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Greenwich Fleet Biomethane Study

Greenwich Council

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Prepared for

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Contents

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1 Executive Summary

Greenwich Council commissioned Cenex to analyse the Greenwich 2008/2009 vehicle fleet data and proposed waste collection profile using the Cenex Biomethane Calculator. The purpose of the analysis was to ascertain the amount of vehicle fuel, revenue, carbon dioxide (CO_2) and air quality savings that could be realised through the introduction of a local Anaerobic Digestion (AD) facility to produce biomethane from the Councils proposed organic waste collection service.

The Cenex Biomethane Calculator has been designed to give an indicative production quantity of biomethane and an indicative revenue value in both combined heat and power (CHP) and vehicle applications. This allows for a quantative decision to be made on whether a more detailed engineering and financial analysis for a particular AD programme should be progressed.

The proposed AD feedstock consists of 20000 tonnes per annum of mixed food waste (kerbside collection) and garden waste at composition levels of 53% and 47% respectively.

The analysis shows that the proposed AD feedstock would produce a biomethane yield of 888341 kg from a single stage AD facility. Assuming that the biomethane produced is first used to heat and power the AD facility this would result in either 3084518 kWh of electricity generation or 414602 kg of vehicle fuel. The annual income generated from electricity sales would be £376311. The fuel savings (based on diesel displacement) range from £166484 to £303831 per annum depending on a diesel price range of 85ppl to 115ppl.

The 20000 tonne facility would service 35 of the Councils 38 RCVs with biomethane saving 1159 tonnes of well-to-wheels $CO_{2,}$ two tonnes of NOx and 0.018 tonnes of particulate matter (PM) from displacing 457824 litres of diesel fuel. A further CO_2 saving of 2134 tonnes per annum is achieved through providing the parasitic energy requirements of the AD facility. This results in a total CO_2 saving of 3293 tonnes per annum on a well-to-wheel basis.

The analysis shows that the most cost effective fleets to replace with gas would be the RCVs followed by the road sweepers.

A facility in the region of 60000 tonnes would be required to service the entire Council fleet assuming the biomethane was used to provide for the parasitic requirements of the plant. If all process energy was imported from national grids, this would reduce the size of the required AD facility to approximately 30000 tonnes per annum.

2 Introduction

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 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)[1].

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 so is a sustainable replacement fuel for natural gas applications, including gas powered vehicles.

Greenwich Council commissioned Cenex to analyse their fleet data and proposed waste collection profile with the Cenex Biomethane Calculator.

The proposed AD feedstock consisted of 20000 tonnes per annum of food waste (kerbside collection) and garden waste at composition levels of 53% and 47% respectively.

The Cenex Biomethane Toolkit was used to derive the following

1. **Gas yield** – the potential amount of biomethane that can be generated using the feedstock specified.
2. **CHP** – the potential amount of electricity and heat that can be generated with an indication of potential revenues and Greenhouse gas (GHG) savings from displacing conventional electricity and fossil heating gas.
3. **Vehicle Fuel** – the amount of vehicle fuel that would be available after accounting for the energy to power the AD plant. An estimate of the additional costs for upgrading and compressing the gas will be provided, plus the fuel duty payable on the gas and the renewable transport fuel obligation income that can be generated.
4. **Vehicle Fleet** – An estimate of the amount of biomethane required to fuel the Greenwich Council fleet, including an assessment of the amount of fossil fuel displaced.
5. **Vehicle Emissions** – The GHG, NOx and PM savings from switching the Greenwich Council fleet from diesel to biomethane.

[1] Data from Gasrec upgrading facility, Aldbury

6. **Vehicle Costs** - An estimate of the relative cost of operating a biomethane fleet compared to a conventional diesel fleet taking into account the additional purchase cost of a gas vehicle.

3 Vehicle fleet data screening

The data provided by Greenwich Council was screened and corrected before analysis. The raw data included instances of unrealistic miles per gallon (mpg) fuel consumption ranging from 60 to 1000+ mpg which Cenex understands is due to original user input error. A total number of 34 out of 593 vehicles were assessed as having out of range mpg due to either the annual mileage or fuel consumed data being outside normal expectations for the particular vehicle or category. The vehicle data was evaluated on a case by case basis to ascertain whether the mileage or fuel usage was incorrect and adjusted to suit the average mpg of the vehicle subset.

The standard subsets of vehicles used by Greenwich were not suitable for direct transfer into the toolkit as they contained a large variety of vehicles with different weight classifications and fuel consumptions. For example, the bus subset contains vehicles from 12500 kg Gross Vehicle Weight (GVW) coaches with an average fuel consumption of 6.9 mpg to minibuses (3.5 – 7 t GVW) with an average fuel consumption of 20.3 mpg. Such a range of vehicle weights in one subset removes clarity with regards payback on the additional cost of a gas vehicle, as the increased capital cost is related to the GVW. Therefore, the vehicle subsets were redefined into appropriate categories by GVW before analysis.

The final category list and screened data is summarised in Table 1 below.

Table 1 - Greenwich vehicle categories and screened data summary

Category	No in fleet	Total litres of fuel	Total km travelled	MPG	Average mileage
Coach (12.5 t GVW)	10	63335.6	155813.9	6.9	9676.0
Car / Light Van (diesel)	94	74991.3	974375.2	36.7	6437.1
Light truck (7.5 t GVW)	12	47781.7	195621.6	11.6	10123.4
Medium truck (13 t - 19 t GVW)	15	39106.2	92136.0	6.7	3814.4
Medium/large diesel van (>1.25 ≤3.5 t GVW)	329	362238.9	2986963.7	23.3	5638.0
Minibus (3.5t - 7 t GVW)	61	94798.9	681037.5	20.3	6933.2
Large Minibus (7t - 12 t GVW)	27	102576.7	404749.0	11.1	9309.2
RCV (26 t GVW t GVW)	38	494887.7	651455.9	3.7	10646.2
Sweeper (3.5 t GVW)	7	48336.8	155410.1	9.1	13787.1
Total	**593**	**1328053.7**	**6297562.9**	**13.4**	**6594.9**

4 Gas Yields

The biomethane yields which could be expected from a 20000 tonne per annum facility, with a feedstock consisting of 53% Organic Fraction of Municipal Solid Waste (OFMSW) and 47% garden waste are displayed in Table 2 below. The data presented includes a 5% gas loss factors and is displayed in a number of units for completeness.

Table 2 - Biomethane production				
	Weight (kg)	**Volume (Nm^3)[2]**	**Energy content (MJ)**	**Energy content (kWh)**
Single stage	888341	1240700	44417060	12338072
Multistage	956361	1335700	47818060	13282794

For the remainder of the analysis a single stage AD facility will be considered.

5 Combined Heat and Power

Assuming the biomethane produced is used to heat and power the AD facility, the remaining gas would be capable of producing 3084518 kWh of electricity for export to the national grid which could provide annual revenue of £376311. The excess heat produced from the AD facility would be 4318325 kWh. The parasitic energy requirements of the AD plant and the factors applied when calculating the available revenues from the sale of power are shown below in Table 3 and Table 4.

Table 3 - CHP calculation factors		
Electricity	**Factor applied**	**KWh produced**
Total electricity produced	35% conversion efficiency	4,318,325
Electricity required by AD system	10% parasitic energy requirement	1,233,807
Electricity available for sale		**3,084,518**
Heat	**Factor applied**	**KWh produced from**
Total heat produced	50% conversion efficiency	6,169,036
Heat required by AD system	15% parasitic energy requirement	1,850,711
Spare heat for sale		**4,318,325**

[2] Nm^3 Normalised cubic meters are cubic meters at 20°C (293.15 K, 68°F) and 1 atm (101.325 kN/m^2, 101.325 kPa, 14.7 psia, 0 psig, 30 in Hg, 760 torr)

Table 4 - CHP revenue factors	
Electricity Generation	**Revenue**
Sale price (p/kwh)	3.2
ROC price (p/kwh)	4.5
Number of ROCs [3]	2
Electricity revenue	**£376,311**
Heat	**Revenue**
Gas price (p/kwh)	2.1
Equivalent gas required KWH	4,798,139
Value of gas displaced	**£100,761**

It should be noted that if a district heating scheme or industrial user of the spare heat could be found then the stated available revenue of £101k per annum from excess heat sales would be reduced due to the additional capital outlay of such a distributed heating scheme.

The CO_2 savings available from the AD facility due to biogas CHP generation as opposed to imported fossil based energy are shown below in Table 5.[4]

Table 5 - CO_2 emission savings	
Electricity use only	1,341 tonnes/year
Electricity and heat use	2,134 tonnes/year

6 Vehicle Fuel

As detailed in Table 6 below, the given feedstock would produce a gross total of 888314 kg of biomethane, of which 469560 kg would be required to heat and power the AD facility leaving approximately 414602 kg of biomethane available for use in the Councils fleet.

Table 6 - Vehicle fuel conversation factors		
CHP for process energy	**Factor applied**	**Biomethane (Kg)**
Gas available for upgrading		888,341
AD Electricity use	10.00%	88,834
AD Heat use	15.00%	133,251
Gas available for upgrading		418,789
Upgrading & compression loss	1.00%	4,188
Total vehicle fuel available		**414,602**

The value of the spare heat after vehicle fuel production is £57k per annum. In line with the CHP revenue assumptions, the excess heat sale value would be reduced due to the additional capital outlay

[3] Renewable Obligation Certificates (ROCs) are issued by the UK government per MWh of electricity produced from renewable sources. These have a financial value. Electricity generation from AD current qualifies for two ROCs per MWh.
[4] Savings based on subtracting the life cycle emissions from AD power generation (Concawe 2007 figures) from the emissions from importing power via the national electricity and gas network (Defra 2007 figures).

of such a distributed heating scheme. The financial value of any excess heat produced has not been taken into account further in this study.

The net cost for upgrading and compressing the biomethane including income earned from the sale of Renewable Transport Fuel Obligation (RTFO) certificates[5] is estimated in the table below.

Table 7 - Vehicle fuel cost factors	
Cost/Revenue element	**Production cost (p/kg)**
Upgrade cost[6]	6.6
Compression costs[6]	7.3
UK Biomethane duty	19.3
Biomethane RTFO certificate income	- 10.0
Total Biomethane cost	**23.2**

It is worth noting that the UK government announced in the 2008 Budget that the duty incentive for a biogas will be removed in 2010 and replaced with an increased RTFO value of 30p per kg.

7 Vehicle Fleet and Emissions

Approximately 1210000 kg (1210 tonnes) of biomethane would be required to power the entire current Greenwich fleet. The available biomethane for use as a road transport fuel from a 20000 tonne AD facility as shown above would be approximately 414 tonnes. Therefore broadly speaking an AD facility treating 60000 tonnes of the suggested waste mix would be required to service the entire fleet. However, as shown below in Table 8, the suggested 20000 kg facility would service the majority of the Councils RCV fleet. The cost module will discuss the benefit of converting each vehicle category to operate on gas.

Greenhouse gas emission savings are considered on a well-to-wheel (WTW) basis. Tank-to-wheel (TTW) CO_2 emissions relate to the conventional tailpipe emissions from a vehicle and can be directly related to the fuel type used and the vehicle mpg. WTW emissions consider the overall carbon foot print of a fuel including emissions during fuel extraction, processing, transportation, dispensing and use. Since biomethane is a hydrocarbon based fuel, as is natural gas and diesel, tailpipe CO_2 emissions are similar. Therefore carbon emission savings are realised due to the embodied carbon within the biomethane which is from a sustainable, rather than fossil source. This embodied sustainable carbon is accounted for through applying wheel-to-wheel methodology to carbon savings.

CO_2 production from fossil fuels increases the amount of green houses gases in the atmosphere, which contributes to global warming. The UK government is committed to reducing the amount of greenhouse gas emissions by 80% by 2050. Complete conversion of the Councils fleet would allow 1329981 litres (1106.5 tonnes) of diesel to be displaced creating a total saving of 3365.5 tonnes of CO_2 equivalent per annum on a WTW basis and a 6.7 and 0.3 tonne saving of NOx and PM respectively.

[5] The Renewable Transport Fuel Obligation (RTFO) is similar to the ROC scheme for electricity generation rewarding energy from renewable sources with a financial premium.

[6] Biogas upgrading and compression costs inc services costs excluding maintenance and equipment payback cost, supplied by Chesterfield Biogas

NOx reacts with ammonia, moisture, and other compounds to form nitric acid and related compounds. 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 Greenwich.

Table 8 below details biomethane consumption and litres of diesel fuel displaced per vehicle category. Emission savings are shown in Table 9.

Table 8 - Biomethane consumption and diesel displaced by vehicle category

Vehicle type	Fleet size	Annual mileage per vehicle	Diesel (mpg)	Biomethane consumption (tonnes)	Diesel displaced	
					litres	tonnes
Car / Light Van (diesel)	94	6437	36.7	68.2	74953	62.36
Road Sweeper (3.5 t GVW)	7	13787	9.1	43.9	48213	40.11
Medium/Large Van (<3.5 t GVW)	329	5638	23.3	329.2	361912	301.11
Minibus (3.5 t - 7 t GVW)	61	6933	20.3	86.2	94712	78.80
Light truck (7.5 t GVW)	12	10123	11.6	43.3	47609	39.61
Large Minibus (7 t - 12 t GVW)	27	9309	11.1	93.6	102942	85.65
Coach (12.5 t GVW)	10	9676	6.9	58.0	63751	53.04
Medium truck (13 t - 19 t GVW)	15	3814	6.7	35.3	38822	32.30
RCV (26 t GVW)	38	10646	3.7	452.2	497067	413.56
Total	**593**			**1,209.9**	**1,329,981**	**1106.54**

Table 9 - CO_2, PM and NOx savings for a biomethane fleet

Vehicle type	WTW GHG savings in tonnes p.a. CO_2 equivalent	NOx saving tonnes p.a.	Pm saving tonnes p.a.
Car / Light Van (diesel)	189.7	0.262	0.019
Road Sweeper (3.5 t GVW)	122.0	0.483	0.005
Medium/Large Van (<3.5 t GVW)	915.8	1.078	0.141
Minibus (3.5 t - 7 t GVW)	239.7	0.246	0.032
Light truck (7.5 t GVW)	120.5	0.609	0.006
Large Minibus (7 t - 12 t GVW)	260.5	1.259	0.012
Coach (12.5 t GVW)	161.3	0.337	0.025
Medium truck (13 t - 19 t GVW)	98.2	0.300	0.003
RCV (26 t GVW)	1257.9	2.123	0.020
Total	**3365.6**	**6.697**	**0.315**

8 Cost benefit analysis

This section analyses the cost of running a fleet on biomethane compared with using diesel fuel. In most circumstances biomethane can be produced at a lower cost than diesel. This section analyses whether the additional cost of purchasing a gas vehicle can be offset through reduced fuel costs. Fuel costs were based on the biomethane production costs estimated elsewhere in this report and the current (July 2009) cost of diesel to Greenwich Council which Cenex have been advised is 0.85p per litre ex VAT.

A reasonable payback period for the premium cost of a gas vehicle was estimated by analysing the current age of the Greenwich fleet. The analysis was conducted to payback the additional cost of the gas vehicles at both the average age of the vehicle sub category and the 3rd quartile age (75% of the current vehicle age range). These are referred to as short and medium payback periods respectively in the charts below. The age profile of the Greenwich fleet is show below in Table 10.

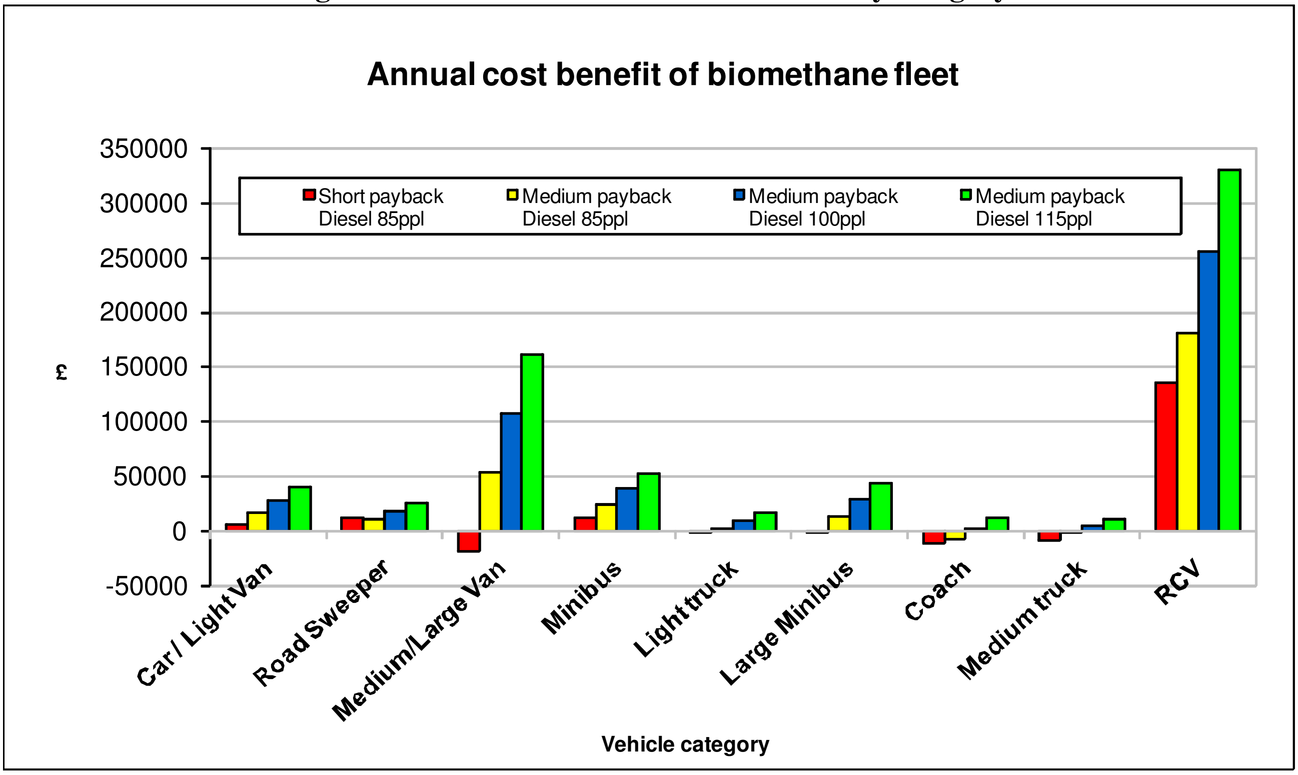
Table 10- Age profile of Greenwich vehicle fleet

Category	Min	Max	Avg	3rd Quartile
Coach (12.5 t GVW)	3	4	3.5	3.8
Car / Light Van (diesel)	1	10	5.7	7.8
Light truck (7.5 t GVW)	2	8	6	6.5
Medium truck (13 t - 19 t GVW)	2	15	8.9	11.8
Medium/large diesel van (>1.25 ≤3.5 t GVW)	1	12	6.6	9.3
Minibus (3.5t - 7 t GVW)	1	11	6.3	8.5
Large Minibus (7t - 12 t GVW)	1	10	6.1	7.8
RCV (26 t GVW t GVW)	1	8	4.7	6.3
Sweeper (3.5 t GVW)	3	5	4.7	5[7]

Cost scenarios include diesel cost at the current rate of 85ppl and future scenarios of 100 and 115ppl. The resultant cost benefit per vehicle category is shown below in Figure 1.

[7] 3rd quartile age for sweepers was set to five years due to skewed fleet distribution of 6 No. five year old vehicles and 1 No. three year old vehicles resulting in an actual third quartile lower that the average vehicle life.

Figure 1 - Cost benefit of biomethane fleet by category



The graphical data above is also shown below in table format.

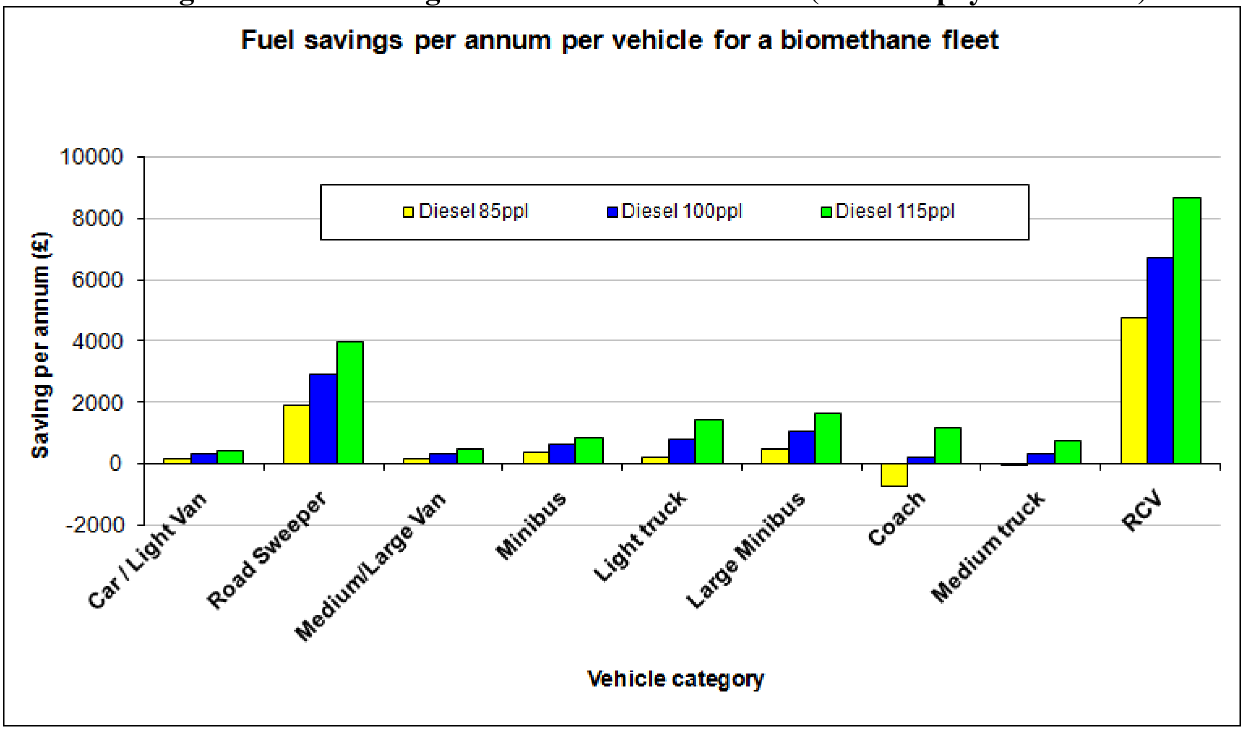
Table 11 - Cost benefit of biomethane fleet by category				
Category	**Short payback Diesel 85ppl**	**Medium payback Diesel 85ppl**	**Medium payback Diesel 100ppl**	**Medium payback Diesel 115ppl**
Car / Light Van (diesel)	6656	17562	28805	40048
Road Sweeper (3.5 t GVW)	12184	13301	20533	27765
Medium/Large Van (<3.5 t GVW)	-18033	53372	107659	161946
Minibus (3.5 t - 7 t GVW)	12095	24625	38832	53039
Light truck (7.5 t GVW)	415	2723	9864	17006
Large Minibus (7 t - 12 t GVW)	-628	13507	28948	44389
Coach (12.5 t GVW)	-10701	-7272	2290	11853
Medium truck (13 t - 19 t GVW)	-8906	-730	5093	10917
RCV (26 t GVW)	135639	180754	255314	329874
Total	**128722**	**297842**	**497339**	**696836**

As shown above, a realistic payback period needs to be considered for the vehicles to make biomethane conversion economic in most cases when the current cost of diesel is considered. The income generated through the conversion of RCVs and Sweepers is more robust against fluctuations in expected vehicle life since, as shown in Table 10 above, these are calculated on the lowest of the sub category amortisation periods of 6 and 5 years respectively. On a category basis the RCVs offer the greatest annual return.

Replacement of the entire Greenwich fleet with gas vehicles on the medium payback model would yield annual returns in the region of £297842, £497339 and £696836 based on a diesel cost of 85, 100 and 115ppl respectively. RCVs which are the most economic fleet available for conversion would alone generate over 50% of the fuel savings, yielding £180754, £255314 and £329874 per annum respectively.

The analysis above shows returns from entire fleet conversions, hence fleets with a larger number of vehicles and a smaller return rate per vehicle may generate a higher income than a very small fleet with a higher return rate per vehicle. This statement is adequately demonstrated by comparing the Greenwich Sweeper fleet to the Meduim/Large van fleet. Based on diesel costs of 85ppl, the Medium/Large van fleet yields an annual fuel saving of just £163 per vehicle but with 328 Medium/Large vans the total fleet saving is £53372. The Sweeper fleet has an annual fuel saving rate of £1900 per vehicle and with just seven vehicles in the fleet return £13301. Therefore, when prioritising vehicles for gas conversion the metric of fuel saving per vehicle per annum should be used which is shown below in Figure 2 and Table 12.

Figure 2 - Fuel savings from biomethane vehicles (medium payback model)



For completeness Table 12 below also details the approximate pence per mile fuel cost saving.

Table 12 - Fuel savings from biomethane vehicles

Category	Diesel 85ppl		Diesel 100ppl		Diesel 115ppl	
	Fuel saving per annum per vehicle (£)	Fuel saving per mile (pence)	Fuel saving per annum per vehicle (£)	Fuel saving per mile (pence)	Fuel saving per annum per vehicle (£)	Fuel saving per mile (pence)
Car / Light Van	187	2.9	306	4.8	426	6.6
Road Sweeper	1900	13.8	2933	21.3	3966	28.8
Medium/Large Van	162	2.9	327	5.8	492	8.7
Minibus	404	5.8	637	9.2	869	12.5
Light truck	227	2.2	822	8.1	1417	14.0
Large Minibus	500	5.4	1072	11.5	1644	17.7
Coach	-727	-7.5	229	2.4	1185	12.2
Medium truck	-49	-1.3	340	8.9	728	19.1
RCV	4757	44.7	6719	63.1	8681	81.5

As shown above the two major gains in utilising biomethane as a transport fuel can be realised by converting the RCV and Sweeper fleet. These fleets are attractive for conversion due to high annual mileage and low fuel consumption relative to the remaining vehicles in the Greenwich fleet.

9 Conclusions

The 20000 tonne facility would service 35 of the Councils 38 RCVs saving 1159 tonnes of CO_2, two tonnes of NOx and 0.018 tonnes of particulate matter from displacing 457824 litres of diesel fuel. A further CO_2 saving of 2134 tonnes per annum is achieved through biogas providing the parasitic energy requirements of the anaerobic digestion facility. This results in a total CO_2 saving of 3293 tonnes per annum.

The analysis shows that the most cost effective fleets to replace with gas vehicles would be the RCVs followed by the road sweepers.

The current (August 2009) UK availability of dedicated gas vehicles correlate well with the profitability rankings of the Greenwich fleet vehicle categories. Available vehicles include the Mercedes Econic RCV, Ravo and Dulevo road sweepers and minibus body configurations of the Iveco Daily and Mercedes Sprinter. No cars or light vans are currently available in the UK market place.

In the short term the economic case is stronger for electricity generation from AD. Annual revenue from electricity sales is in the region of £376311 against using the biomethane in road transport applications earning potential fuel savings from £166484 to £303831 per annum based on a diesel price range of 85ppl to 115ppl. However, some additional benefits exist from using biomethane as a road transport fuel which have not been given a financial value in this analysis which include improving local air quality and transport noise levels in Greenwich. Biomethane powered vehicles also provide a method of decarbonising the councils transport fleet whilst delivering a cost saving compared with other low carbon options such as fleet electrification or liquid biofuels which may add cost to council operations.

10 Exclusions

The Cenex biomethane calculator does not include for the capital and maintenance cost of an AD facility, which is assumed to be similar for both CHP and vehicle fuel applications. The calculator also excludes revenues gained through diverting waste from landfill. Hence, capital and maintenance costs may be neutralised depending on the value of the waste diverted from landfill.

The Cenex biomethane calculator has been designed to give an indicative production quantity of biomethane and an indicative revenue value in both CHP and vehicle applications. This should allow a quantative decision to be made on whether a more detailed engineering and financial analysis for a particular AD programme should be progressed. All units are quoted as output from the calculator tool, unit resolution does not relate to the accuracy. Cenex accept no responsibility for decisions made on the basis of toolkit analysis data only and any reliance placed on the information is therefore strictly at the Clients risk.