Biogas as a road transport fuel

An assessment of the potential role of biogas as a renewable transport fuel

Research undertaken for the National Society for Clean Air and Environmental Protection

Biogas is produced from the process of anaerobic digestion of wet organic waste, such as cattle and pig slurries, food wastes and grown wet biomass. There is growing interest in its use as a fuel for transport applications. Drivers include the increasing regulation and taxes on waste disposal, an increasing need for renewable fuel sources and measures to improve air quality. The Government's biomass task force recently recommended that "the Government carries out an economic and environmental assessment of the potential of AD biogas as an alternative (renewable) fuel to displace diesel." The aim of this report is to explore the idea put forward by the biomass task force and others, that there is a role for biogas in transport. It is believed to be the first time this issue has been studied at a broad policy level.

This report presents the findings of a research project assessing the potential role of biogas as a transport fuel. It was funded by BOC Foundation, Greenwich Council, The Energy Savings Trust, and Cenex. For further details of the research and of the funders, see inside back cover.

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ISBN 0 903 47461 1
ISBN 978 0 903 47461 1

Produced and printed in England

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Executive Summary

There is growing interest in the use of biogas as a fuel for transport applications. Some of the drivers behind this are the increasing regulation and taxes on waste disposal, an increasing need for renewable fuel sources, the EC's Biofuels Directive, the proposed Renewable Transport Fuel Obligation (RTFO), measures to improve local air quality and the need for clean transport fuels in urban areas. The aim of this study is to examine the potential role of biogas as a transport fuel in the UK.

The report sets out the resource that is available for producing biogas, together with the basic details of production technology and estimates the theoretical maximum amount of gas that could be produced in the UK. It goes on to explore how this gas can be used in vehicles, describing the basic technology requirements, vehicle availability and fuel supply issues. The energy and emissions data on biogas as a transport fuel are analysed, and the costs of producing and using the fuel are also estimated.

Experiences of developing and using biogas and gas vehicles in the UK and other countries, and the lessons learnt are outlined. Building on this experience, two scenarios are developed for the use of biogas as a transport fuel in the UK: a high scenario and a low scenario, and the environmental impacts of both estimated. The market barriers and means of overcoming them are also examined.

Conclusions from the Research

- The main feedstocks for biogas production through anaerobic digestion (AD) are agricultural manure wastes and food wastes. The UK generates some 30 million dry tonnes of this waste material a year, capable of producing some 6.3 million tonnes of oil equivalent of methane gas. Theoretically this could meet around 16% of transport fuel demand;

- To be used as a transport fuel biogas has to be upgraded to at least 95% methane by volume and it can then be used in vehicles originally modified to operate on natural gas. However, there is little availability of gas-fuelled vehicles and a very limited refuelling infrastructure;

- Biogas fuelled vehicles can reduce CO_2 emissions by between 75% and 200% compared with fossil fuels. The higher figure is for liquid manure as a feedstock and shows a negative carbon dioxide contribution which arises because liquid manure left untreated generates methane emissions, which are 21 times more powerful as a greenhouse gas than CO_2. Hence there is a double benefit by reducing fossil emissions from burning diesel and reducing methane emissions from waste manure;

- Biogas will give lower exhaust emissions than fossil fuels, and so help to improve local air quality, although technology changes in future years – for example, the introduction of particulate traps and selective catalytic reduction – may reduce this advantage;

- The availability of cost data for biogas production is poor, but data from Sweden and the US suggest that biogas can be produced in the UK at a cost of between 50-60p/kg, including duty (at the reduced rate of 9p/kg) but excluding VAT. This range is comparable to the current price of CNG at around 55p/kg;

- Nevertheless, the economics of using biogas or CNG sold at this price as a vehicle fuel are not very attractive. In terms of fuel costs, biogas is about 40% cheaper to run than diesel and 55% cheaper to run than petrol, but these fuel cost savings are off-set by higher capital costs, some £25,000 for heavy duty vehicles and £5,000 for light duty vehicles, and potentially higher maintenance costs. When these are taken into account only HGVs using gas are competitive with a diesel vehicle over an operating life of four years. This reflects the current market position where the only gas-fuelled vehicles having any success are HGVs operating on trunk routes;

- Currently all the biogas that is produced in the UK from both sewage treatment and landfill is used to produce electricity and heat. The environmental and economic factors involved suggest that electricity production from biogas offers greater CO_2 saving benefits and better economics and requires a lower subsidy (in the form of the Renewables Obligation) than biogas used for road transport. However, the balance is fairly fine and our simple analysis would bear much greater study to get a more robust answer to this question. It also suggests that only small changes in the economic variables on each side of the equation could switch the balance. For example the current rises in oil prices or the inclusion of biogas in the Renewable Transport Fuels Obligation (RTFO) could shift the balance;

- The CO_2 benefits of biogas compared to other transport fuels seem fairly strong. However, if the UK is to pursue a policy of using biogas for transport it will be important to incentivise the market for biogas rather than the production plant itself. The main mechanisms that could be used are discussed in the report and include the RTFO, fuel duty rebates, vehicle grants and infrastructure grants;

- There is a significant resource available for the production of biogas in the UK allowing us both to manage a waste issue and to provide a source of renewable fuel. In developing a biogas industry a number of disciplines are involved from waste management, through energy use and production to transport operation. Success factors in other countries have been a greater level of integration of actors in the value chain such as the municipal authority, waste management organisations and transport operators. It is this level of integration and an appropriate policy framework that will be needed in the UK.

Recommendations

This study has really only been the start of examining all the issues around the role of biogas as transport fuel. The main issues that warrant further study are:

- How is the market for anaerobic digestion likely to grow in the future, compared to other waste management technologies and new technical developments, and what is a realistic level of biogas production and at what cost in the UK?
- Is there a role for biogas from energy crops and how does this compare with other uses of energy crops?
- How does using biogas for transport compare with using it to produce electricity, considering a range of environmental and economic factors, practicality and societal needs? Therefore what is the best use of this biogas resource?
- In relation to the above there is also a need for more detailed work on:
  - the energy, carbon and air pollutant emissions life cycle for biogas as a transport fuel;
  - a better handle on the whole issue of the economics of production and use of biogas as this is still fairly opaque;
- In the longer term it is also important to explore further the potential role of biogas in a hydrogen economy, as it is one of the routes to renewable hydrogen;
- Finally there is a need to examine in more detail the different incentives that are available to support biogas, their likely impacts and the most sensible package of support.

On a more practical level addressing some of these questions could be supported by one or more demonstration projects, building on the work of existing biogas plant to build practical hands-on experience of how a biogas industry can develop.

Contents

1: Introduction

Biogas is produced from the process of anaerobic digestion (AD) of wet organic waste, such as cattle and pig slurries, food wastes and grown wet biomass. The AD process produces CO_2, methane and a digestate that can be used as fertiliser. The methane (biogas) can be burned to provide heat and/or electricity, or it can be used as a transport fuel in compressed form in the same way as compressed natural gas (CNG). This report examines the role that biogas can play as a transport fuel.

1.1 The Drivers for Biogas as a Transport Fuel

There is increasing interest in the use of biogas as a fuel for heat and electricity production, and as transport fuel. The key drivers behind this are:

- The increasing regulation and taxes on waste disposal such as the landfill tax, the landfill allowance and trading scheme and the animal by-products regulations, which are forcing local authorities and the waste industry to look for new routes for treating organic waste;
- An increasing need for renewable fuel sources to help reduce our carbon emissions and mitigate climate change and, supported by the climate change programme, the Renewables Obligation, as well as the EC's Biofuels Directive and the proposed Renewable Transport Fuel Obligation (RTFO);
- The recent report from the Government's biomass task force, which is looking to promote greater use of biomass in the UK;
- Measures to improve local air quality and the need for clean transport fuels in urban areas.

The Government's biomass task force, although focusing on heat and electricity, sees a role for biogas in transport and has as one of its recommendations that "the Government carries out an economic and environmental assessment of the potential for AD biogas to replace fossil diesel." This report aims to go some way towards addressing this recommendation.

Similarly the recent proposals for an RTFO will be particularly important in the future development of biogas as a transport fuel. The current proposal for the obligation does not include biogas, but this is under review as part of the development of the full scheme.

1.2 Study Objectives and Methodology

The aim of this study was to explore the idea put forward by the Government's biomass task force and others that there is a role for biogas in transport in the UK. As such it is perhaps the first time this issue has been studied at a broad policy level. In particular the study has attempted to address the following questions:

- What is the theoretical and practical biogas resource available from the UK waste stream?
- What technologies are available to produce biogas suitable for transport applications?
- What are the technical and practical issues concerned with developing a biogas-powered vehicle fleet?
- What is the current state of experience with transport biogas in the EU and UK?
- What is a realistic scenario for transport biogas within the UK energy matrix?
- What are the costs and environmental benefits of a biogas fleet in the UK?

To address these issues the study comprised two main elements:

1. A desk review – pulling together the major available information and reports on biogas and transport, covering the potential resource in the UK, production technology, production costs, vehicle and fleet issues and existing experience in the EU and UK.

2. A scenario analysis – the data from the desk review was used to carry out a cost analysis of producing biogas for transport use, and to estimate the environmental impacts/benefits on a "well-to-wheels" basis, consider potential uptake scenarios in the UK and discuss possible policy measures for supporting the development of a market for biogas as a transport fuel.

1.3 Structure of the Report

This report sets out the findings of this study. Section 2 sets out the resource that is available for producing biogas, together with the basic details of production technology and estimates the theoretical maximum amount of gas that could be produced in the UK. Section 3 then explores how this gas can be used in vehicles, describing the basic technology requirements, and vehicle availability and fuel supply issues. The energy and emissions data on biogas as a transport fuel are set out in section 4 and the costs of producing and using the fuel are estimated in section 5.

Section 6 reviews experience of developing and using biogas and gas vehicles in the UK and other countries, and the lessons learnt from this experience. Building on this experience, section 7 proposes two scenarios for the development of biogas as a transport fuel in the UK: a high scenario and a low scenario, and the environmental impacts of these two scenarios are estimated. This section also looks at the potentials to developing this market and how these barriers may be overcome. Finally, section 8 summarises the conclusions from the research and gives recommendations for taking the debate forward.

2: Resource Availability and Production Technology

Biogas, a mixture of largely methane and carbon dioxide, is produced from the anaerobic digestion of organic materials. This section assesses the total amount of material potentially available to produce biogas in the UK, the production technology for the biogas production process, and the total amount of gas that could be produced.

2.1 Resource Availability

Biogas can be produced by the anaerobic digestion of a range of organic wastes, with the key wastes being:

- Sewage sludge;
- Wet manure slurries from intensive styles of agriculture;
- Dry manures from animal beddings, known as farm yard manure (FYM);
- Waste from food processing;
- Food and organic waste from restaurants and other commercial operations;
- Household kitchen and garden waste.

All these wastes can be treated in other ways as well, such as landfill, direct spreading to land and composting. These alternatives may not be without value and are shown in Figure 2.1 – The Biogas Route Map. Each of these main waste areas is discussed briefly below, with the potential resource available shown in Table 2.1.

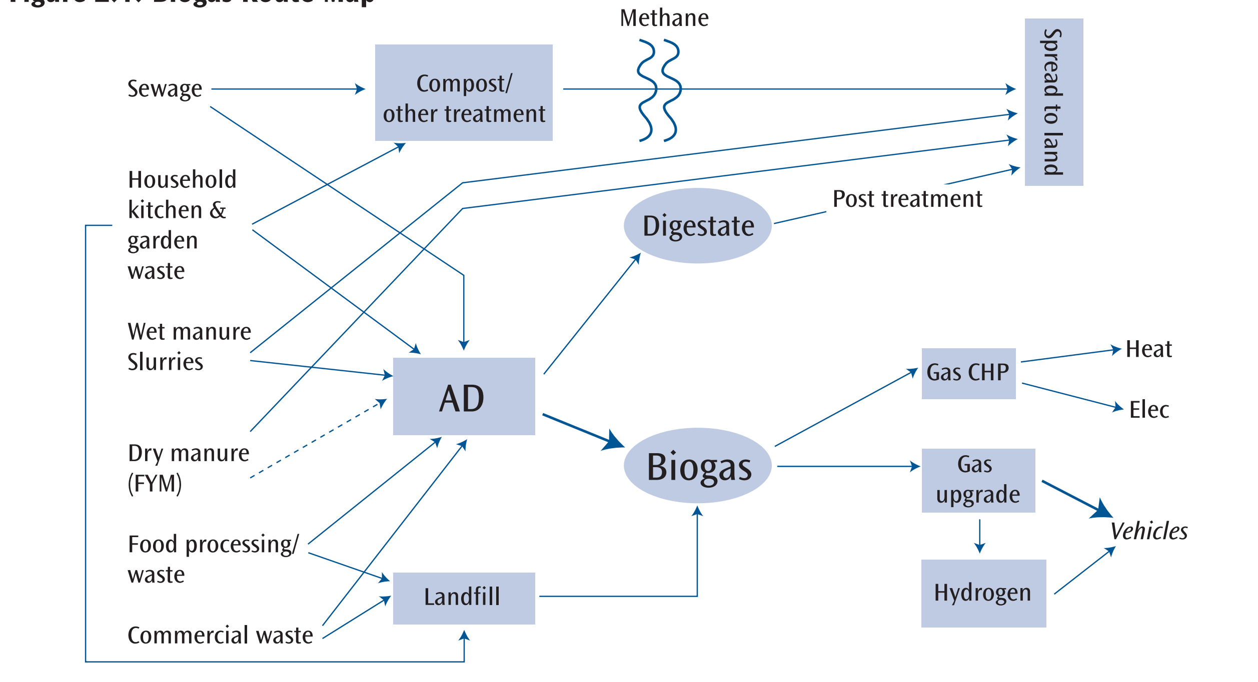
Sewage sludge

There are about 35 million tonnes of sewage sludge produced each year. Initial treatment through settling tanks and other processes including some anaerobic digestion reduces this amount to some 25 million tonnes. Currently 55% of the sludge is spread direct to land, 25% is incinerated, 9% goes to landfill and 12% is disposed in other ways[1]. The amount spread to land is considered a valuable agricultural resource, and is used for soil conditioning.

Currently a small amount of the raw sewage sludge is treated by anaerobic digestion (AD) to produce biogas and a semi-solid digestate that is generally spread back to land. The digestate from the AD process is potentially a better soil conditioner than direct spreading of the raw sludge as it is much lower in pathogens (which reduce the smell) whilst it still contains all the nutrients. Data from the DTI suggests that there are currently some 38 digestion plants related to sewage works[2]. These plants are those that have been registered under the Non Fossil Fuel Obligation (NFFO) and are using the biogas to generate electricity and a small amount of heat. Much of this energy is being used in the process itself, especially the heat, with the remainder being sold under the NFFO agreement.

Theoretically all of the raw sewage sludge could be treated by AD, although there will be issues of practical scale for some of the smaller plants. Therefore with an estimated solid content of 4% there is a resource of some 1.4 million dry tonnes of sewage sludge as a feedstock for AD in the UK, which at present is largely untapped.

Figure 2.1: Biogas Route Map



1 Data from the DEFRA waste online website
2 Based on plants with NFFO contracts, from DTI data

Table 2.1: Total Feedstock Availability

Material	Dry tonnes per year	Current disposal routes				
		Landfill	Spreading	Compost	Incineration	Other
Sewage sludge	1,400,000	9%	54%		25%	12%
Wet manure slurries						
Dairy cattle	2,016,000		100%			
Pig manure	535,000		100%			
All poultry	1,515,000		100%			
Dry manure						
Cattle	6,253,140		100%			
Pig	4,532,414		100%			
Horses	458,172		100%			
Commercial food waste	6,295,000	11%	11%	49%	10%	19%
Domestic food waste	7,510,644	72%		9%	19%	
Total	30,515,370	20%	55%	12%	8%	4%

Notes:
1 Sewage sludge from DEFRA waste online website
2 Animal manure data taken from Biomass task force report, 2006
3 Commercial waste data from Environment Agency Commercial and industrial waste survey 2002/3
4 Domestic waste data from DEFRA annual waste arising survey 2003 and OU Household waste survey 2004

Wet manure slurries
Agriculture produces a large amount of organic waste that can be processed through AD to produce biogas and a digestate for soil conditioning. Wet manure slurries are the waste most commonly associated with AD including pig slurries from slatted and part slatted pig systems, slurries from dairy herds in winter housing, and poultry manure. Traditionally this material is spread back to land like sewage sludge. However, the material naturally degrades whilst in storage and produces significant amounts of methane, a powerful greenhouse gas. The National Emissions Inventory estimates that there are about 260,000 tonnes of methane emissions from animal wastes each year.

Dry animal manures (Farm yard manure)
In addition to the wet animal slurries there is a large amount of straw based animal bedding that is again traditionally spread back to land. These slurries could also be digested. Whilst the quantities involved are large, they are widely dispersed and land spreading is a practical use of this material by farmers. So although this is a potential material for AD plants, it is likely to be a longer-term option for use in AD.

Wastes from food processing and commercial premises
Another source of high quality organic matter is waste from the food processing industry, catering outlets and other commercial premises. Waste management in this area is changing dramatically with the new animal by-products directive that is forcing companies to look at new disposal routes. Anaerobic digestion offers a suitable disposal route for this material, with the added advantage of producing a useable energy by-product in the form of biogas. The Environment Agency's commercial and industrial waste survey in 2002/3 estimated that the amount of food and animal waste available from this source was some 6.3 million tonnes. This waste stream is already quite well segregated and so a considerable amount, some 49%, is already composted or recycled.

Household waste
There are about 30 million tonnes of domestic waste collected each year, with around 24% of this being kitchen waste – some 7.5 million tonnes[3]. Additionally there are another 4.2 million tonnes (17%) that is garden waste. Currently about 15% of the garden waste is recycled through composting schemes, and this level of composting is set to increase. We have assumed that in general garden waste will continue to be recycled through composting schemes and have, therefore, only included food waste in the resource potential in Table 2.1.

Energy crops
Lastly it is possible to grow crops such as forage (grass), straw and maize, specifically as a feedstock for an AD process. However, no estimate has been made of the available resource that could be used for AD and none has been included in Table 2.1. This is a resource that may only be developed after AD is established with waste feedstocks, and when the economics make it possible to produce gas from specifically grown feedstocks. However, there is increasing interest in this feedstock especially as technologies improve, with the potential for the methanisation of syngas produced via the thermal treatment of lignocelluloses feedstocks. Some studies have suggested that the energy yield from using crops to produce biogas is significantly better than for biodiesel or bioethanol.[4]

3 DEFRA annual waste arisings survey 2003 and Open University household waste survey 2004
4 'Summary and analysis of the production of bio-methane in Sweden, BioMil and the Swedish Gas Centre, March 2005

2.2 Production Technology

There are three key elements in the anaerobic digestion process:

- Pre-digestion treatments
- Digestion
- Post digestion treatment of the biogas and digestate

2.2.1 Pre-Treatments

The main aim of pre-treatments is to get the material being digested into a suitable form. The necessary pre-treatments will depend on the feedstock being used but can include:

- Sorting and removal of inorganic materials such as stones, grit and glass;
- Shredding or maceration to reduce the size of the material being digested;
- Mixing different feedstocks together if more than one is being used;
- Adding water or other liquids;
- Pasteurisation or sterilisation of some feedstocks such as animal by-products to reduce pathogens.

The pre-treat elements can be a significant part of the process and when the plant is used for municipal waste the pre-treat is often part of a wider municipal waste sorting facility. Recently considerable research has gone into pre-treatment methods in order to improve the digestion process and increase gas yields.

2.2.2 Digestion

This is the main part of the process where the material is naturally degraded (digested) by bacteria in sealed airtight vessels. There are a range of characteristics that define the different types of digesters. The key characteristics are:

Low or high solid digesters – low solid digesters treat material that is in a fairly liquid state with between 15-20% solids, such as sewage sludge or manure slurries, and require continuous mixing. High solid digesters have material with 20-40% solids with the material feed-in on belts or screws. These systems do not have internal mixing, and are generally smaller as they can take more organic material per volume.

Single or multi stage systems – the digestion process is actually comprised of several distinct phases. The main stages are hydrolysis and acidogenesis, where the material is broken down into simple organic acids, and methanogenesis where the methane is formed. A single-stage digester carries out all stages of digestion in a single vessel, a multistage digester aims to optimise the process by different vessels carrying out different parts of the process. Typically a multistage digester has two vessels optimising the two processes set out above.

Mesophilic and thermophilic systems – mesophilic systems operate at around 35°C and require little external heating; thermophilic systems operate at 55°C and require considerably more heating energy. Mesophilic systems tend to produce less gas and have a retention time for the material being digested of 15-30 days. Thermophilic systems tend to produce more gas and, although harder to control, do have a shorter retention time of 12-15 days.

Batch or continuous flow systems – as the name suggests, some systems are batch systems where the material is fed in one go and left for the full retention time, whereas continuous flow systems gradually feed material into the system and draw off gas and digestate at the same time. Smaller systems tend to be batch and larger systems continuous.

Traditional digesters were low solid, single stage, mesophilic digesters such as have been used in the sewage treatment industry for many years. However, as the range of material being digested has increased and the economics of using the gas for power and energy has grown, systems have moved to try to obtain better gas yields. This has seen a move to higher solids systems, with multi-stages and thermophilic processes. However, there is still considerable scope for continuing to optimise systems for better gas production.

2.2.3 Post-Treatment[5]

The main post treatment of concern in this study is the cleaning or 'upgrading' of the raw biogas to make it suitable for use in vehicles. There may also be a need to process the digestate.

Gas upgrading

Once the raw gas has been produced from the digestion process, it has to be upgraded to natural gas quality in order to be used in normal vehicles, that are designed to use natural gas. In practice this means that carbon dioxide (CO_2), hydrogen sulphide (H_2S), ammonia, particles and water (and sometimes other trace compounds) have to be removed so that the product gas for vehicle use has a methane content of about 95-98% by volume. In different countries, there are different fuel quality standards for vehicle fuel use (see section 3.2). This upgraded gas is generally referred to as bio-methane and this is the term best representing upgraded biogas used in vehicles as opposed to the raw gas produced by the AD process. Gas upgrading is normally performed in two steps where the main step is the process that removes the CO_2 from the gas. Other contaminants (e.g. H_2S) are normally removed before the CO_2-removal and the water dew point can be adjusted before or after the upgrading (depending on process). The processes used in biogas upgrading are reasonably well developed.

Carbon dioxide removal

For an effective use of biogas as a vehicle fuel, it has to be enriched in methane. This is primarily achieved by carbon dioxide removal, which also provides a consistent gas quality with respect to energy value. At present four different methods are used commercially for carbon dioxide removal, but the most common technologies for biogas upgrading are the water scrubber technology and the pressure-swing-absorption technology.

Hydrogen sulphide removal

Hydrogen sulphide is always present in biogas, although concentrations vary with the feedstock. It has to be removed

5 Sources: "Biogas upgrading and utilisation", IEA Bioenergy Task 24, Paris, 1999; and "Anaerobic Digestion of Agro-industrial wastes – Technical summary on gas treatment", AD-NETT, Novem, 2000

in order to avoid corrosion in compressors, gas storage tanks and engines. Several methods have been developed. Based on the Swedish experience, air-oxygen dosing in the biogas and iron chloride dosing to the digester slurry are the most suitable for small-scale operations. For larger scale operations when upgrading to natural gas quality is the objective, chemical absorption of H_2S might become more feasible.

Water removal
Several methods are available based on separation of condensed water or using gas drying. For upgrading to natural gas quality, gas drying techniques are preferred.

Digestate treatment
The digestate that is produced by the process can also be treated further. Commonly the digestate is settled out to provide a liquid fertiliser and a semi-solid sludge, both of which can be spread direct back to the land as soil conditions. The solid digestate can also be treated further by composting, drying or pelleting to get a more manageable or friable product to be used for a range of horticultural purposes.

2.3 Gas Potential

The gas generated by anaerobic digestion depends both on the feedstock being used and the efficiency of the digestion process. The efficiency of digesters has been improving over the last 10 years or so as have the gas yields, as AD has moved from being just a waste treatment process to a waste and energy generation process. Early digesters that were used for sewage treatment were typically producing 100m^3 or less of methane per tonne of input material. More modern systems which are treating mixed municipal waste are getting figures of 300m^3 of gas per tonne or more. The Environment Agency, in their information concerning waste treatment technology, suggest that this can be improved further.[6]

As well as the technology, the types of materials going into the digester have a large impact on gas yields. There are three basic aspects of the input material that affect gas yields: the total volatile solids in the material (i.e. the proportion of material that can be digested), the expected gas yield from the volatile solids, and the likely proportion of the biogas that is methane. These can be combined to give what we have termed the gas factor, the total methane yield per tonne of input material. Averaged data for a range of materials are shown in Table 2.2.

This shows that manures give lower yields than food wastes. This is because the manures have already been digested once in the animal gut and so the gas potential is lower. Therefore gas yields for digesters taking farm waste can be increased by including some food wastes.

Using the gas factor for the various feedstocks and the estimated amounts of available feedstock we can calculate the total amount of gas that could be produced by AD in the UK. This data is shown in Table 2.3.

Based on this data we have a total gas potential from AD in the UK of some 7.4 billion cubic metres of methane. This is equivalent to some 263,000 TJ of energy or 6.3 million tonnes of oil equivalent. If all of this energy were used for transport it would replace around 16% of our current road transport fuel demand[7]. It is also clear that the largest potential for biogas is from food waste due to the amount available and its potential for high gas yields.

The only elements of this potential that are already being tapped are the digestion of sewage sludge and landfill gas.

Table 2.2: Approximate Estimated Methane Yields for a Range of Feedstocks

Material	% volatile solids	Gas yield in m3/kg	% CH4	gas factor, m^3/tonne
Sewage sludge	0.75	0.4	0.65	195
Wet manure slurries				0
Dairy cattle	0.8	0.25	0.65	130
Pig manure	0.75	0.4	0.65	195
All poultry	0.75	0.45	0.7	236.25
Dry manure				0
Cattle	0.8	0.2	1	160
Pig	0.9	0.2	1	180
Horses	0.25	0.3	1	75
Commercial food waste	0.8	0.55	0.75	330
Domestic food waste	0.8	0.55	0.75	330

Notes:
1 Data for wet slurries and food waste taken from 'An introduction to anaerobic digestion of organic wastes', Fabien Monnet, 2003, for Remade Scotland
2 Data for dry manure taken from a private communication with Clare Lukehurst, adviser to Community Renewables Initiative, from her response to the biomass task force draft report, 2006
3 Sewage sludge data assumed the same as pig manure

6 Environment Agency Waste Technology data centre on their website and personal communication with Don Ridley at the Environment Agency
7 DTI figures for transport fuel use in 2004 were 38 million tonnes of petrol and diesel

Table 2.3: Total Methane Potential from AD in the UK

Material	Dry tonnes per year	Gas factor, m3/tonne	Total CH4	Energy value,TJ	Tonnes of Oil equivalent
Sewage sludge	1,400,000	195	273,000,000	9,719	231,400
Wet manure slurries					
Dairy cattle	2,016,000	130	262,080,000	9,330	222,144
Pig manure	535,000	195	104,325,000	3,714	88,428
All poultry	1,515,000	236.25	357,918,750	12,742	303,379
Dry manure					
Cattle	6,253,140	160	1,000,502,400	35,618	848,045
Pig	4,532,414	180	815,834,520	29,044	691,517
Horses	458,172	75	34,362,900	1,223	29,127
Commercial food waste	6,295,000	330	2,077,350,000	73,954	1,760,801
Domestic food waste	7,510,644	330	2,478,512,520	88,235	2,100,834
Total	30,515,370		7,403,886,090	263,578	6,275,675

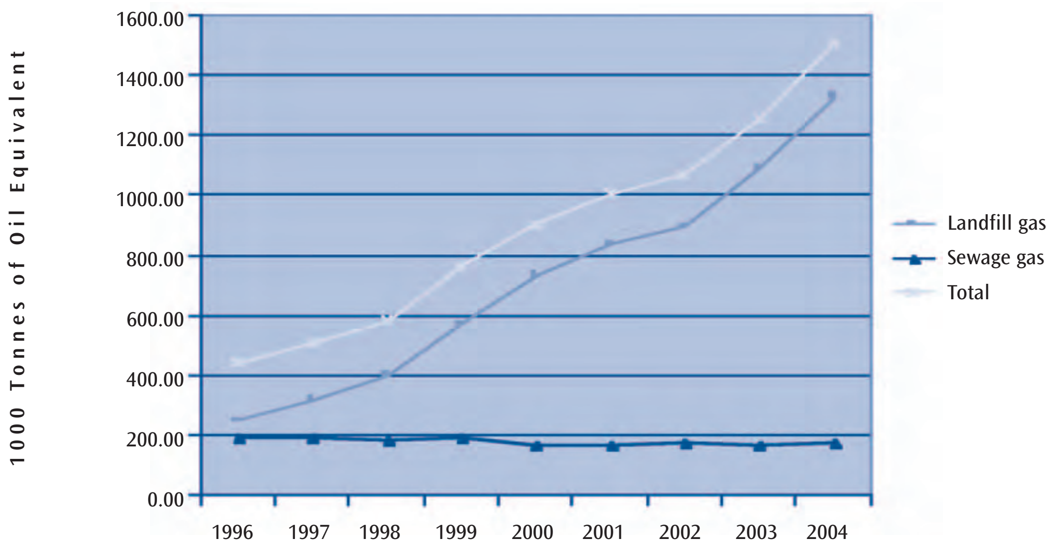
Notes:
1 The energy content values are taken from DTI energy statistics
2 Landfill gas is not included

Landfill gas is effectively uncontrolled anaerobic digestion of the organic content of current waste going to landfill. These two sources of biogas are currently being used to produce heat and electricity. Under the Non-Fossil Fuel Obligation (NFFO) and the current Renewables Obligation, DTI data suggests there are some 38 AD plants at sewage works with a capacity of 61 MW, and 308 generating plants from landfill gas with a capacity of 660MW.

The total amount of biogas generated from these sites is shown in Figure 2.2. This is based on electricity production data from the DTI and assumes a 30% conversion efficiency from gas to electricity. From this we can see that the use of AD in sewage works has been relatively constant over the last 10 years. By contrast, the use of landfill gas has been growing rapidly.

The data suggests that we already capture most of our sewage waste, about 75%, for production of biogas and have a significant amount of landfill gas. These two sources together are equivalent to about 24% of the total maximum we could produce from AD. However, the amount of landfill gas will decrease in the future as the UK is forced to reduce the amount of organic waste sent to landfill due to the EU Landfill Directive. This organic waste will be directed to other treatment processes, with one of them being AD. The development of the AD sector and the true economic potential for AD in the UK will then depend on the economics of other routes for treating organic wastes and the relative markets for biogas.

Figure 2.2: Current Biogas Generated from Landfill and Sewage Treatment



3: Use of Biogas in Vehicles

3.1 Vehicle technology

3.1.1 Light-Duty Vehicles

Light-duty vehicles fuelled by natural gas or bio-methane will almost without exception be fitted with spark-ignition engines running at stoichiometric air:fuel ratios and will be fitted with a three way catalytic converter. In most cases these vehicles will be what is called "bi-fuel", where they retain a petrol system alongside the gas system. This allows the vehicle to be run on either petrol or gas, as circumstances require. However, in some cases the vehicle is designed to run solely on natural gas or bio-methane and is optimised for operation on this single fuel.

3.1.2 Heavy-Duty Vehicles

The position with heavy-duty engines is somewhat different with both lean-burn and stoichiometric spark-ignition engines being made available in the market. These engines are based on the larger diesel engines, although they use spark-ignition rather than compression ignition. These engines, not being derived from petrol-engines, are always designed to operate solely on gas as dedicated gas engines. These engines are also up to 50% quieter than their diesel equivalents.

There has also been some development in the substitution of diesel by gaseous fuels, both NG and LPG. These systems are referred to as "dual fuel" engines and use diesel as pilot ignition. The gaseous fuel is introduced into the cylinder with varying degrees of precision, ranging from fumigation of the inlet manifold to much more accurate injection into the individual ports of the engines onto the back of the inlet valves. High rates of substitution of CNG for diesel, sometimes up to 90% have been claimed. However an average of 70% is representative of fleet operation. This approach allows a vehicle to operate with the low emission benefits of natural gas whilst retaining the inherent power, efficiency and long life of compression ignition engines.

3.1.3 Fuel Storage

The gas fuel is stored on the vehicle in one of two basic forms – compressed or liquefied. Use in the compressed form, such as compressed natural gas (CNG), is the most common form of fuel storage on the vehicle. The gas is stored at high pressure, some 200 bar, in tanks. The amount of energy stored in compressed gas is significantly less than the energy stored in the same volume of liquid fuel such as diesel. Therefore the operating range of vehicles tends to be reduced.

To get round this range issue, some vehicles store the gas in liquefied form commonly known as liquefied natural gas (LNG). The gas is both cooled and compressed to become a liquid, which is again stored in high-pressure tanks on the vehicle. This method is more common in heavy vehicles as range and payload are more critical to the vehicle operation.

3.2 Fuel Quality and Supply Issues

Varying natural gas or biogas quality beyond acceptable limits can be detrimental to engine performance. One of the major concerns in varying natural gas compositions in reciprocating engines is engine knock. The anti-knock property of natural gas can be expressed as methane number and is analogous to octane rating of gasoline. In addition to the anti-knock quality, the operating performance of an engine on a low methane number fuel may be important. Low methane number is usually the result of the presence of high hydrocarbons in the fuel. In addition to the methane number, the Wobbe index is also an important parameter for gas engines as it determines both the power and equivalence ratio and changes that might result in poor operational and environmental performance.

The Wobbe index is a calculated number – the calorific value of the gas divided by the square root of the relative density, i.e. $CV/\sqrt{RD}$ where CV is the calorific value and RD is the density of the gas relative to air. The CV and RD combined in this way provide an indication of how energy can be delivered to the burner, in the case of a domestic appliance, or the combustion system in the case of an internal combustion engine.

3.2.1 Natural Gas Standards for Homologation

The fuels used in the process for homologation of the emissions performance of light-duty vehicles and heavy-duty engines are specified such that the vehicle/engine will be able to maintain its emissions and durability performance on gases likely to be found across the European gas supply market.

In the case of Natural Gas there are generally two types of fuel, high calorific value gas (H-gas) and low calorific gas (L-gas). These gases differ significantly in their energy content expressed by the Wobbe Index, and also in their λ-shift factor. Natural gases with a λ-shift factor between 0.89 and 1.08 are considered to belong to the H-range, while natural gases with a λ-shift factor between 1.08 and 1.19 are considered to be in the L-range. The composition of the reference fuels used for homologation purposes reflects the extreme variation of λ-shift factor. The Reference fuels used for homologation comprise two groups of fuels in the following ranges:

- The H-range, whose extreme reference fuels are G_R and G_{23},
- The L-range, whose extreme reference fuels are G_{23} and G_{25}.

The characteristics of G_R, G_{23} and G_{25} reference fuels are summarised in Table 3.1. When vehicles are tested they are approved using these test fuels to ensure that they will perform on typical gas compositions that they are likely to encounter. Heavy-duty vehicles can be approved across all fuel ranges by testing on G_R and G_{25}, or approved for a restricted range of gases, either H-Range or L-Range gases. Light-duty vehicles are tested for operation across the full range of gases and so are tested on G_{25} and G_{20}.

Table 3.1: Gas standards for vehicle emissions testing

Characteristics	Units	G_R	G_{23}	G_{25}	G_{20}
Methane	%-mole	87 ± 2	92.5 ± 1	86 ± 2	100
Ethane	%-mole	13 ± 2	-	-	-
Balance (*)	%-mole	1	1	1	1
N_2	%-mole	-	7.5 ± 1	14 ± 2	-
Sulphur	mg/m³	10	10	10	10

* Inerts + C_{2+}

Table 3.2: Properties of Swedish Biogas to SS 15 54 38

Property	Units	Requirement Type A	Requirement Type B	Test Method
Wobbe index $_{lower}$ (1)	MJ/m³	44.7 – 46.4	43.9 – 47.3	SS-ISO 6976
Methane (volume at 273 K, 101.3 kPa)	%	97±1	97±2	ISO 6974
Motor Octane Number (MON)		130	130	2)
Dewpoint at highest storage pressure t = lowest monthly daily average temperature	°C	t - 5	t - 5	ISO 6327
Water content	mg/m³	32	32	SS-EN ISO 10101-1, -2,-3
$CO_2 + O_2 + N_2$ by volume, max. Of which O_2, max	% %	4,0 1.0	5,0 1.0	ISO 6974
Total sulphur	mg/m³	23	23	ISO 6326-1,-2,-4 SS-EN ISO -3,-5
Total nitrogen compounds calculated as NH_3	mg/m³	20	20	ISO 6974 5)
Alcohol		6)	6)	

3.2.2 Standards for Biogas

There is currently only one standard adopted within an EU member state for the use of Biogas as a transport fuel. Sweden has a published standard - SS 15 54 38 : "Motor fuels – Biogas as fuel for high-speed otto engines".

The standard deals with specific characteristics relevant to the use and storage of biogas produced by anaerobic digestion for use as a motor fuel. It does not cover fuel which might be mixed with other compounds, e.g. hydrogen, propane etc. Consequently the standard reflects a fuel with a high methane number. In addition, production of fuels in Sweden is governed by a number of regulations which must be adhered to as appropriate. Biogas produced to this standard is able to be used in engines developed for use on Natural Gas without modification[8]. Two gas specifications are provided, Biogas A for engines without λ-control, and Biogas B for engines with λ-control. The characteristics of the two gases are shown in Table 3.2.

Biogas produced to this standard is subject to a number of storage and handling requirements:

- It shall not include dirt, oil or other substances which can damage engine fuel systems;
- The potential for oil carry-over from gas compressors needs to be mitigated by the use of molecular oil filters downstream of the compressor;
- Alcohol may not be added to avoid freezing as this can cause corrosion in storage tanks;
- The gas shall be odorised to enable the detection of gas at up to a concentration of 20% of its flammability limit. The odorising medium shall not be harmful to health. It may also increase the sulphur content in the fuel.

The upper Wobbe index limit for types A and B gases specified in the standard are below the upper limit of 51.85 MJ/m³ specified in the GS(M)R regulations so gases produced to this standard should be acceptable for introduction into the UK national grid.

8 There is already a standard for natural gas vehicles, and industry sources suggest that biogas will have to conform to this standard

3.2.3 Refuelling Stations

There are two basic methods of fuelling compressed natural gas vehicles: slow-fill and fast-fill. Slow fill systems take gas directly from the compressor into the vehicle. Refuelling time for a large vehicle can be in excess of three hours and these systems are therefore only suitable when sufficient refuelling time is available outside the hours of operation, e.g. bus operations overnight. Fast fill systems using compressors and cascade fuel storage tanks can refuel vehicles in about the same time or a little longer than normal liquid fuel vehicles.

In the UK, the large fleet operators, and particularly those with heavy-duty vehicles, typically tend to have their own fuelling facilities because they receive price discounts for the large volumes of fuel that they purchase. Also, fleets have their own maintenance facilities and tend to prefer staying in control of their fuelling equipment and operations.

Liquefied natural gas requires a completely different set of fuelling considerations since it is a cryogenic, liquid fuel. Special insulated storage tanks are required to store the fuel on site and LNG vehicles can only fuel on a fast-fill basis. However, the need to locate next to a gas supply main, as with CNG stations, is removed. This has caused some problems in planning approvals for CNG stations due to the access requirements of vehicles not being acceptable.

Compared with conventional refuelling stations the number of locations able to refuel vehicles with CNG or LNG is extremely limited on mainland Britain. The Energy Savings Trust state that there are 31 NG refuelling sites in the UK, all of which are associated with a fleet operator but allow third party access. This compares with a total (public and private) of 622 in Germany and 521 in Italy[9].

3.3 Vehicle Availability and Cost

On mainland Europe, the availability of natural gas fuelled vehicles and engines reflects the progress in the development of refuelling infrastructure, particularly in Germany and Italy. Passenger cars are available from European OEMs including Fiat, Opel, PSA, Ford, VW, Mercedes and Volvo. Vans are available from PSA, Fiat, Ford, Iveco, Daimler-Chrysler and Opel. Daimler-Chrysler, Volvo, Scania, Iveco, Cummins Westport, John Deere, Clean Air Power and MAN all offer CNG engines for use in trucks and buses. In addition the Czech Tedom group builds CNG buses with a Tedom engine, and the Czech Ekobus company build buses with engines from Cummins Westport. The only European manufacturer of HD engines without an NG option is the Dutch DAF group.

In contrast the availability of CNG fuelled vehicles in the UK is very poor, reflecting the poor provision of refuelling infrastructure and low interest from vehicle operators. It also means that care must be exercised in assessing the operating performance experience with CNG (and perhaps biogas) from a limited number of vehicle models.

3.3.1 Passenger Cars

The only OEM to offer CNG fuelled passenger cars in the UK is Volvo, who offers S60, S70, V70, variants. Inherent in the application of gaseous fuels to passenger cars has historically been a lack of range and impact upon load space. This impact has been removed in the range of bi-fuel Volvo CNG/petrol cars by engineering the gas tanks under the floor.

For example the Volvo S80 Bi-Fuel has a five cylinder, 2.4-litre bi-fuel engine powered by compressed natural gas (CNG) or biogas with gasoline as a back-up. The engine uses separate fuel systems, and automatically switches to the back-up gasoline system should the primary gas supply run out. Typically, a tank of CNG or biogas will give a range of 250-300 km (155-186 miles), and the reserve petrol tank provides an additional range of about 350 km (217 miles)[10]. A bi-fuel Volvo driven on biogas reduces greenhouse gases by almost 100%. Driving on CNG reduces greenhouse gas carbon dioxide emissions by approximately 25% compared to gasoline, according to Volvo's figures. Also according to Volvo, the operating costs of the bi-fuel cars are between 20-60% less than gasoline models, and 20-40% less than diesel, given current fuel costs and taxes[11].

As an example of emissions performance, the V70 estate powered by a 2.4 bi-fuel petrol/CNG engine has CO_2 emissions[12] of 169 gm/km compared with 166 gm/km for a 2004 1/2 MY Ford Mondeo Estate powered by a 90 PS 2.2 litre Duratorq diesel engines. NO_x emissions for the V70 are stated as 0.017 gm/km versus 0.197 gm/km for the Mondeo. Both vehicles comply with Euro IV emission standards.

3.3.2 Light-Goods Vehicles

Iveco and Daimler-Chrysler offer CNG versions of their most popular ranges, the Iveco Daily and the Mercedes-Benz Sprinter, although the Mercedes Sprinter has recently been discontinued. The Mercedes NGT Sprinter was a mono-fuel vehicle, utilising a dedicated engine optimised to run on NG. The standard fit tanks provide a quoted range of 250 km which might be considered low for some operations. Range can be extended to 350 km by fitting additional tanks, resulting in a 200 kg payload reduction penalty. The Daily CNG is mono-fuelled and is certified to EEV emission standards.

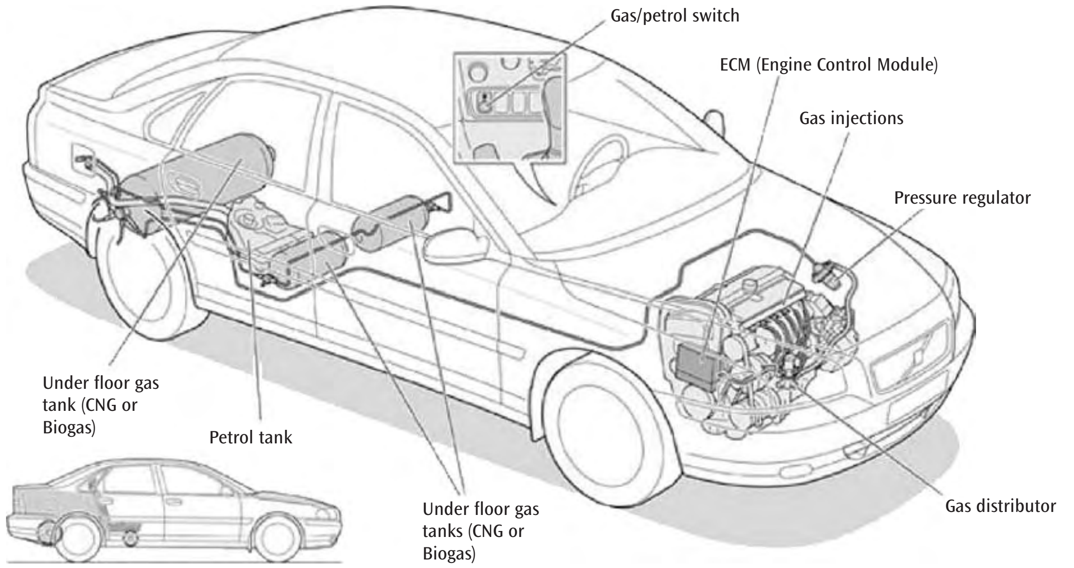
3.3.3 Buses and Heavy-Duty Vehicles

In the UK Daimler-Chrysler state that the Citaro 12 metre bus can be made available as a CNG variant meeting Euro IV emissions limits. In the medium-duty category, Iveco offer the Eurotech as a CNG variant in the UK. This vehicle is a dedicated CNG vehicle. The engine is certified in line with the Environmentally Enhanced Vehicle (EEV) standard indicated in the EU heavy-duty exhaust emissions directive.

At the heavy-duty end of the market, Foden offered a dual-fuel diesel/NG variant to the Alpha range of tractors and rigids powered by Caterpillar C-12 engines with Clean Air Power dual-fuel systems. These engines operate on both natural gas and diesel fuel simultaneously. During normal operation, the majority of the fuel burned is natural gas, while diesel fuel serves as a pilot for combustion. The engines have been certified to Euro IV emissions requirements. Fuel is stored as LNG in cryogenic tanks which provides an effective range on gas of around 500 km. Whilst this is below that associated with diesel operation, it is a practical option. For a diesel equivalent range, storage as CNG would require tanks 4-5 times as heavy as the standard

9 Gas Vehicle Report – January 2006
10 Information obtained from Volvo web sites
11 CNG fuel has a reduced fuel duty rate of 9p/kg
12 VCA fuel consumption database

Figure 3.1: The Volvo S80 Bi-Fuel[13]



diesel tanks which would be very expensive and reduce cargo capacity.

In addition Clean Air Power offer various conversions to allow engines to run on the dual fuel natural gas system. Recently they have developed a system for DAF trucks and are working on a Mercedes Axor version. Also the Hardstaff group offer engine repowering to DAF vehicles involving the Cummins Westport range of engines.

13 Diagram obtained from the Volvo website

4: The Energy and Emissions Footprint

This section examines the life-cycle carbon dioxide emissions and exhaust emissions of biogas compared to other vehicle fuels, specifically fossil petrol and diesel, and biodiesel, bioethanol and compressed natural gas. The data has been presented for light-duty vehicles, both cars and vans, and heavy-duty vehicles covering heavy goods vehicles (HGVs) and buses. The focus of the analysis has been on carbon emissions and the potential benefits of biogas against other biofuels.

In addition this section compares the carbon benefits of using biogas as a vehicle fuel with the benefits of using it for electricity production through the use of CHP. This allows us to consider what the most appropriate market may be for biogas either to produce electricity or as a vehicle fuel.

4.1 Life-Cycle Carbon Dioxide Emissions

The key study for estimating the life-cycle or well-to-wheel (WTW) energy and greenhouse gas (GHG) emissions was the *Well-to-Wheels analysis of future automotive fuels in the European Context* by Concawe/EUCAR/JRC (December 2005). This study provides the definitive data for a baseline 1.6 litre passenger car. To provide an estimate of the WTW energy and GHG figures for other vehicle types we combined:

- The well-to-tank (WTT) expended energy (i.e. excluding the energy content of the fuel itself) per unit energy content of the fuel,
- with the tank-to-wheels (TTW) energy consumed by the vehicle per unit distance covered for the other vehicle categories.

The GHG figures calculated with this process represent the total grams of CO_2 equivalent emitted in the process of delivering 100 km of vehicle motion on the New European Drive Cycle (NEDC), in the case of LDVs, or 100 km of operation under real world operating conditions in the case of HGVs of 38 tonne GVW and buses operating in an inner city environment.

Whilst Concawe analysed a formidable number of fuel pathways/technologies the following have been selected as reasonable comparisons for the purposes of this study:

- Conventional gasoline and diesel;
- CNG EU mix as applied to a stoichiometric spark ignition engine;
- LNG as applied to dual fuel diesel/NG;
- Biogas from municipal waste, liquid manure and dry manure as applied to a stoichiometric spark ignition engine;
- 100% and a 95/5 blend ethanol from sugar beet, pulp to fodder as applied to a port injected spark ignition;
- 100% and 95/5 blend RME, as applied to a compression ignition engine.

The calculated energy consumed per unit distance for each of the vehicles categories is shown in Table 4.1. The details of how this fuel consumption data was derived are discussed in Annex 1. This Table illustrates the difference in efficiency between the diesel (compression ignition) and gasoline (spark ignition) engines, with the diesel engine being some 15% more efficient. It also shows the differences in energy content of the fuel with, for example, considerable more ethanol compared to petrol needed to drive the same distance, due to the lower energy content of ethanol. These factors will affect the overall WTW energy use and emissions from the vehicle.

Using the base wheel to tank data from the Concawe report for a passenger car these fuel consumption figures are then used to calculate the WTW GHG emissions for each vehicle and fuel category. The results of these calculations are shown in Figures 4.1 to 4.4 including the base Concawe data for a passenger car. The Figures compare the WTW and TTW emissions for each of the fuels, allowing the relative impacts of each of the sides of the life-cycle to be seen.

The overall picture in all four cases is similar as you might expect. On a tank-to-wheel basis, the GHG exhaust emissions alone give the methane vehicles a slight benefit over diesel and biodiesel, and a more significant benefit over petrol and ethanol. On a well-to-wheel basis the reduction in GHGs compared to diesel is around 30% bioethanol, 50% for biodiesel and 75% to 200% for biogas. The greatest reduction in emissions is for biogas made from liquid manure. The reason the reduction is so high is that left untreated the liquid manure will give rise to substantial methane emissions, which are a potent greenhouse gas. So by processing this manure into biogas for use in vehicles you are not only replacing fossil fuel emissions, but also removing a source of methane emissions and so you get a double benefit.

This analysis suggests that biogas used in vehicles will give a substantial greenhouse gas emissions reduction benefit compared to both fossil fuels and other current liquid biofuels.

4.2 The Carbon Benefits of Vehicle Fuel vs Electricity Production

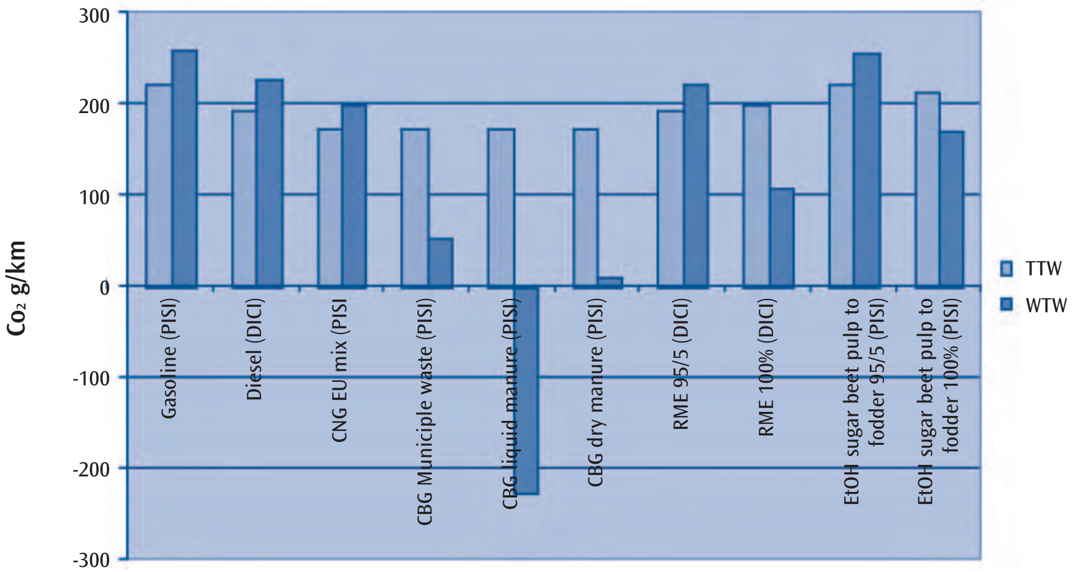
One of the questions raised by this study is whether from an environmental point of view it is better to use the biogas as a transport fuel or to produce electricity as is currently being done. This section addresses the question by looking at the amount of CO_2 that will be replaced by using the gas for either electricity production or as a vehicle fuel. The analysis is done on a simple replacement basis from the point at which the biogas has been produced. The benefits of methane removal from the feedstock are the same whichever route is chosen, so this is not considered in the analysis. The replacement is done on the basis of CO_2 emissions at point of use, i.e. exhaust emissions for vehicles, or combustion at the power plant for electricity, and so does not consider full life-cycle emissions.

Table 4.1: Calculated Fuel Consumption for Each Vehicle Category

		Fuel Consumption, kg/100km		
		LGV	**HGV**	**Bus**
Gasoline (PISI)		6.93	-	
Diesel (DICI)		5.95	31.4	44.84
CNG EU mix (PISI)		6.19	34.65	48.28
CBG Municipal Waste (PISI)		6.19	34.65	48.28
CBG liquid manure (PISI)		6.19	34.65	48.28
CBG dry manure (PISI)		6.19	34.65	48.28
Diesel/NG Dual fuel	Diesel	-	2.65	
	NG	-	25.38	
95/5 Ethanol (PISI)		7.06	-	
100% Ethanol (PISI)		10.96	-	
95/5 RME (DICI)		5.99	31.58	45.11
100% RME (DICI)		6.76	35.64	50.9

Notes: HGV based on 38 tonne artic, Bus based on 88-seat double deck bus

Figure 4.1: Greenhouse Gas Emissions for a 1.6 l Passenger Car



It is assumed that rate of biogas production from a normal mix of slurry and food wastes as feedstock material is approximately 250 m^3 of methane per tonne of material. The energy content of this volume of methane is 8,900 MJ or 2,472 kWh.

4.2.1 Biogas Production for Vehicles

When using the output gas for vehicle fuel it is necessary to account for the fact that some of the gas will be used for process energy, mainly heating. It is assumed that the amount of gas needed for this purpose is about 20%. This leaves a total amount of gas that can be used in vehicles per tonne of input material as 200m^3, the equivalent of 144 kg.

In terms of vehicle use we might assume that this gas is used in an HGV fleet as is currently the case for the majority of gas vehicles in the UK. The average fuel consumption for a typical large HGV using gas estimated above is 34.65 kg/100 km. Therefore 1 tonne of material producing 144 kg of useable gas would allow an HGV to travel 416 km. Based on the TTW CO_2 analysis above the same truck using diesel and travelling 416 km would produce 413 kg of CO_2. Therefore the gas produced from 1 tonne of input material used as a vehicle fuel would replace 413 kg of CO_2.

Figure 4.2: Greenhouse Gas Emissions for 2002 European Class Weighted Average Light Goods Vehicle

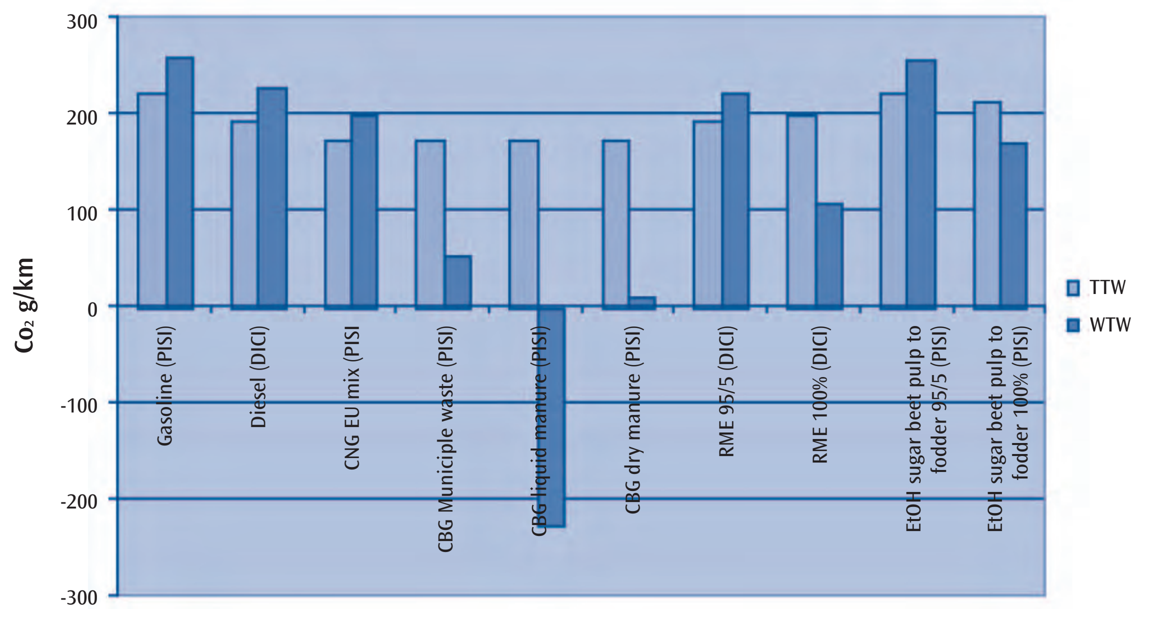


Figure 4.3: Greenhouse Gas Emissions for 2002 Generic 38 tonne Heavy Goods Vehicle

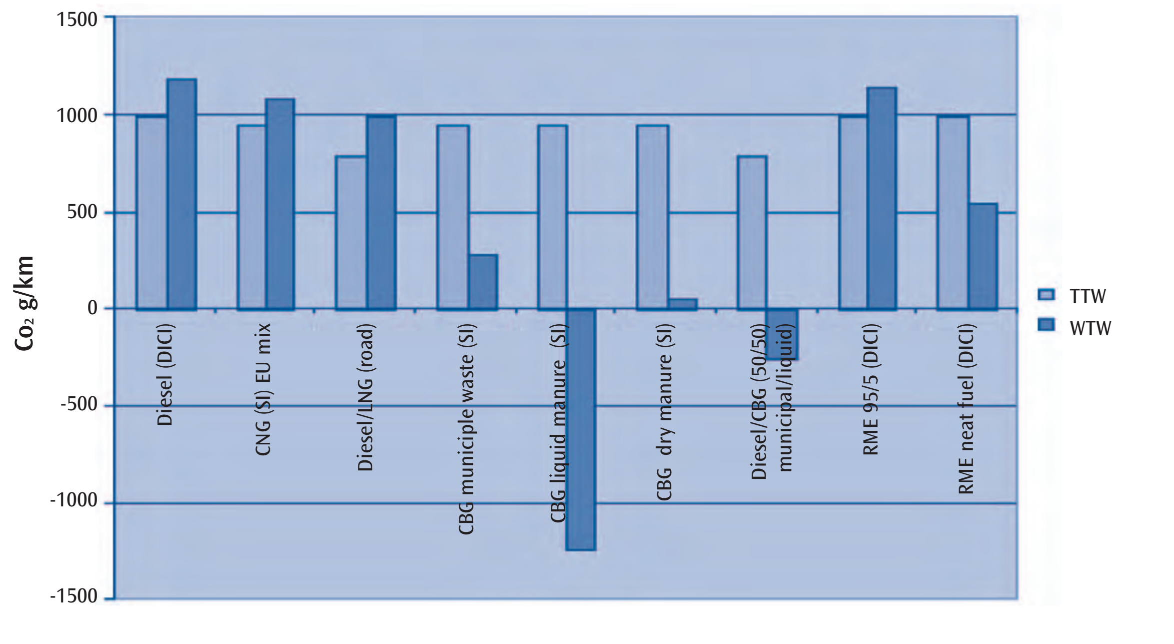


Table 4.2: Potential CO_2 Emissions Replaced by Biogas Generated Electricity

Efficiency of CHP plant	Productivity, kWh/tonne	CO_2 replaced kg/tonne
30%	741	454.1
35%	865	529.8

Figure 4.4: Estimated TTW and WTW GHG Emissions for a Bus

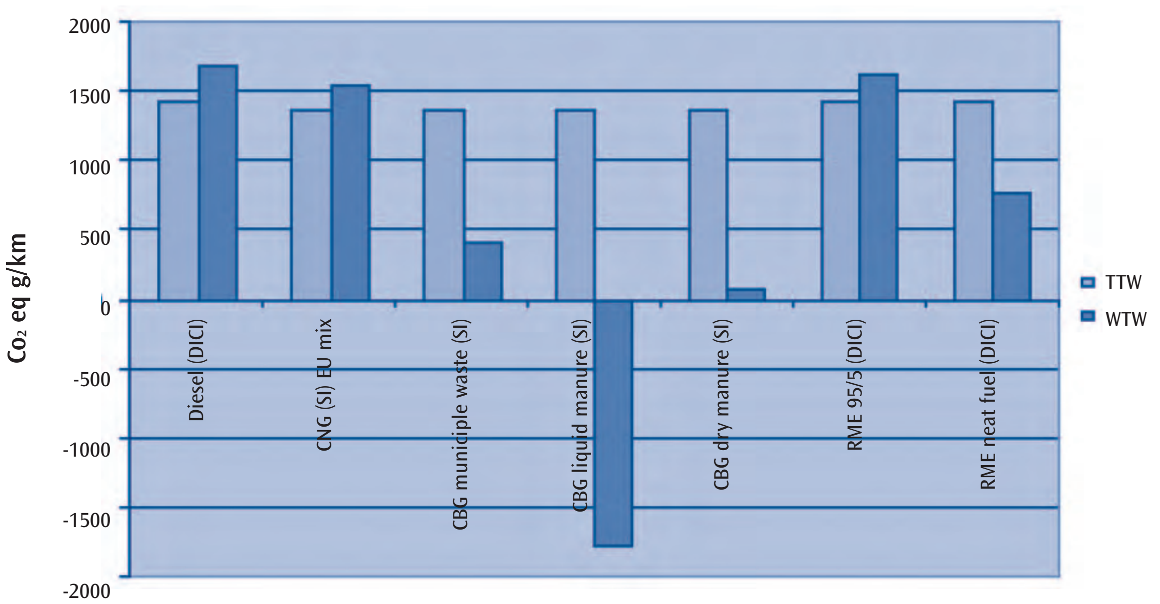
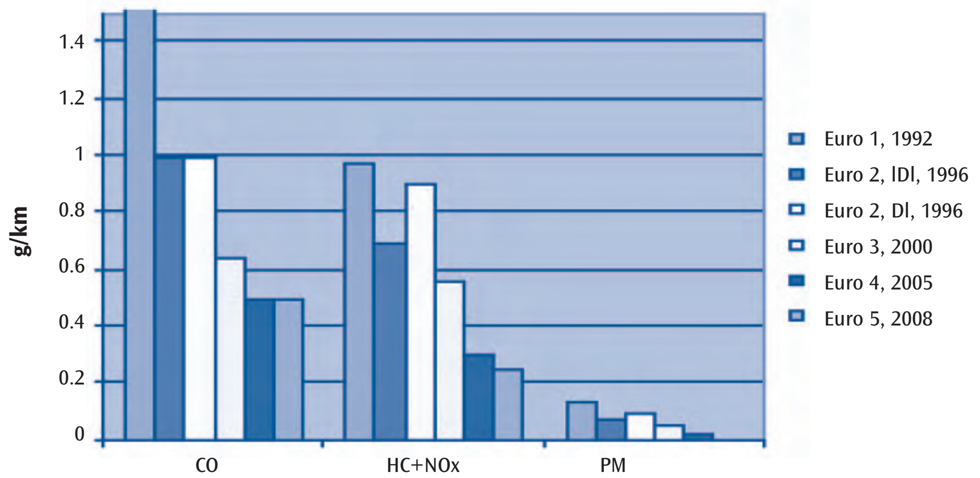


Figure 4.5: Vehicle Emission Standards for Diesel Passenger Cars



4.2.1 Electricity Production

If the biogas is put through a CHP plant, the waste heat can be used for the process and the electricity sold to the grid. If the CHP plant produces electricity at between 30-35% efficiency then between 741 kWh and 865 kWh will be produced of tonne of feedstock material. Data from the DTI[14] suggests that the current mix of fuels to generate electricity in 2005 was producing 0.612 kg of CO_2 per kWh. Based on this data, the amount of CO_2 that would be replaced by the electricity produced by the CHP unit is shown in Table 4.2.

This basic analysis suggests that the CO_2 replacement benefit for using biogas to generate electricity is likely to be greater than using it as a vehicle fuel, but is the same order of magnitude. However, if the waste heat from electricity production can be used then this would give a further advantage for electricity production.

4.3 Exhaust Emissions and Air Quality

Vehicle emissions are one of the main contributors to local air pollution. In the UK about 90% of the local authorities that have declared air quality management areas have done so on the basis of transport emissions. However, emissions from vehicles have reduced dramatically with the introduction of progressively more stringent EU emissions standards for new vehicles. An example of the improvement in emissions for diesel passenger cars is shown in Figure 4.5.

Despite this improvement air quality problems are expected to continue into the future. The pollutants of most concern are particulate matter (PM) and oxides of nitrogen (NO_x). These are also the pollutants that are associated largely with diesel vehicles. Spark ignition engines tend to give much lower emissions of these pollutants and hence there is interest in promoting their use in areas of poor air quality.

The range of methane-powered vehicles and emissions data available in the UK is limited. The only published data for light-duty vehicles powered by CNG are for the Volvo range of bi-fuel passenger cars. As an example the emissions for the Volvo S60 are certified against petrol car standards and give NO_x figures of 0.017 g/km, combined HC+NO_x of 0.08 g/km and CO of 0.558 g/km (PM emissions are not measured). The CO figure comfortably meets Euro V standards, and the NO_x figure is very low although there is not a specific NO_x standard. However, the HC+NO_x figure is worse than the Euro V standard although much better than Euro IV. This combined figure is largely a result of methane emissions from unburnt fuel.

The data on heavy-duty vehicles is a little better but still difficult to get hold of. With heavy-duty vehicles there is a voluntary EU emissions standard called the Enhanced Environmental Vehicle (EEV) that is more stringent than the Euro V standard being introduced in 2008. The EEV standard was introduced to allow member states to incentivise very low emission vehicles. The data set out in Table 4.3 show emissions results for a number of heavy-duty vehicle engines against the Euro V and EEV standards for PM and NO_x.

These data show that all the vehicles meet EEV standards for particulate matter, but not for NO_x. The spark ignition engines generally seem capable of meeting the EEV NO_x standard except for the Cummins Westport C engine. The Cleanair Power caterpillar engine is a dual fuel engine using both diesel and gas, in a compression ignition engine. This dual fuel technology would appear to have the same difficultly with NO_x emissions as a traditional diesel engine.

This would suggest that spark ignition gas engines are generally very clean, meeting Euro V or EEV emissions limits. Dual fuel vehicles have very low PM emissions, as with the spark ignition engines, but suffer from higher NO_x emissions like a traditional diesel. Therefore in urban operation, air quality benefits will best be achieved with spark ignition buses and HGVs.

Table 4.3: Heavy Duty Gas Vehicle Emissions Data

Vehicle/Engine		PM (gm/kWh)	NOx (gm/kWh)	Comment
Iveco Daily (1)		<0.02	<2.0	Meets EEV
Iveco 8469 9.5 l (1)		0.01	1.1	Meets EEV
Cummins Westport B Gas Plus 5.9 l (1)		<0.02	<0.02	Meets EEV
Cummins Westport C Gas Plus 8.3 l (1)		<0.03	<3.5	Meets Euro IV
Cummins Westport ISL G 8.9 l (2)		<0.01	<0.2	Meets US 2010 requirements
Cleanair Power Caterpillar C12 (1)	G_{25}	0.014	3.34	Meets Euro IV
	G_R	0.009	3.37	Meets Euro IV
Euro V limit over ETC		0.03	2.0	-
EEV limit over ETC		0.02	2.0	-

1 Tested over European Transient Cycle
2 Tested over US FTP Transient Cycle

14 DTI, Energy Trends, March 2006, P21

5: Economics of Biogas

There is very little robust economic information on biogas production available in the open literature. Most of the relevant experience with biogas for vehicle use has been in Sweden and France, and few data have been published for UK conditions. Hence the calculations in this section are generic and are based on derived data. It has been necessary to use reasonable assumptions about the practicalities and costs involved in a UK biogas production industry. As a result, the calculations should be regarded only as indicative; the estimated cost ranges are meant to be general guidelines, not costs for a specific project.

The economic analysis of biogas use in vehicles comprises three elements:

- The manufacturing and production costs of the biogas in a form suitable for use as a vehicle fuel;
- The infrastructure costs associated with delivery of the biogas fuel to refuelling stations;
- A comparison of the fuel costs of vehicles operating with biogas compared with the costs of using ULSD fuel and compressed natural gas.

Biogas for transport applications needs to command a sufficiently high price in the market in order to attract the development of commercial production operations. The relative economics of the markets for biogas as a vehicle fuel as against biogas for heat and electricity production are crucial for the prospects of this technology. Hence the economic analysis has also to consider the relative economics of the markets for biogas as a vehicle fuel as against biogas for electricity and heat production in CHP plant, and to take into account the gate fees for processing different waste types in the anaerobic digestion system.

5.1 Biogas Manufacturing and Production

It is assumed in this analysis that the biogas is produced from a centralised anaerobic digestion (CAD) plant which is sufficiently large to operate at a commercial scale. This type of plant is commonly used in Sweden and elsewhere in mainland Europe for biogas production, but its use in the UK has been very limited. However, there have been several previous studies in the UK of CAD economics involving the production of heat and electricity via CHP plant, and relevant data can be used from some of these.

A CAD system that is used to create biogas for electrical generation has two major components. The first is the system to generate and collect the biogas, and the second is the system to generate the electricity. If the biogas is to be used as a vehicle fuel, a similar type of digester is needed to generate and collect the biogas, which is then upgraded to natural gas quality by removing the carbon dioxide, hydrogen sulphide and water content of the biogas.

Estimating the costs of a digester system for biogas production is more speculative than for a digester-electrical generator system. Although a few facilities have been built on landfills in the UK, to date no biogas upgrading facility has been built at a CAD plant in the UK. It has been necessary to make use of Swedish and US data for much of the economic analysis for CAD biogas production as a vehicle fuel. Equivalent data for UK conditions is not available.

The capital costs of an anaerobic digester are high and therefore a considerable level of investment must be undertaken in order to install the system components. Moreover, capital costs are dependent on site-specific factors such as plant size and engineering, location and waste composition, and the degree of pre-treatment of feedstock that may be needed before the anaerobic digestion process.

Operating costs include costs associated with staff, insurance, transportation of feedstock from source, annual licences, pollution abatement and control, disposal costs of excess bio-fertiliser, and other maintenance requirements. Tanks for storage of the biogas and co-products are also needed on site.

Indicative ranges of costs for biogas plant were given in a report on anaerobic digestion commissioned by Remade Scotland[15] as follows:

- Farm scale plants with a capacity of some 3,000 tonnes/year of input – £100,000 to £200,000, with £2,000 operating costs;
- Community scale digesters treating waste from several farms range from £500,000 for 10,000 tonnes/year plant to £5 million for a 1-200,000 tonne/year plant, with operating costs between £30,000 and £500,000 per year;
- Large scale plant treating municipal waste range from £3 million for a 5,000 tonne/year plant to £12 million for a 100,000 tonne /year plant, with operating costs between £100,000 and £900,000 per year.

The British Biogen 'Good Practice Guide on Anaerobic Digestion'[16] suggests plant costs including CHP are in the range of £3,000-£7,000 per kWe of generating capacity. They suggest a small scale farm system with a digester capacity of 150m^3 would cost £60,000-£70,000, and a large municipal waste system with a capacity of 10,000m^3 would cost between £3-4 million.

This data suggests the capital costs range from £50-£500 per tonne/year capacity and operating costs range from around £10 to £20 per tonne of waste treated.

5.2 Upgrading of Biogas to Natural Gas Quality

The raw biogas being produced from a digestion vessel is between 55-70% methane, with the remainder being largely CO_2 and small amounts of water vapour, fine grit, hydrogen sulphide (H_2S) and ammonia. To use the gas in a vehicle engine and get smooth operation the biogas needs to be upgraded by removing the CO_2 and other contaminants so that it is at least 95% methane.

15 'An Introduction to Anearobic Digestion of Organic Wastes', Fabien Monnet, Remade Scotland, 2003
16 'Anaerobic Digestion of farm and food processing residues', British Biogen, 1997

Table 5.1: Summary of Costs for the Production of Biogas Used as a Vehicle Fuel

Process	Biogas (sewage sludge)		Biogas (organic waste)	
	SEK/Nm³	p/Nm³	SEK/Nm³	p/Nm³
Production	0 – 1.5	0 – 11	1.5 – 2.5	11 – 18
Upgrading	1 – 2	7 – 15	1 – 2	7 – 15
Compression	1	7	1	7
Total	2.0 – 4.5	14 – 33	3.5 – 5.5	25 - 40

Table 5.2: Estimated Approximate Costs for a Hypothetical Anaerobic Digester and Biogas Upgrading Plant (p/Nm³)

Anaerobic digester		Biogas upgrading		Total cost
Capital	Operation & Maintenance	Capital	Operation & Maintenance	
5.0	1.0	3.5	13.7	23.2

Upgrading of biogas is a relatively new technology but experience from Sweden and other countries indicates that it is possible to upgrade biogas with high reliability and at reasonable cost. The Swedish experience has suggested that biogas can be a viable fuel with fiscal incentives (such as lower fuel duty), and can reduce CO_2 emissions in urban transport.

The economic and technical performance of Swedish upgrading plants was studied in 2003 and presented in a recent report by the Swedish Gas Centre (www.sgc.se). Data from 11 of the Swedish upgrading plants with longest operation experience were included in the study[17]. Some of the main conclusions are:

- The upgrading cost depends very much on the plant size. Small plants for <100 Nm³/h of raw gas have upgrading costs between 3 and 4 € c/kWh upgraded gas whereas upgrading plants in the range 200-300 m³/h of raw gas have upgrading costs around 1- 1,5 € c/kWh of upgraded gas;
- The electricity demand for upgrading corresponds to 3-6% of the energy content in the upgraded gas;
- The function of the upgrading plant is generally acceptable after the commissioning period.

Another Swedish report on the potential for biogas gives data on the costs of biogas upgrading and pressurisation[18]. Table 5.1 shows the costs per Nm³ for production of biogas for vehicle use (upgraded and pressurised) from this Swedish data[19]. The costs, excluding VAT, are estimated in the report as 1.8-5.0 SEK per litre gasoline equivalent (or 13-37 p/litre gasoline equivalent). The costs for the gas refuelling station and the costs of delivery to the station from the production plant, which may vary depending upon construction requirements, location, safety and other regulatory needs, capital amortisation etc, are additional.

In the Swedish Gas Council report[20], Swedish Biogas AB are quoted as estimating a cost range for the production of biogas used in vehicles, reflecting different production conditions, in the order of 3.50-4.50 SEK/Nm³ (or 26-33 p/Nm³). This range also includes crop based biogas. The higher feedstock cost when using crops is partially compensated for by lower treatment costs for upgrading in the biogas plant. The range of 3.50-4.50 SEK/Nm³ is considered to be sufficient to guarantee a price for the end customer that does not exceed the price of taxed gasoline in Sweden. The pre-tax market price for biogas used as a vehicle fuel in Sweden is claimed to be about 70% of the total consumer price of gasoline (including tax). Hence with the full tax rebated, biogas in Sweden can be competitive with gasoline or diesel fuels.

The estimated cost range from this Swedish data is equivalent to 36-46 p/kg including compression costs. However, for use in vehicles, the biogas would also need to be delivered to the refilling station, with additional costs for transportation from the CAD plant, and the retailing and other operating costs at the filling station.

A detailed report for the Californian dairy industry has also examined the production and use of biogas as a vehicle fuel and other energy applications[21]. Table 5.2 shows estimated costs (in p/m³ of biogas) for a hypothetical anaerobic digestion and upgrading plant producing upgraded biogas using feedstock from a dairy herd of 8,000 cows[22]. The methane produced from the feedstock is assumed to be approximately 1 m³ per cow per day. The operating costs in the Californian report are based on actual cost data from the Linkoping plant and the capital costs are based on actual costs at the Boras plant, both in Sweden.

17 "Biogas upgrading and use as transport fuel", O. Jönsson, Swedish Gas Centre, 2004
18 "Summary and analysis of the potential for production of renewable methane (biogas and SNG) in Sweden", Johan Rietz, Swedish Gas Council, March 2005
19 Currency conversion from SEK to UK£, at rate of 13.7 SEK=£1
20 "Summary and analysis of the potential for production of renewable methane (biogas and SNG) in Sweden", Johan Rietz, Swedish Gas Council, March 2005
21 Source: "Biomethane from dairy waste - A sourcebook for the production and use of renewable natural gas in California" - A report for Western United Dairymen, July 2005
22 US cost data have been converted to UK£ using the rate of $1.75=£1

The estimated total cost of 23.2 p/Nm^3 from the US study is equivalent to 32.3 p/kg at a pressure of 1 bar, and at 15°C. This cost is similar to the calculations from the Swedish study. However, for use in vehicles, the biogas would need to be compressed. Applying the compression costs from the Swedish study of 7p/Nm^3 to the US data gives an overall cost of 30.2 p/Nm^3, equivalent to 42 p/kg.

Furthermore, as with the Swedish estimates, there would be additional costs associated with delivery to the refilling station, comprising the costs of transportation, retailing and operating costs at the filling station.

From the evidence of these two studies, it is suggested that biogas from a CAD plant can be produced, upgraded and compressed for use as a vehicle fuel at a cost of between 36-46 p/kg, at the plant gate.

5.3 Infrastructure and Distribution Costs

Infrastructure costs for delivery and retailing of compressed biogas at filling stations for road transport operators are likely to be similar to those for compressed natural gas. UK data are available from the late 1990s, when CNG refuelling stations were being developed and installed by gas suppliers and other organisations. Costs have been quoted at £150,000 for a system which provides fast-fill for a whole fleet (as used by the London Borough of Merton), and at £250,000 for a bus fleet in Southampton[23]. Since it is likely that the main uses of biogas would be for captive vehicle fleets with refilling stations at their home depots, these data seem reasonable for use in the economic analysis.

For the purposes of this study, it is assumed that the biogas is supplied to users in gaseous form, and is not liquefied, since this would require additional costs and energy inputs for the liquefaction process and for liquid biogas storage and delivery.

Overall, it is assumed that the infrastructure costs add a further 5 p/kg to the cost of delivering biogas to the refilling station, giving a range of 41-51 p/kg before tax and fuel duties. Including fuel duty at 9p/kg gives a "best estimate" of the price for biogas of 50-60p/kg before VAT[24]. Discussions with suppliers of CNG in the UK suggest that the current retail price for CNG, excluding VAT, is around 55p/kg to operators, so this suggests that biogas could be competitive with CNG and sold at similar prices. However, this conclusion should be treated with some caution due to the lack of relevant UK data.

5.4 The Costs of Biogas in Transport Applications

The cost implications of operating a vehicle fleet on biogas or CNG comprise three elements:

- The additional capital cost of the CNG vehicles;
- Maintenance and other running costs;
- Fuel costs savings or penalties.

5.4.1 Vehicle Capital Costs

With a limited availability of CNG vehicles available there is a similar lack of vehicle cost data for the UK. However, the following would appear to be reasonable costs for UK vehicles based on information from vehicle manufactures, operators and the Energy Savings Trust:

- Car – £3,000 to £4,000 more than equivalent petrol;
- Van – £5,000 more than equivalent petrol;
- HGV spark ignition engine – £25,000 to £35,000 more than standard diesel;
- HGV Dual fuel conversion – £20,000 to £25,000.

In markets which are more developed these costs may be lower and would be expected to decrease in the UK if vehicles became more widely available.

5.4.2 Maintenance Costs

Again there is little hard information available on maintenance costs of CNG vehicles compared to diesel equivalents. Some experience from Sweden suggests that the additional costs of maintaining spark ignition CNG buses compared to the diesel equivalents was 1p/km. With dual-fuel conversions where the engine remains a compression ignition diesel using both CNG and diesel there is some evidence to suggest that maintenance costs are no higher, but given that there are two fuelling systems it also seems reasonable to assume that there might be a slight increase. For light duty vehicles using a bi-fuel version of an existing petrol engine it is likely that the maintenance costs will be slightly more than the petrol equivalent, again due to the two fuelling systems. Therefore we have assumed a maintenance increase cost of 1p/km for all gas vehicles.

Table 5.3 uses the limited data described above to estimate the additional capital and maintenance costs in terms of p/km and £/year for typical CNG vehicles. This estimate assumes an average of a four year commercial life of the vehicle over which the additional capital costs have to be repaid. The mileage data is taken from DfT data[25] and is the average for LDVs under 7.5 tonnes and HDVs over 33 tonnes.

5.4.3 Fuel Economy

A spark ignition engine which is typically used for CNG vehicles is less efficient than a diesel engine and so there is a fuel efficiency penalty. For light-duty vehicles this may be around 20% compared with an equivalent diesel, and for heavy-duty vehicles may be as much as 40% or more. The evaluation of CNG buses in Stockholm as part of the trendsetter project showed a fuel consumption penalty of some 60% in urban operation. However, with the latest technology and high loads the efficiency difference between diesel and CNG would seem to be between 15% and 25%.

On the other hand CNG used in a spark ignition engine and compared to a petrol equivalent will have similar or slightly better fuel consumption. Similarly if a dual-fuel conversion of a heavy-duty vehicle is used, and if the diesel efficiency is maintained, then the fuel consumption is assumed to be similar to the original diesel engine. In the case of the dual-fuel vehicle it will typically use about 30% diesel and 70% CNG in its fuel mix.

23 "Report of the Alternative Fuels Group of the Cleaner Vehicles Task Force - an assessment of the emissions performance of alternative and conventional fuels", DTI, 2000
24 Using the Swedish data from 2003, and ignoring any effects of increases in capital costs etc due to price rises
25 'Transport of Goods by Road in the UK:2004'

Table 5.4 shows fuel costs comparing equivalent diesel, petrol and CNG vehicles. The estimates are based on data from the Concawe well-to-wheels study[26] for the light-duty vehicles, similar assumptions for heavy-duty vehicles and typical retail prices for vehicle fuels. This data shows that there are considerable fuel costs savings when running both light-duty and heavy-duty vehicles on CNG. If biogas can be sold at a similar price to CNG, then biogas can offer similar fuel cost savings.

5.4.4 Cost Comparisons

Although there are fuel costs savings with CNG (and potentially with biogas) these need to be offset against the additional capital costs of the vehicles and any additional operating and maintenance costs. Table 5.5 shows this comparison with the fuel costs combined with the additional capital and operating costs for the CNG vehicles in terms of both p/km and £/year.

This analysis suggests that for light-duty vehicles CNG (and potentially biogas) is more expensive than both petrol and diesel, with the fuel costs savings not offsetting the additional capital costs. For heavy-duty vehicles the CNG dual-fuel option is the most cost effective, with the costs savings offsetting the additional capital costs comfortably within the four year commercial life. The spark ignition option appears to be less cost effective, with the high costs for re-engining the vehicles and the slightly lower fuel costs savings compared to dual-fuel vehicles, but can still compete effectively with diesel fuelled vehicles. These results largely explain why the only market for CNG vehicles that has had any success in the UK is that for HGVs.

Table 5.3: Additional Capital and Maintenance Costs for CNG Vehicles

		Capital, £			Maint	Total	
	km/year	total	per year	per km		p/km	£/year
Van	29,000	5,000	1,250	0.04	0.01	5.31	1,540.00
HGV SI	95,000	30,000	7,500	0.08	0.01	8.89	8,450.00
HGV Dual fuel	95,000	20,000	5,000	0.05	0.01	6.26	5,950.00

Table 5.4: Fuel Cost and Fuel Consumption Comparing Diesel, Petrol and CNG

Vehicle type		Fuel	Fuel consumption		Fuel price (exc VAT)		Fuel cost	
	km/year		l/100km	kg/100km	diesel (l)	CNG (kg)	p per km	£ per year
Light goods	29,000	Gasoline	9.4		0.73		6.90	2001.57
		ULSD	7.1		0.77		5.45	1579.77
		CNG		6.2		0.55	3.41	988.90
Heavy goods	95,000	ULSD	37.6		0.77		28.85	27406.17
		CNG SI		34.65		0.55	19.06	18104.63
		CNG Dual	3.17	25.38	0.77	0.55	16.39	15571.62

Note: Diesel and petrol prices from DTI retail costs data, CNG prices from operator information to study.

Table 5.5: Total Fuel and Additional Operating Costs

Vehicle type	km/year	Fuel	Costs	
			p/km	£/year
Light goods	29,000	Gasoline	6.90	2001.57
		ULSD	5.45	1579.77
		CNG	8.72	2528.90
Heavy goods	95,000	ULSD	28.85	27406.17
		CNG SI	27.95	26554.63
		CNG Dual	22.65	21521.62

26 Well-to-Wheel analysis of future automotive fuels in the European context, Concawe, EUCAR and JRC, Dec 2005

Making the somewhat favourable assumption that biogas can be produced and sold at a price similar to CNG, the economics of using biogas as a vehicle fuel appear to be attractive for heavy-goods vehicles. However, as stated earlier, the lack of up-to-date Swedish data and any relevant UK data for biogas production costs means that care must be exercised and that this observation is not a definitive result.

5.5 Biogas Used for CHP

The next step in the economic analysis is to assess whether producing biogas for vehicle use is more attractive than generating electricity from biogas, using biogas as the fuel for a CHP system. For CHP applications, the economics are more complex, since the gross income from the CAD plant will depend on several site specific factors, including the proximity of suitable heat loads and ease of access to the local electricity distribution grid. The overall economics will also be affected by the relative cost of existing waste treatment or handling systems and the value of the conventional energy sources that are replaced. Other relevant factors are the local electricity prices, on-site electricity demand and the type of energy contract. CAD systems will qualify as renewable generators under the Renewable Obligation, and there will be a value for the Renewable Obligation Certificate (ROC) associated with the electricity generated from the site. Another source of income will be the value of the Levy Exemption Certificate under the Climate Change Levy.

Gate fees can be obtained for handling waste streams, and sales of co-products may also be important. As noted above, these revenue streams may also apply to biogas production for vehicle use, so they have been omitted from this part of the analysis. However, the presence of these revenues may make the overall economics more attractive to investors. Hence the revenue streams from biogas production using a CAD for CHP can be from several different markets:

- Sales of electricity – electricity from renewable sources is likely to continue to command premium rates, and can be distributed via the local electricity grid to end-users;
- Sales of ROCs – electricity qualifying as a renewable source will attract an ROC value and a value for the Climate Change Levy. ROCs can be traded on the open market, and currently have a value of around 4-4.5 p/kWh;
- Sales of heat – where heat markets exist close to the production site, heat sales can be an additional source of income when operating combined heat and power plant. Heat sales could have a value of around 2p/kWh[27];
- Gate fees – charges made for processing wastes. These appear to be in the range of £40-£75/tonne of feedstock used in the plant[28];
- Sales of co-products – fibre and liquid products from the AD process can be sold as a substitute for fertiliser.

UK experience of CAD plant for CHP applications is limited to the Holsworthy plant in Devon[29] which is the only large-scale biogas production facility in the country. The electricity produced is being sold at 5.93p per kWh (2003 price level) under a 15 year Non-Fossil Fuel Obligation (NFFO) contract granted to Holsworthy Biogas. The price is index-linked and will increase or decrease over time according to the Retail Price Index. The revenue from the electricity sales is of the order of £800,000 per year. Currently it is believed that there is no revenue from exportable heat.

Other studies can also be used to examine revenues from CHP plant. One study suggested that a large CAD plant processing 100,000 tonne/year of cow slurry, which represents approximately 8,000 cows, would produce an electrical output of 31.1 kWh/tonne of feedstock[30]. At a selling price of 4.5 p/kWh for electricity, the total income for a year from electricity would be £140,000, excluding the value of any ROCs generated by the system.

5.6 Comparison of Biogas for Vehicles with Biogas for CHP

An approximate economic comparison can be made between the use of biogas for vehicles with biogas used for electricity production. This has been done by calculating the value of one tonne of AD feedstock material in producing upgraded biogas to vehicle fuel specification, and comparing this value with the value of one tonne of AD feedstock material used in producing electricity from a CHP plant. The rate of biogas production from a normal mix of slurry and food wastes as feedstock material is approximately 250 m^3 of methane per tonne of material. The energy content of this volume of methane is 8,900 MJ or 2,472 kWh. Income from gate fees and the sales of co-products are assumed to be equivalent in each case, so these items have been omitted from the calculation.

5.6.1 Biogas Production for Vehicles

When selling the output gas for vehicle fuel it is necessary to account for the fact that some of the gas will be used for process energy, mainly heating. It can be assumed that the amount of gas needed for this purpose is about 20%. This leaves a total amount of gas that can be sold per tonne of input material as 200m^3. Assuming that the AD plant operator can sell his biogas at a forecourt price equivalent to fossil CNG, the effective price of the biogas would be 33 p/m^3 (excluding fuel duty and VAT[31]). The value of gas sales from 1 tonne of feedstock material is then £66.24.

5.6.2 Electricity Production

If the biogas is put through a CHP plant, the waste heat can be used for the process and the electricity is sold to the grid. Assuming that the AD plant operator can sell electricity to the grid at 4.5 p/kWh, and in addition, obtain the benefit of a ROC at 4.5 p/kWh, the total revenue from the "green" electricity sales is 9 p/kWh. The value of the electricity production in terms of the input of feedstock material is shown in Table 5.6.

This suggests that currently biogas production for vehicle use would not be quite such an attractive market in comparison with electricity production from CHP plant. This also

27 Source: "Economics of anaerobic digester systems", Ofreg, N Ireland
28 Source: "Feasibility study – AD in Northern Ireland", Eunomia Research and Consulting
29 "Holsworthy Biogas Plant Case Study", Devon County Council, Renewable Heat and Power Ltd, Countryside Agency, 2003

footnotes continued on p25

highlights the benefits that the renewables obligation is giving to ‘green’ electricity sales, basically doubling their market value.

However, it is also important to note that for both vehicle fuel and electricity production and sales, the revenue generated is between £50 and £75 per tonne of waste, which is at least comparable if not greater than the waste management fees that are being generated. Therefore the sales of vehicle fuel or electricity are extremely important to the success of AD plants.

Table 5.6: Revenue from Electricity Sales

Efficiency of CHP plant	Productivity	Value
30%	741 kWh/tonne	£66.75/tonne
35%	865 kWh/tonne	£77.87/tonne

30 Source: “An Introduction to Anaerobic Digestion of Organic Wastes”, Remade Scotland, November 2003
31 Using the CNG forecourt price of 61 p/kg, which includes the reduced rate of fuel duty and VAT

6: Biogas Experience So Far

Experience with biogas use in vehicles in the UK is extremely limited, with little or no current examples. Therefore the focus of the review of experience in the UK is on:

- The production of biogas and how it is currently used for heat and power, and issues in relation to selling the biogas into a transport market;
- Experience in the UK of natural gas vehicles.

Biogas is, however, used as transportation fuel in a number of other countries, and in Europe has reached a major breakthrough in municipalities in Sweden and France, and to a lesser extent in a handful of other European cities. The environmental benefits of using biogas are most obvious when used by heavy vehicles in city traffic as an alternative fuel to fossil diesel. Although the experience reported in the literature is relatively limited, a number of lessons learnt and success factors can be identified.

6.1 Development of Biogas in the UK

In the UK there is a history of using anaerobic digestion of sewage sludge at major sewage treatment works which, when compared to many other EC countries, is still a significant source of biogas. In fact data from Eurostat (Figure 6.1) shows the UK is actually the biggest producer of biogas in Europe just ahead of Germany. In addition, the capture and use of landfill gas in the UK has, in the last 10 to 15 years, overtaken sewage treatment as the major source of biogas in the UK. In both cases the biogas is used to create heat and electricity rather than vehicle fuel. If these two sources of biogas are included in UK biogas production estimates, then the UK is one of the largest producers of biogas in Europe.

Although there is significant experience of using AD for treating sewage in the UK, if we consider the use of AD for treating farm and food wastes to produce biogas, the UK is lagging far behind other countries in Europe. There are many hundred farm-scale AD plants in Germany, Austria and Denmark, and a growing number of large centralised plants fed from agricultural waste, food waste and sewage that are producing heat, electricity and vehicle fuel. In contrast in the UK there are only a handful of plants that have been built for these purposes, and perhaps the two most well known examples are at Holsworthy in Devon and the work in South Shropshire by Greenfinch.

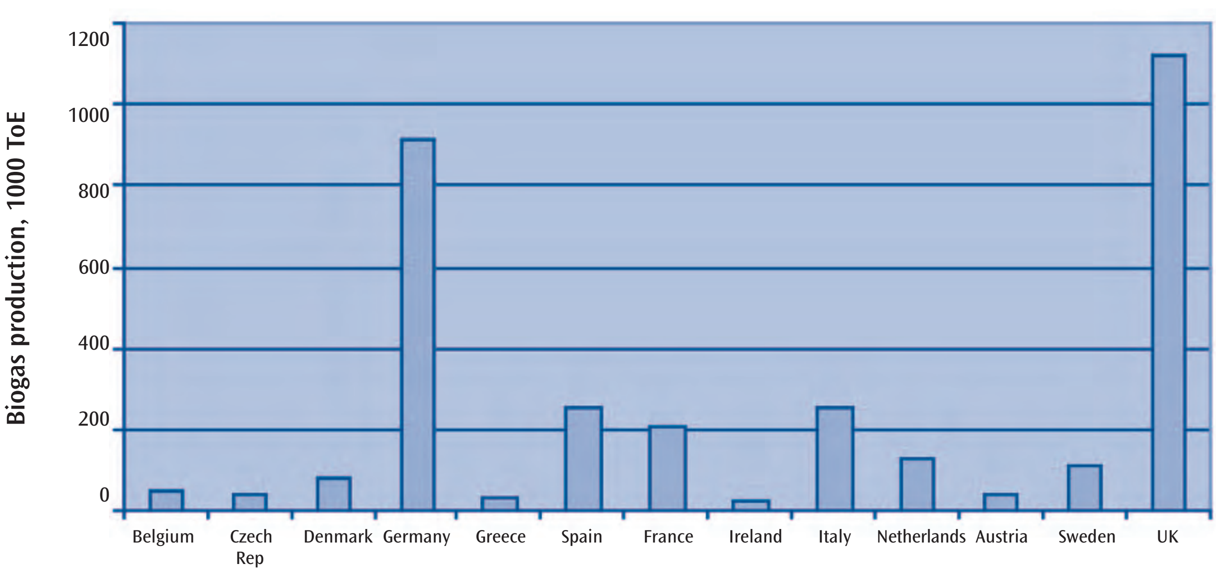
6.1.1 Holsworthy, Devon

The Holsworthy biogas plant was conceived in 1992 as the first biogas plant of its kind in the UK. It was designed to take some 130,000 tonnes of farm and food waste, and produce some 4 million m^3 of methane per year. The methane is burnt in large gas engines to produce electricity and heat. The capacity of the engines is enough to produce 2MW electrical output and 14.4MW of heat output.

Funding for the plant was secured in 1997 with an EC grant of £3.8 million against a total project cost of some £7.5 million. They also secured a Non-Fossil Fuel Obligation (NFFO) contract for the electricity production based on a feedstock of 80% cattle slurry. Construction started in June 2001 and the plant was operational by the end of 2002.

However, the story of Holsworthy has not been a happy one, beset with financial and regulatory problems. The financial problems of the site led to insolvency in 2003 and again in 2005. The plant is now under the management of

Figure 6.1: Biogas Production across Europe



Source: Eurostat data for 2003

Summerlease whose main area of expertise is in landfill gas and power generation. The financial problems of the site related to two main areas – insufficient revenue from electricity sales and gate fees, and costs of complying with legislation.

The NFFO contract was based on a requirement for 80% of the feedstock to be cattle slurry. The first problem with this is that the requirement for a high level of cattle slurry has reduced the amount of gas that can be produced from feedstock such as food and animal by-products, thus affecting electricity production. It has also limited the amount of gate fees that can be taken for the waste foods and animal by-products. The second problem with the NFFO agreement is that although it has given them a good price for their electricity it has not allowed them to benefit from Renewable Obligation Certificates that are currently trading at £45/MWh.

One of the key legislative problems was odour compliance, a problem which was exacerbated by the increased need to treat animal by-products following the foot and mouth outbreak in 2001. The cost of compliance was the main reason for the company going into administration for a second time. The second legislative issue is the cost of regulation to the company which amounts to some £150,000 in fees to the Environment Agency for various PPC and waste licences. A large proportion of this relates to licensing costs for land spreading of the digestate – £80,000 per year – incurred because the digestate is still considered a waste rather than a co-product of the plant.

Experience from Holsworthy to date would suggest that:

- AD plants need a flexible operating regime to allow them to maximise incomes from different revenue streams such as gate fees and product sales, depending on market conditions. It also suggests that waste gate fees for non-farm wastes are a key income stream for these plants;
- The current level of environmental legislation for such plants can be both a financial and managerial barrier to their success.

The current owners of Holsworthy are keen to make the plant a success and are building up a substantial amount of experience that they can bring to future investments. However, they still feel the market is not yet right for investment in new plant and that there is a lack of technical expertise for this type of AD process in the UK.

6.1.2 The South Shropshire Trials

South Shropshire DC started working with Greenfinch, a company that develops AD equipment, in 1998. This initial trial was a scheme to treat kitchen waste from 1,200 homes in the district. The trial ran over a period of two years during which time they treated 300 tonnes of household waste and generated 140m^3/h of biogas per tonne of waste material. The trial proved technically successful and led to the decision to build a full-scale scheme.

The full-scale scheme can take 5,000 tonnes of household kitchen and garden waste, generating heat and electricity with the gas that is produced. The scheme has been supported by Defra and Avantage West Midlands. The scheme is currently commissioned with full operation due in 2006, and thus there is no operational experience to date.

6.1.3 Technology Availability

The main market for AD plants was for sewage treatment works back in the 1980s. The use of AD for other feedstocks in the UK is limited and so is the technology availability from UK suppliers. However, there are a small number of UK companies that are trying to develop products for use in the UK; these include Greenfinch, BioPlex and Organic Power who have both production technology and vehicle technology. However, the largest suppliers for biogas equipment, and with technical experience, are in Germany, Denmark, Austria, Switzerland and Sweden.

6.2 Experience with Natural Gas Powered Vehicle Fleets in the UK

Much of the experiences of operators using natural gas vehicles can be applied to the potential use of biogas vehicles. According to the European Association of Natural Gas Vehicles there are some five million natural gas vehicles in use worldwide, of which 1.4 million are in Argentina and about one million in Brazil. Italy's fleet of 380,000 NGVs is by far the biggest in Europe, followed by Germany with 38,000 and France with 8,000. In Spain there are more than 500 public sector natural gas vehicles operating in Madrid, including buses and refuse collection vehicles.

Many European countries have experienced positive results with natural gas as a vehicle fuel. With the building of extensive fuel infrastructures and vehicle suppliers active in the market with natural gas options, this fuel has become a part of the fuel mix in several countries. Overall, it appears that natural gas has proved popular as a fuel for trucks, buses and larger vehicles in those countries where specific tax incentives in favour of natural gas have been available.

By contrast, UK experience with natural gas as a vehicle fuel has been less positive. Early pilot trials on using CNG buses has shown them to be not economically viable. The most success has been with HGVs, where some significant fleets have been developed, which is in contrast to most other countries where buses and cars have been most successful. Table 6.1, from data supplied by the Natural Gas Vehicle Association (NGVA), shows the current number of NGVs operating in the UK.

6.2.1 CNG in buses[32]

In the UK, there have been several field trial projects involving alternative fuels in buses. These have included LPG, CNG, biofuels and electric vehicles. Experiences in a "real-world" situation have not been totally successful and it is only those operations that have committed to a large enough number of CNG buses to develop and support the necessary infrastructure, both in maintenance and refuelling, that have had the greatest benefits. Table 6.2 lists brief details of field trial projects involving CNG for buses in the UK. Most of these bus operations were conducted during the 1990s, and many have now ceased, either due to technical difficulties, or to the adverse economics of operating natural gas vehicles.

32 Data obtained from "The Route to Cleaner Buses", published by TransportEnergy, September 2003

The experience of operating four CNG buses on Park and Ride routes in Southport is representative of UK trials of CNG buses. The vehicles formed one aspect of the European Commission JUPITER-2 project to reduce exhaust pollution and save energy and to demonstrate sustainable transport policies in the Merseytravel region. The CNG buses started operating in February 1999.

The perceived environmental impact of the CNG buses was about half that of cars and diesel buses. The operating performance of the CNG vehicles was however worse than that of the electric and clean diesel buses. The CNG vehicles showed poor reliability during the initial period of operation and although the majority of these problems were solved, reliability levels continued to be lower than would be expected for vehicles of their age. Additionally, there were some problems with the gas refuelling plant that were attributed by the bus operator to variations in fuel quality and water in the gas.

Overall emissions from the CNG buses were considerably lower than those observed in previous comparable European projects. CNG has specific benefits in terms of NO_x and particulate emissions (PM) compared with diesel-powered vehicles. Overall emissions are a function of all the vehicles operating in the project areas and the degree to which a modal shift was achieved from cars to buses. Results showed virtually zero PM emissions while CO_2, NO_x and hydrocarbon (HC) emissions were each reduced by 3-5%. Total transport energy use in the project areas was reduced by 3%.

Fuel cost comparisons depend upon the effective level of duty in force at the time. During the course of the SMART*eco* project, changes in the fuel duty structure were made in favour of CNG and LPG. Paradoxically, these changes made CNG less commercially attractive for bus use. In overall cost benefit terms, the SMART*eco* project had a short payback time of around two years. However, the use of CNG buses would be commercially disadvantageous to an operator at present. JUPITER-2 demonstrated that integrated transport projects, consisting of investment in alternative fuels, innovative technologies and transport management measures could influence modal split in favour of public transport and bring environmental benefits from reduced emissions and noise.

The CNG buses contributed significantly to the success of the JUPITER-2 project and continued to operate successfully. Due to the various route enhancements included within the overall project, it is difficult to assess the specific contribution of quieter CNG buses to the observed modal shift from cars, but the pollution benefits are clear.

Table 6.1: Current NGV fleet in the UK

Cars	Vans	Heavy Goods Vehicles		Total Vehicle Parc
		<7.5 tonnes	>7.5 tonnes	
44	38	110	316	508

Table 6.2: UK Examples of Cleaner Fuels in Buses Trials[33]

Location	Vehicles	Project	Equipment	Key findings
LB Camden	3 minibuses Community Transport fleet	ASTI accessible Minibus project 1995-1998	Iveco-Ford van conversions with dedicated Iveco gas engine	Technically successful, capital costs high
LB Merton	19 dedicated CNG minibuses and coaches	CNG local authority vehicle fleet Current	Iveco Daily	High capital costs, weight penalty of on-board fuel storage. Driver training and awareness needed
Southampton	6 converted and 10 dedicated CNG buses	Entrance project Hampshire County Current	Dennis Dart midi bus	High fuel use, high capital cost, good public response
Birmingham	14 CNG buses on commercial service route	Travel West Midlands CNG demonstration Current	Volvo bus with dedicated lean-burn engine	High fuel use, high capital costs, some technical and maintenance problems
Merseyside	4 CNG buses on Park and Ride route in Southport	JUPITER-2 project Merseytravel Current	Dennis bus with dedicated gas engine	High capital and fuel costs
Northampton	6 dedicated CNG buses	CNG bus fleet Current	Volvo bus with dedicated lean burn engine	N/A

33 Information sources: 'Report of the Alternative Fuels Group of the Cleaner Vehicles Task Force', DTI , London, March 2000; European Commission THERMIE programme, 1999; International Association of Natural Gas Vehicles, 2002

6.6.2 CNG in HGV Fleets

In contrast to the CNG experience with buses, which tends to have been focused on demonstration and trials, use of CNG within HGV fleets has perhaps shown more success. The vehicles cover high mileages typically ranging from 80,000 to 180,000 miles per year with no diesel fuel subsidy as with bus operation. There is therefore severe pressure to minimise fuel costs, which dominates operational costs.

CNG as a transport fuel was seen by a number of UK fleet operators as providing potential financial benefits to their operations, principally those shown in Table 6.3.

As with the experience with buses it is only those operations that have committed to a large enough number of vehicles to develop and support the necessary infrastructure, both in maintenance and refuelling, that have had the greatest benefits. Also in order to be commercially successful, the fleet usually needs to embark on an engineering programme to improve reliability and operability.

Caratrans Limited which runs a fleet of 66 heavy trucks, 27 of these on compressed natural gas (CNG), commenced their programme in 1999. Their fleet comprises a mixture of ERFs with Detroit diesel engines and Scanias, converted to CNG after already completing 800,000 km (500,000 miles). Initially, the range of the ERF units was insufficient for out and back operation on one fill, with vehicles needing to fill once in each direction on the trip from Crewe to East London Docks. In order to increase range, larger storage tanks with working pressure increased from 200 to 250 bar enabled the range of the ERF vehicles to be extended to 900 km. The conversion of the Scania diesel engines to dedicated CNG resulted in an engine that met the Euro V standard and a driving range of 770 km (480 miles).

Refuelling is carried out on-site at the Crewe depot. This is owned and operated by CNG Services Limited. Three Greenfield compressors, three dispensers and 3,660 litres of cascade storage at 300 bar combine to provide an almost seamless supply of CNG. Refuelling time is now equivalent to or better than an equivalent diesel fill and considerably cleaner for the driver and surroundings.

After 22 million km (15 million miles) on CNG, Caratrans suggests that their CNG vehicles use 10-15% more energy than diesel due to the relative inefficiency of the spark ignition engine. Despite this, with diesel at 68 pence/litre, running costs of diesel vehicles in the fleet equates to around 38 pence per mile whereas the CNG running costs equate to around 25 pence per mile.

The company has also reaped a number of benefits from its programme including:

- Extending oil filter life from a manufacturer's recommendation of 6 to 18 weeks;
- Extending the manufacturer's recommended oil and spark plug change from 6,000 km to 150,000 km;
- The ability to use cheaper oil at £1.70 per litre compared to £6.00 recommended.

Hardstaff Group runs a fleet of 150 vehicles with around 80 vehicles running on LNG/CNG. The core of the fleet is based around Foden Alpha tractor units powered by dual fuel diesel/NG Caterpillar C12 engines. Like Caratrans, Hardstaff has devoted resources to addressing vehicle range, and has developed a system with additional CNG tanks fitted to trailers, with gas being supplied via flexible hoses to the tractor unit. Hardstaff has also recognised the need to have refuelling infrastructure on-site and ships LNG (currently from Norway) by tanker to its facility at Kingston-on-Soar. Including transportation costs Hardstaff indicate a saving of £8-9,000 per vehicle per year.

Table 6.3: Examples of UK CNG Fleet Operators

Fleet	Location	Vehicles
Caratrans	Crewe	14 ERF with dedicated CNG DDC Series 60 engines, 13 Scania Series 3 CNG conversions
ACC Distribution (co-op)	Alfreton, Cumbernauld	60 Foden Alpha CNG
William Armstrong	Cumbria	13 Foden Alpha dual fuel diesel/LNG
Hardstaff Group	Kingston-on-Soar, Nottinghamshire	80 Foden Alpha dual fuel diesel/CNG Caterpillar engines and Foden/ DAF Rigids using Cummins Westport NG engines
William West	Cumbria	38 Foden Alpha dual fuel diesel/LNG
Safeway (Morrison)	Bellshill, Lanarkshire Aylesford, Kent	Scania CNG conversions by IMPCO. Currently not being used by Morrisons (and switched back to diesel fuel).

6.3 International Experience of Biogas as a Transport Fuel

6.3.1 Sweden

The Swedish experience can be used to help point the way forward in the UK, although the specific circumstances of energy supply and demand in Sweden have been the major factors in influencing the take-up of this vehicle fuel option. The development of biogas as vehicle fuel in Sweden has been a result of a combination of a surplus of gas from existing biogas plants, primarily at their municipal sewage treatment plants, and a low electricity price that forces the biogas fuel into markets other than electricity production. A potential market for biogas is as a road vehicle fuel, and there are reported to be more than 7,000 vehicles in Sweden running on biogas and natural gas today[34].

All of the biogas plants in Sweden that are in the planning or construction phase will be equipped with possibilities to deliver a biogas that is upgraded to natural gas quality, either for direct use as a vehicle fuel or for injection into the national natural gas grid. The fuel is being used in both heavy-duty and light-duty vehicles. Also, Sweden appears to be the only country in the world with a national standard for biogas as vehicle fuel. This standard essentially states that the methane content must be higher than 95% and also sets limits for dew point, sulphur content and some other minor constituents.

Currently there are some 14 local fleets (e.g. in the cities of Linköping, Uppsala, Kristianstad) where the major part of the urban public transport is operated on biogas. In addition many Swedish cities are promoting the use of biogas in private cars through a range of incentives including:

- Free parking;
- Lower tax on biogas vehicles when used in commercial traffic;
- No tax on biogas as vehicle fuel;
- Exemption from city gate tolls for biogas vehicles;
- Special lanes for biogas taxis;
- Financial support for investment in biogas vehicles;
- At the national level company tax is reduced by 40% when gas vehicles are chosen by staff.

These benefits have created a very positive climate for the development of the biogas vehicle sector – for example some 15% of the large Volvo vehicle sales are now CNG bi-fuel vehicles. Furthermore, the development of the biogas vehicle sector has been undertaken in close co-operation between natural gas distributors and biogas distributors. Sweden does not have a very well developed distribution system for natural gas and co-operation has been necessary to create a nationwide distribution system for methane gas. The tax on natural gas as vehicle fuel is small enough to make the market still interesting but big enough to make upgrading of biogas viable and competitive with natural gas.

A good example of the use of biogas in Sweden is the EC supported Trendsetter project. Twenty-one buses and three refuse collection vehicles were purchased for use with biogas in Stockholm. During the project, the operating features of these vehicles were evaluated with respect to technical performance and user acceptance. The key results from the project were:

- The total extra cost of the biogas vehicles was about 700,000€ ;
- CO_2 emissions were reduced by 86%, NO_x, CO and particulates by 50%, but emissions of hydrocarbons increased by 20 times;
- Maintenance costs increased from 0.033 € /km to 0.045 € /km. This cost increase derived from the use of an Otto engine which needed more service and changes of spare parts than a diesel engine. The consumption of engine oil was also twice as high in the biogas vehicles compared to diesel vehicles;
- Fuel consumption increased by 60% in comparison with the consumption of corresponding diesel vehicles. This is due to the fact that the diesel engine is more energy efficient than the Otto engine, especially when operating at low loads;
- Driver acceptance was monitored – this showed that 90% of drivers were satisfied or very satisfied with their experiences from driving heavy biogas vehicles, and a majority said they would recommend others to drive these types of vehicles. The refuse collection vehicles were also appreciated by residents, as they are much quieter than conventional vehicles.

As part of the development of biogas in Stockholm, four biogas fuel filling stations were built in the business districts of the city. Three of the stations were built by AGA Gas AB, and one by Statoil. About 8 million Nm^3 of biogas per year will be delivered through these stations, and a further network of at least 10 more stations is being planned. The extended network will serve more than 1,000 biogas vehicles operating in the city.

6.3.2 Lille, France

In 1990 Lille Metropolis decided to start an urban bus service, fuelled by natural and/or purified biogas, produced from the fermentation of sludge from a local sewage treatment plant. After an experimental project and a successful test period, it was decided to introduce a new fleet of such vehicles into full service. The final objective is to convert the entire fleet (400 buses).

By the end of 2005, Lille Metropolis had:

- Purchased 128 gas/biogas buses, and is operating a total fleet of 170 gas/biogas buses;
- Purchased a new CNG and biogas compression station for the buses;
- Built a new bus depot and modified certain depot features (gas detectors, ventilation systems, and lighting), to guarantee bus operation and maintenance safety.

The dual compression station, using both supplies of natural gas and biogas, is able to cope with fluctuations in biogas

34 Biogas as a transportation fuel, Jonsson and Persson, Swedish Gas Centre, 2003

production, and maintain sufficient supplies for servicing the bus fleet. The total cost of the operation per km of biogas bus is equivalent to that of fossil fuel operation, and the biogas cost similar to that of natural gas. The success in Lille has encouraged the public transport authorities to continue to invest in biogas buses, with the objective of converting their entire fleet to biogas by 2015, and constructing sufficient biogas supply capabilities for the fleet.

6.3.3 Switzerland

There has been active development of biogas for vehicles in Switzerland. Some 750-800 vehicles are currently operating on biogas in Switzerland, with a network of over 40 refuelling stations located around the country.

Biogas is promoted in Switzerland through a variety of public and private sector measures:

- It is exempt from fuel taxation;
- There is a definition of the minimum feed-in volumes of biogas via an initiative between the gas companies and fuel suppliers, together with an agreement regarding prices for upgraded biogas, and the branding of biogas and mixed fuels;
- New refuelling stations are given financial support by the gas industry foundation;
- A promotional campaign involves the gas suppliers and other partners.

As a result of the tax exemption, biogas can be sold for 45% less than petrol at the refuelling stations (biogas is around 0.63 €/litre for petrol equivalent volume, compared with 0.95 €/litre for petrol). This gives an acceptable payback for the additional investment required of around 3,000 Swiss Francs for the vehicle. The tax lost through the exemption is actually recovered by increasing the tax on petrol.

6.4 Lessons Learnt for Developing Biogas for Transport

Biogas has been produced and used in vehicles for a number of years now. There have been a few early experiences with landfill gas in the UK and some limited success with CNG vehicles, but much greater development of the fuel in mainland Europe, particularly Sweden. Interest in biogas is being driven largely by the following factors:

- Reduced environmental impact, since fossil gasoline and diesel are replaced by a renewable fuel;
- Clean air, since gas fuelled vehicles can emit less nitrogen oxides, particulates and hydrocarbons than gasoline or diesel (depending on which Euro emission standard and engine technology is being compared);
- Reduced dependence on oil and better fuel security;
- Biogas can be produced from a variety of feedstock: waste and by-products which have to be treated anyway; sewage sludge, municipal bio-wastes, and waste from the agro-food sector;
- Biogas is in many cases not the priority but biogas production is a way to improve environmental efficiency of waste treatment processes;
- Upgraded biogas is similar to natural gas and existing CNG infrastructures and vehicles can be used. Natural gas can be complementary in security of supply and the natural gas grid can transport upgraded biogas.

The question is, then, why has there been more success in mainland Europe and less in the UK?

6.4.1 The Challenges of the UK Market

Clearly the UK has had success in the development of anaerobic digestion of sewage wastes, driven largely by environmental legislation. The focus has been on AD as a waste treatment process and not as an energy production system. The gas yields have not been a priority, nor has there been a great deal of effort in using the gas output as a useful product. The current use of the gas is for heat energy input into the process and some generation of electricity. The main reasons for the use of the gas to produce electricity would seem to be:

- A relatively strong electricity price giving potentially a better return than for vehicle fuel;
- Fairly straightforward to sell to the electricity market;
- A lack of knowledge of the potential vehicle market.

To get greater production of biogas it is necessary to increase the gas yields by using more advanced AD technology and to use a wider range of feedstocks such as waste food and animal manures. This will require the strong regulatory measures for waste treatment, which are now being put in place, and a strong market for the biogas as a vehicle fuel.

However, the market for gas vehicles, or more precisely CNG vehicles, has not been a success in the UK. CNG was first promoted as a vehicle fuel through the EST Powershift programme from about 1997 to 2004. However, relatively few vehicles were supported through grants in this period, mainly due to the economics and practicalities of operating natural gas vehicles. EST data indicates that around 250 CNG vehicles were funded, comprising 120 light commercial vehicles, about 100 heavy vehicles (including buses), and 20-30 cars.

Based on the Powershift experience, it is clear that there are several reasons why the UK market has lagged behind other European markets with natural gas vehicles, including:

- Lack of availability of natural gas as a vehicle fuel. There are very few natural gas fuelled vehicles or natural gas refuelling stations in the UK. However, a grant programme to part-fund the construction of natural gas refuelling stations was announced in August 2005 by DfT (managed by EST) and it is hoped this will improve the situation in due course;
- Limited availability of CNG vehicles in the UK. Natural gas vehicles and engines are available from many manufacturers including Cummins, Ford, General Motors, Iveco, Volkswagen and Volvo. However, these manufacturers do not seem to actively promote the natural gas option in the UK;

- Reluctance of operators to try new fuels especially with higher capital costs for the vehicles;
- The Bus Service Operators Grant removes any financial incentives for bus companies to use CNG, a market that has been very strong in other EC countries.

These are the classic symptoms of a new technology trying to get to market: no one will supply the products to the market until there are buyers and there are no buyers until there is confidence in the availability of the vehicles and fuel.

Nevertheless, there has been some success with a few HGV fleets in the UK, with the main reasons for their success being:

- The ability to generate costs savings from lower fuel costs for high mileage vehicles;
- Investment in a significant fleet of vehicles to get economies of scale in terms of vehicle costs and refuelling infrastructure;
- Active involvement in the vehicle technology to ensure that operators get the products and reliability they need.

6.4.2 Success Factors from Other Countries

The drivers behind the success of biogas as a vehicle fuel in other countries have been strongly related to environment concerns such as air quality, climate change and waste management. At a more practical level there seem to be two specific reasons why the biogas has been used elsewhere in Europe as a vehicle fuel rather to generate electricity:

- Electricity prices have not been as strong as in the UK so other outlets for biogas have been sought;
- There is a greater level of vertical integration between the biogas producers and municipal transport fleets.

This latter point is probably particularly important and helps explain why the bus market for both CNG and biogas has been much stronger in countries such as Sweden and France.

For example, the experience of Lille in the operation of a biogas bus fleet shows that with adequate political engagement a substantial improvement in the environmental impact of the public transport operation can be made. A strategy which takes account of all the issues, including infrastructure development and vehicle operations is vital. The conversion to biogas bus fleets depends on the control of the complete value chain from gas production, to distribution and implementation in the vehicle fleet. Economic evaluation based only on a sub-set of the bus fleet cannot be sufficient to approach the problem of converting a complete regional fleet. Lille metropolis demonstrated the technical, environmental and economical feasibility of such conversion on a large scale.

In terms of the wider experiences of developing the CNG bus market, a recent study by the International Association for Natural Gas Vehicles (IANVG)[35] found that those operations that committed to a large enough number of CNG buses to develop and support the necessary infrastructure, both in maintenance and refuelling, had the greatest success. This requires long-term commitment and motivation by the operating organisation, combined with the opportunity to benefit from fuel cost savings and the need to meet strict environmental performance.

Clearly, many of these lessons from the international bus operators' market, together with the limited experience of natural gas vehicles in the UK, will apply to the potential development of biogas vehicles. The focus of the international natural gas vehicle market has been on medium and heavy commercial vehicles. This has been partly due to the availability of heavy-duty dedicated natural gas engines, and partly because the economics of scale of fuel supply can provide some cost savings to large fleet operators of these vehicles, where tax incentives can also be used to make the economic case.

35 Biogas as a transportation fuel, Jonsson and Persson, Swedish Gas Centre, 2003

7: A Future Role for Biogas as a Transport Fuel?

7.1 Drivers for Using Biogas in Transport

There are two main drivers that are giving an impetus to finding a role for biogas as a future transport fuel:

- The need to find new ways of managing organic wastes, as opposed to landfill, and the legislation behind this;
- Reducing carbon emissions and managing the threat of climate change.

7.1.1 Managing Organic Wastes

This agenda is being driven by the EU Landfill Directive that is aimed at reducing the amount of landfill in the EU, especially of organic wastes. The targets that the UK has adopted are a reduction in organic waste going to landfill of 25% by 2010, rising to 65% by 2020. The mechanism designed to meet these targets is the Landfill Allowance Trading Scheme (LATS), launched in April 2005. This scheme sets an allowance for organic waste disposable (household) for each waste authority, which reduces over time in line with the targets. The penalty for exceeding the allowance is £150/tonne. However, authorities are allowed to trade allowances if they can reduce the amount of material they send to landfill below their allowance.

This Landfill Directive and the LATS provide a significant incentive to develop organic waste treatment processes such as AD. It effectively sets a market of 65% of all organic waste that needs to be treated and sets an upper limit to treatment costs of £150/tonne. The market in allowances will establish a price which treatment processes need to meet. The current market for waste gate fees is around £50/tonne, as used in our economic analysis above, but as the EU Directive bites there will be pressure to treat greater volumes of waste and push the price up potentially towards the £150/tonne penalty. This effect would significantly improve the economics of biogas production.

Alongside the LATS scheme the UK also has a landfill tax that came into effect in 2004 at £15/tonne and applies to all waste both household and domestic. The cost is rising over time to a maximum of £35/tonne. The current tax rate is £21/tonne. These tax rates will also affect gate fees for waste treatment plants.

A third piece of legislation that will affect the market for AD is the Animal By Products Directive, which prohibits any raw meat or fish going to landfill and any meat or fish wastes (cooked or raw) being used in animal feeds. This means that there is a significant waste stream from food processing and catering businesses that needs specialist waste treatment. AD is approved to treat most categories of this waste stream.

7.1.2 Climate Change, Air Quality and Biofuels

Carbon emissions from transport are continuing to rise in this and other countries, and are proving to be the most difficult source of emissions to tackle. In recognition of the role that biofuels have in reducing carbon emissions from transport, the Biofuels Directive sets a target of 5.75% of all transport fuels to be biofuels by 2010. The UK has taken the approach of the Renewable Transport Fuels Obligation (RTFO), as a means of meeting the Directive. The RTFO, discussed in more detail below, sets an obligation on fuel suppliers to supply 5% of their total fuel volumes as biofuel by 2010/11.

The analysis has shown that compared to other biofuels, biogas has the potential to reduce carbon emissions. Its fuel life-cycle CO_2 emissions are much lower than for the other fuels. As such it would seem sensible – as is being done in some other countries – to promote biogas as one of the fuels that can meet the Biofuels Directive targets. However in the UK the place of biogas in the RTFO is currently uncertain.

Transport emissions have a major impact on local air quality. In the UK this is being tackled through the process of local air quality management which seeks to meet the air quality standards set out in EU Directives and adopted in the UK Air Quality Strategy. As part of this process areas not expected to meet air quality limits are declared air quality management areas (AQMAs). Some 90% of areas declared so far have been on transport grounds, and relate to particulate emissions and NO_x emissions.

CNG powered vehicles have been shown to produce generally lower emissions of particulates and NO_x. Therefore the use of natural gas and biogas vehicles has a role to play in meeting local air quality standards in towns and cities – a role which has been recognised across Europe where the use of natural gas and biogas vehicles in urban areas is promoted. Although this has not yet happened in the UK (as described above in section 6), the need to meet air quality limits could potentially act as a driver for biogas in the UK given the right incentive framework. In many European cities air quality has been the main driver.

7.2 Scenarios for Biogas as a Future Transport Fuel

This section looks at two potential scenarios for the uptake of biogas as a transport fuel in the UK: a low scenario that might be achieved with limited support, and a high scenario which might be the maximum we are likely to achieve. We look first at the amount of biogas generated under each scenario, then where this gas may be used in the vehicle fleet, and finally the energy use and emissions benefits of each scenario. It is assumed that in each scenario all the biogas produced will be used as vehicle fuel.

7.2.1 Biogas Production Scenarios

The role of AD in the future will depend very much on how AD competes against other waste treatment technologies that are being driven by the same waste management legislation. Competing technologies include composting, waste derived fuels and energy from waste, gasification systems and thermal treatment. An assessment of all these competing technologies is well beyond the scope of this study, although a recent ERM report on recycling and energy from waste[36] gives an insight into what future scenarios for waste treatment might look like.

For our low scenario we have assumed a limited growth in the use of AD in what might be considered its key markets. The assumptions made are as follows:

- Use of AD in sewage treatment works will remain at its current level of about 75%;
- Small uptake of treatment of wet animal manures, treating 10% of the available feedstock;
- No use of AD to treat dry manures and they continue to be spread to land;
- Low uptake, 10%, of AD for the treatment of food waste.

The high scenario is based on the AD scenario used in the ERM report noted above. This report suggests that the maximum potential for separating out organic material from municipal waste streams for use in AD is 65%. Using this as a yard-stick, and focusing on the key feedstock of food waste, we have made the following assumptions:

- AD in sewage treatment rises to 90%;
- AD of wet animal slurries rises to 30% with a significant amount still spread to land;
- Small amount of dry manure is treated by AD, 10%;
- 65% of food waste is treated by AD.

These assumptions give the total amount of biogas available under each scenario as shown in Tables 7.1 and 7.2. The low scenario is equivalent to about 10% of the theoretical maximum or about 1.5% of total UK vehicle fuel use; the high scenario is equivalent to about 48% of the theoretical maximum or about 8% of total UK vehicle fuel use.

7.2.2 Biogas Fleet Scenarios

Whilst the penetration of natural gas vehicles within transport operations in the UK can only be considered as minimal, its major impact has been seen in heavy goods vehicle fleets over 7.5 tonnes GVW. This category includes a total of 426 vehicles as opposed to 44 passenger cars and 38 light goods vehicles. The main advantages of natural gas to the operator are seen as:

- Reduced operational cost (mainly fuel) on long haul operations (under current fiscal regimes);
- Quieter operation allowing night time deliveries;
- Reduced air quality emissions allowing access to congestion charging and low emission zones.

Although reduction in GHGs may figure in large blue chip companies CSR policies, this is not currently seen as a dominant operational driver to the take up of NG vehicle fleets. Equally there are currently too many barriers to encourage take-up of natural gas powered passenger cars by the car owning public. However the growing visibility of the impact of carbon emissions on climate change may well influence take-up of natural gas vehicles in the near future.

Increases in gas powered bus fleets are not considered likely at present due to the existence of the Bus Service Operators Grant (BSOG) which refunds most of the duty on fuel and effectively removes the duty incentives for any alternative fuel or technology other than diesel. Furthermore until there is a much more comprehensive and accessible refuelling infrastructure, coupled with greater vehicle availability, passenger car take-up will remain essentially static at zero penetration.

This study therefore considers two take-up scenarios:

- Slow but continued increase in the number of haulage and distribution companies employing natural gas vehicle fleets over 7.5 tonnes GVW;
- A more rapid increase in natural gas vehicle fleet numbers, coupled with an increase in natural gas fuelled light-goods vehicles.

Table 7.1: Low Biogas Production Scenario

Material	Dry tonnes per year	Gas factor	Total CH4, m3	Energy value, TJ	Tonnes of Oil Equivalent
Sewage sludge	1,050,000	195	204,750,000	7,289	173,550
Wet animal slurries					
Dairy cattle	201,600	130	26,208,000	933	22,214
Pig manure	53,500	195	10,432,500	371	8,843
All poultry	151,500	236	35,791,875	1,274	30,338
Farm yard manure					
Cattle	0	160	0	0	0
Pig	0	180	0	0	0
Horses	0	75	0	0	0
Commercial food waste	629,500	330	207,735,000	7,395	176,080
Domestic food waste	751,064	330	247,851,252	8,824	210,083
Total	2,837,164		732,768,627	26,087	621,109

36 'Impacts of Energy from Waste and Recycling on UK Greenhouse Gas Emissions', ERM, 2006

Table 7.2: High Biogas Production Scenario

Material	Dry tonnes per year	Gas factor	Total CH4, m3	Energy value, TJ	Tonnes of oil Equivalent
Sewage sludge	1,260,000	195	245,700,000	8,747	208,260
Wet animal slurries					
Dairy cattle	604,800	130	78,624,000	2,799	66,643
Pig manure	160,500	195	31,297,500	1,114	26,528
All poultry	454,500	236	107,375,625	3,823	91,014
Farm yard manure					
Cattle	625,314	160	100,050,240	3,562	84,804
Pig	453,241	180	81,583,452	2,904	69,152
Horses	45,817	75	3,436,290	122	2,913
Commercial food waste	4,091,750	330	1,350,277,500	48,070	1,144,521
Domestic food waste	4,881,919	330	1,611,033,138	57,353	1,365,542
Total	12,577,841		3,609,377,745	128,494	3,059,377

Table 7.3: CO_2 Savings of a Switch from Diesel to Biogas

	HGV CO_2 g/km		LGV CO_2 g/km	
Technology	TTW	WTW	TTW	WTW
Diesel (DICI)	995	1182	192	259
CBG Municipal Waste (SI)	953	289	174	53
CBG liquid manure (SI)	953	-1242	174	-226
Average CBG	953	-477	174	-87
Difference	42	1659	18	346

Table 7.4: Carbon Benefits from Future Transport Biogas Scenarios

Scenario	Gas available		vkm replaced	Total CO_2 benefit, tonnes	
	m3	Kg		TTW	WTW
Low - HGVs	732,768,627	527,593,411	1,522,636,108	63,951	2,525,998
High					
HGVs	2,526,564,422	1,819,126,383	5,250,003,993	220,500	8,709,566
LGVs	1,082,813,324	779,625,593	1,259,492,073	22,131	435,244
Total	3,609,377,745	2,598,751,976	6,509,496,065	242,631	9,144,811

We will assume that scenario 1, with only HGVs using biogas fuel, will provide the market for the low biogas production scenario. The high production biogas scenario will be met by the market growth of HGVs and LGVs, with the assumption that 70% of the fuel is used by HGVs and 30% by LGVs.

7.2.3 Carbon Dioxide Benefits

The fuel consumption data derived in section 4 gives the average gas consumption of an HGV as 34 kg/100 km and the consumption for an LGV as 6.2 kg/100 km. Using this fuel consumption data we can then calculate the number of vehicle kms driven by HGVs and LGVs in each scenario for the amount of biogas available and this is shown in Table 7.4.

Assuming the vkm driven by biogas replace diesel we can then calculate the CO_2 savings from this replacement. This calculation uses the TTW and WTW CO_2 data derived in section 4 for HGVs and LGVs and is shown in summary in Table 7.3. For the actual analysis we used a composite biogas figure comprising 50% from municipal waste and 50% from liquid manure. The difference between the CO_2 figures for biogas and diesel is then the CO_2 benefit of replacing diesel with biogas.

Combining the CO_2 data with the vkm driven on biogas gives the total CO_2 benefit of the biogas replacing diesel in HGVs and LGVs for each scenario, as shown in Table 7.4. This shows that in our low scenario the full WTW benefit would be some 2.5 million tonnes of CO_2, which is equivalent to a 10% reduction of the total emissions from the current HGV fleet.

With the high scenario, where considerably more biogas is being used for both HGVs and LGVs, we see an annual saving of 9.1 million tonnes of CO_2. This is equivalent to a 34% reduction in current HGV emissions and 3% reduction in LGV emissions.

7.3 Barriers and Incentives

7.3.1 The Barriers

The data and analysis suggests there is a significant environmental benefit from the development of biogas as a vehicle fuel, however, there are clearly a number of barriers to overcome given the current limited development of both AD and gas vehicles. The key barriers would appear to be:

- There is limited experience with centralised AD systems treating a range of waste materials, and so the risks for investment are seen as high;
- Currently the economics and practicality of using biogas for electricity production are more favourable than using it as a vehicle fuel;
- There is also limited understanding of using biogas as a vehicle fuel in the biogas production industries;
- The current UK gas vehicle market suffers from poor availability of both refuelling infrastructure and vehicles, and so provides a limited market to potential fuel suppliers;
- The additional capital costs of gas vehicles outweigh the potential fuel costs savings n most cases, and so it is viewed as an uneconomic fuel by vehicle operators;
- The lack of experience of gas vehicles and the limited fleet sizes in the UK has resulted in concerns about reliability of gas vehicles.

Biogas suffers the typical fate of many new technologies, so when compared to conventional petrol and diesel, biogas suffers from a lack of economies of scale. While they remain few in number the cost of production plant, components, refuelling stations, and storage etc remain high. These factors increase the overall fuel costs of biogas to the vehicle user. Also when compared to using petrol or diesel vehicles there is a risk involved for the user/purchaser of a vehicle running on another fuel. Often the technology has not been sufficiently demonstrated to establish such a level of confidence. High profile and extensive testing is required to overcome the lack of experience of designers and engineers, and the need to educate public entities and regulators.

Using alternative fuels often requires more effort than using conventional fuels – for example in getting a vehicle converted or having to undertake refuelling in a different way. Public perception is also important and the consumer must see the change as a change for the better, and understand the benefits. Leadership from government, and other environmentally aware organisations would help to remove this inertia.

Vehicle manufacturers respond to market demand. So long as there is little demand for vehicles with alternative fuels, they will do little to introduce such products, and so long as the products are not available, there is little demand.

7.3.2 Incentivising the Market

If the benefits that are offered by biogas are to be realised, then we need to stimulate the market for greater uptake of the technology. There are a number of market incentives that could be considered to help the biogas market develop.

Fuel duty

Biogas used as a vehicle fuel is currently not distinguished from other road fuel gases, such as CNG or LPG, for fuel duty purposes. The current duty rate is 9p/kg. In addition VAT is applied to all road fuels at the standard rate of 17.5%. The fuel duty rate provides an economic incentive for all road fuel gases, since it is equivalent to 6.6 p/litre on an equivalent energy basis, compared with ULSD which incurs the full fuel duty of 47.1 p/litre. Biogas has a fuel duty advantage of 40.5 p/litre over fossil diesel. Biodiesel and bioethanol also incur a reduced fuel duty at 27.1 p/litre.

Therefore biogas has the same incentive over petrol and diesel as fossil gas fuels such as CNG and LPG, but as the WTW analysis shows, it has a significantly greater CO_2 saving benefit than the fossil gases. In several other countries biogas has a lower duty rate than fossil gases and in some cases is zero rated. Consideration could be given to zero rating biogas to recognise its benefits over fossil gas.

It is worth noting that biogas for vehicle use actually receives a larger fiscal incentive than biogas for electricity under current policies. For electricity production, the value of the ROC at 4.5 p/kWh is equivalent to £33-£39/tonne of feedstock dependent on the CHP plant efficiency. For biogas, the fuel duty advantage is equivalent to £62-£68/tonne of feedstock, dependent on the gas yield.

Bus Service Operators' Grant (BSOG)

This mechanism is designed to give passengers lower fares by reducing fuel costs. It operates through a rebate to bus operators of most of the duty they pay on vehicle fuel. The rebate is currently fixed at about 80%. This rebate effectively removes any duty incentive for using alternative fuels in the bus industry, and has made this market very difficult for gas vehicles.

In other countries, in both Europe and elsewhere in the world, the bus market has been the dominant market for gas vehicles. This is driven mainly by the air quality benefits of the gas fuels in urban areas. If biogas is used then there is both an air quality and climate change benefit. This potential is effectively blocked by the current BSOG arrangements in the UK. Therefore to access this market it will be necessary for the forthcoming BSOG review to reformulate the grant in such a way that it maintains the duty incentives that are designed to support uptake of clean fuels.

Vehicle Grants

The capital costs of the vehicles are currently a major deterrent to developing a vehicle market. Capital grants for vehicle conversion have been used by DfT in the past in their promotion of the alternative fuels markets for LPG and CNG under the Powershift programme. This programme ran over the period from the mid 1990s until 2005, and it has now been closed. DfT had proposed four new programmes offering grants for vehicles with lower emissions:

- Low Carbon Bus Programme to provide grants to bus operators for purchasing low carbon buses;
- Low Carbon Vehicle Programme grants to encourage the purchase of low carbon cars and car derived vans;
- Air Quality Retrofit Programme which would provide grants for the retrofitting of air quality abatement equipment to existing vehicles, including vans, buses, coaches and HGVs.
- Air Quality Vehicle Programme which would provide grants to purchasers for eligible vehicles meeting the European Commission's emission standards for Enhanced Environmental Vehicles (EEVs) as detailed in Directive 1999/96/EC.

Grants would have been no more than 30-40% of the additional cost of purchasing and running these vehicles[37] over five years compared to a conventional equivalent vehicle. However, DfT has recently decided not to pursue the implementation of these programmes, feeling that they would not be cost effective ways to support the market.

There have been concerns from several stakeholders over the sustainability of vehicle grants for promoting a market, with the risk that the market will collapse when the grants are withdrawn. However, there is general disappointment that these grants have not been pursued as many feel they are an important mechanism to help overcome the initial risk to operators of trying new technologies.

Infrastructure Grants

As described above the poor refuelling infrastructure for gas fuels is proving to be a market impediment for both fossil and biogas. DfT is funding a programme of infrastructure grants for refuelling and recharging stations for alternative, cleaner fuels. EST is managing the programme, which received State Aid approval in August 2005.

Funding is available for several non-traditional fuels, including natural gas/biogas stations. Grants cover the costs of civil engineering/construction, hardware and labour costs, with funding of up to 30% of eligible costs for natural gas/biogas dispensers. Additional amounts are permitted for SMEs and where the station is located in a region with special assistance under European Commission rules. Vehicles should be available that operate on the specified fuel, and they must have demonstrated emissions' savings over equivalent petrol or diesel fuelled vehicles. The site must have third party access and not be too close to a similar refuelling station. Project partners must be signed up to the project and planning to use the site to fuel their vehicles.

Renewable Transport Fuels Obligation

The Government has announced that it will introduce a Renewable Transport Fuels Obligation (RTFO). The level of obligation will be 5% by 2010, and the anticipated start date is April 2008.

An RTFO will require transport fuel suppliers to provide evidence which demonstrates that, on aggregate, their UK fuel sales over the course of a period include a specific percentage of renewable transport fuels. As an alternative to supplying renewable fuels, obligated companies can pay a buy-out penalty, which is calculated in proportion to their shortfall in meeting their obligation. Buy-out penalties go into a buy-out fund, which is re-distributed to transport fuel suppliers who have supplied renewable fuels to the market. The obligation will have requirements, as yet undetermined, relating to the environmental performance of fuels used to meet the obligation. For example, the 'carbon life-cycle' of the fuel and the sustainability of how the feedstocks are produced will be important factors in determining the environmental benefits of a renewable fuel.

DfT has undertaken a feasibility study for the RTFO and has recently concluded a stakeholder consultation exercise. The detailed design and procedures will be developed during the next few months, with a view to announcing the formal public consultation and legislative process in Autumn 2006. At present biogas is not clearly included in the RTFO framework. Although it clearly is a renewable transport fuel, it is seen only as a niche market product. Most attention has been paid to biodiesel and bioethanol as liquid fuels that would be blended respectively with diesel and petrol, and these renewable fuels are expected to form the main basis of the obligation. The reasons for this would appear to be:

- Biogas potentially already has significant support through the fuel duty system, currently amounting to about 40.5 p/litre equivalent, compared to biodiesel and bioethanol at 20p/litre;
- The proposed RTFO is based on the duty system and since biogas is not differentiated in this system it cannot be easily administered within the RTFO;
- The current RTFO is based on volume of fuel sold and it is not easy to include a gas in a system based on volume;
- It is not clear, with the current limited supply industry for gaseous transport fuels, where the obligation would lie.

These last three issues are related to the structure of how the proposed RTFO is being implemented, and are not necessarily easy to address in order to allow biogas to be included. At a very minimum to include biogas in the RTFO it would be necessary to:

- Identify biogas separately in the duty system, possibly through a self certification route;
- Have a standard litre equivalence for accounting for biogas in the RTFO framework;
- Biogas could then be used to meet the obligation alongside biodiesel or bioethanol.

37 In compliance with EU State Aid rules

8: Conclusions and Recommendations

The production and use of biogas as a fuel for road transport is a wide and complex topic, and apart from applications in treating sewage waste, a relatively new topic. This study has drawn together existing information to paint a picture of the role biogas might play as a transport fuel. In some cases the data available is very limited and some simplifying assumptions have had to be made. However, this is the first time that biogas as a transport fuel has been explored in any detail as a policy option for the UK. As such this study is a starting point rather than a conclusion, and raises many issues that bear further study.

8.1 Why Consider Biogas as a Transport Fuel?

There are four main drivers that support the use of biogas as a transport fuel:

- Biogas is a renewable fuel, derived from the anaerobic digestion of organic wastes or biomass crops, and as such it can contribute to reducing carbon emissions from transport and tackling climate change;
- As a renewable fuel biogas helps move us away from our dependence on fossil fuels, especially oil, and so is important with regard to security of energy supply;
- As a product of an organic waste treatment process the use of biogas also helps in the management of waste, so it is both a waste treatment and energy production process;
- The exhaust emissions from biogas-fuelled vehicles are relatively low in particulates and nitrogen oxides and so can contribute to improving local air quality.

There are a number of policies and legislative instruments that support these drivers and again suggest biogas as an option to pursue, these include:

- Climate change and carbon reduction targets;
- EU Biofuels Directive – with targets for biofuel use in transport;
- EU Landfill Directive, LATS and the landfill tax – driving a reduction in organic waste going to landfill;
- EU animal by-products directive – restricting the landfill of animal waste or use in animal feeds;
- Local air quality management – with the key issues being particulate and NO_x emissions from transport.

8.2 What Potential Resource Do We Have?

The main feedstocks for biogas production through AD are agricultural manure wastes and food wastes. It is estimated that the UK generates some 30 million dry tonnes of this waste material a year. Given some basic assumptions about production technology and gas yields, this material may produce some 6.3 million tonnes of oil equivalent of methane gas. With current transport fuel demand at around 38 million tonnes of petrol and diesel, this suggests that biogas in the UK could theoretically meet around 16% of transport fuel demand.

However, all this material is not going to be processed through AD to produce biogas, as there are a number of other potential ways to dispose of or manage it. Two scenarios have been proposed as potential developments of the AD market: a low scenario where there is a minimal development of AD, and a high scenario where AD becomes the dominant waste treatment process for organic waste. The low scenario suggests around 0.6 million tonnes of oil equivalent methane could be produced and the high scenario raises this to about 3 million tonnes of oil equivalent. The high scenario equates to just under half the theoretical maximum and is about 8% of total UK transport fuel use.

The current exploitation of AD in the UK is dominated by its use in the sewage treatment industry, where about 75% of sewage is treated by AD, which makes the UK the biggest producer of biogas in the EU. In addition the UK's use of landfill gas is significant and these two sources together provide an amount of biogas equivalent to 24% of our theoretical maximum. However, landfill gas will reduce due to the Landfill Directive and the use of AD for other waste streams is extremely limited. In this respect the UK is far behind the experience in many other EU countries. So there is still some way to go before the UK can have a broad based biogas industry, especially one that provides vehicle fuel. Furthermore the development of this industry is very much a question of how the different waste treatment technologies will compete in meeting the legislative targets and what incentives are available in terms of fiscal incentives such as capital allowances. This is a question well beyond the scope of this report, but an area that warrants further detailed work.

8.3 What are the Practicalities of Using Biogas as a Vehicle Fuel?

To be used as a transport fuel, biogas has to be upgraded to at least 95% methane by volume and it can then be used in vehicles originally modified to operate on natural gas. These vehicles store the gas in high-pressure cylinders on the vehicle and use the fuel in three types of engines:

- Dedicated spark ignition gas engines;
- Bi-fuel spark ignition engines allowing the use of both gas and petrol;
- Dual fuel diesel engines that run on a mixture of gas and diesel, typically 70% gas and 30% diesel.

The technology for these vehicles is reasonably well developed and there is a good range of vehicles available across Europe and in other countries. However, the availability of these vehicles in the UK is very poor as there is currently no viable market. Volvo offers a CNG variant of the S60 and V70 passenger car range, Iveco offer their Daily van with a gas engine, and also provide a CNG version of their Eurocargo HGV.

Hand-in-hand with the lack of vehicles available in the UK, there is also a limited refuelling infrastructure. This again shows the lack of development of the gas vehicle market in the UK. Currently there are only about 500 gas vehicles operating in the UK, with most of these being HGVs. This is in comparison to 500,000 in Italy, 30,000 in Germany and 10,000 in Ireland.

The lack of a gas vehicle market in the UK seems to be related to the following main factors:

- It is currently not an economically attractive option for transport operators;
- There is a lack of experience/credibility of the fuel and so the risks of changing to the fuel require a high level of commitment and a significant level of benefit to the user;
- There is a lack of vehicle availability and refuelling infrastructure.

If these issues are not addressed then the market will remain stagnant.

8.4 What are the Environmental Benefits of Biogas as a Vehicle Fuel?

Two environmental aspects of biogas as transport fuel have been considered: exhaust emissions and air quality, and carbon emissions and climate change. In terms of exhaust emissions, although the data is limited, gas vehicles – both natural gas and biogas – would appear to comfortably meet Euro V or EEV emissions standards with regards to PM and NO_x. Therefore they can have a role in combating local air pollution, especially in urban areas. In fact one of the major uses of gas vehicles throughout the world could be in urban bus fleets to help reduce PM and NO_x emissions in comparison to diesel vehicles.

In terms of carbon emissions we have looked at the major well-to-wheel study done by CONCAWE. This study suggests that liquid biofuels such as bioethanol and biodiesel can reduce carbon emissions, on a CO_2 equivalent basis, by 30-60% compared to mineral diesel. By contrast, biogas can reduce emissions by between 75% and 200%. The higher figure is for liquid manure as a feedstock and shows a negative carbon dioxide contribution. This negative contribution arises because liquid manure left untreated generates methane emissions, which are 21 times more powerful as a greenhouse gas than carbon dioxide, and so there is a double benefit by reducing fossil emissions from burning diesel and reducing methane emissions from waste manure.

This suggests that biogas has a major carbon benefit compared to other transport fuels and is also comparable to the cleanest fuels in terms of pollutant emissions. In addition biogas vehicles are likely to have a noise benefit over conventional diesel vehicles, which will again be important in urban operations. Therefore the environmental credentials of biogas as a vehicle fuel would appear to be very strong.

Therefore if biogas were introduced into the vehicle fleet we would expect some environmental benefits to accrue. An estimate of these benefits has been made using the high and low biogas production scenarios proposed. With the low scenario it is assumed that the gas will be used largely by HGVs, as is currently the case, giving a total annual emissions saving of 2.5 million tonnes of CO_2. The high scenario assumes the fuel will be used in a mixture of HGVs and LGVs, giving a total annual emissions saving of 9.1 million tonnes of CO_2.

8.5 How Do the Economics Stack Up?

The availability of cost data for biogas production is poor. Many of the costs are very plant specific depending on the site, other infrastructure required, what feedstocks are being used and so on. Also biogas is often viewed as a by-product from what is a waste treatment process, and so the economics are viewed from the point of view of how much it costs to treat a tonne of waste. However, data from Sweden and the US suggest that biogas can be produced and sold in the UK at a cost of between 50-60 p/kg, including duty (at the reduced rate of 9 p/kg) but excluding VAT, which is comparable to the current price of CNG to transport operators in the UK at around 55 p/kg.

However, the economics of using biogas or CNG sold at this price as a vehicle fuel would appear not to be very attractive. Again due to the lack of vehicles for sale in the UK and limited data on fuel consumption, a fairly simple estimate of operating costs had to be made. In terms of just fuel costs, the analysis suggests that biomethane would be about 40% cheaper to run than diesel and 55% cheaper to run than petrol. But these fuel cost savings are offset by higher capital costs, some £25,000 for heavy-duty vehicles and £5,000 for light-duty vehicles, and potentially higher maintenance costs. When these are taken into account only HGVs using gas are competitive with a diesel vehicle over an operating life of four years. This reflects the current market position where the only vehicles having any success are HGVs operating on trunk routes and particularly those using the dual-fuel technology.

In other countries around the world the bus market has been the most successful in terms of utilising alternative fuels such as biogas. However, this is not the case in the UK. The lack of success in the UK is due to the very competitive nature of the bus market linked to the Bus Service Operators' Grant (BSOG). The effect of the BSOG, which provides a rebate on fuel duty for bus service operations, is to remove the duty differential between diesel and other alternative fuels. When this is done the cost of operating biogas vehicles will be considerably higher than diesel vehicles.

8.6 Is it Better to Use Biogas for Producing Heat and Electricity?

Currently all the biogas that is produced in the UK from both sewage treatment and landfill is used to produce electricity and heat. The question is why is this the case and is this a better use for the gas? We have attempted to address this question with two fairly simple pieces of analysis:

- What is the carbon benefit of using the biogas to produce electricity as opposed to using it as a vehicle fuel?
- How do the economics of the two uses compare?

In the first instance we simply looked at how much CO_2 would be replaced if the gas was used in an HGV and replaced diesel, compared to producing electricity and replacing electricity from the current mix of generating technologies. This analysis suggested that gas produced from 1 tonne of waste material if used in a vehicle would reduce CO_2 emissions by 413 kg, but if used for electricity would reduce emissions by 454 kg. This suggests that electricity is the better environmental option.

With regards to the economics a simple comparison was done of the revenue generated by using the fuel for vehicles compared to generating and selling electricity. This analysis suggested that the revenue from the gas produced by 1 tonne of waste would be about £66 when used as a vehicle fuel and £66-77 when used to generate electricity. Again the balance would appear to be in favour of electricity production.

This comparison does suggest that the current use of biogas for electricity is the best environmental and economic option. However, the balance is fairly fine and our simple analysis would bear much greater study to get a more robust answer to this question. It also suggests that only small changes in the economic variables on each side of the equation could switch the balance. For example the current rises in oil prices or the inclusion of biogas in the RTFO could shift the balance.

However, this question also needs to be addressed in the wider context such as the potential local air quality benefits of biogas as a vehicle fuel, compared to power generation, and the potentially significant carbon benefits of biogas over other possible transport fuels.

8.7 How Can We Support a Developing Transport Biogas Market?

The environmental benefits of biogas compared to other transport fuels would appear strong, and although there is a case for using the gas for electricity production, it would seem sensible to provide sufficient incentives to allow a market for biogas in transport to develop. In order to pursue a policy of using biogas for transport we need to ask what support is needed? In addressing this we have looked at developing the transport market for biogas rather than the production plant itself. The main mechanisms that could be used are:

- *The RTFO* – it makes sense to include biogas in the RTFO as its credentials for reducing carbon emissions are better than other biofuels. If this is done it provides additional revenue for biogas producers to sell the biogas as a transport fuel and could well tip the economics in this direction;
- *Fuel duty* – the current duty regime does not distinguish between natural gas and biogas as a transport fuel, and so does not recognise the benefits of biogas as a renewable fuel. There is therefore an argument for reducing further or removing the duty on biogas. The effect of this would be to increase the level of fuel cost savings an operator would make using biogas and so make it a more attractive option;
- *BSOG* – this effectively blocks the use of biogas and other alternative fuels in the bus market. Unless BSOG is reformed this will remain the case and a significant opportunity will be lost;
- *Vehicle grants* – grant programmes in the form recently considered by DfT, providing a 30-40% grant on additional vehicle costs would make a significant improvement in the economics of operating biogas vehicles;
- *Infrastructure grants* – these already exist and given sufficient incentives to the operators to use the fuel, will support a more rapid expansion of the refuelling network and so strengthen the market.

A study of how the mechanisms will affect the market and how they relate has not been carried out. However, it is clear that to stimulate the use of biogas as a transport fuel these incentives must provide significant benefit to the transport operator, to overcome the perceived risks of switching to a new technology, not just make biogas competitive, at least in the short term as the technology is being established.

8.8 Where Next?

There is a significant resource available for the production of biogas in the UK allowing us both to manage a waste issue and to provide a source of renewable fuel. Whether this fuel is used for vehicles or electricity it would appear to be worth exploiting more than is currently done. In developing a biogas industry we must recognise that we are crossing a number of disciplines from waste management, through energy use and production to transport operation. Therefore there is a wide range of experience and skills needed, as well as the involvement of many different stakeholders that do not traditionally work together. As noted earlier one of the success factors in other countries has been a greater level of integration of actors in the value chain such as the municipal authority, waste management organisations and transport operators. It is this level of integration and an appropriate policy framework that will make biogas in the UK happen.

With regards to taking the work of this study forward, it is recognised that this is really only the start of examining all the issues around the role of biogas as transport fuel. The study has raised a number of questions that need to be looked at further. The main issues that warrant further study are:

- How is the market for AD likely to grow in the future, compared to other waste management technologies and consider new technical developments, and hence what is a realistic level of biogas production we might achieve?
- Is there a role for biogas from energy crops and how does this compare with other uses of energy crops?
- How does using biogas for transport really compare with using it to produce electricity, considering a range of environmental and economic factors, practicality and

societal needs? Therefore what is the best use of this biogas resource?

- In relation to the above there is also a need for more detailed work on:
  - the energy, carbon and air pollutant emissions life-cycle for biogas as a transport fuel;
  - a better handle on the whole issue of the economics of production and use of biogas as this is still fairly opaque.
- In the longer term it is also important to explore further the potential role of biogas in a hydrogen economy, as it is one of the routes to renewable hydrogen.
- Finally there is a need to examine the different incentives that are available to support biogas, their likely impacts and a sensible package of support.

On a more practical level addressing some of these questions could be supported by one or more demonstration projects, building on the work of such schemes as those in Holsworthy and South Shropshire, to build practical hands-on experience of how a biogas industry can develop. In particular these schemes will need to address:

- The logistics of gathering the variety of feedstocks – wastes and specifically grown crops – that may be required for the AD plant;
- Optimisation of the AD process, including the increasing gas yields, gas purification and the environmentally-acceptable disposal of waste products;
- Cost and physical form of distributing biogas to vehicle users.

Annex: Fuel Consumption Calculations Used in Estimating Life-Cycle GHG Emissions

Fuel consumption and CO_2 emissions data has been available for passenger cars since the 1980s as it is required by EC Directive 80/1268/EEC. However, this has not been the case for light-goods vehicles (LGVs) or heavy-goods vehicle (HGVs) until much more recently. Therefore the amount of data for these latter vehicles is much more limited, and virtually non-existent for alternative fuelled vehicles. Ideally this data is required to make a formal assessment of well-to-wheel (WTW) energy and greenhouse gas (GHG) emissions for each of the vehicle types.

In the absence of appropriate data for the purposes of the determination of WTW energy and GHG emissions it has been necessary to make assessments of the impact of natural gas (and biogas) against gasoline spark ignition and diesel light-goods vehicles, and diesel powered heavy trucks and buses. The sources of information and data used for this purpose were:

- The National Atmospheric Emissions Inventory (NAEI);
- In-service fuel consumption data from fleet users;
- Transport of Goods by Road in Great Britain 2004 (DfT);
- Emissions data from chassis dynamometer tests on HGVs and Buses;
- Type approval data from homologation tests.

Fuel Consumption and CO_2 Emissions from Passenger Cars

The Concawe study used the ADVISOR model to determine fuel energy (MJ/km) necessary to perform the NEDC cycle, and GHG (g CO_{2eq} /km) emitted during the cycle. The reference vehicle used in the ADVISOR model was typical of a European 5-door compact saloon car with a 1.6 litre engine comparable to a VW Golf. Within the model a set of minimum performance criteria was created. Vehicles were modelled using 2002 technology and with performance improvements factored in to produce a 2010 scenario. All powertrain/fuel combinations were required to meet these criteria. It should be noted that when the gas vehicles were modelled, the 2002 PISI bi-fuel NG vehicle suffered a 12% torque loss in gas mode which prevented it meeting these criteria. The criteria were met when switched to gasoline. A dedicated CNG vehicle was also modelled which required the powertrain to be upsized from 1.6 to 1.9 litres in order to meet these performance criteria.

To provide a context for this data we compared the (TTW) CO_2 emissions from Concawe with those from passenger car data in the National Atmospheric Emissions Inventory (NAEI) managed by NETCEN. This NAEI data is presented as a spreadsheet and can generate speed emission curves for regulated emissions and CO_2 emissions for the full range of vehicles in the current UK vehicle parc. The average speed of a vehicle when tested over the NEDC is 33.6 km/hr. This figure was entered into the NAEI model for a gasoline and a diesel passenger car of <2.0 litre engine capacity. Table A1 compares the results from the Concawe work with those from the NAEI.

Light-Duty Goods Vehicles

TNO collected CO_2 emissions data from the top selling 30 light goods vehicles in Europe in 2002. Whilst the data is not fully up-to-date and is purely based on sales in mainland Europe, due to the global nature of the automotive industry and more specifically to the number of collaborative manufacturing agreements concerning LGVs, the data is considered appropriate for application to a UK scenario. Table A2 shows the average Tank-to Wheel (TTW) CO_2 emissions by vehicle class for diesel and gasoline powered vehicles.

These CO_2 figures represent a vehicle, which has a reference mass of around 1600 kg, i.e. at the mid-point of Class II vehicles.

For the purposes of this study the class weighted average CO_2 emissions determined by TNO were compared with the GHG emissions values presented within the Concawe report. This was then translated to produce new figures for the cycle energy, well-to-tank (WTT) and well-to-wheel (WTW) GHG emissions based on 2002 PISI and DICI technology. Whilst this is not considered particularly rigorous, it is considered appropriate within the scope of this study but it must be stressed that all energy and GHG figures presented can only be considered as a guide.

Table A1: Comparison of CO_2 Emissions – Passenger Cars

	CO_2 Emissions (gms/km)		Difference
Vehicle	Concawe (1)	NAEI (2)	
Gasoline (PISI)	224	177	27%
Diesel (DICI)	183	155	18%

1 Figures from Concawe are for Euro III vehicles with Direct Injection
2 The figure derived from NEAI is for Euro II vehicles and is likely to include indirect and direct injection engines

Table A2: TNO TTW Exhaust Emissions CO_2 for LGVs

	Gasoline	Diesel	Difference
Class I	179	160	10.1%
Class II	184	175	4.8%
Class III	283	227	19.8%
Average	222	192	13.6%

Table A3: Fuel Consumption of 2002 Class Weighted Generic Light-Goods Vehicle

	Fuel Consumption		
	kg/100 km	**l/100 km**	**Miles/gallon**
Gasoline (PISI)	6.93	9.24	30.5
Diesel (DICI)	5.95	7.13	39.6
CNG EU mix (PISI)	6.19	40.1	-
CBG Municipal Waste (PISI)	6.19	40.1	-
CBG liquid manure (PISI)	6.19	40.1	-
CBG dry manure (PISI)	6.19	40.1	-
95/5 Ethanol (PISI)	7.06	9.39	30.1
100% Ethanol (PISI)	10.96	13.89	20.5
95/5 RME (DICI)	5.99	7.12	39.6
100% RME (DICI)	6.76	7.73	36.5

Table A4: CO_2 Emissions from Heavy-Goods Vehicles

FIGE cycle			NAEI		
Vehicle	**CO_2 (gm/km)**	**F/C (l/100 km)**	**Vehicle**	**CO_2 (gm/km)**	**F/C (l/100 km)**
Rigid vehicles			Generic Euro I	643	24
Euro I – 7.5 tonne	401	15			
Euro 2 – 7.5 tonne	366	14	Generic Euro II	628	24
Euro 2 – 7.5 tonne	420	16			
Euro 2 – 13 tonne	503	19			
Articulated vehicles			Generic Euro I	1692	64
Euro I – 38 tonne	695	26			
Euro II – 32 tonne	657	25	Generic Euro II	1467	56
Euro II – 38 tonne	706	27			

Table A3 shows fuel consumption in kg/100 km, litres/100 km and miles per gallon for a 2002 class weighted generic European light-goods vehicle if running on gasoline, diesel, CNG and compressed biogas. This is the fuel consumption derived by comparing the TNO data with the Concawe data.

Fuel Consumption and CO_2 Emissions from Heavy-Duty Goods Vehicles

There is a limited amount of data available on HGV fuel consumption and CO_2 emissions, however data from a limited number of chassis dynamometer tests over the FIGE drive

Table A5: Fuel Consumption and CO_2 emissions from HGVs

	DfT – 2004		Fleet data	
Vehicle	**CO_2 (gm/km)**	**F/C (l/100 km)**	**CO_2 (gm/km)**	**F/C (l/100 km)**
Rigid 17 – 25 tonnes	779	29.4	678 (1)	25.7
Artic >33 tonnes	946	35.8	995 (2)	37.6

1 18,000 kg design GVW
2 44,000 kg design GVW

Table A6: Fuel Consumption and CO_2 Comparison for Diesel and Diesel/LNG Dual Fuel 38 Tonne HGV

	Fuel consumption		
	Diesel l/100 km	**Natural gas kg/100 km**	**TTW CO_2 gm/km**
Diesel	37.6		995
Dual fuel	3.2	25.38	782
% reduction			21.5%

cycle were examined, alongside the emissions factors given for HGVs in the NAEI data set. The FIGE cycle comprises three phases – urban, suburban and motorway – and has an average speed across the cycle of 58.98 km/hr. CO_2 data from vehicles tested over the cycle are compared with CO_2 values derived from the NAEI at 59 km/hr in Table A4.

Compared with tests carried out over the FIGE cycle, the NAEI CO_2 and fuel consumption values appear to be in the order of 60-70% higher for 9 tonne rigids, 27% higher than 13 tonne rigids and 230% higher than 30-38 tonne articulated vehicles. Given this large discrepancy two other sources of data were examined: *Transport of Goods by Road in Great Britain 2004* (DfT), and fuel consumption from fleet operations. Average fuel consumption of rigids in the 17-25 tonnes class, and articulated vehicles over 33 tonnes is shown in Table A5. Equivalent TTW CO_2 figures are also shown. When the range of vehicles within the DfT figures is taken into account, fleet data for the 18 tonne rigid and the 44 tonne articulated vehicle correlate well.

Without a more detailed understanding of the basis of the NAEI model, the figures we derived from the NAEI may not necessarily reflect CO_2 emissions from HGVs. These data have, therefore, not been used in this study. Whilst some test data is available from dynamometer tests over the FIGE drive cycle the loading factor applied to these tests may not be fully representative of in-service operation, particularly for heavier vehicles. Fuel consumption figures from DfT statistics and fleet operation for rigid and articulated vehicles correlate well. Actual data from diesel, CNG and diesel/LNG dual fuel vehicles has also been obtained. Therefore these data have been used for this study.

Fleet data for in-service gas consumption for a diesel/LNG powered HGV is quoted as 25.38 kg/100 km. Assuming similar total energy requirements for pure diesel or dual fuel operation, Table A6 shows the theoretical TTW CO_2 figures for both diesel and dual fuel operation. The reduction in TTW CO_2 emissions is in-line with some limited test results from chassis dynamometer tests over the FIGE cycle where CO_2 reductions of 21 to 24% have been seen.

Using this data the fuel consumption factors used for estimating the WTW CO_2 emissions were calculated and are shown in Table A7. This Table shows fuel consumption in kg/100 km, litres/100 km and miles per gallon (where appropriate) for a generic 38 tonne heavy goods vehicle if running on diesel, CNG (Stoichiometric SI), compressed biogas, and Diesel/NG dual fuel.

Fuel Consumption and CO_2 Emissions from Buses

Compared with HGVs there is more data available on bus fuel consumption and CO_2 emissions. The NAEI data was taken as a starting point and in this case compared with Euro III vehicles tested over the Millbrook London Transport Bus (MLTB) cycle based on data analysed by the bus working group of the Low Carbon Vehicle Partnership (LowCVP). The MLTB is a highly transient cycle and is based on the operation of buses over Route 159 in London. The average speed over the cycle is 14 km/hr.

The vehicles examined by LowCVP covered a range of 23 buses operating in urban environments from the smallest (midi bus – 58 passengers) to the largest (double decker – 88 passengers). The major proportion of buses were tested at 50% GVW. Although this test requirement has since been amended to unladen weight plus 50% total passenger load, it

Table A7: Fuel Consumption of 38 Tonne Articulated Heavy-Goods Vehicle

		Fuel Consumption		
		kg/100 km	l/100 km	Miles/gallon
Diesel (DICI)		31.4	37.6	7.5
CNG EU mix (PISI)		34.65	-	-
CBG Municipal Waste (SI)		34.65	-	-
CBG liquid manure (SI)		34.65	-	-
CBG dry manure (SI)		34.65	-	-
Diesel/NG dual fuel	Diesel	2.65	3.17(1)	-
	NG	25.38		-
95/5 RME (DICI)		31.58	37.52	7.53
100% RME (DICI)		35.64	40.77	6.95

1 Diesel part of dual fuel

Table A8: CO_2 Data for Buses from the LowCVP and NAEI

LowCVP		F/C	NAEI		F/C
Vehicle	CO_2 (gm/km)	l/100km	Vehicle	CO_2 (gm/km)	l/100km
Midi bus	931	35	Generic E I	1084	41
Double decker	1461	56	Generic E II	966	37

can be considered as representative of loadings across shift operations. Table A8 compares CO_2 emissions from the lightest and heaviest buses tested with figures derived from the NAEI at an average speed of 14 km/hr.

It is assumed that the generic Euro I and Euro II buses represented in the NAEI are composite buses based on a class weighted average for the vehicle parc. Notwithstanding this, the CO_2 levels generated by the model may underestimate those produced in operational service, at least for larger buses. From the test data examined by LowCVP, the bus working group derived a linear relationship between total passenger capacity and CO_2 emissions. This relationship defined the CO_2 performance of Euro III buses (as tested over the MLTB) as the baseline from which Low Carbon Buses will be accredited. This relationship is:

$$CO_2\ (TTW) = 0.0637\ ((\text{number of passengers} \times 68Kg) + ULW) + 461.03$$

This relationship has been used in the GHG and energy calculations for buses. This gives the fuel consumption values shown in Table A9.

Table A9: Fuel consumption of 88 seat double-deck bus

	Fuel Consumption		
	kg/100 km	**l/100 km**	**Miles/gallon**
Diesel (DICI)	44.84	53.7	5.26
CNG EU mix (PISI)	48.28	-	-
CBG Municipal Waste (SI)	48.28	-	-
CBG liquid manure (SI)	48.28	-	-
CBG dry manure (SI)	48.28	-	-
95/5 RME (DICI)	45.11	53.59	5.27
100% RME (DICI)	50.9	58.23	4.85

This report presents the findings of a research project assessing the potential role of biogas as a transport fuel. It was funded by the following organisations:

- BOC Foundation
  The BOC Group established the BOC Foundation for the Environment in 1990. Since then, it has supported over 100 environmental projects in the UK that propose practical solutions to environmental problems.

- Greenwich Council
  Greenwich Council actively supports initiatives to improve the environment.

- The Energy Savings Trust
  The Energy Savings Trust is a non-profit organisation, funded by the Government and private sector. It has two goals; to achieve the sustainable use of energy and to cut carbon emissions, one of the key contributors to climate change.

- Cenex
  Cenex is an industry-led public-private partnership set up with the aim of assisting UK industry to build competitive advantage from the global shift to a low carbon economy. It supports innovation through a Knowledge Transfer Network dedicated to low carbon and fuel cell technologies and through brokering a programme of activities focused on technology demonstration, targeting early market adoption and supply chain development.

The research was performed by Sustainable Transport Solutions Ltd

A project steering group, provided valuable input and support:

- Andrew Whittles, Formerly Greenwich Council, now Cenex
- Barry Beecroft, BOC Foundation for the Environment
- Carolyn Vannan, NSCA
- David Cherry, Leeds City Council
- Jonathan Murray, Low Carbon Vehicle Partnership
- Lola Fadina, Department for Transport
- Rob Pilling, NSCA
- Robert Evans, Cenex
- Roger Pitman, Environmental Health, Oxford City Council
- Stefania Bobowski, Energy Savings Trust
- Stephen Finnegan, Arup

Further Review and consultation was provided by the NSCA Cleaner Transport Forum, which brings together organisations with an interest in transport and the environment. Members include representatives from the oil and motor industries, local authorities, retail and distribution interests, and environment and transport consultancies.

Full details of the project are available on the NSCA website: www.nsca.org.uk

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