Camden Biomethane Trial Results

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Contents

1 Summary

The following report details the methodology and results of a trial conducted in the London Borough of Camden. The trial compared two Iveco Daily dedicated gas vehicles operating on a street cleansing cycle. One Iveco Daily was fuelled with biomethane and the other by natural gas. The trial sought to compare the vehicles with respect to performance, emissions, reliability and usability.

The newer model Daily, running on biomethane displayed a 6% fuel economy improvement, and a 53% reduction in well-to-wheel CO_2 emissions when compared with the natural gas vehicle. Analysis showed the biomethane fuel to be higher quality than the natural gas used in the trial. No reliability issues were evident from either vehicle during the six month period.

2 Introduction

To understand some of the issues effecting alternatives to conventional liquid fossil fuels a trial was undertaken in the London Borough of Camden comparing street cleansing vehicles fuelled by natural gas and biomethane. The trial aimed to evaluate the performance, emissions, reliability and usability of the differently fuelled vehicles.

Biomethane and natural gas is used extensively throughout the world as a transport fuel. There are circa 7,296,595 gas vehicles operating in the world which break down to 7,000,000 light duty vehicles, 164,000 busses and 134,000 HGVs[1]. However uptake in the UK has been slow and fleet managers have little or no experience of the fuels. Uptake has been restricted further due to the low availability of right hand drive gas vehicles in the UK. Looking at the UK market:

- There are currently (June 2009) no gas passenger cars available in the UK market
- Iveco has provided a version of the Daily van that operates on natural gas since 2003 and Mercedes are introducing a range of Sprinter variants during mid 2009
- Mercedes and IVECO offer dedicated gas HGVs
- Hardstaff and Clean Air Power convert a range of heavy vehicles to run simultaneously on a mixture of both diesel and gas, which is known as dual fuel operation.

To facilitate the growth and acceptance of biomethane as a road transport fuel in the UK a number of trials are now taking place. These include a trial by Leeds City Council where dedicated and dual fuel biomethane powered RCVs are to be compared. Also Sainsbury's have trialled Mercedes Axor HGVs converted by Clean Air Power for dual fuel operations.[2] The Camden trial has particular relevance as it involves the natural gas

[1] Cenex biomethane toolkit, Vehicle availability topic sheet 8
[2] Trial details from Cenex Biomethane Conference 2009 presentation slides, available at http://divacreative.com/biomethane

commercial van sector, which is timely given the pending introduction of a number of new vehicles and vehicle configurations in the UK market during 2009 and 2010, i.e. VW Caddy, Mecedes Sprinter and the new Iveco Daily range. These vehicles are capable of operating on natural gas or biomethane fuel.

Biomethane is created during the anaerobic digestion process. Anaerobic digestion is a process where organic matter naturally breaks down in the absence of air. The gas produced during this process is known as biogas and mainly consists of carbon dioxide (CO_2) and methane (CH_4) at a mix of approximately 35% and 65% respectively. Where anaerobic digestion takes place in a landfill site, the biogas typically comprises of CO_2 and CH_4 at 34% and 45% respectively, with the remaining gas predominantly comprising of nitrogen (N_2).

The combustion of biogas produced from the anaerobic digestion of recently composed organic matter such as waste, biomass and manure is said to be carbon neutral. The products sequester carbon as they grow and this embodied carbon is then released in the form of CO_2 when the product is combusted. This sequestration and subsequent release of carbon is part of a sustainable cycle and therefore does not increase the net amount of greenhouse gases in the atmosphere.

The biogas produced from the anaerobic digestion of organic matter can be upgraded to 95%+ methane content and this product is then known as biomethane. Biomethane has the same basic characteristics of natural gas and can hence be a sustainable replacement for natural gas applications.

3 The Trial objectives

The six month trial set out to assess the performance of a Compressed Biomethane Gas (CBG) powered vehicle measured against existing vehicles running on Compressed Natural Gas (CNG).

The project aimed to demonstrate that biomethane is a technically competitive and environmentally sound fuel that can be directly substituted for natural gas. Environmental performance was assessed through quantifying the CO_2 reductions.

To assess the success of the fuel a number of metrics were considered. These were performance (fuel consumption), reliability, emissions and usability. The trial aimed to quantify CO_2 savings by performing a well-to-wheel analysis on the fuels used. This analysis quantifies the green house gas emissions during the extraction, processing, delivery, dispensing and combustion of the fuel.

In addition, the trial looked to evaluate whether biomethane has any associated fuel quality or other issues effecting vehicle reliability which blighted the early introduction of natural gas as a transport fuel in the UK. This was of particular interest to Veolia, the vehicle operator, as anecdotal evidence suggested a number of operational difficulties had been experienced in its current CNG fleet due to moisture content in the natural gas and its low calorific value.

3.1 Project partners

The Camden biomethane trial was a collaborative project between a number of partners. Each organisation and the scope of their involvement is summarised below.

Veolia Environmental Services operated and monitored the performance of two Iveco Daily vehicles on a street cleansing round in the London Borough of Camden. Veolia has been operating a fleet of CNG Iveco Dailys since the start of their contracts with Westminster and Camden in 2003.

Gasrec supplied the biomethane from their upgrading facility at Albury using recovered biogas from a stranded landfill site. The biomethane vehicle pictured below was supplied by Gasrec.

Figure 1 - Biomethane powered Iveco Daily

Stormont truck and van provided maintenance support and advice for the trial vehicle.

Iveco, the vehicle manufacturer, provided technical support to the trial.

Cenex provided financial assistance and evaluation support.

4 Methodology

The following sections describe the trial methodology and analysis aspects in more detail.

4.1 The vehicle

Iveco designs, manufactures, and markets a broad range of light, medium and heavy commercial vehicles and first released a dedicated CNG vehicle in 1998. The two types of vehicle used in the trial were both commercially available dedicated CNG or CBG 6.5 tonne Dailys in chassis cab cage tipper configuration.

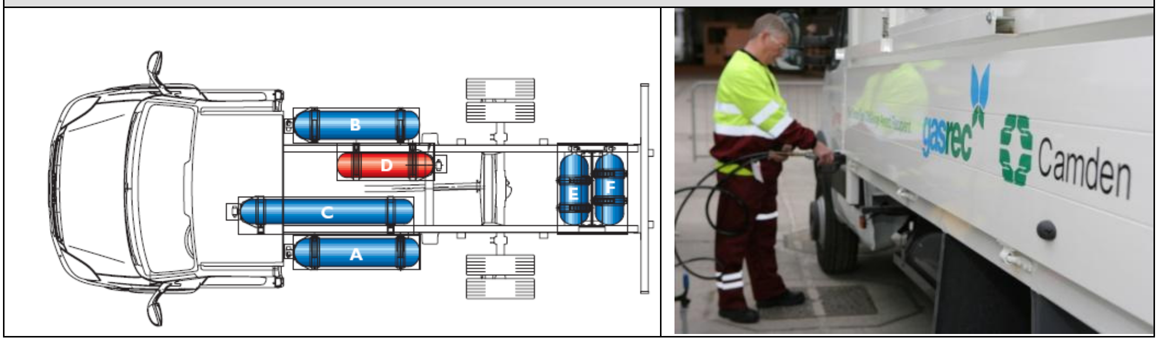
The Iveco Daily 65C11G, originally released in 2003 performs street cleansing duties utilising CNG fuel, and the new model Iveco Daily 65C14G, released in 2008, performed similar duties utilising CBG fuel. For simplicity, these vehicles will be referred to as the CNG Daily and CBG Daily in the remainder of this report. The basic architecture of the Daily models tested are summarised below in Table 1. The Daily gas vehicles are built around a diesel engine block design with a replacement cylinder head. This is a robust method of designing diesel durability levels into a dedicated gas engine.

Table 1 - Iveco daily vehicle architecture

Characteristic	Iveco Daily 65C11G (CNG Daily)	Iveco Daily 65C14G (CBG Daily)
Model year	2003	2008
Fuel	CNG/CBG	CNG/CBG
Engine Capacity	2.8 litres	3.0 litres
Engine Cylinders	4 (16v)	4 (16v)
Engine Power	106hp @ 3800 rpm	136hp @ 2730-3500 rpm
Engine Torque	220Nm @ 2200 rpm	350Nm @ 1500-2735 rpm
Gears	6 speed synchromesh	6 speed synchromesh
Fuel Cylinders	220 litres / 272 litres	220 litres / 272 litres
Gross vehicle weight	6500 kg	6500 kg

The CBG Daily has five gas storage tanks as standard plus one optional; all storage tanks are filled through a central filling nozzle and located at chassis level to allow van configuration changes. The tank configuration and filling arrangements are shown below in Figure 2.

Figure 2 - CBG Daily gas tank and filling arrangement



4.2 The route and duty

Veolia operated the CNG and CBG Dailys for street cleansing duties in the London Borough of Camden. Street cleansing is the removal of litter, detritus and vegetation from the public highway. This also includes collection of fly tips, service of on-street litter bins and collecting sweepers' bags (waste collected by manual beat/barrow sweepers) from within their assigned area. The waste is then taken to either Hornsey Street or Hendon waste transfer stations.

The CNG Daily vehicles are each assigned to an area within the Borough of Camden. Thirteen vehicles are used in the Borough on street cleansing service during the morning shift (06.00 – 14.00). Nine of these CNG Dailys are then double shifted for use on the evening shift (14.00 – 22.00). The CNG Daily monitored during this trial did not have a fixed daily route but could have been assigned to any of a number of street cleansing routes. The CBG vehicle was used in the Highgate area on the morning shift and the Kentish Town area in the evenings.

The vehicles stop regularly depending on the type of street it is in (i.e. busy high streets will have more litterbins and sweepers' bags than residential side streets). It is not usual for the engine to be left running at each stop as the driver is usually in and out quickly; however if there is a need to stop for longer or if the driver has to leave the vehicle unattended for any reason then the engine will be switched off and the keys removed.

Most of the Camden Borough is fairly flat and gradients are minimal. However there are some areas in the north of the Borough where the gradients can be quite steep. The Highgate area where the CBG Daily vehicle was assigned to on the morning shift is one of these steeper areas and hence is a more demanding route than other routes.

4.3 The fuel

The biomethane fuel was supplied by Gasrec from their upgrading plant based at a landfill site in Albury. The Gasrec upgrading equipment is fed biogas recovered from the landfill as the organic matter content decomposes.

The process recovers approximately 85% of the available methane in the biogas that is produced, yielding an upgraded gas which has a methane content of > 96%.

The Gasrec process produces liquefied biomethane. This enables the fuel to be efficiently transported which is desirable given the current lack of gas fuelling infrastructure in the UK. Due to the low volumes required for this trial, the biomethane was first dispensed to compressed storage at Hardstaff Portal Services in Nottinghamshire. During this process, the liquid product was dispensed through a multi-stage pump to deliver CBG at 250 bar directly into a storage cascade which was then delivered to Camden.

A fuel dispenser was included in the system to give an accurate measure of the amount of fuel used per refill. Figure 3 below shows an example of gas storage cylinders and a dispenser.

Figure 3 - Pressure cascade storage cylinders and dispenser

The temporary CBG filling station was based at Camden Council's transport depot on York Road.

4.4 Data capture (Veolia)

To evaluate the performance, sustainability, reliability and usability of the two differently fuelled Iveco Daily vehicles, the following were monitored as part of the trial:

- Fuel consumption
- Fuel quality
- Oil analysis
- Preventative maintenance inspections
- Tailpipe and well-to-wheel emissions
- Driver feedback

These will be discussed further as the results are displayed in the following sections.

5 Fuel analysis

The composition of the biomethane and natural gas used were analysed to confirm the quality of the fuel and the upgrading process and determine whether the biomethane used met standards appropriate for use as a transport fuel.

The fuel analysis was essentially looking to identify the amount of methane and level of contaminants in the gas. A low level of methane would produce a fuel with a low calorific value and hence reduce the range, efficiency and performance of the vehicle. A high level of siloxanes, which are formed in the breakdown of silicon during anaerobic digestion, could form deposits on components such as pistons and valves and cause a significant increase in engine wear. Hydrogen sulphide, also a common by product of the anaerobic digestion process particularly in food waste from high protein substrates, is highly corrosive and damaging to any mechanical system.

The biomethane analysis conducted by an independent laboratory confirmed the high quality of the biomethane supplied by Gasrec. The main properties of which are displayed below in Table 2.

Table 2 - Gas analysis results[3]

Material	Unit	Camden depot biomethane	Kentish Town CNG
Methane	%	98.0	95
Nitrogen	%	1.0	3
Oxygen	%	0.35	0.35
Carbon dioxide	%	< 0.02	1.14
Hydrogen sulphide	ppm	< 1	< 1
Siloxanes	mg/m^3	< 1	NA

The hydrogen sulphide and siloxane levels in the biomethane were below the minimum level of detection for the analysis laboratory, therefore it is likely that the actual level of these contaminants are below the amounts stated above and are below maximum working levels recommended by vehicle manufacturers.

There is no UK standard for biomethane road fuel. The standard commonly referred to is the Swedish biogas standard SS 15 54 38. Under this standard two quality levels are specified - a higher quality Type A biogas specification for vehicles without lambda control and low specification Type B for vehicles with lambda control. The fuel parameters analysed suggest that the Gasrec biomethane would meet the higher Type A specification. The CNG by comparison has lower methane content gas and will have a lower calorific value.

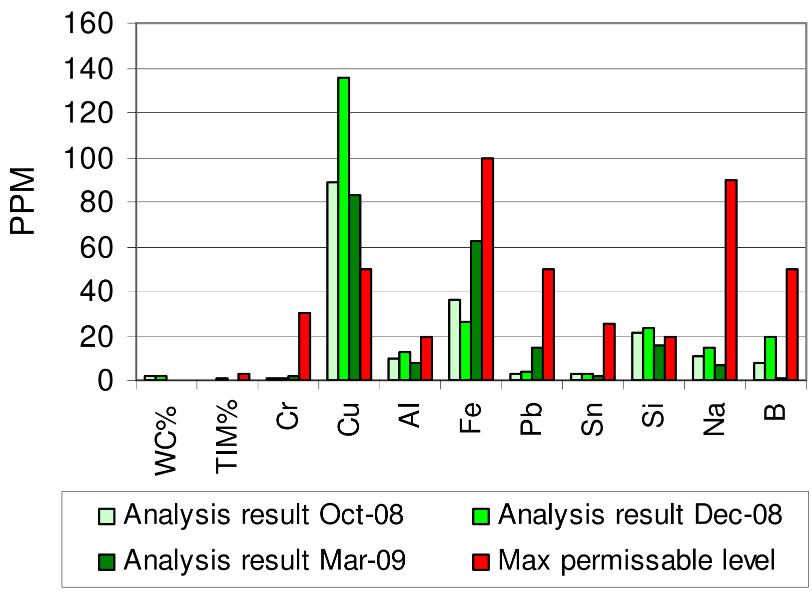
6 Oil analysis

The engine oil from the Iveco Daily CBG vehicle was analysed in October 2008, December 2008 and March 2009 to determine whether the gaseous fuel was having any negative effects on oil properties which are not normally identified through trials and maintenance observations alone.

Figure 4 Shows the results of the analysis plotted against the maximum recommend working levels of each analysed substance[4].

[3] TES Bretby gas analysis report no.38231 biomethane, and no. 38255 natural gas.
[4] Maximum recommended levels from the Fleetsolve oil analysis guide

Figure 4 - Oil analysis results



Key			
WC	Water content	**Pb**	Lead
TIM	Total insoluble matter	**Sn**	Tin
Cr	Chromium	**Si**	Silicon
Cu	Copper	**Na**	Sodium
Al	Aluminium	**B**	Boron
Fe	Iron		

The oil analysis showed a number of items of interest which are discussed below.

6.1 Copper content

There was a high copper content in the engine oil on each test occasion. High copper content in engine oils is a well documented process as reported in the Practising Oil Analysis publication which states '*… in oil for new engines with less than 1,500 hours of service life, the cooler core becomes an active reaction site for the ZDDP (zinc dialkyl dithiophosphate), resulting in copper sulphides forming on the copper cooler tubes. These sulphides later slough off into the oil, contributing to a rising copper concentration that can reach well over 300 ppm. Over time the cooler core copper surfaces will begin to pacify as a clear varnish-like coating forms over the copper sulphide. The release of copper sulphides into the oil will then begin to slow considerably or stop altogether. It can take several oil changes for this to occur. Until then, copper levels from 100 ppm to more than 300 ppm might be expected.*[5]'

[5] http://www.oilanalysis.com/article_detail.asp?articleid=524

Other sources of copper in the engine oil can arise from engine coolant leaks and accelerated wear of copper bushings and components. Since accelerated wear patterns were not observed in the most common wear metals, aluminium and iron, it is reasonable to conclude that the copper content was most likely due to copper leaching as described above, which is associated with engine component material selection rather than fuel properties.

6.2 Water

The October and December 2008 analysis indicated a 2% water content in the engine oil. The Fleetsolve oil analysis report sheet commented that the source of the water is either from a coolant leak, the fuel or condensation build up during the winter months. No coolant leak was apparent during the preventative maintenance inspections.

6.3 Wear components

Levels of common wear components like aluminium and iron were low, especially in the context of a new engine. Silicon content was evident at around 20 ppm which is the recommended maximum working limit. Silicon is normally derived from dust and contamination in the engine and would point towards a need for maintenance in the air intake system. Silicone can be used in engine oil as an anti-foaming agent and different brands of oil differ on the amount of added silicone, it is therefore good practice to deduct the amount of silicon present in a virgin oil sample to get a representation of additional silicon in the engine. A subsequent virgin oil sample analysis showed 7 ppm of silicon which requires deducting off the values in the test sample and results in an acceptable working level in the engine oil.

The Base Number (BN) is also an important oil analysis test when the fuel in use may contain high levels of sulphur and/or organic halogens which can be common in landfill gas. The base number is a measure of the alkalinity of the oil and hence its ability to neutralise acids. If the fuel contains high sulphur levels the engine operator may need to shorten oil drains, or select an oil with a higher BN; this will be evident by a reduction in engine BN number during oil sampling.

The BN number of a virgin oil sample in trial was 10.5 which was maintained through operational life of the oil.

6.4 Insoluble matter

Insolubles are the solid contaminants which remain in the lubricating oil, such as dust, dirt and carbon particles, in addition to wear metals that have not been removed through filtration. When insolubles are present, particularly in large quantities, they can promote foaming and will generally increase the oil's viscosity and engine wear rate. In addition, some natural gas engines that operate in an unbalanced condition will generate soot due to incomplete combustion.

The level of TIM (total insoluble matter) in the oil was low and within recommended working levels.

7 Fuel consumption and refuelling

Table 3 below shows the total and daily mileage of the trial vehicles. The CGB Daily displayed a 6% efficiency improvement in fuel consumption when compared with the CNG Daily.

Table 3 - Fuel consumption		
	CBG Daily	**CNG Daily**
Distance travelled	53 km per day 5590 km total	86 km per day 9642 km total
Fuel consumption	24.7 kg / 100 km 2016 kg total	26.3 kg / 100 km 3538 kg total
Average refuelling time	Avg 18.1 mins Range 6 – 50 min	Avg 4.8 mins Range 3 – 5 mins

It is reasonable to assume that the superior fuel efficiency performance of the CBG Daily can be attributed to the following factors

- Improvements in drive train and engine management technology
- Increased methane content of biomethane when compared with CNG
- High mileage of CNG Daily

Historic issues associated with gas quality and particularly the moisture content associated with the Kentish Town CNG caused no problems during the trial period. Previous issues experienced by Veolia include wet gas causing reliability problems through reducing the available space in the fuel tank via condensation and subsequent water carryover into the fuel delivery components causing starting difficulties and corrosion. Wet gas issues were eliminated from the mains compressor stations at Camden by installing improved desiccant units.

The biomethane used in this trial did not suffer from moisture issues due to the high quality biogas upgrading plant, which removes moisture before pressure swing adsorption treatment, and so the gas can then be liquefied at -160 °C.

Refuelling times from the Camden York Road depot were slow due to the bespoke low volume nature of the temporary installation, which is evident when compared to the refuelling times for the CNG station. Figure 5 below shows the manual nature of the temporary refilling procedure which involved manual operation of isolation, low, medium and high pressure values.

Figure 5 - Dispenser valve unit

8 Preventative maintenance checks

A Preventative Maintenance Inspection (PMI) was carried out every six weeks for the CBG Daily and after three months for the CNG Daily. The PMI consists of mainly routine maintenance items including specific gas system (tanks, brackets, pipes connections etc) integrity checks, gas engine diagnostics and an exhaust smoke test.

A calibrated smoke meter is used to assess the density of the smoke from compression ignition (diesel) engine vehicles. The Euro V permissible smoke level is set at 0.5 g. The CBG daily emitted 0.0181 g and the CNG 0.38 g of smoke respectively, again the results show the differences between a new vehicle and the older higher mileage CNG variant which also required regular oil top up.

All inspections during the routine PMI regime showed no reliability issues.

9 Emission analysis

Emissions from a road transport fuel are considered on a well-to-wheel basis, which quantifies the energy usage and associated emissions from fuel production to combustion. Well-to-wheel (WTW) emissions can be broken down into two fractions, well-to-tank (WTT) and tank-to-wheel (TTW) emissions. The well-to-tank emissions comprise of the CO_2 emitted during fuel production (i.e. extraction, processing, transportation and dispensing). The tank-to-wheel emissions are more commonly known as tail-pipe emissions, and can be broken down into greenhouse gas and air quality emissions.

9.1 Well-to-tank emissions

The well-to-tank emissions of the natural gas supply were taken from the figures used in the RTFO (Renewable Transport Fuels Obligation).[6]

A WTT analysis was undertaken on the Gasrec process, which can be broken down into the following,

Table 4 - Gasrec WTT analysis	
Fuel preparation stage	**Emissions (g CO_2 / kg methane)**
Feedstock transportation	0 g
Gas upgrading	1373 g
Transportation	8.85 g
Dispensing	28 g

As shown above there are no emissions associated with feedstock transportation as the waste has been delivered to landfill as part of the waste management cycle. The majority of emissions arise from the imported energy used during the upgrading and liquefaction process. The relatively low transportation emission displays the efficiency of using a liquefied fuel when transportation to end user is required, but the flip side of that emission saving is displayed in the dispensing fraction where the liquid fuel is pumped into the storage cascade as a gas at 250 bar.

The figures above can be converted into an emission per MJ of fuel which allows different fuel types to be analysed. The well-to-tank emissions from the above analysis correlate to 31g CO_2 per MJ fuel used. This value then feeds into the well-to-wheel (WTW) analysis to compare the emissions to natural gas vehicles.

9.2 Tank-to-wheel emissions

The tank-to-wheel or tailpipe emissions from natural gas and biomethane are broadly similar as the fuel combusted in essentially methane. The CO_2 emitted from the combustion of biomethane is a product of recently decomposed organic material that has sequestered carbon from the atmosphere during its production. This sequestration and subsequent emission of CO_2 is in a sustainable cycle of use, as opposed to unlocking stored fossil carbon and increasing the net amount of CO_2 in the atmosphere. For this reason, the biomethane is given a carbon credit when calculating the well-to-wheel emissions which takes into account the embodied carbon in the organic matter. In section *9.3 Well-to-wheel analysis* below the carbon credit is equal to the tail pipe CO_2 emissions from the vehicle.

Turning to other emissions, published air quality data from the Iveco Daily is shown in Table 5. Air quality emission analysis did not form part of the Camden trial, but the emissions table below reveals emissions from the Daily on the regulated cycle improve

[6] Explanation of WTW greenhouse gas saving methodology can be found at http://www.dft.gov.uk/consultations/archive/2007/rtforeporting/carbonreporting.pdf

on maximum levels of the future proposed Euro VI legislation which is due to come into force around 2013.

Table 5 - Iveco Daily CNG air quality emissions			
Emission	G25 CNG (g/kwh)	Euro VI HD (g/kwh)	% reduction from permitted level
CO	1.15	4	62 %
NMHC	0.019	0.16	88 %
CH_4	0.193	0.5	61 %
NOx	0.28	0.4	30 %
HC	0.199		
PM	0.0047	0.01	53 %

Although all the emissions listed above are hazardous to health, of most interest to local policy makers and air quality analysts are reductions in NOx and PM (Particulate Matter). NOx reacts with ammonia, moisture, and other compounds to form nitric acid and related particles. Particulate matter PM_{10} (of size ten microns and below) can be inhaled deep into the lungs. Human health concerns of increased NOx and PMs include effects on breathing and the respiratory system, damage to lung tissue, and premature death. This is particularly relevant in highly populated and congested city areas such as Camden.

Table 5 reveals that NOx and PM levels are 30% and 53 % respectively below Euro VI maximum permitted levels (> 90% lower than Euro III limits).

9.3 Well-to-wheel analysis

Table 6 below shows the CBG Daily has a WTW emission saving of 53% when compared to the natural gas vehicle. The data is derived from the emissions stated per MJ of fuel. The WTT emission per MJ of fuel can be multiplied by the number of MJ in a kg of fuel to give an emission figure per kg of fuel used. The real world fuel consumption from the trial is used as a multiplier to give a CO_2 emission per 100km.

Table 6 - Well-to-wheel analysis			
Fuel	**Emissions kg CO_2/MJ**	**Emissions kg CO_2/kg fuel**	**WTW kg CO_2 / 100 km**
CBG	0.031	1.40	34.5
CNG	0.062	2.80	76.0

The RTFO figure used for the CNG emission includes both processing and combustion CO_2, the CBG emission includes only the WTT emissions as the combustion fraction is removed due to the embodied carbon in a renewable fuel such as biomethane.

Information received from Glasgow and Leeds City council regarding a 3.5 tonne Iveco Daily diesel on a similar city centre street cleansing cycle give a fuel consumption of between 10 and 13 mpg. This equates to a similar WTW emission to that of the CNG vehicle used in the trial. CO_2 savings from Diesel to CNG are commonly declared as approximately 10%. Taking into account the smaller capacity vehicle used in the Leeds and Glasgow applications it is reasonable to assume that further CO_2 savings of circa 10% could be achieved when compared to a diesel.

It is important to note that a conservative approach to CO_2 savings has been used, which does not account for the fact that lower emissions from a biomethane fuel delivery and dispensing method could be used for a higher volume filling station. Also, the standard emission factor of 473 g CO_2 emitted per kwh of UK grid electricity consumed, that was used in the RTFO methodology was increased to 537 g CO_2/kwh for this study based on the release of the Defra 2008 emission factor figures.[7]

10 Usability

Feedback from Veolia employees who were operating the vehicles on a daily basis is summarised in Table 7.

Table 7 - Driver feedback summary

CBG Daily	**CNG Daily**
Steering / gear change / acceleration / brakes / noise good	Steering / gear change / acceleration / brakes / noise average. Vehicle is 5/6 years old and the fact that it is double shifted means the vehicle is in equivalent condition to a 10/12 year old van.
Sometimes it took too long to fill up with gas	Sometimes it took too long to fill up with gas
Full tank of gas did two full shifts	Full tank of gas does 1- 1 1/2 shifts
No step up onto the back of the vehicle	The vehicle has a step up onto the back of the vehicle

The feedback on performance aspects of the biomethane vehicle was all positive. The slower refuelling time issues are discussed elsewhere in this report and the CNG Daily was filled at a high rate due to the higher daily mileage and fuel consumption when compared to the CBG vehicle.

[7] Defra greenhouse gas emission factors for company reporting http://www.defra.gov.uk/environment/business/reporting/pdf/ghg-cf-guidelines-annexes2008.pdf

11 Conclusions

The results from this trial support the assumption that biomethane can be directly substituted for natural gas as a road transport fuel with no apparent maintenance or operational difficulties.

The CO_2 emission savings when switching from natural gas to biomethane were conservatively calculated to be 53%. Although a diesel comparison vehicle was not used in the trial, evidence from the performance of lower weight capacity Iveco Dailys on similar street cleansing routes in Leeds and Glasgow city centre suggest that a further circa 10% CO_2 saving could be achieved if comparing biomethane to a diesel equivalent suggesting an approximate CO_2 saving of 63%.

No maintenance issues were experienced with the vehicles during the trial, although the older 2003 model CNG powered vehicle did require a biweekly oil top up.

The oil analysis on the CBG Daily showed no evidence of accelerated engine wear or insoluble deposits out with normal working levels. The analysis did however display a two percent water content on two occasions, the reason for which was not identified during the trial.

The biomethane supplied by Gasrec for the trial had a high methane (98%) content with a low level of wear components, siloxanes and hydrogen sulphide. The compressed natural gas had a lower methane content (95%).

Type approval figures for the vehicles reveal that air quality emissions from the Iveco natural gas vehicle on the legislated cycle are below the proposed limits for future Euro VI legislation. Notably PM and NOx are 30% and 53% below these levels respectively.

The Iveco Daily operating on CBG displayed an overall 6% reduction in fuel consumption despite operating on a more onerous route.

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