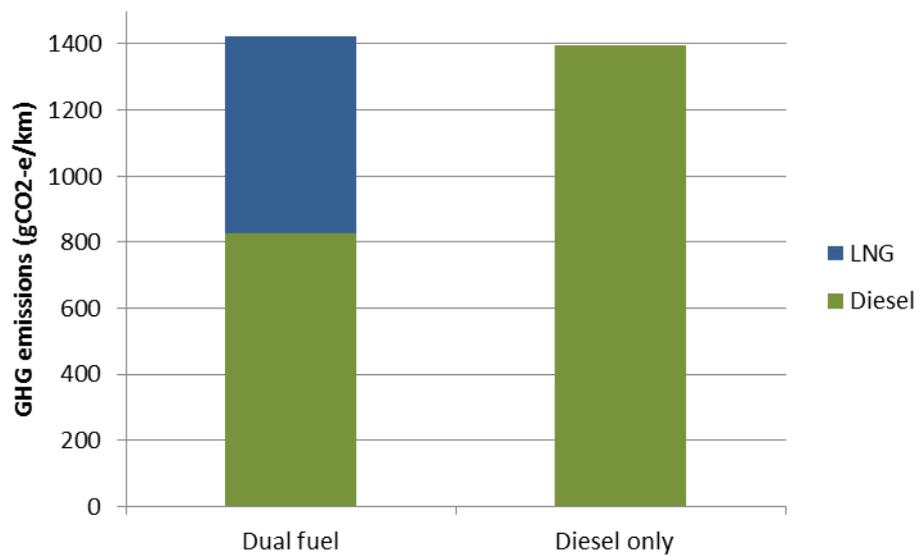


Figure 5  
Comparison of LNG and diesel fuel costs

