NATURAL GAS
FOR HEAVY DUTY VEHICLES
THE FUEL OF THE FUTURE

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1. INTRODUCTION

For many years the diesel engine has been the main source of motive power for the commercial transport industry. While having a lower specific power output than the equivalent sized petrol engine the diesel generally has a higher reliability factor and a longer life. However, concern about transport produced environmental pollution over the last twenty or so years has resulted in detailed scrutiny of the exhaust emission characteristics of both petrol and diesel fuels. The emissions of primary concern are carbon monoxide, for its asphyxiating effects unburnt hydrocarbons and oxides of nitrogen for their contribution to photochemical smog, carbon dioxide for its contribution to the Greenhouse Effect and particulates for their potentially carcinogenic and mutagenic effects.

The oil shocks of the 1970's also highlighted the dependance of the transport industry on liquid fuels and to its sensitivity to both the availability and price of these fuels.

As a result of these issues the past ten years has seen a substantial effort to seek alternative fuels which are both less environmentally damaging and less affected by variations in availability and price.

A number of alternative fuels have been considered including the alcohols - methanol and ethanol, and the gases - propane and natural gas. This paper looks at the potential of the last of these alternatives - natural gas - as a replacement for diesel in heavy duty engines, both in the public transport and commercial trucking sectors.

2. WHAT IS NATURAL GAS?

Natural gas is a mixture of components, including methane, ethane, propane, butane and small amounts of higher hydrocarbons. Its properties compared to diesel are shown in Table 1.

Table 1. Characteristics of Natural Gas and Diesel

	Natural Gas	Diesel
Nett Specific Energy MJ/kg	42 - 44	43
Octane Rating	120	-
Cetane Rating	-	55
Hydrogen/Carbon ratio	3.6	2.2

The most obvious difference between the two fuels is the ignition quality. Without going into the details of fuel rating it can be summarised by saying that diesel has a short ignition delay period (time between start of injection and the point of pressure rise) making it suitable for the compression ignition process. Natural gas on the other hand has a high resistance to auto ignition or knock and a high delay period which makes it unsuitable for 100% compression ignition operation.

3. DUAL - FUEL NATURAL GAS/DIESEL

While natural gas is not generally used in the 100% compression ignition mode it can be satisfactorily used as a partial replacement for diesel. This is known as the dual- fuel principle.

Dual-fuel operation is common place in industrial applications, particularly with medium and slow speed engines. In the automotive application the use has been much more limited due to operational factors. Figure 1 shows a typical dual-fuel application in which natural gas is aspirated or injected into the air intake and the amount of diesel is reduced to a level dependant on the operating condition and the engine type.

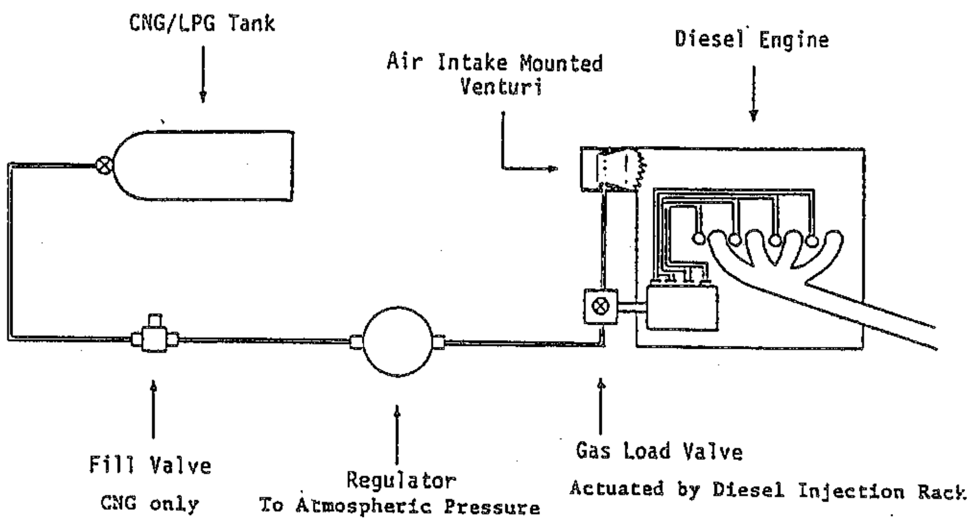

Figure 1: Dual Fuel Gas/Diesel Installation

The first large scale use of dual fuel automotive engines was by a bus fleet in Vienna, Austria in the 1970's. These engines used a mixture of LPG and diesel to reduce smoke levels.

In the early 1980's a number of New Zealand trucks were fitted with dual-fuel systems and several million kilometres covered in total. However, the experience with these vehicles showed that because of the large variations in speed and load that occur in the automotive application the gas/diesel control systems were not capable of providing the optimum substitution characteristics to achieve the expected cost savings. (Refs 1,2) Since that time considerable research has been carried out on microprocessor systems that vary the gas/diesel ratio at multiple points throughout the load/speed range. At the time of writing this paper, however, none of these systems appear to be commercially viable.

4. SPARK IGNITION NATURAL GAS

As noted in section 2 natural gas has a very high octane rating. This makes it ideally suited to high compression operation with spark ignition and a feasible alternative to the diesel engine for heavy duty engine applications.

4.1 Power Output

Table 2. Specific Power Outputs For Various Engine Types

Engine Type	Typical Specific Power Output kw/litre
Light Duty Petrol	40
Light duty CNG	38
Diesel N/A	17
Diesel T/C	22
Heavy Duty Nat Gas N/A	17+
Heavy Duty Nat Gas T/C	22+

Table 2 shows the typical specific power output of various configurations of petrol, diesel and natural gas engines. As can be seen, in the light duty range the power output for natural gas is around 5% less than for petrol, even if the compression ratio in the natural gas engine is raised to suit the octane rating. The main reason for this difference is the fact that in the light duty engine, whether on petrol or natural gas all the air is used for combustion. Because of the difference in the ideal fuel air ratio there is less air available for combustion with natural gas and hence the power output is lower.

In the heavy duty application, however, the situation is very different. The diesel engine never uses all the air that is available to ensure that excessive smoke is not formed. Consequently the aspiration of natural gas into the airstream does not have a detrimental effect on the comparative power output. In fact it is generally possible to have a higher power output on natural gas than on the equivalent diesel engine although this should only be done if there is confidence that the higher power output will not detrimentally effect engine durability.

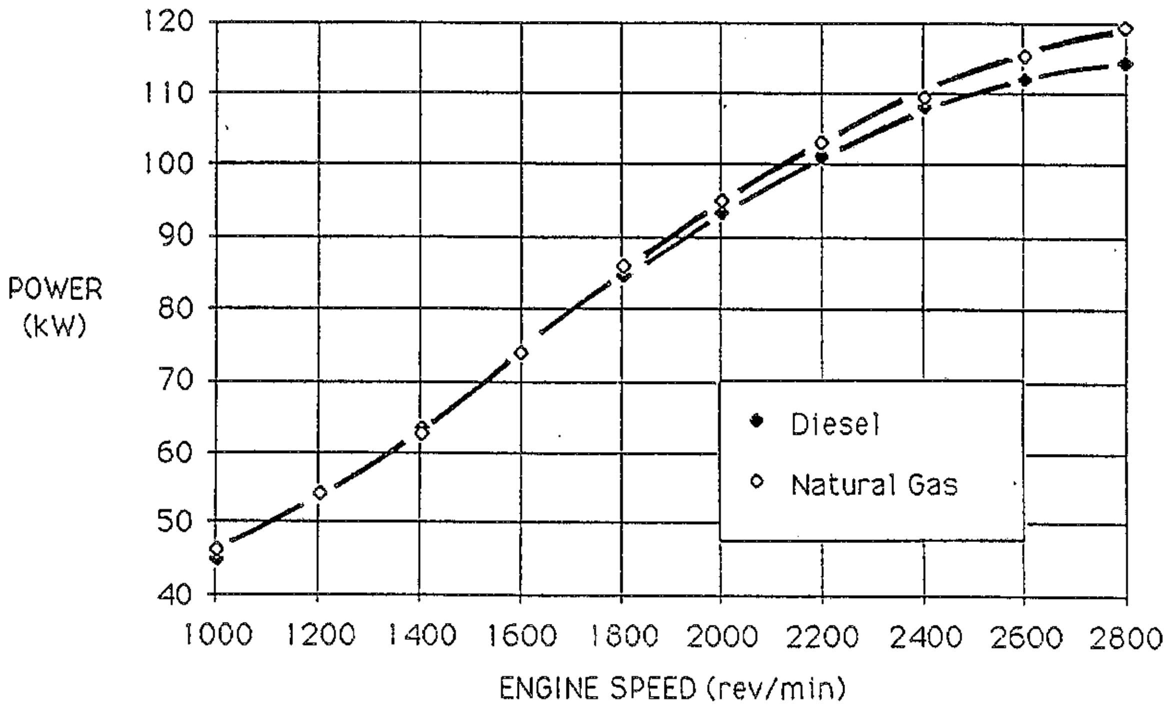

Figure 2: Power Output For Isuzu 6BG1 Diesel and Gas Engines

Figures 2, 3 and 4 illustrate the power outputs of three natural gas engines produced in New Zealand together with their diesel equivalents . In the case of the Isuzu 6BG1 the aim was to produce a gas engine that gave the same power as the diesel. The Mercedes OM401 on the other hand was to be used in a bus which had been modified to carry extra passengers and hence the gas engine was set up to give more power than the diesel. The Mack E6-300/350 is an example of where the engine was running on diesel at the lower of two power options so it was possible to uprate it to the higher power level on gas.

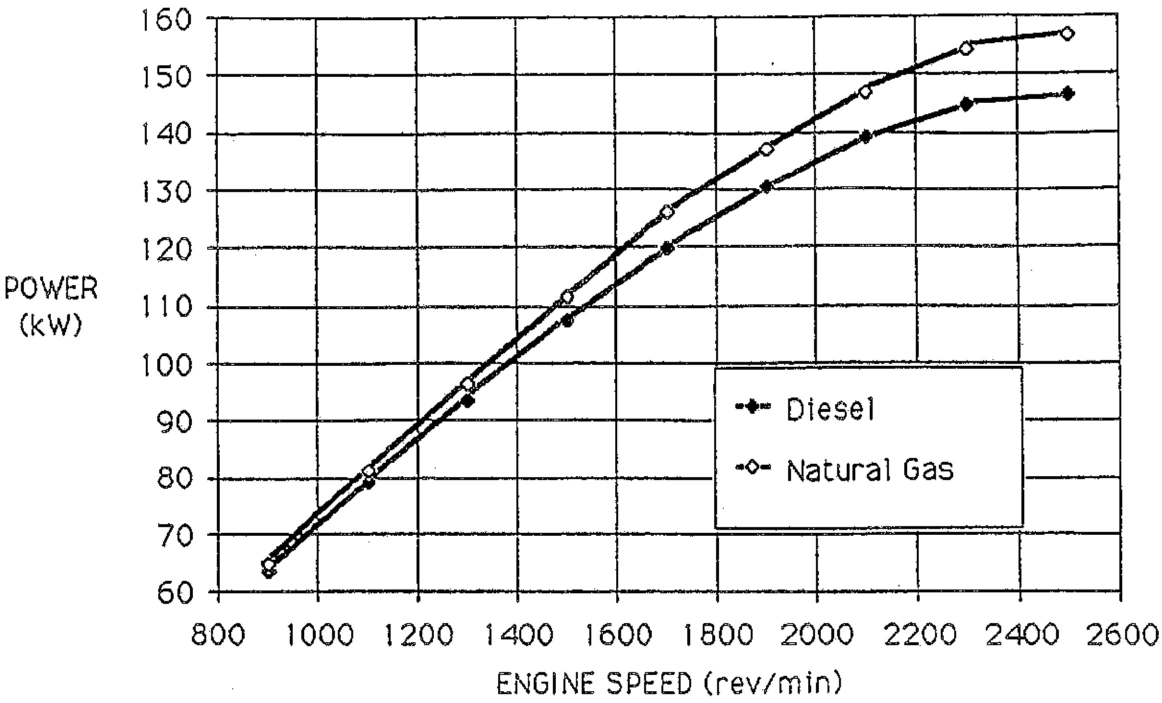

Figure 3: Power Output For Mercedes OM401 Diesel & Gas Engines

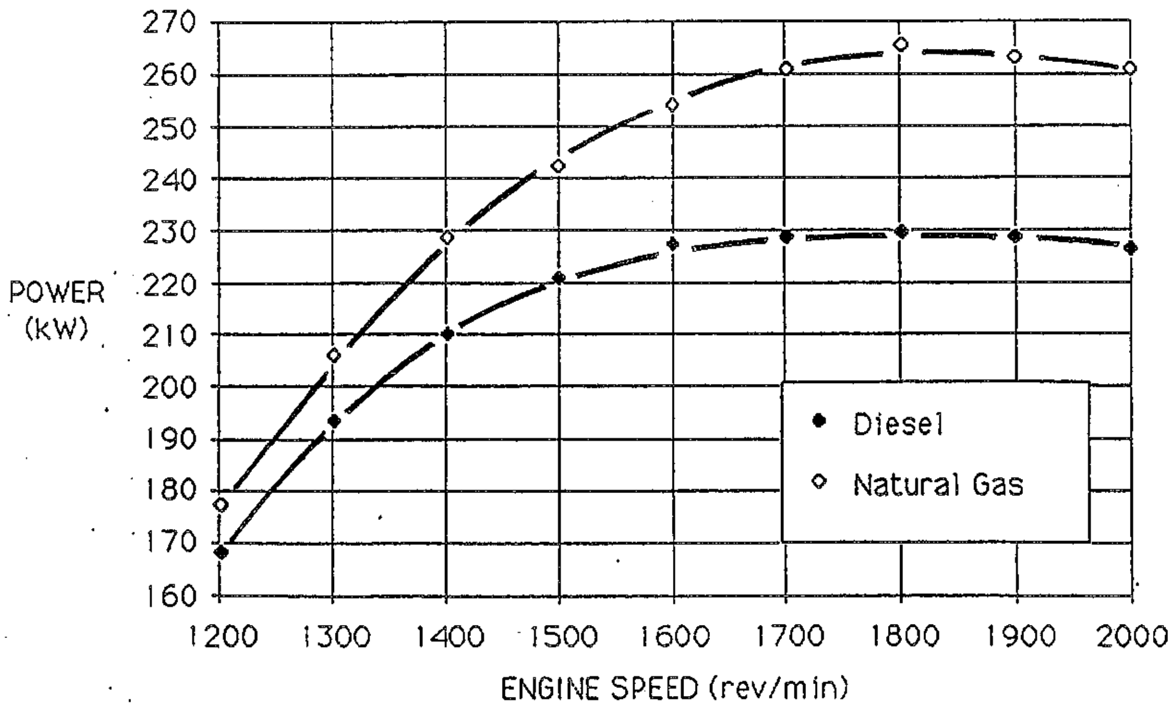

Figure 4: Power Output For Mack E6 300 bhp Diesel Engine and 350 bhp Gas Engine

4.2 Fuel Economy

One of the advantages of the diesel engine compared to its petrol engine counterpart is the lower specific fuel consumption. Diesel engines typically are in the order of 220 gm/kwh whereas the best petrol engines are closer to 300 gm/kwh. Natural gas has excellent combustion qualities and with optimised compression ratios and ignition timing it is possible to achieve specific fuel consumption rates very close to those of a diesel.

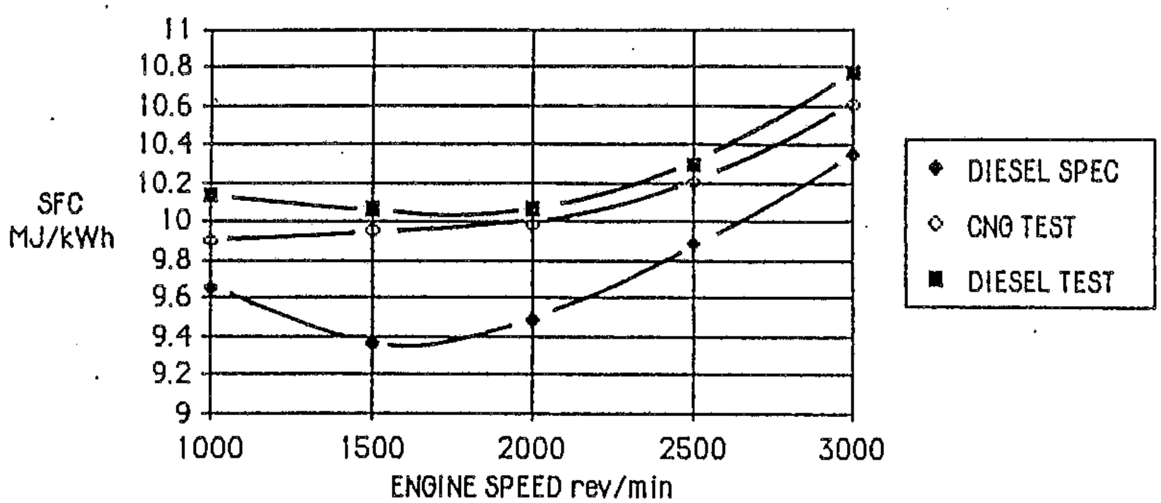

Figure 5: Specific Fuel Consumptions For Diesel and Gas Nissan FE6 at Full Load

Figure 5 shows the relative specific fuel consumption rates at full load for a Nissan FE6 engine running on diesel and natural gas. As can be seen there is very little difference between the two fuels.

Under real life operating conditions gas engines have tended to be slightly less efficient than diesels by between 5% and 15%. This is due to the relatively lower efficiency of the spark ignited gas engine at lighter loads. It should be pointed out however, that these results have been obtained comparing the current state of the art diesel engines with gas technology that is in its relative infancy. It is expected that with the advances in microprocessor gas injection systems that are currently under development considerable improvements in gaseous fuel economy will be forthcoming.

4.3 Exhaust Emissions

New Zealand does not have any legislation controlling exhaust emissions so it is very easy to adopt the attitude that there is nothing wrong with the diesel engine. Overseas however, emissions are a major cause for concern. High density traffic populations combined with certain climatic conditions can give rise to smogs that are dangerous to health. Acid rain from sulphur bearing fuels such as diesel can destroy entire forests. The burning of fossil fuels is giving rise to increased levels of carbon dioxide in the atmosphere which is generally accepted as being the main contributor to global warming or the "Greenhouse Effect".

All those issues have led the vehicle industry to investigate alternative fuels which are less polluting than diesel or petrol. The most likely candidate at this point in time appears to be natural gas. It produces very little carbon monoxide, the unburnt hydrocarbons are predominantly methane, which is effectively non-reactive from a photochemical smog aspect, the NO_x levels can be minimised using lean burn technology and the higher hydrogen to carbon ratio means that less CO_2 is produced per unit of fuel burnt.

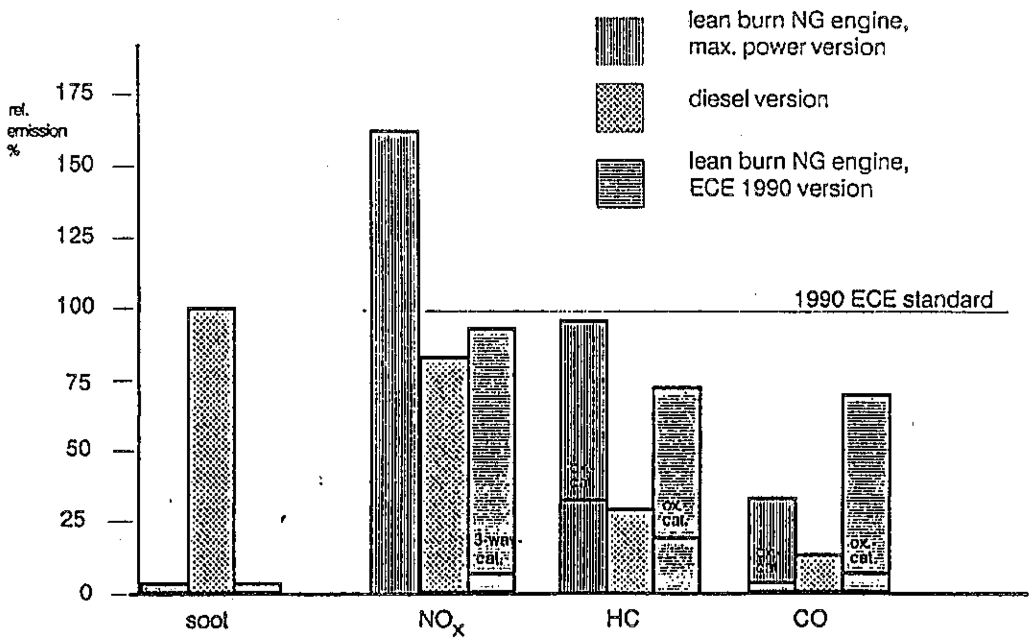

Figure 6. Exhaust Emissions From Natural Gas and Diesel Engine (Ref 3)

Figure 6 shows the relative exhaust emissions for the Mercedes M447 engine in diesel and gas forms. The most significant differences in the 98%+ reduction in soot between diesel and gas and the 70% reduction in NO_x by using a 3-way catalyst with gas.

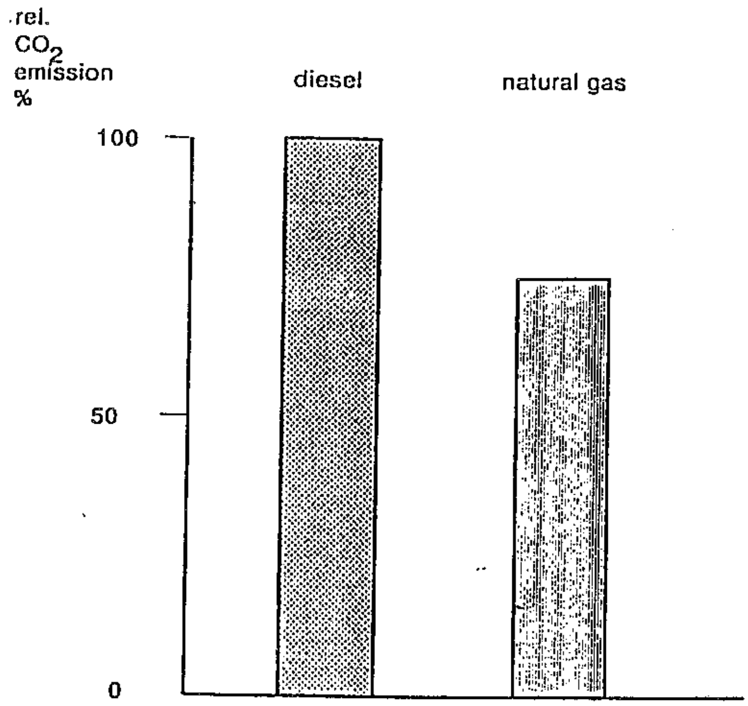

Figure 7: CO_2 Emissions From Natural Gas and Diesel Engine (Ref. 3)

As shown in Figure 7 the CO_2 emissions are around 25% lower from a gas engine compared to a diesel engine of the same energy consumption. In practice, because the energy consumption of the gas engine tends to be slightly higher than the diesel for the same power output the advantage of gas over diesel is reduced to around 20%.

4.4 Noise

One of the lesser known advantages of the gas engine over the diesel is the lower engine noise level. Diesel engines are noisy due to mechanical noise from the injection systems and the noise of combustion associated with the high pressure rise rate of the diesel combustion process. The spark ignition gas engine does not have the mechanical component noise and the combustion noise is lower due to the lower pressure rise rate. A comparison of the noise levels for two engines is shown in Table 3.

Table 3: Noise Levels From Diesel and Gas Engines

Engine Speed rev/min	Engine 1. Noise Level dBA* Diesel	Gas	Engine 2. Noise Level dBA# Diesel	Gas
1300	106.8	104.9	-	-
1500	106.6	105.1	75	70
1700	109.1	108.2	-	-
1900	110.9	108.9	-	-
2500	-	-	82	76
3000	-	-	85	78

* Measured around the engine on engine dynamometer (Ref 4)

\# Measured at driver's position in bus on chassis dynamometer (Ref 5)

As an increase of 3dBA represents a doubling in intensity it can be seen that the noise levels from the gas engines are considerably lower than from the diesel engines. The figures shown in Table 3 were taken at full load, for part load conditions the differences between gas and diesel were even greater.

4.5 Range and Refuelling

While natural gas has very good combustion characteristics, in compressed form as CNG it has a much lower energy density than diesel. As a comparison a 500 litre diesel tank contains 18,000 MJ of energy whereas 500 litre water capacity of CNG contains only 4500 MJ. Consequently CNG powered trucks and buses must refuel more often than diesels.

In practice this need not be a problem if the fuel capacity is sized correctly to the vehicle operation. With the fast fill CNG systems that are now available in Australia and North America it is possible to fill a 500 litre vehicle in less than 5 minutes. Even with the technology used in New Zealand buses are refuelled on CNG during the cleaning process in the same time as the diesel vehicles.

5. LIQUIFIED NATURAL GAS

A technology that has yet to be seen in New Zealand but is receiving considerable attention in Australia, North America and Europe is liquified natural gas or LNG. As its name implies this is natural gas in a liquid form similar to LPG. Its main advantage over compressed natural gas is its much higher energy density. Using the same comparison as earlier, 500 litres of CNG contains 4500 MJ of energy whereas 500 litres of LNG contains 11,600 MJ or approximately 2/3 that of a similar capacity of diesel.

The gas is held in the liquid form in the storage tanks, both at the refuelling station and on the vehicle, by maintaining it at a very low temperature. To burn it in the engine it is gasified by heating it in a vapouriser after which it is metered into the engine similar to CNG. The characteristics of the heavy duty LNG engines are effectively the same as for the CNG engines; i.e. similar power output, lower smoke levels and less noise than the diesel engine.

Experience with automotive LNG includes a bus fleet in the USA during the 1970's and more recently a 350 bhp International truck in Australia. This latter vehicle is running between Alice Springs and Ayers Rock hauling LNG to a power station. This vehicle commenced service in 1990 and to date has been running quite satisfactorily.

6. THE FUTURE

No doubt the diesel engine will be with us for many years yet as development continues to reduce emissions and improve performance. However, the advantages of natural gas are now being recognised and many engine manufacturers are undertaking development to assess the potential. At the present time MAN and Mercedes offer gas engines for bus applications and Renault, Mack, Cummins, Scania, Isuzu and Nissan all have either bus or truck engines at various stages of development. It is therefore expected that within the next two to five years the heavy duty natural gas engine will be widely available as an option to diesel.

7. REFERENCES

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