A REPORT ON THE SUCCESS OF THE 2013 – 2014 EASI-LPG PROOF OF CONCEPT PROJECT

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1 EXECUTIVE SUMMARY

The concept was successfully proven, with a range of improvements in fuel consumption ranging from 9% to 15.9%. In addition, there was a recorded maximum improvement in Adblue consumption of 25%.

The figures stated above are taken from the maximum improvement as the settings for the LPG controller were changed several times during the project.

There were slight differences in the degree of improvement between the ‘live’ data and that recorded at the MIRA Proving Ground. These differences can be explained by the differences between a ‘live’ operational profile and the test profiles used at the Proving Ground.

Whilst the fully fitted cost of the EASI-LPG system is only £4,200 ex VAT the payback period is of course influenced by other factors such as: the annual distance travelled; fuel consumption; price of diesel; price of LPG; ratio of LPG consumed to diesel consumption and the percentage improvement in fuel consumption.

2 INTRODUCTION

The needs of both society and operators of commercial vehicles that use diesel as the fuel for their internal combustion engines are aligned. These are the need to reduce harmful emissions from diesel engines and to reduce fuel consumption and costs for operators. This document outlines the background to this Proof of Concept (PoC) project, which set out to determine if adding, small, variable amounts of Liquefied Petroleum Gas (LPG) to the inlet manifold (known as LPG fumigation) of a diesel fuelled internal combustion engine would improve combustion. That the improvement in combustion would reduce fuel consumption; thereby reducing all emissions. Additionally, that the enhanced combustion would reduce further the creation of these harmful emissions; resulting in a double environmental benefit.

The companies that tested the EASI-LPG system have asked not to be identified and therefore they are referred to as company A, B, C, D and E.

This document will introduce the background to the project, the EASI-LPG system and explain the methodology applied. After which the analytical tool applied will be introduced the results will be discussed. Finally, a conclusion will be drawn.

3 BACKGROUND

The aim of the project was to determine if the concept of LPG fumigation could be applied in a cost-effective manner to modern Compression Ignition (CI) engine.

The concept, known as LPG fumigation became popular in the 80s, as a potential way of improving the efficiency of the unsophisticated (non CANbus) trucks available at the time, but it failed technically. The key technical challenge is the development of a control system that injects into the air intake only the optimum amount of LPG. This optimum amount varies according to certain variables. By listening in on the CANbus to key signals the EASI-LPG system can consistently deliver the optimum amount of LPG required. The outcome of the project was to develop an innovative and highly cost-effective system, thereby increasing its beneficial (commercial and environmental) impact to operators and society. Improved combustion will result in less Carbon Monoxide (CO), Nitrogen Oxides (NOx) and Particulate Matter (PM).

Diesel fuel is one of the largest costs for operators of Large Goods Vehicles (LGVs) - those with a Gross Vehicle Weight (GVW) of 18 tonnes and greater. It is also an increasing cost for operators of passenger carrying vehicles or Public Service Vehicles (PSVs), because the Bus Service Operators Grant (BSOG) is slowly being removed. Furthermore, the burning of diesel in a Compression Ignition (CI) internal combustion engine creates emissions. Treating the regulated emissions, so that the engine remains legal has continually added cost, as the emissions regulations have gradually been tightened. The impact upon operators' costs, profitability, cash flow and each vehicle's environmental footprint will be significant.

For a given amount of energy required by a diesel engine, less diesel will be required due to the improvement in combustion. This is because when travelling over a specific distance less fuel is burned in the engine and so less emissions per mile or kilometre is created. Reducing the amount of diesel fuel consumed will have major and wide benefits. At the macroeconomic level it will result in a reduction of oil imports and a reduction in all emissions – many of which are harmful to human health. The economic benefit to operators will be a major reduction in their fuel bills. Operating costs will be reduced further, because less NOx being created will reduce the amount of Adblue required for Selective Catalytic Reduction (SCR) systems (which all Euro VI engines have fitted) and less operational and maintenance costs associated with Diesel Particulate Filters (DPFs) because less PM will be created. From 2014 Euro VI, necessitated all truck manufacturers to fit SCR systems that consume Adblue.

On a societal level this project will have an important positive effect on the general health due to a reduction of airborne pollutants. In 1998 it was estimated by the Environment Agency that the health effects from transport based emissions cost the UK £1.5 billion. Since then engines have become cleaner, but air quality in many cities and large towns has become a serious issue as PM and NOx levels have exceeded targets. PM pollution alone is estimated to have contributed to ~370,000 premature deaths in Europe (Spatial assessment of PM10 and ozone concentrations in Europe. 2005). Particulates emitted from modern diesel engines (Diesel Particulate Matter) are typically in the size range of 100 nanometres (0.1 micrometer). These soot particles also carry carcinogenic components like benzopyrenes and are linked to serious health effects, including lung cancer and other cardiopulmonary mortality. These are two of the emissions that will be reduced through the application of the LPG enhancement unit to trucks and buses, especially buses operating in a city environment. Reduction in airborne pollutants will have a positive impact by reducing NHS costs.

The environmental benefits are a reduction in greenhouse gases such as CO_2 and other harmful emissions such as CO and NOx. Desk based research suggested reductions in PM of up to 90%, NOx reductions up to 45% and CO reductions of up to 20%. Examination of the fuel consumption data contained in UK Energy in Brief 2012 estimated that in 2011 trucks, buses and coaches consumed just over 1 billion litres of diesel, which equates to 2.6 million tonnes of CO_2.

If too little LPG is injected then little or no improvement in fuel consumption will occur. If too much LPG is injected it results in diminishing returns and has the potential to damage the engine. It is therefore critical to have a controller that can ensure that the correct amount of LPG is injected all the time.

Whilst the system has been designed for retrofit, due to its simplicity it could also be fitted online by a truck or bus manufacturer.

4 THE EASI-LPG SYSTEM

The philosophy behind the EASI-LPG system is that it should be simple and cost effective. Cost effective is defined as payback in eighteen months or less. Its simplicity should enhance its reliability, reduce costs and minimise downtime when fitting to a vehicle.

4.1 EASI-LPG

The most important component is the controller and this patented device along with all the other components can be fitted to a vehicle in eight manhours, which means that vehicles need not necessarily be taken out of service, unless they are being double or triple shifted. An annual maintenance cost of £400 includes the engine oil analysis and changing of key components including LPG filters and injectors.

The EASI-LPG system is a highly cost-effective solution to reducing fuel costs and environmental impact. There are no engine modifications required other than fitting LPG gas injectors into the air intake post turbo and a vapouriser into the cooling system. This means that there are no vehicle manufacturers or legislative issues.

This philosophy has resulted in a price of £4,200 for a system that is fully fitted and ready to drive away, except for putting LPG in the vehicles LPG tank. This means that the cost of the EASI-LPG system is a fraction of the cost of current dual fuel systems. Only one small LPG fuel tank is added to the vehicle. There is a national refuelling infrastructure (1,400+ stations), so an operator would not necessarily have to purchase or rent a refuelling facility.

4.2 VEHICLE MANUFACTURERS AND WARRANTY

Truck manufacturers commit millions of pounds to their own research programmes to reduce emissions and do not like third party equipment fitted to their vehicles. There are many reasons for this, mainly to do with commercial sensitivity. For example, manufacturers prefer to fit their own aerodynamic systems to their vehicles despite specialist third party suppliers making more efficient aerodynamic kits. Whilst manufacturers do not prohibit the fitting of third party equipment they do raise the issue of the potential impact upon warranty. Whilst this might be criticised as a barrier to entry it can be viewed as a fair point that requires a fair response. To mitigate this issue, the EASI-LPG system has two effective responses. The first is that Btrack (the owners of EASI-LPG) has its own separate insurance, so that should the EASI-LPG system be found by an independent assessor to have damaged an engine, then it will be covered by EASI-LPGs own insurance. Additionally, engine oil analysis is incorporated to monitor the condition of the engine before, during and after the trial and to support the view that the EASI-LPG system does no harm to the engine.

5 METHODOLOGY

Communications have taken place with the Vehicle Operator Services Agency (VOSA) to ensure that there are no problems with fitting the EASI-LPG system to a truck or bus. They have advised that they will want to inspect the first two fittings to buses. From a manufacturer’s warranty point of view no changes are made to the engines electronics and no engineering work is done to the cylinder head.

5.1 ANALYTICAL TOOL: IFSITS

The testing of a fuel saving intervention testing is a complex issue and involves knowledge of vehicle engineering, vehicle operations, applicable variables including their sensitivities and advanced statistical techniques. The Imise Fuel Saving Intervention Testing System (IFSITS) meets all of these requirements and has been designed to ensure that any fuel saving intervention can be tested in a manner that produces robust data, which is then subjected to rigorous statistical analysis. This will ensure that those who have an interest in the outcome can have confidence in the results. It is a powerful and flexible tool can be applied in laboratory testing, testing at a test track and in 'live' operations.

The data is analysed using a battery of proven powerful statistical tests from which a result or range of results is obtained. A number of different appropriate statistical tests are applied, because all tests have their strengths and weaknesses and the level of certainty that we work to is designed to be solid enough to withstand scrutiny in a court of law.

If all of the statistical tests indicate a positive effect then it can be stated that the intervention worked; given any additional remarks that might be required due to the investigation into the sensitivity of the intervention to variables associated with the vehicle's technology and its operational profile. If there is a wide spread in the results from the statistical analysis or even some tests revealing a negative result, then this indicates that certain variables might had had a stronger influence than anticipated and further investigation is required. A negative result from each of the statistical test shows that the intervention did not work.

In this document IFSITS is now explained in the context of the 'live' testing that was conducted.

5.2 PRE-TEST PREPARATION AND ANALYSIS

The methodology requires that a full understanding of the intervention and how it works is required by the IFSITS analyst. Additionally, a complete understanding of the technology employed by the vehicle or vehicles to be tested along with their operational profile is required. This is required so that any variables to which the intervention may be sensitive can be identified and addressed, otherwise the data cannot be considered robust. Once addressed the data collection and reporting mechanisms can be agreed, which for 'live' or 'in-fleet' testing require that data is sent to the IFSITS analyst daily.

5.3 TESTING SEQUENCES

The sequence in which events occur can be influenced by the type of intervention. If the use of the intervention can be stopped or removed then it permits an extra test period referred to as the ‘as before’ period. Most test periods involve a ‘before’ period, which is the settling in period or baseline prior to the application of the intervention and it is also used to minimise the ‘Hawthorne Effect’. This is followed by the ‘after’ period, when the intervention is applied. The length of time of both periods is dependent upon the frequency of data required and how often it is produced, In the case of motor vehicles twenty daily or identical shift fuel consumption figures should suffice for most, although the final decision must be made by the analyst. The extra test period mentioned at the beginning of the paragraph enables an ‘as before’ period to be analysed, which provides for an even more robust test.

5.4 CONTROL VEHICLES AND REPEATABILITY

The use of control vehicles is required to enable the identification and mitigation of any seasonal effects that may influence the data. Repeatability, which is very important can be reinforced through the use of the ‘before’, ‘after’ and ‘as before’ sequences and by introducing the intervention to the test vehicles at different points in time. For example, if there are ten control vehicles and ten test vehicles the intervention sequence could be four test vehicles in test week one, followed by three test vehicles the next week and then three test vehicles in week three.

5.5 VEHICLE SELECTION

A random selection of vehicles is not appropriate in this sort of testing. Vehicles are selected based on their ability to produce an accurate result. IFSITS selects the ‘test’ and ‘control’ vehicles having examined their fuel consumption data. Then discussions take place with the operational management to ensure that there are no operational issues relating to the vehicles selected by IFSITS that would impinge on the testing.

6 RESULTS

The results from five operational LGVs are presented in this section plus the testing of a Mercedes Vito van at the MIRA Proving Ground.

The methodology includes two types of evaluation programmes. The first is ‘live’ in operations and the second is conducted at the MIRA Proving Ground. Data generated in ‘live’ operations is subject to random events, which results in greater volatility. Such data volatility is reduced significantly with evaluations undertaken in controlled conditions such as those at the MIRA Proving Ground. Obviously, this leads to the inevitable trade-off between accuracy and representativeness.

6.1 COMPANY A

The best improvement in fuel consumption was 9%, which was achieved at the LPG 3 setting.

6.1.1 A: METHODOLOGY

In order to reduce the impact of seasonality the test vehicle (TEST VEH) was monitored in conjunction with control vehicles (CNTRL 1, CNTRL 2 and CNTRL 3). Fuel consumption data was collected both 'live' and at the MIRA Proving Ground for analysis. The 'live' data was supplied from the manufacturers own telematics system. All the data collected has been analysed using the Imise Fuel Saving Interventions Testing System (IFSITS). In addition, the condition of the engine in the 'test' vehicle was monitored using engine oil analysis before and during the trial.

6.1.2 A: EVALUATION UNDER 'LIVE' CONDITIONS

A number of vehicles were recommended by the operational management and their fuel consumption data was analysed using the IFSITS system to identify the test and control vehicles – from a mathematical point of view. The recommendations from IFSITS were discussed with the operational management and one test and a number of control vehicles were agreed upon. During the test period some of the 'control vehicles' were removed from the analysis due to them exhibiting 'out of pattern' properties. These 'out of pattern' properties can be caused by a change in the operational profile or because of maintenance work conducted on the vehicle. When a group of 'control' vehicles are being monitored it is not unusual for some to show 'out of pattern' behaviour and therefore must be removed from the analysis. Failure to remove such vehicles can result in erroneous analysis and results.

The format applied was to establish the baseline fuel consumption in Miles per Gallon (MPG) then to activate the LPG settings, which would be designated LPG x. Every time the settings in the LPG controller were changed the LPG reference number would be changed up by one digit. For example, a change to the settings for LPG 1 would result in the designation changing to LPG 2. This is shown in Table 1 below.

Table 1 LPG Activation, Controller Setting Dates and MPG

SETTING	FROM	TO	Test V	Cntrl 1	Cntrl 2	Cntrl 3
			MPG			
Baseline	02/09/2013	16/05/2014	8.86	8.78	9.12	11.58
LPG 1	16/05/2014	23/05/2014	9.51	9.19	10.13	11.99
LPG 2	23/05/2014	11/06/2014	9.52	8.97	8.70	11.68
LPG 3	11/06/2014	27/06/2014	9.97	9.24	10.69	12.23
LPG 4	27/06/2014	04/07/2014	9.62	9.31	9.73	12.39
LPG 5	04/07/2014	25/07/2014	9.68	9.14	9.86	12.30
LPG 6	25/07/2014	23/08/2014	9.64	9.05	9.77	12.16
LPG 7 No LPG	23/08/2014	12/09/2014	9.29	9.28	10.02	12.25
LPG 8	15/09/2014	23/09/2014	9.81	9.22	10.01	12.14

The initial baseline figure was based upon data from 2nd September to the 16th May 2014. Obviously, this time period includes a major part of the seasonal trough, which produces a low baseline figure. Therefore, a secondary in-depth analysis of the data was applied to remove the trough data and identify what the fuel consumption was in the short period prior to the activation of the EASI-LPG. The IFSITS system identified that the period 1st May 2014 to the morning of the 16th May 2014 was the true baseline period. This more accurate baseline figure is 9.15 Miles per Gallon (MPG).

Reviewing the fuel consumption data produced during the different LPG settings shown in Table 1 determined that the optimum setting was that of LPG 3.

The same methodology was applied to the control vehicles to determine the correct baseline periods and fuel consumption. The results are shown in Table 2.

Table 2 LPG Control Vehicles Performance

CONTROL VEHICLE	FROM	TO	BASELINE MPG	LPG 3 MPG	DIFF MPG	DIFF %
CNTRL 1	01/05/2014	16/05/2014	9.14	9.24	- 0.10	-1.1%
CNTRL 2	01/05/2014	16/05/2014	9.88	9.77	0.11	1.1%
CNTRL 3	01/05/2014	16/05/2014	11.99	12.23	- 0.24	-2.0%

It can be seen in Table 2 when comparing the independent baseline periods with the LPG 3 period there were both improvements and deterioration in the 'control' vehicles fuel consumption. Overall it can be seen that if the percentage differences are averaged there was a less than one percent change. This therefore suggests that the change in performance of the test vehicle during LPG 3 was not - on average - seasonally influenced. The analysis of the data therefore concludes that the deseasonalised improvement in fuel consumption during LPG 3 was 9% ((9.97-9.15)/9.15).

6.1.3 A: RESULTS FROM TESTING AT MIRA PROVING GROUND

This test is predominantly a series of constant speed tests conducted at 40 MPH, 50 MPH and 56 MPH (or lower if the road speed limiter has been set lower) to simulate non-urban operations. A stop-start urban simulation was also conducted.

High-Speed: Fuel consumption is measured separately when the vehicle accelerates from 0 to 40, from 40 to 50 and from 50 to 56 (or lower pre-set speed). The overall average improvement in fuel consumption recorded at MIRA with the LPG 8 setting (which is the same as LPG 6) was 9.8%. This is very close to the LPG 8 period figure of 7.3% ((9.81-9.15)/9.15).

The improvement in fuel consumption for the stop-start evaluation was of the order of 7.7%.

6.1.4 A: ENGINE OIL ANALYSIS

The results of the engine oil analysis have not indicated any damage to the engine.

6.1.5 A: REVIEW

The evaluation exercise has proven that improvements in fuel consumption can be achieved. The optimum setting was LPG 3 that resulted in an improvement of 9% in 'live' operations. The evaluation conducted at the MIRA Proving Ground also recorded an improvement when under controlled conditions.

6.2 COMPANY B

In this specific test no control vehicles were used, because the vehicle did a diverse range of jobs during the day and then during the night was used with a drawbar trailer. The optimum setting to date was LPG 2, which improved the nightshift fuel consumption by 10.5% and the dayshift fuel consumption by 6.3% to 23.3%.

6.2.1 B: METHODOLOGY

The methodology includes two types of evaluation programmes. The first is 'live' in operations and the second is conducted at the MIRA Proving Ground. Data generated in 'live' operations is subject to random events, which results in greater volatility. Such data volatility is reduced significantly with evaluations undertaken in controlled conditions such as those at the MIRA Proving Ground. Obviously, this leads to the inevitable trade-off between accuracy and representativeness.

Fuel consumption data was collected both 'live' and at the MIRA Proving Ground for analysis. All data collected at all stages has been analysed using the Imise Fuel Saving Interventions Testing System (IFSITS). The 'live' data from the Btrack telematics system and cross checked against the operator's bulk fuel tank management system. In addition, the condition of the engines in the 'test' vehicle was monitored using engine oil analysis before and during the trial.

6.2.2 B: EVALUATION UNDER 'LIVE' CONDITIONS

The format applied was to establish the baseline fuel consumption in Miles per Gallon (MPG) then to activate the LPG settings, which would be designated LPG x. Every time the settings in the LPG controller were changed the LPG reference number would be changed up by one digit. For example, a change to the settings for LPG 1 would result in the designation changing to LPG 2. The impact of the different settings can be seen below in Tables 3 & 4.

Table 3 Nightshift performance

			NIGHTSHIFT			Change	
	From	To	Miles	Gallons	MPG		
Baseline	14-Apr-14	09-May-14	2,396	268	8.93		
LPG 1	10-May-14	24-May-14	1,384	147	9.42	5.5%	5.5%
LPG 2	27-May-14	21-Jun-14	2,607	264	9.87	4.8%	10.5%
LPG 3	23-Jun-14	27-Jun-14	677	69	9.79	-0.8%	9.6%
LPG 4	28-Jun-14	28-Aug-14	6,477	661	9.80	0.1%	9.7%
LPG 5 No LPG	29-Aug-14	09-Sep-14	977	103	9.47	-3.4%	6.0%
LPG 6	09-Sep-14	13-Oct-14	3,643	372	9.79	3.4%	9.7%

Clearly, the settings applied at LPG 2 had the greatest impact, which is supported when the dayshift data is reviewed, as shown in Table 4.

Table 4 Dayshift performance

Daily Distance		Baseline	LPG 1	LPG 2	LPG 3	LPG 4	LPG 5	LPG 6
	From	14 April 2014	10 May 2014	29 May 2014	23-Jun-14	30-Jun-14	29-Aug-14	10-Sep-14
	To	09 May 2014	23 May 2014	20 June 2014	27-Jun-14	28-Aug-14	09-Sep-14	13-Oct-14
Records		5	8	9	1	24	4	13
0 - 75 miles	Miles	275	350	520	72	1,328	228	765
	Gallons	35	46	62	11	178	34	113
	MPG	7.88	7.54	8.37	6.59	7.45	6.63	6.78
			-4.3%	6.3%	-16.4%	-5.34%	-15.87%	-13.9%
Records		2	2	1	1	16	3	7
76 - 150 miles	Miles	160	160	88	85	1,461	236	660
	Gallons	20	21	10	10	175	35	81
	MPG	7.97	7.57	8.54	8.54	8.36	6.81	8.11
			-5.0%	7.2%	4.9%	4.91%	-14.45%	1.8%
Records		10	1	3	2	4	1	1
151+miles	Miles	2,242	224	553	358	646	238	221
	Gallons	240	22	48	34	65	23	25
	MPG	9.36	10.40	11.57	10.50	9.93	10.42	8.81
			11.1%	23.7%	12%	6.16%	11.4%	-5.8%

The dayshift data was split into three different distance based categories to reduce the overall volatility in the data. This does mean that the resultant analysis of the data in each of the three categories is not as robust as would be liked. Therefore, it should be viewed as being indicative rather than authoritative.

6.2.3 B: RESULTS FROM TESTING AT MIRA PROVING GROUND

The data that resulted from the testing at MIRA where the vehicle was operated at 40 MPH, 50 MPH and 56 MPH on the high-speed circuit supported the 'live' data and analysis. The overall improvement on the high-speed circuit was 8.3%, which is close to the current nightshift figure of 9.7%. Like the evaluations conducted with other test vehicles the range of individual improvements at the different road speeds varied. This suggests that the EASI-LPG system still requires further modifications. The stop-start figures showed an improvement of 13.7%, which contradicts the 'live' data. The reason for this is likely to be related to the short distance involved in the stop-start circuit and the resolution of the in-cab fuel consumption display, which in this vehicle only displayed half litre units.

6.2.4 B: ENGINE OIL ANALYSIS

The engine oil analysis has shown no problems or increases in contaminants in the engine oil.

6.2.5 B: REVIEW

The EASI-LPG system has shown improvements in fuel consumption. As the LPG settings have been changed the improvements in fuel consumption have fluctuated. It is clear from the data in Tables 3 and 4 that the LPG 2 setting is the optimum setting at present.

6.3 COMPANY C

Analysis of the data suggests that LPG 1 was the best LPG controller setting with a potential improvement in fuel consumption of 11% based upon LPG 1 and LPG 3 controller settings. Analysis of the 'live' data initially revealed a pattern that gave concern for any conclusions drawn from the 'live' data. Upon further investigation this suggests an improvement of 11%. Results from the MIRA Proving Ground suggest improvements in fuel consumption of up to 10% on the high-speed circuit.

6.3.1 C: METHODOLOGY

The methodology includes two types of evaluation programmes. The first is 'live' in operations and the second is conducted at the MIRA Proving Ground. Data generated in 'live' operations is subject to random events, which results in greater volatility. Such data volatility is reduced significantly with evaluations undertaken in controlled conditions such as those at the MIRA Proving Ground. Obviously, this leads to the inevitable trade-off between accuracy and representativeness.

In order to reduce the impact of seasonality the ‘test’ vehicle (Test) was accompanied by a ‘control’ vehicle (Control). Fuel consumption data was collected both ‘live’ and at the MIRA Proving Ground for analysis. All data collected at all stages has been analysed using the Imise Fuel Saving Interventions Testing System (IFSITS). The ‘live’ fuel consumption data was sourced from the operator’s tank refuelling records. The data at MIRA was recorded from the vehicle’s in-cab display.

In addition, the condition of the engines in the ‘test’ vehicle was monitored using engine oil analysis before and during the trial.

6.3.2 C: EVALUATION UNDER ‘LIVE’ CONDITIONS

Two vehicles were recommended by the operational management and their fuel consumption data was analysed using the IFSITS system to determine the ‘test’ and ‘control’ vehicles – from a mathematical point of view. The recommendations from IFSITS were discussed with the operational management and the test and control vehicles were agreed upon.

The ‘test’ and ‘control’ vehicles were both doing the same work and both had regular drivers. When either regular driver was not driving the vehicle or either vehicle was temporarily moved to other work that fuel consumption data has been omitted from the analysis.

The format applied was to establish the baseline fuel consumption in Miles per Gallon (MPG) then to activate the LPG settings, which would be designated LPG x. Every time the settings in the LPG controller were changed the LPG reference number would be changed up by one digit. For example, a change to the settings for LPG 1 would result in the designation changing to LPG 2. The fuel consumption for the different settings is shown in Table 5 below. LPG 3 is a short period when no LPG was used – this was a planned change. When the LPG tank was refilled (LPG 2 a) it retained the LPG 2 settings.

Table 5 Test vehicle fuel consumption

From	To	Condition	Miles	Gallons	MPG	Diff Abs	Diff %
08 October 2013	08 May 2014	Baseline	29,518	3,844	7.68		
27 May 2014	25 June 2014	LPG 1	4,838	572	8.45	0.77	10.07%
27 June 2014	29 August 2014	LPG 2	7,195	923	7.79	0.12	1.51%
09 September 2014	11 September 2014	LPG 3 No LPG	864	116	7.46	- 0.22	-2.89%
15 September 2014	26 September 2014	LPG 2 a	1,713	222	7.73	0.05	0.63%

The baseline includes the trough period that occurs and generally reduces the overall MPG. Despite this there was a 10% improvement in fuel consumption. Unfortunately, due to changes in work patterns and driver changes the control vehicle data did not aligned with the test vehicle data as strongly as expected. The analysis of the data is shown in Table 6.

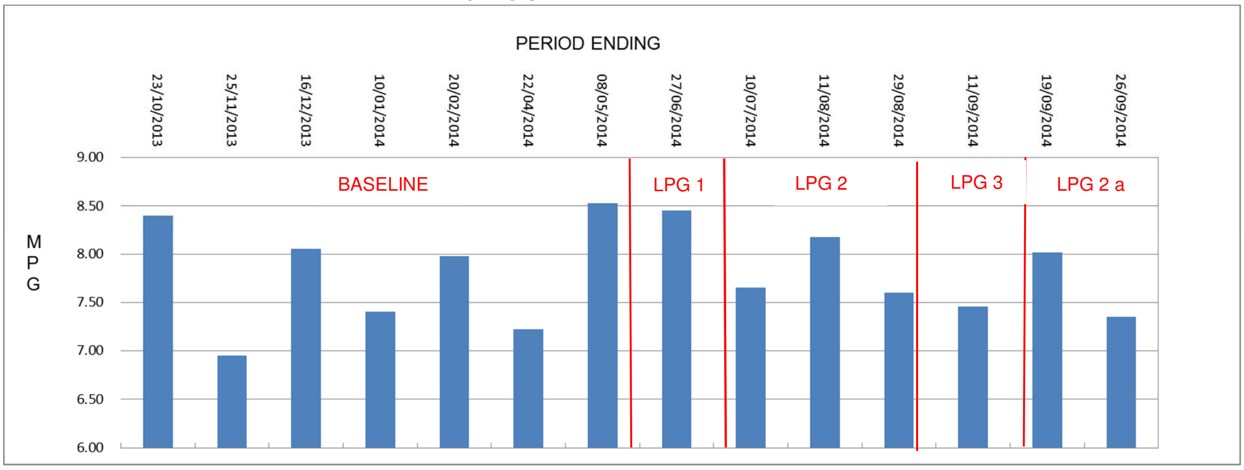
Table 6 Control vehicle fuel consumption

From	To	Condition	Miles	Gallons	MPG	Diff Abs	Diff %
07 October 2013	08 May 2014	Baseline	29,002	4,019	7.22		
11 June 2014	25 June 2014	LPG 1	2,366	330	7.17	- 0.05	-0.68%
27 June 2014	01 August 2014	LPG 2	5,822	924	6.30	- 0.91	-12.64%

Comparing the data in the two tables it can be seen that whilst the ‘test’ vehicle improved by 10% the ‘control’ vehicle’s fuel consumption deteriorated slightly. However, a more in-depth analysis of the ‘test’ vehicle data reveals some strange patterns, which are shown in Chart 1 below.

The pattern shown in Chart 1 suggests other variables being at work that have influenced the test vehicle’s performance. For example, the period 22/4/2104 to 27/6/2014 saw the fuel consumption improve to 8.5 MPG from 7.2. This was just before the EASI-LPG system was activated and is far greater than any seasonal change.

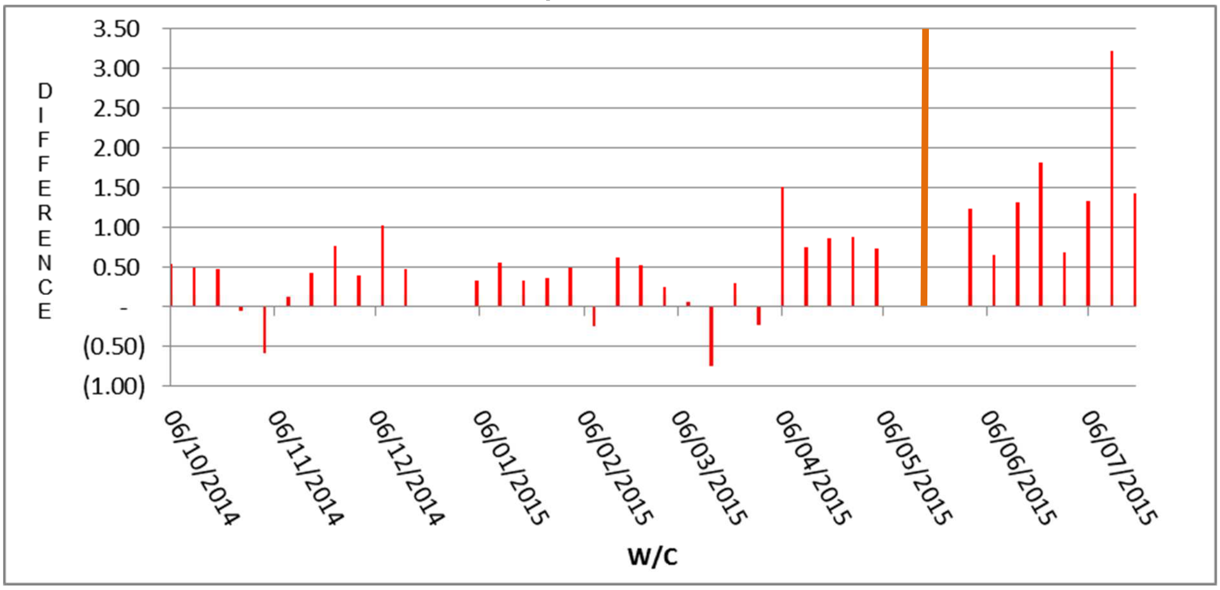
Chart 1 Underlying patterns in the test vehicle data



The existence of this pattern means that any conclusions drawn from the ‘live’ data must be treated with caution. Therefore, considerable weight needs to be given to the data recorded at the MIRA Proving Ground.

To enable a deeper analysis, the difference in weekly fuel consumption between the two vehicles is shown in Chart 2 below. The fuel consumption of the ‘test’ vehicle was usually better than that of the ‘control’ vehicle. The columns to the left of the brown line (the separator) are the differences in MPG during the baseline period. The columns to the right are those during LPG 1.

Chart 2 Difference in fuel consumption between the test and control vehicles



The average difference between the 'test' and 'control' vehicles before the LPG was activated was 0.40 MPG and after the LPG was activated the average difference was 1.46 MPG. The average fuel consumption before the LPG was activated was 7.63 (test vehicle) and 7.23 (control vehicle). Once activated this changed to 8.11 (test vehicle) and 6.65 (control vehicle). However, in the week commencing 17/7/2014 there was an exceptionally low MPG figure of 5.03 for the 'control' vehicle accompanied by a very high MPG of 8.25 for the 'test' vehicle. These figures have been removed in the following analysis. The resultant data is shown in Table 7 below. Only data where both vehicles were driven by their regular drivers in the same week on the same job is shown.

Table 7 Differences in LPG

W/C	Test	Control	Difference in MPG
06/10/2013	7.75	7.20	0.54
13/10/2013	8.69	8.20	0.49
20/10/2013	8.01	7.53	0.48
27/10/2013	6.57	6.62	- 0.05
03/11/2013	6.48	7.06	- 0.59
10/11/2013	7.46	7.34	0.13
17/11/2013	7.25	6.82	0.43
24/11/2013	7.95	7.19	0.77
01/12/2013	8.11	7.72	0.40
08/12/2013	7.96	6.93	1.03
15/12/2013	7.54	7.06	0.48
22/12/2013			
29/12/2013			
05/01/2014	7.43	7.10	0.33
12/01/2014	7.92	7.36	0.56
19/01/2014	7.89	7.55	0.34
26/01/2014	8.22	7.86	0.36
02/02/2014	8.02	7.52	0.50
09/02/2014	7.45	7.69	- 0.24
16/02/2014	8.12	7.49	0.63
23/02/2014	7.47	6.94	0.53
02/03/2014	7.26	7.01	0.25
09/03/2014	7.43	7.38	0.05
16/03/2014	5.87	6.61	- 0.74
23/03/2014	7.56	7.26	0.30
30/03/2014	7.15	7.37	- 0.22
06/04/2014	7.06	5.55	1.51
13/04/2014	7.29	6.54	0.75
20/04/2014	8.30	7.43	0.86
27/04/2014	8.70	7.81	0.88
04/05/2014	8.35	7.61	0.74
11/05/2014			
18/05/2014			
25/05/2014	LPG ACTIVATED		
01/06/2014	8.65	7.42	1.23
08/06/2014	8.46	7.80	0.66
15/06/2014	8.01	6.69	1.32
22/06/2014	8.48	6.66	1.82
29/06/2014	7.65	6.96	0.69
06/07/2014	7.50	6.17	1.33
13/07/2014			
20/07/2014	7.90	6.47	1.43

The low figure of 6.65 for the control vehicle after the LPG was activated has been influenced by the deterioration to 5.03. Removing that week's data for the test and control vehicles changes the average fuel consumptions to 8.09 (test vehicle) and 6.88 (control vehicle). The percentage change is calculated as:

Test vehicle ((8.09-7.63)/7.63) = 6.1%

Control vehicle ((7.23-6.88)/7.23= -4.9%

The overall improvement in MPG as a percentage than becomes 11%, because this is the absolute difference between the two percentages.

6.3.3 C: RESULTS FROM TESTING AT MIRA PROVING GROUND

Fuel consumption is measured separately when the vehicle accelerates from 0 to 40, from 40 to 50 and from 50 to 56 (or lower pre-set speed). The overall improvement in fuel consumption for the high-speed and stop-start circuits at MIRA was of the order of 10% and 7%.

Similarly, to the other evaluations conducted at the MIRA Proving Ground the improvement in fuel consumption on the high-speed circuit fluctuated. Therefore, the LPG controller requires further development to maximise the fuel saving under all conditions. The testing at MIRA, which was done under controlled conditions, is a robust result, whilst 'live' data can be highly volatile and influenced by many factors.

6.3.4 C: ENGINE OIL ANALYSIS

Engine oil analysis did not find any harmful effects resulting from the introduction of the EASI-LPG.

6.3.5 C: REVIEW

The best improvements occurred at the LPG 1 setting, which whilst only 'live' data indicates improvements of 11%.

Changing the LPG settings of the test vehicle from LPG 1 to LPG 2 resulted in a reduction in fuel efficiency from 8.45 MPG to 7.79 MPG. When the LPG 2 setting was tested at MIRA it recorded an improvement of 10% compared to when the LPG was switched off. However, during the 'live period when the test vehicle was without LPG (LPG 3) a deterioration in MPG of only 4.3% was recorded. Due to the issues around the 'live' data the preferred technique to determine the impact of the LPG system is to compare LPG 1 with LPG 3, which indicated an improvement of 13% ((8.45 - 7.46)/7.46). The caveat to be applied is that LPG 3 is a very short period.

6.4 COMPANY D

There was an overall average improvement in fuel consumption of 9.8% (‘live’ data) and 9.1% (MIRA Proving Ground). Improvements were not consistent across the operational profile and therefore opportunities exist to increase the fuel consumption improvements.

6.4.1 D: METHODOLOGY

The methodology includes two types of evaluation programmes. The first is ‘live’ in operations and the second is conducted at the MIRA Proving Ground. Data generated in ‘live’ operations is subject to random events, which results in greater volatility. Such data volatility is reduced significantly with evaluations undertaken in controlled conditions such as those at the MIRA Proving Ground. Obviously, this leads to the inevitable trade-off between accuracy and representativeness. In order to reduce the impact of seasonality the test vehicle was monitored alongside several control vehicles.

Fuel consumption data was collected both ‘live’ and at the MIRA Proving Ground for analysis. The data collected at all stages has been analysed using the Imise Fuel Saving Interventions Testing System (IFSITS).

In addition, the condition of the engine in the ‘test’ vehicle was monitored using engine oil analysis before and during the trial.

6.4.2 D: EVALUATION UNDER ‘LIVE’ CONDITIONS

A number of vehicles were recommended by the operational management at the company and their fuel consumption data was analysed using the IFSITS system to identify the ‘test’ and ‘control’ vehicles – from a mathematical point of view. The recommendations from IFSITS were discussed with the operational management and one test and several control vehicles were agreed upon.

The format applied was to establish the baseline fuel consumption in Miles per Gallon (MPG) then to activate the LPG settings, which would be designated LPG x. Every time the settings in the LPG controller were changed the LPG reference number would be changed up by one digit. For example, a change to the settings for LPG 1 would result in the designation changing to LPG 2.

Analysis of the fuel consumption data involves data from the ‘test’ vehicle’s CANbus system and from the diesel tank refuelling data. The data applicable to the ‘control’ vehicles was exclusively taken from the tank refills. Previous research has found that the CANbus fuel consumption data tends to show a better fuel consumption than that indicated by analysis of tank filling data. There are several reasons for this, which include fuel theft, fuel evaporation and the electronic conversion settings in the vehicle's fuel management programme, to name but a few.

6.4.3 D: RESULTS TO DATE

The baseline figure for the 'test' vehicle is based only upon the tank refuelling figures the other figures (LPG 1 to LPG 4) in Table 8 are based upon the CANbus data and collected and transmitted via the Btrack telematics system. Therefore, before accepting these figures, care must be taken to allow for over optimistic figures from the CANbus and the impact of seasonality on the fuel consumption figures.

Table 8 Initial Fuel Consumption Results – Test Vehicle

CONDITION	FROM	TO	MILES	GALLONS	MPG	Difference in MPG	Difference %
BASELINE	01 July 2013	25 April 2014	54,782	4,425	12.38		
LPG 1	26 April 2014	17 June 2014	8,139	588	13.85	1.47	11.8%
LPG 2	19 June 2014	29 August 2014	13,656	938	14.57	2.19	17.7%
LPG 3	01 September 2014	18 September 2014	3,491	245	14.24	1.86	15.0%
LPG 4	19 September 2014	29 September 2014	1,873	128	14.60	2.22	17.9%

LPG 1 refers to the settings in the EASI-LPG electronic controller, which manages the amount of LPG that is fed into the air intake of the engine. These settings were later changed (LPG 2).

Whilst investigating the data (test and control vehicles) several issues have come to light. The first refers to Table 1; the improvement after the settings were changed from those at LPG 1 to those of LPG 2 indicates that the LPG system works and that the change to the settings resulted in an improvement of 5.2% ((14.57-13.85) / 13.85), although the impact of any seasonal effect remains to be determined.

LPG 3 refers to a period when the vehicle was deliberately operated without any LPG and the data shows only a small drop in fuel consumption of 2.3% ((14.57-14.24)/14.24). This is an unexpected result and contradicts a figure of 16% ((13.67-11.78)/11.78) that was produced when the vehicle operated without LPG on the 6th May for the day. LPG 4 refers to the period when LPG was reintroduced. Currently, no reason for the small drop in fuel consumption has been found. LPG 4 is the same setting as LPG 2.

To deal with the seasonal effect upon fuel consumption, the fuel consumption data from the 'control' vehicles is examined. However, before accepting this data, it has to be subject to the same scrutiny as the 'test' vehicle data, to ensure that there have been no out of pattern changes. These out of pattern changes, if not eliminated, can in extreme cases lead to 'false positive' and 'false negative' results. Generally, though, if not eliminated they tend to either increase or reduce the calculated change in fuel consumption of the 'test' vehicle. The latter happened in four of the seven 'control' vehicles in this evaluation. This did however leave three 'control' vehicles and the analysis of the data is shown in Table 9 below.

Table 9 Fuel Consumption Analysis Test and Control Vehicles – Tank Refill Only

Condition	Test	Control 1	Control 2	Control 3	Control Total	Control Change MPG	Control Change %
Baseline Miles	54,782	46,725	60,075	40,342	147,143		
LPG 1 Miles	9,209	8,694	7,789	5,687	22,170		
LPG 2 Miles	8,388	5,810	7,037	4,711	17,558		
Baseline Gallons	4,425	3,508	4,886	3,265	11,660		
LPG 1 Gallons	684	646	617	457	1,719		
LPG 2 Gallons	601	426	559	367	1,352		
Baseline MPG	12.38	13.32	12.29	12.36	12.62		
LPG 1 MPG	13.47	13.47	12.62	12.45	12.89	0.27	2.17%
LPG 2 MPG	13.95	13.65	12.58	12.84	12.99	0.37	2.91%
LPG 1 MPG Change	1.09	0.33	0.29	0.48			
LPG 2 MPG Change	1.57	0.18	- 0.04	0.39			
LPG 1 MPG % Change	8.81%						
LPG 2 MPG % Change	12.66%						

Key factors to emerge from Table 9 are:

1. The change from LPG 1 to LPG 2 resulted in an improvement in fuel consumption of 3.5% ((13.95-13.47) / 13.47) shown by the tank refuelling data, which is close to the CANbus data figure of 5.2%.
2. The 'control' vehicles improvement from 2.17% to 2.91% was in line with expectations, based upon previous research conducted into seasonality.
3. Taking the seasonal influence into account the overall improvement at the LPG 2 setting is calculated to be 9.75% (12.66%- 2.91%).

6.4.4 D: RESULTS FROM TESTING AT MIRA PROVING GROUND

Fuel consumption is measured separately when the vehicle accelerates from 0 to 40, from 40 to 50 and from 50 to 56 (or lower pre-set speed). The overall average improvement in fuel consumption was of the order of 9.1% on the high-speed circuit and 6.8% on the stop-start circuit.

The relationship between the MIRA figures and the 'live' figures is sensitive to the vehicles operational profile. It is also clear from the analysis of the MIRA data that the EASI-LPG system needs configuring to achieve the 16% saving in all conditions.

6.4.5 D: ENGINE OIL ANALYSIS

Analysis of the engine oil samples has found there to be no adverse effects caused by the introduction of the EASI-LPG system.

6.4.6 D: REVIEW

The EASI-LPG system has shown that it can improve the fuel consumption of the test vehicle, without harming the engine. The results from the testing at MIRA clearly indicate that the improvement in fuel consumption is not consistent across the operational profile. Consideration needs to be given to modifying the LPG system so that the improvements in fuel consumption can be optimised. This is a point confirmed by reviewing the data from <u>all</u> the test vehicles in the project.

The small reduction in fuel consumption at LPG 3 is still unexplained, but could have been due to a change in the operational profile. Whilst accepted as a recorded figure it does not align itself with either the remaining 'live' data or the results from the evaluation at the MIRA Proving Ground.

6.5 COMPANY E

Definite improvements in fuel consumption (12% to 16%) and Adblue consumption (9% to 25%) have been achieved.

6.5.1 E: METHODOLOGY

The methodology includes two types of evaluation programmes. The first is 'live' in operations and the second is conducted at the MIRA Proving Ground. Data generated in 'live' operations is subject to random events, which results in greater volatility. Such data volatility is reduced significantly with evaluations undertaken in controlled conditions such as those at the MIRA Proving Ground. Obviously, this leads to the inevitable trade-off between accuracy and representativeness.

To reduce the impact of seasonality the test vehicle (TEST) was accompanied by control vehicles (CNTRL 1 and CNTRL 2).

Fuel consumption data was collected both 'live' and at the MIRA Proving Ground for analysis. All data collected at all stages has been analysed using the Imise Fuel Saving Interventions Testing System (IFSITS).

In addition, the condition of the engines in the 'test' vehicle was monitored using engine oil analysis before and during the trial.

The Adblue consumption data was reported in miles per gallon of Adblue and this has also been analysed.

6.5.2 E: EVALUATION UNDER 'LIVE' CONDITIONS

A number of vehicles were recommended by the operational management at Company E and their fuel consumption data was analysed using the IFSITS system to identify the test and control vehicles – from a mathematical point of view. The recommendations from IFSITS were discussed with the operational management and one 'test' and two 'control' vehicles were agreed upon.

The format applied was to establish the baseline fuel consumption in Miles per Gallon (MPG) then to activate the LPG settings, which would be designated LPG x. Every time the settings in the LPG controller were changed the LPG reference number would be changed up by one digit. For example, a change to the settings for LPG 1 would result in the designation changing to LPG 2.

Unfortunately, the operator did not fill the vehicles LPG tank for five weeks after the system had been fitted and activated and no data LPG data was supplied for the month of August or September, which also had a planned 'no LPG' period. During the 'LPG active' period the manager overseeing the project was off ill and no mechanism had been put in place to ensure the continuity of refilling the LPG tank.

However, using the data provided by the vehicles telematics system a baseline has been established followed by a short period with the EASI-LPG system active (LPG 1). Then due to the managers absence a short period with no LPG (LPG 2) and then another short period with the LPG system active (LPG 3). At the start of LPG 3 the settings in the controller used to determine how much LPG should be fed into the system was changed. The results can be seen in Table 10 below.

Table 10 Fuel consumption results

Cntrl 1	From	To	Miles	Gallons	MPG	Difference	Difference
Baseline	01/11/2013	16/06/2014	81,521	8,711	9.36		
LPG 1	17/06/2014	29/06/2014	5,205	540	9.63	0.28	3.0%
LPG 2	30/06/2014	06/07/2014	1,977	205	9.63	0.27	2.9%
LPG 3	07/07/2014	31/07/2014	4,348	418	10.39	1.04	11.1%
Test							
Baseline	01/11/2013	16/06/2014	82,129	8,902	9.23		
LPG 1	17/06/2014	29/06/2014	2,388	200	11.94	2.71	29.4%
LPG 2	30/06/2014	06/07/2014	2,636	256	10.31	1.08	11.7%
LPG 3	07/07/2014	31/07/2014	8,624	743	11.61	2.39	25.9%
Cntrl 2							
Baseline	01/11/2013	16/06/2014	44,581	4,085	10.91		
LPG 1	17/06/2014	29/06/2014	2,691	250	10.75	- 0.17	-1.5%
LPG 2	30/06/2014	06/07/2014	982	116	8.48	- 2.43	-22.3%
LPG 3	07/07/2014	31/07/2014	7,130	641	11.13	0.21	1.9%

The results shown in Table 10 are clearly impressive. It can be seen that the control vehicle CNTRL 2 has problems either caused by a change in operational profile or an engineering problem. Therefore, CNTRL 2 and its data have to be omitted from the analysis. Clearly, LPG 1 was the best setting to reduce fuel consumption that shows an improvement in fuel consumption of 1.63 MPG (2.71-1.08), which equates to 15.9%.

The setting of LPG 3 was the one that was tested at the MIRA Proving Ground and using the data from Table 10 it can be seen that the improvement in ‘live’ fuel consumption was 1.31 MPG (12.7%). The Adblue data also reinforces the fuel consumption figures, as shown in Table 11.

Table 11 Adblue consumption LPG 1 V LPG & LPG 3 v LPG 2

	Test	Difference	%
Baseline	244		
LPG1	410	81	25%
LPG2	329		
LPG3	360	31	9%

One of the premises of the EASI-LPG is that less NOx is produced therefore reducing the demand for Adblue. From an operator's point of view there are two immediate financial savings; fuel and Adblue.

6.5.3 E: RESULTS FROM TESTING AT MIRA PROVING GROUND

Due to a delay there was only time to conduct the High-Speed test. This test is predominantly a series of constant speed tests conducted at 40 MPH, 50 MPH and 56 MPH (or lower if the road speed limiter has been set lower) to simulate non-urban operations. The urban simulation was not conducted.

Fuel consumption is measured separately when the vehicle accelerates from 0 to 40, from 40 to 50 and from 50 to 56 (or lower pre-set speed). It was noted during the test and from the meteorological data that when the vehicle was tested with the LPG activated the wind strength increased. However, a positive result of an overall improvement of 11.2% was still achieved.

This result of 11.2% at MIRA is very close to the 'live' LPG 2 result of 12.7% and given the change in atmospheric conditions it is likely that the MIRA result would have been slightly higher than the 'live' result.

6.5.4 E: ENGINE OIL ANALYSIS

The engine oil analysis found no indications of any harm to the engine.

6.5.5 E: REVIEW

At the current setting (LPG 3) the financial saving (excluding the costs of the EASI-LPG and LPG fuel) based upon an annual average annual mileage of 100,000 miles is £5,460. If the EASI-LPG controller is reset to its LPG 1 setting the saving would be £6,639. *Note: this is based upon fuel prices in October 2014*.

6.6 BTRACK MERCEDES VAN

A sixth LPG system was fitted to a Mercedes Vito van operated by Btrack Solutions Limited who owns the EASI-LPG system. The system fitted to the van was tested at the MIRA Proving Ground for the purpose of evaluating number of different setting in one day under controlled conditions. The data was sourced using the Btrack in-cab display that produced data to three decimal points. This provides a very high resolution and improves accuracy considerably. The three road speeds applied during the testing were 40 MPH, 50 MPH and 70 MPH and the resultant fuel consumption figures are shown in Table 12.

Table 12 Mercedes Vito: Proving Ground Fuel Consumption Results

	MPG			
MPH	Baseline	Setting 1	Setting 2	Setting 3
40	50.4	75.1	70.6	81.2
50	50.1	67.3	72.1	66.6
70	34.4	37.0	39.5	39.7
Overall	42.4	52.0	51.2	53.2

The data in Table 12 can be expressed as percentage improvement and is shown in Table 13.

Table 13 Mercedes Vito: Proving Ground Fuel Consumption Percentage Improvements

	MPG			
MPH	Baseline	Setting 1	Setting 2	Setting 3
40		49%	40%	61%
50		34%	44%	33%
70		7%	15%	15%
Overall		23%	21%	26%

Tables 12 and 13 shows clearly that whilst the improvements in fuel consumption are substantial the improvements are not consistent and the controller needs further development.

7 PAYBACK MODEL

Any payback period is of course influenced by such factors as: the initial cost; the annual distance travelled; fuel consumption; price of diesel; price of LPG; ratio of LPG consumed to diesel consumption and the percentage improvement in fuel consumption. The model below in Table 12 is based upon a less than best performance achieved in the proof of concept trial with an annual distance travelled of 150,000 kilometres.

Table 14 Payback Model

Without LPG			With LPG	
130,000	Annual Kilometres			
80,778	Annual Miles			
£ 0.89	£ per litre of diesel		£ 0.50	Cost per litre of LPG
£ 0.25	Adblue cost per litre		12.5%	Improvement in MPG
8.00	Miles per Gallon		10%	Average percentage of LPG to diesel
5%	Adblue ratio to diesel		20%	Reduction in Adblue consumption
10,097	Gallons of diesel			
45,903	Litres of diesel consumed		40,803	Litres of diesel consumed with LPG
			4,080	Litres of LPG Consumed
			£ 2,040	LPG Cost
£ 40,854	Fuel cost without LPG		£ 36,314	Fuel cost with LPG
£ 574	Adblue cost without LPG		£ 510	Adblue cost with LPG
£ 41,428	Total cost		£ 38,865	Total cost
			6.09	Tonnes of CO2e LPG
122.65	Tonnes of CO2e Diesel		109.03	Tonnes of CO2e Diesel
	Overall Saving		**£ 2,563**	
EQ Cost			**Annual Cost**	
£4,500	Depreciation over 5 years		£ 900	
	Maintenance inc oil analysis		£ 520	
	Annual Cost		£ 1,420	
Outright Purchase: Net Saving per Vehicle				
	GBP saved		**£ 1,143**	
	Tonnes of CO2e saved		**7.54**	

Clearly there are major financial and environmental savings to be made.

8 CONCLUSION

The EASI-LPG system has proven itself to work and in many cases to be economically viable without further development. This conclusion is drawn based upon the fuel consumption data generated in both the 'live' trials and under controlled conditions at the MIRA Proving Ground. More detailed analysis of the data produced at the MIRA Proving ground has identified that there is the potential to increase the improvements in fuel consumption even further, through optimisation of the controller for all operational conditions.