*Measure title:* **Clean Vehicles Trials**

*City:* **Norwich** *Project:* **SMILE** *Measure number:* **5.4**

# A Introduction

## A1 Objectives

The measure objectives (modified because of major extra effort necessary to create a supply chain of biodiesel) are:-

- Create a supply chain within Norfolk for high-quality biodiesel and biodiesel blends for delivery in blended form to participating vehicle fleets and for general purchase across Norfolk and surrounding counties.
- Introduce 5% biodiesel operation on 64 buses in two companies operating in and close to urban areas.
- Introduce 5% biodiesel operation in at least 40 mini-buses and coaches operating from a site in Norwich (possibly up to 100 vehicles total).
- To increase blend concentration up to 20% in selected taxis, mini-buses and coaches in this fleet as confidence is gained and, if successful, to higher blends.
- Introduce 5% increasing to 100% biodiesel operation on 10 buses operating public service routes in and near Norwich to evaluate the optimum blend for performance and emissions.
- Work with Norfolk Police Authority to introduce biodiesel to police vehicles, initially at 5% blend.
- Evaluate the benefits of biodiesel for emissions and greenhouse gas reduction in bus, taxi and police fleets operating in urban areas.
- Demonstrate the evaluation of benefits of biodiesel use to bus and other fleet operators, especially for urban use.
- Increase citizens' awareness of clean fuels and vehicles.

## A2 Description

The use of biodiesel for urban vehicle fleets has been hindered in the UK by problems of supply and (perceived) technological barriers, especially in blends greater than 5%. In bus fleets there are some additional fiscal barriers.

This measure is intended to demonstrate the technical feasibility of using biodiesel at a range of blends as well as to allow evaluation of its effect on $CO_2$ and other emissions, especially in urban areas.

The objective of Measure 5.4 is to provide a clearer understanding to operators, to local authorities and to the public of how biodiesel can help provide cleaner public vehicles in inner city areas and reduce transport-related greenhouse gas emissions. The Measure demonstrates provision of a biodiesel and biodiesel blend supply chain, demonstrates biodiesel use by bus operators, taxi and other vehicle fleets, provides information on fuel economy and emissions behaviour of diesel and biodiesel blends, and creates wide public awareness of biofuels.

Involvement with different transport organisations and a private transport hire company should serve to encourage other organisations in the UK learn to from the experiences of this project

The trials, conducted in and around the city of Norwich, will provide a technical scientific evaluation of the implications of using biodiesel in the UK, in an environmental context. This is something that has yet to be conducted and well documented in the UK. The measure will benefit from experience of biodiesel use in CIVITAS I.

The key tasks of measure 5.4 are:-

- Setting up and organising the logistics and infrastructure for the supply, storage and management of mixing biodiesel fuel blends and dispensing them into transport fleets.
- Researching, sourcing and implementing the modifications necessary to run vehicles on blends of higher concentrations of biodiesel.
- Evaluating comparatively the fuels' performance in fleets using controlled onboard measuring techniques and analyses for fuel economy. Understanding driving behaviour is a prerequisite of this process and as such the equipment will also provide for useful evaluation and tools for driver training and performance evaluation.
- Investigating and calculating the life cycle environmental impacts of biodiesel production from waste oil and expansion to rapeseed feedstocks and the implications for wider dissemination of biodiesel in fleet transport.

# B Measure implementation

## B1 Innovative aspects

**Innovative Aspects**:

- Use of new technology/ITS
- Targeting specific user groups
- Other – Evaluation of the use of biodiesel fuel made from waste oils in UK vehicle fleets

The innovative aspects of the measure are:

- Creating a supply chain for biodiesel blends from B0 to B100 that sources high quality biodiesel from used oils and enables delivery by tanker of any blend required to a customer's fuel store.
- Being able to evaluate more effectively than previous biodiesel evaluation studies by using on-road fleet vehicle measurements– including both exhaust emissions and full greenhouse gas lifecycle assessment – inclusive of fuel economy/costings –and specific to public transport fleet operators.
- Its use at high concentrations will have particular application where arrangements with fuel producers can secure the necessary supply quantity.
- Involvement with different transport organisations and a private transport hire company should serve to encourage other organisations across the UK and in other EU countries to learn from the experiences of this project.

- The use of biodiesel from used cooking oil, especially at higher blends, presents several issues that the Measure will tackle in order to provide guidance and confidence to operators and evidence to local authorities. This measure is focusing primarily on biodiesel from used oil because this material offers significantly higher greenhouse gas savings than biodiesel from virgin plant oils such as RME (rape methyl ester) and the new supply chain to be established will be based on biodiesel from used oil.
- A modestly priced device that can display second-by-second fuel economy in real time is being trialled in collaboration with our partner Anglian Bus and an innovative SME, Lysanda Ltd. This technology can potentially monitor detailed variation in fuel economy between ULSD and biodiesel blends. More generally, it has the potential to offer vehicle fleets the potential to make real and continuing savings in fuel economy as a consequence of driver training and continuing awareness – it can take eco-driving to a new dimension.

## B2 Situation before CIVITAS

Biodiesel operation of vehicle fleets was poorly developed in the UK. There was no biodiesel operation of buses, municipal vehicles, taxis or police vehicles in Norwich or Norfolk.

Biodiesel manufactured from used vegetable oil has been used by some companies in Norfolk at up to 100% concentration within the heavy goods vehicle sector but there is no evidence of good practice available from this use. We are aware, however, that some fleet companies have experienced problems with biodiesel use and this has created a negative perception across the industry. Blocked filters on fuel lines in cold weather have been a persistent problem with biodiesel manufactured from used cooking oil. As the Measure developed, and after our original partner, Global Commodities went into administration, more information came out about some of these issues. We were shown pictures of deposits in a CPS Fuels storage tank where they had stored biodiesel.

There has been no supply chain in the UK for high blends of biodiesel (above B5) to be supplied ready-blended by tanker to a customer’s fuel store. Manufacturers of biodiesel have delivered pure biodiesel to customers and made up the required blend concentrations by splash blending into customers' on-site fuel storage tanks. Indeed, this was the manner of delivery initially proposed for the Measure with fuel manufactured and delivered by our partner Global Commodities.

We have shown during the work for this Measure, however, that this method of blend make-up can create inhomogeneous product because of poor mixing of biodiesel with ULSD. Our original partner delivered biodiesel in this way but we have abandoned this method of blend make-up and worked with fuel supply companies to enable biodiesel storage on site at the fuel supply depot in heated tanks. This is blended with diesel at the appropriate concentration into a tank of the delivery truck. This way a homogeneous blend of the correct composition is assured.

The issue of NOx emissions and fuel economy has been studied predominantly by using engine laboratory bench tests using engines that may not be wholly representative of actual on road vehicle emissions. Much of this work has been done in the United States where engines and biodiesel fuel are often different to the situation in the UK and Europe. In the UK there have been few measurements even of this kind so the estimates of NOx emissions (of particular interest in Norwich because of the Castle Meadow Low Emission Zone – CIVITAS SMILE Measure 6.2) have been made with reference to work elsewhere, primarily in the United States, where engines and vehicles are different and the majority of biodiesel is made from soya oil (soya methyl ester biodiesel is little used in Europe).

Only recently (during this measure) has a real vehicle trial in the US (McCormick et al 2006 - US National Renewable Energy Laboratory), been published where onboard emission measurement has been conducted specifically evaluating exhaust emissions of biodiesel. In this US study, little change was found in NO emissions for B20 fuel compared to diesel. A similar study at this level has not, to the knowledge of the authors, been published in the UK or Europe.

## B3 Actual implementation of the measure

The measure was implemented in the following stages:

**Stage 1: M0- M20 – Planning:** *Background research; liaison with partners and specialists; background data collection and analyses; Evaluation design, equipment sourcing and costing. Researching vehicle warrantee issues and bio diesel safe parts/ fittings to vehicles etc; planning and assessing the effectiveness of blending logistics etc.*

**Stage 2: M20 – M45 - Demonstration:** *Fuel economy, emissions testing, life cycle evaluation, and maintenance evaluation).*

## B4 Deviations from the original plan

The deviations from the original plan comprised:

- **Deviation 1** – The intended supplier of biodiesel in this measure (Global Commodities) was put under forced administration and left the project altogether in month 18. The deterioration of their biodiesel quality delayed the measure implementation during months 1-18. The company had claimed that their product was compliant with the EN14214 standard for biodiesel but this proved not to be the case for the majority of the product we received and our other Partner, Anglian Bus, quite correctly, refused to use Global product.


**Figure 1 shows biodiesel at room temperature in our laboratory (see below) as supplied in 2005 by Global Commodities, our original partner and manufacturer of biodiesel from used cooking oil.**

**Figure 2 shows deposits in the bottom of a road tanker used by CPS Fuels to store biodiesel (before they became involved with the Measure). It is possible that this product was also manufactured by Global Commodities.**

The original project plan envisaged that Global Commodities would manufacture the biodiesel to be used in this work, would deliver pure biodiesel to partners' sites, would splash blend to achieve the desired biodiesel blend (see B2, for concerns about splash blending). The removal of Global Commodities as a Partner in the measure allowed a quality source of biodiesel to be secured and delivered using a local fuel distribution company. We were obliged to establish a laboratory for biodiesel evaluation while Global were still part of the project in order to evaluate their product and, hopefully, help them improve the quality of their product to make it acceptable to the other partners.

**Figures 3 and 4: Biodiesel laboratory**

Using the facilities we established, we also identified quality problems with the product from several other small producers of biodiesel from waste cooking oil. Eventually, we were able to secure a supply of high quality product from Argent Energy Ltd in Scotland. Argent's factory was established with assistance from the EU (quite separately from CIVITAS) and came on stream as this project was beginning. We worked also with a local company (CPS Fuels Ltd) that was able to tanker biodiesel from Argent's factory in Scotland to their depot in Norfolk, to store it in a heated tank, blend it and supply it to partners and to other customers. We were very encouraged by CPS Fuels' willingness to set up these facilities; from their point of view, they were able to establish a new fuel market to supply many existing and new customers as well as partners in CIVITAS SMILE.

**Figure 5 shows the tank heater unit and controls**


**Figure 6 shows the lagged and heated transfer pipe**

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|---|---|
| **Figure 7 shows the mixing unit** | **Figure 8 shows Civitas SMILE participants from Norfolk and Malmo visiting CPS Fuels and observing the mixing/loading unit** |

However, this process was interrupted by the takeover, without warning, of CPS Fuels only a short while after the company had finished setting up these facilities. The new owner closed down the supply depot where the biodiesel was stored and we were obliged to find another company in the region to tanker, store, blend and supply biodiesel and blends. This process is not straightforward because biodiesel made from used oil can throw down precipitates at temperatures below approx 10C and hence any storage tank as well as on-site supply lines must be lagged and heated. No fuel supply companies are set up to provide such facilities (Global did not supply product via a fuel supply company; instead they delivered pure biodiesel direct to the user company to be splash blended into the on-site fuel storage tank; we discovered serious issues with this manner of fuel delivery during the project as noted above: B2). We were eventually able to find a new fuel supply partner, Pace Petroleum Ltd, and storage and blending facilities were established early in 2008 at the Pace depot at King's Lynn, Norfolk, so permitting the supply of high quality biodiesel and biodiesel blends not only to this project but to any fleet operator in the East of England interested in using high quality biodiesel or biodiesel blends. However, the extended delays involved in creating the supply chain seriously delayed the programme of evaluation of biodiesel in vehicle fleets which continues as this document is written.

**Figure 9: Heated and lagged tank and delivery line at Pace Petroleum King's Lynn depot**

- **Deviation 2** – NCS – Norfolk County Services Ltd – a business wholly owned by Norfolk County Council, were intending to use a B5 biodiesel blend when they moved to a new depot site with dedicated fuel tanks. They currently refuel at a commercial service station because there is not room on their present site for buses to refuel. The move has been delayed due to planning and other issues. This has delayed their involvement. It is hoped the site and tanks will be ready in the very near future, before the end of the project.

- **Deviation 3** – The Taxi Company have been using blends up to B50 biodiesel blend instead of the planned B20 blend. B50 has been used as fuel for 40 of the larger fleet vehicles (Executive people carriers, minibuses and coaches). Although the company has many tens of taxis bearing its logo, these do not fill up at the depot but at public filling stations. Hence we were unable to bring taxis into the project as initially planned.

- **Deviation 4** – Because of the delays in establishing the fuel supply chain, we have not been able to follow the ABA method for establishing accurate emissions and fuel economy data (see C 1.1 below). However, we have no reason to believe that the data obtained are not valid. We have been able to examine fuel economy trends across the vehicle fleet of the partner bus company using data obtained with vehicles running on ULSD (see C1.2). These data demonstrate that considerable errors appear even when automated fuel monitoring systems are in use and care must be taken in analysis and data clean up. Because of the time delays in creating the fuel supply chain (Deviation 1), we have only limited running data for vehicles running on most biodiesel blends which means that this fleet-based approach cannot be taken to compare ULSD fuel consumption with fuel consumption of biodiesel blends. However, we have obtained data for two series of vehicles, one running on a B5 biodiesel blend and one running on a B20 biodiesel blend. Neither data set indicates any significant change in fuel economy either from ULSD (B0) to B5 or from ULSD to B20. In addition, the B5 set cover a period before and after exhaust retro-fit for emissions reduction (Measure 6.2) and similarly show no significant change in fuel economy with retro-fitting. We have monitored exhaust emissions on a EuroIV Scania bus that is warrantied for B100 use and the on-board computer also provides fuel economy information that permits a comparison with B0.

- **Deviation 5 -** To permit more accurate measurement of fuel economy during actual vehicle use, to compare ULSD and biodiesel blends in specific situations, and to enable comparison of fuel economy during different road and driving conditions we identified a fuel meter that could be fitted to the fuel supply system of a bus (see C1.1 Indicator 3). We were advised on the particular fuel meter that would be appropriate for this use on appropriate buses from our partner's bus fleet (Anglian Bus) and the electronics company that supplied the interfaces to the exhaust gas monitoring equipment also fitted interfaces to the fuel meter output. In principle, this system could have provided unique and important information on fuel economy and on driver behaviour but we found that the data collection rate was insufficient to provide the required accuracy. Hence we do not have accurate fuel economy information from this source – it could have provided almost real-time information not just on overall trip economy but on fuel economy, and the comparison between ULSD and biodiesel blends, in specific situations, for example during idling, at high torque, in rapid acceleration, under high loading… . However, as noted in B1, we are trialling a sophisticated but low-cost device that can calculate instantaneous fuel-economy in almost real time from analysis of engine data collected from the on-board diagnostic unit (OBD) of a Euro IV vehicle. This will be trialled on Euro IV Optare vehicles of Anglian Bus and, if successful, will have very wide application for driver training and enabling vehicle fleets to maximise fuel economy.

- **Deviation 6 -** The Measure Plan has been expanded to take account of the many issues identified during the project – these changes will be included and commented upon below. The extra work necessary to establish a reliable supply of high quality biodiesel and blends was substantial but has been successfully achieved placing Norfolk at the forefront of biodiesel supply capability in the UK. However, this essential activity has meant that there has been a time delay in completing the original work planned.

## B5 Inter-relationships with other measures

The measure is related to other measures as follows:

**Measure 6.2 -** Introduction of a Low Emission Zone (LEZ) (Norwich)

- Buses using biodiesel will travel through the Norwich Castle Meadow Low Emission Zone so specific evaluation of exhaust emissions of nitrogen oxides from vehicles using biodiesel will be covered by the remit of evaluation in measure 6.2. On road vehicle tests are being conducted to consider if any changes in exhaust emissions may impact air quality. Smoke (opacity), carbon monoxide, hydrocarbons and nitrogen oxides and exhaust carbon dioxide will be monitored in vehicles using biodiesel to evaluate any changes.

# C Evaluation – methodology and results

## C1 Measurement methodology

### C1.1 Impacts and Indicators

| NO. | INDICATOR | DESCRIPTION | DATA /UNITS |
|---|---|---|---|
| 2 | Set up costs<br>Operating costs | Costs per PT pkm | Euros/pkm, quantitative, derived or measurement |
| 3 | Vehicle fuel efficiency | Fuel used per vkm, per vehicle type | MJ/vkm, quantitative, derived or measurement |
| 4 | Fuel mix | Energy used per type of fuel, per vehicle type | MJ, quantitative, derived or measurement |
| 8 | CO2 emissions | CO2 per vkm | G/vkm, quantitative, derived |
| 10 | NOx emissions | NOx per vkm | G/vkm, quantitative, derived |
| 11 | Small particulate emissions | Pm10 per vkm | G/vkm, quantitative, derived |
| 13 | Awareness level | Degree to which the awareness of the policies/measures has changed | Index, qualitative, collected, survey |

Detailed description of the indicator methodologies:

- **Indicator 2** (*Set up and operating Costs*) – Cost per litre of ULSD and Biodiesel will be collected during the project in combination with fuel economy data, (distance per litre of fuel) and apportioned by blend fraction. Other costs, such as extra vehicle maintenance and set up will be reported as an incorporated and separated value as a cost per passenger km.
- **Indicator 3** (*vehicle fuel efficiency*) – Fuel economy data will be collected from vehicle fleets from odometers and the fuel volumes needed to refuel each vehicle (litres). This raw data will be 'cleaned' for errors. The mass per volume conversion factor will be used to derive a MJ/km value for the fuel economy data along with presenting the original km/litre data collected. More detailed fuel usage data may be collected with an accurate fuel flow meter onboard buses during the emissions monitoring test route. If this is viable g/kWh could be reportable over the vehicle engine speed range.
- **Indicator 4** *(Fuel mix)* - Gross heating value of the fuels will be established using a bomb calorimeter for indicator 3 above, also blend consistency will be checked by establishing the ester concentration using Fourier transform infrared spectroscopy (FTIR) methods

- **Indicator 8** *(Greenhouse gas emissions)* - Net greenhouse gas emissions produced by the manufacture and use of biodiesel will be evaluated using a lifecycle assessment approach covering data made available by the supplier on the production of biodiesel and information on its constituents, compared to mineral diesel . This is also known as a well to wheel approach for vehicle fuel comparisons. These values will be reported comparatively as $CO_2$ equivalent emitted per vehicle km based on the fuel mix used. Overall changes in greenhouse gas emissions due to the measure will also be reported.

- **Indicator 10 and 11***(NOx, Smoke and other pollutant emissions*) - This aspect is more specifically associated with measure 6.2, where capacity for measurement of vehicle exhaust emissions has been allocated. Equipment for onboard measurement of NOx, Smoke and other exhaust emissions will be used to evaluate for any changes in vehicle exhaust pollution emissions using different biodiesel blends in buses.

- Emissions testing of vehicles are conducted using an A, B, A approach: Bus exhaust emissions are measured, where possible, using mineral diesel (A1) then measured again after changing to a biodiesel blend (B) for at least two weeks, then the vehicle will be fuelled by mineral diesel (A2) and repeat tested once more. This is performed to ensure that any measured differences in emissions from vehicles using fuels $A_1$ and B can be accepted, or discounted if drift is observed. This may be due to variability in measured emissions independent of using biodiesel such as vehicle wear, maintenance, change in mineral diesel properties and significant environmental variation (climatic factors). Significantly greater differences in emissions between A1 to A2 tests than B tests shall render any changes in measured emissions from the bus whilst operating on biodiesel fuel B as inconclusive. The NOx sensor is calibrated with standard gas concentrations before and after tests to assess for any apparatus measurement drift.

- Environmental effects, (temperature, humidity etc) are (to be) accounted for, as best as possible, by correcting emissions results using established standardising methods.

- **Indicator 13** *(Awareness Level*) - Public surveys (n=800) conducted before and after the measure’s demonstration and dissemination activities will evaluate any changes in the level of public awareness of biodiesel use in public transport as part of the CIVITAS Smile initiative.

## C1.2 Establishing a baseline

**Baseline cost of operation**

The baseline cost of operation will vary from company to company. For a bus company, these costs will include fuel costs and vehicle maintenance costs in particular. It is unlikely that staff costs will change unless there are major issues or problems. If biodiesel or biodiesel blends are used, then a number of additional costs appear. For the fuel supply company these will include the setting up of storage and blending facilities (as noted above in B4), and for the fleet operator these may include extra fuel costs (or a reduction in fuel cost if biodiesel is cheaper than ULSD) and any extra maintenance costs that result from biodiesel use (for example more frequent oil changes).

We have not been privy to the maintenance costs of our partners which are subject to commercial confidentiality. However, because biodiesel use is not yet routinely established, we are unable to identify any major changes to maintenance costs that might arise. As regards the costs to the fuel supply company, as we note below, these will likely be absorbed across the product range and will not be identifiable in the cost of biodiesel or biodiesel blend to a fleet operator.

The price the fuel supply company charges for biodiesel or biodiesel blends is a commercial decision affected partly but not entirely by the cost of biodiesel from the manufacturer. As we note below, although the price pressures on raw materials for biodiesel from used cooking oil will be different to those on crude oil products, and the price of biodiesel and ULSD may not be expected to move in parallel, in commercial practice, the fuel supply company will decide either to price biodiesel and blends at the same cost as ULSD or a little lower if it is desired to create sales volume. CPS Fuels took the latter strategy while Pace Petroleum take the former.

For this reason, we find that, in reality for the Measure, the baseline cost of operation does not change as a fleet operator uses biodiesel or blends rather than ULSD. We explain in more detail below the various influences on costs and on decision-making by fleet operators on what fuel to buy and why there are significant disincentives for operators to use biodiesel or blends on a regular basis. These disincentives are principally to do with warranty issues but also reflect the purchasing philosophies of large and of small operators.

The cost to the fuel supply company of setting up a biodiesel storage and blending facility is highly dependent upon the facilities already in place. We have not been privy to the detailed costs incurred first by CPS Fuels and then by Pace Petroleum in cleaning, lagging and heating a biodiesel storage tank and in supplying a distribution line from the tank to the fuel dispenser where the fuel is blended into the road tanker for delivery. Where a distribution line already exists, as was the situation with CPS Fuels, there will be a considerable cost saving. This cost will anyway be absorbed by the fuel supply company along with other capital expenditure made from time to time and recovered in the profit from total fuel sales. These two companies were willing to invest in such facilities because they believed that they could obtain a competitive advantage in being able to supply biodiesel blends. Other fuel supply companies can only supply conventional road fuel, ULSD (which in the UK should contain up to 2.5 per cent biodiesel from 2008 according to the UK's Renewable Transport Fuels Obligation, the UK response to the EU Biofuels Directive).

Fleet operators are particularly concerned about the cost of fuel and will endeavour to keep this as low as possible. Fuel costs are a major component of total costs for bus companies in particular. Large and small companies will have different strategies to keep fuel costs down and these different strategies impact differently on the possibility for using biodiesel or blends rather than ULSD.

Large companies such as First Eastern Counties Buses, a partner in CIVITAS SMILE, will typically have a national contract with a major fuel supplier. Because of the very large volumes of fuel to be supplied, a very competitive fuel price can be arranged. First Group across the UK has a contract with BP. The existence of this contract created problems for this Measure because BP were unable (or unwilling) to supply any biodiesel blends. It was not practical or economic for the Measure to set up a separate fuel tank for biofuel and biofuel blends at the First Bus depot in Norwich as was done with Anglian Bus in Beccles and Dolphin Taxis in Norwich. Hence there was no practical route for First Bus in Norwich to run its buses on B5 as was originally planned.

Initially, First Bus in Norwich were unwilling to examine the possibility of obtaining B5 from any other supplier. However, a couple of years into the project, and following management changes, First Bus in Norwich did change suppliers in order to be able to trial B5 blend and obtained B5 fuel for their whole Norwich fleet (over one hundred buses) firstly from Harvest Energy and, more recently, from Greenergy. We are not privy to the financial arrangements made for this supply and hence cannot make explicit comparison with the cost of ULSD. However, this change of attitude demonstrates that, notwithstanding whatever is stated in a detailed Measure Plan, management buy-in is essential for progress to be made. The biodiesel in these B5 blends would have been sourced on the open market by these companies and would not have been manufactured explicitly from used vegetable oil as is the case for the biodiesel obtained from Argent Energy Ltd.

First Bus were confident in running buses on a B5 blend because B5 is within the EN590 ULSD fuel specification. Hence there are no warranty issues for any vehicles running on B5. For higher biodiesel blends this may not be the case and many vehicle makers will not warranty vehicles for biofuel blends higher than B5. Some operators may ignore this issue and CPS Fuels ran all their vehicles from the Forncett St Peter depot where they stored and blended biodiesel on a B20 blend without any apparent problems for a few months until the company was taken over and the depot was closed down. If a company feels constrained by warranty issues yet wishes to trial biodiesel blends higher than B5 on certain vehicles, it will have to provide a separate tank to hold the biodiesel blends to fuel the vehicles that will be running on biodiesel while the rest of the fleet runs on ULSD sourced from the principal fuel storage tank. Tank purchase or hire can add a considerable cost to operations. 20,000 litre tanks used in this project cost of the order of Euro 500-1000 per month to hire. It is unlikely that a fleet operator will wish to bear such an extra cost. This fact means that, in normal commercial circumstances, there can be a significant financial disincentive for a fleet operator to run vehicles on biodiesel or blends, even if the fuel per litre is cheaper than ULSD.

The production cost of biodiesel depends in particular on raw materials costs. For biodiesel made from virgin plant oils such as rape oil (the majority source for biodiesel in the EU), the cost depends on the vegetable oil price. This varies with the commodity markets and may vary in quite different ways to the oil price. Early in the project, several large biodiesel facilities were planned for the UK. Late in 2008, price pressures have forced at least some of the projects to be abandoned or delayed.

For biodiesel made from used vegetable oil, the price pressures are different. At the start of this project, there were only a few manufacturers of biodiesel from used oil in the UK and Global Commodities were the largest of these. Supply of oil exceeded demand and biodiesel could be manufactured at a very competitive price compared to ULSD. However, during the life of this project, many other manufacturers have set up, including Argent Energy that manufactures around 45,000 tonnes per year. This increase in manufacturing capability has put significant price pressure on the cost of used oil. The cost to the fuel supply company may still be competitive with ULSD, but it becomes harder to offer a significant price advantage to a fleet operator. [A knock-on impact of the increased competition for used oil may also have been a decline in quality of the product from Global Commodities. The company could no longer source only the highest quality used oil with the result that the product offered to the Measure in 2005 and 2006 may be been significantly inferior to that which they had demonstrated when the project was being set up; the production facilities, unlike those at Argent Energy, were inadequate to manufacture high-quality biodiesel from poor quality oil].

Notwithstanding the various price inputs to the cost of biodiesel to the fuel supply company, the price that the fuel company charges a fleet operator will depend on commercial judgement. Many suppliers, including Pace Petroleum, charge the fuels at a similar rate. The biofuel price shadows the fossil fuel price. Some small producers may offer a lower price for biodiesel if raw materials are competitively priced but, as already noted, we have not found any such producers that produce consistently good quality product and cannot recommend such suppliers for bus companies where reliability is critical. However, Dolphin Taxis have obtained cheaper product from a local small-scale supplier on occasion via splash blending. We have no power to direct a company we are working with on the project to purchase from a particular supplier. As raw material prices vary, it can also be the case that biodiesel sourced in this way becomes uncompetitive with ULSD or that raw materials become in short supply. The company that supplied Dolphin Taxis now indeed has difficulties in sourcing raw material.

How do these pricing issues impact on the fuel purchasing decisions of smaller fleet operators? Unlike companies such as First Group, smaller bus fleets do not have exclusive contracts with fuel suppliers but search for the cheapest supplier on the day they require a delivery of fuel. Per litre prices will vary from one supplier to another and one particular supplier will not always provide the cheapest fuel. This is the situation for our partner Anglian Bus. On occasion, Pace Petroleum, the company that stores, blends and delivers biodiesel and biodiesel blends may offer the cheapest price per litre. As biodiesel and biodiesel blends are charged at the same price as ULSD by Pace, Anglian can, on occasion, purchase B5 blend for their whole fleet. Most of the time, however, fuel from Pace will not be a competitive option against other suppliers of ULSD. Hence a company such as Anglian will not make a commitment to use B5 (or any other biodiesel blend) except when Pace Petroleum are the cheapest supplier. We note this variability in price from the fuel suppliers but have not examined the background in detail. Most suppliers of road fuel turn over their stock quite rapidly and we assume that the price charged on any particular day will reflect the price they were able to obtain from their suppliers, the major distributors. This price in turn will depend on specific factors that are likely to vary on an almost constant basis. Hence, the lowest cost fuel distributor to the fleet operator is likely to vary almost at random.

Because not all Anglian Bus vehicles are warrantied for use of biodiesel blends above B5, Anglian will not purchase higher blends of biodiesel for its main fuel tank, even if these are available at a competitive price. For the work on this project, a supplementary fuel tank has been installed to provide a store for blends above B5 for the vehicles that Anglian are willing to run on higher blends. However, as just noted, this would not be a commercial option for normal operations and the tank will be removed at the end of the project.

What all this means is that everyday use of biodiesel blends above B5 is restricted to fleet operators that are not concerned about warranty issues and wish to trial biodiesel at B5 or higher. Even then, for there to be an economic incentive to do this, either the fuel economy would have to be higher than for ULSD or the biodiesel price per litre would have to be lower than for ULSD (and also other costs would have to remain similar). CPS Fuels were indeed offering biodiesel blends at a competitive price compared to ULSD and were planning to expand their sales far beyond use in the vehicles taking part in this project. Pace Petroleum, however, presently offer biodiesel blends at the same price as ULSD, possibly because they hope to recoup investment made in setting up the biodiesel storage facility at their depot. Given that the evidence shows that fuel economy, at least up to B20, is not significantly different for biodiesel compared to ULSD, there is little economic incentive, at present, for fleet operators to purchase biodiesel blends unless they wish to demonstrate to their customers or to the public their commitment to lower-carbon operations.

This situation would change if there was an economic gain in using a low carbon fuel. In the UK, excise duty on biodiesel has been reduced by 20 pence per litre compared to ULSD, but this reduction merely brings prices more or less in line. The UK decided (after CIVITAS SMILE was underway) to fulfil its obligations under the EU Biofuels Directive by introducing the RTFO (Renewable Transport Fuels Obligation) which obliges fuel suppliers to introduce a minimum biofuel content in road transport fuel (2.5 per cent in 2008). There are no incentives or bigger excise duty or tax breaks for lower-carbon, higher blend biodiesel than B5.

It will be apparent that there are many variable or uncertain costs in biodiesel and biodiesel blend supply. For evaluation purposes, we assume that where an operator is willing to use a biodiesel blend the cost of any blend is similar to that of ULSD on the day (as is the case for fuel from Pace Petroleum). We ignore any extra costs of tanks and so forth that are unlikely to be acceptable to most fleet operators. This means that there will be no change in costs compared to use of ULSD.

These circumstances in the UK, where bus operators are free to choose fuel on a cost basis on the day are rather different to the situation in some other EU countries where the strategic passenger transport authority can require particular renewable fuels to be used. This is why the use of any lower carbon fuel in fleet operations is much less common in the UK than in some other EU countries. Fleets in the UK are almost exclusively diesel powered whereas in many European cities, either higher biodiesel blends, natural gas or, more recently, biogas, have been trialled and widely used.

Existing vehicle maintenance costs are assumed the same as with mineral diesel operation, until any differences are reported by exception by the fleet operators. (None have during the trials to date). There is good evidence from operations in continental Europe that increased frequency of oil changes is required when higher blends of biodiesel are used. This is a consequence of the higher lubricity of biodiesel relative to ULSD which means that it can gain access to the engine oil from the cylinders more readily than ULSD. Insufficient experience has been gained in this work to provide evidence although our testing technique for blend level (FTIR, Fourier-Transform Infra-Red Spectroscopy) seems well-suited to testing engine oil for biodiesel ingress.

**Fleet fuel efficiency**

Baseline fleet fuel economy has been recorded for vehicle fleets involved in the trial. The data is derived from odometer readings manually entered into fuel management systems by drivers on each occasion that the vehicle's fuel tank is filled with fuel. The fuel management system also records the volume of fuel used to fill the vehicle's tank.

This process is open to human error. Quality checking of the data has been carried out to correct, where possible, any anomalous data. An accepted methodology is used (multi pass) for removal of anomalous outliers from the sample datasets (Rosner 1983).

The data show the variation in fuel economy. This is expected with this data evaluative approach. Variation observed in the fuel economy data will be due to many influences such as variations in driving style, vehicle load (passengers) and road environment (Figs 1 and 2). (Similar data for individual vehicles are available if required.)

To reduce the effects of this noise as much as possible during comparison a sample of vehicles data are selected for analyses by consistency and quantity of their fuel economy data, (i.e. those vehicles with regular similar routes and drivers), and those with a greater number of data collected. Also data maybe aggregated by standardising each vehicle's fuel economy data, to check whether sample distributions are sufficiently normal.

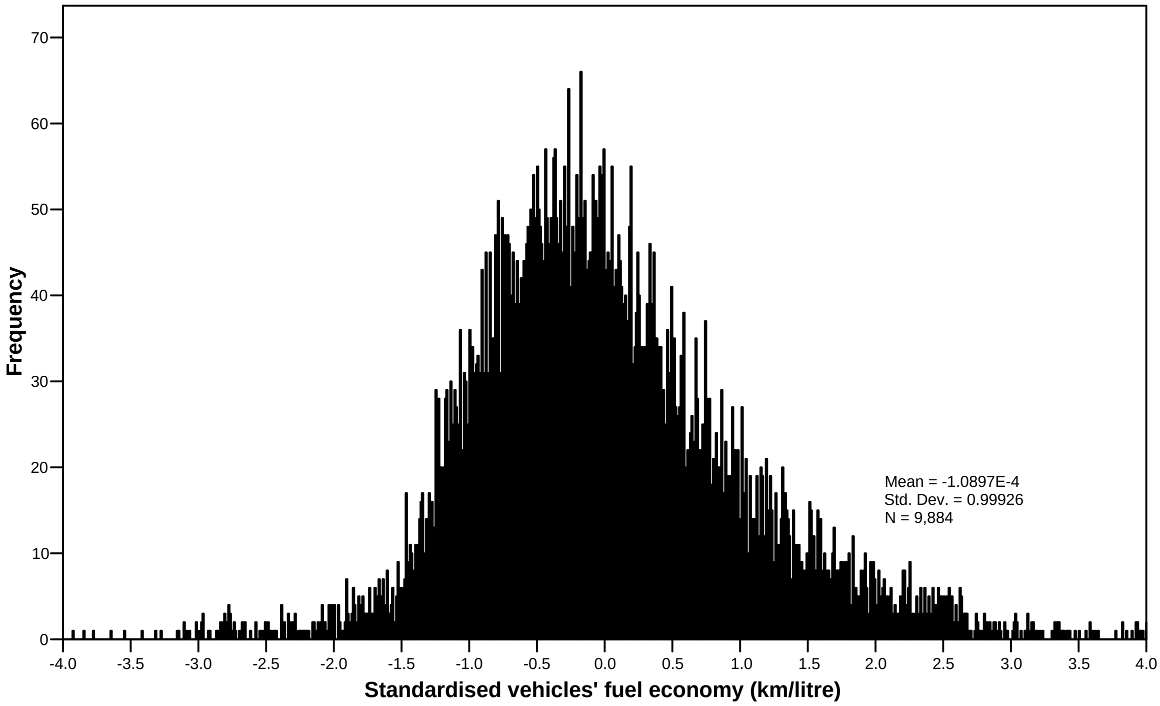



**Fig 1. Raw Data taken from fuel economy records of 13 selected vehicles with nominally similar engines. The fuel economy data of each vehicle has been standardised and the data aggregated in the above frequency graph. Note the kurtosis of the distribution spread – the overall mean -1.069, biased by this distribution, is not a good measure of central tendency for comparative purposes.**

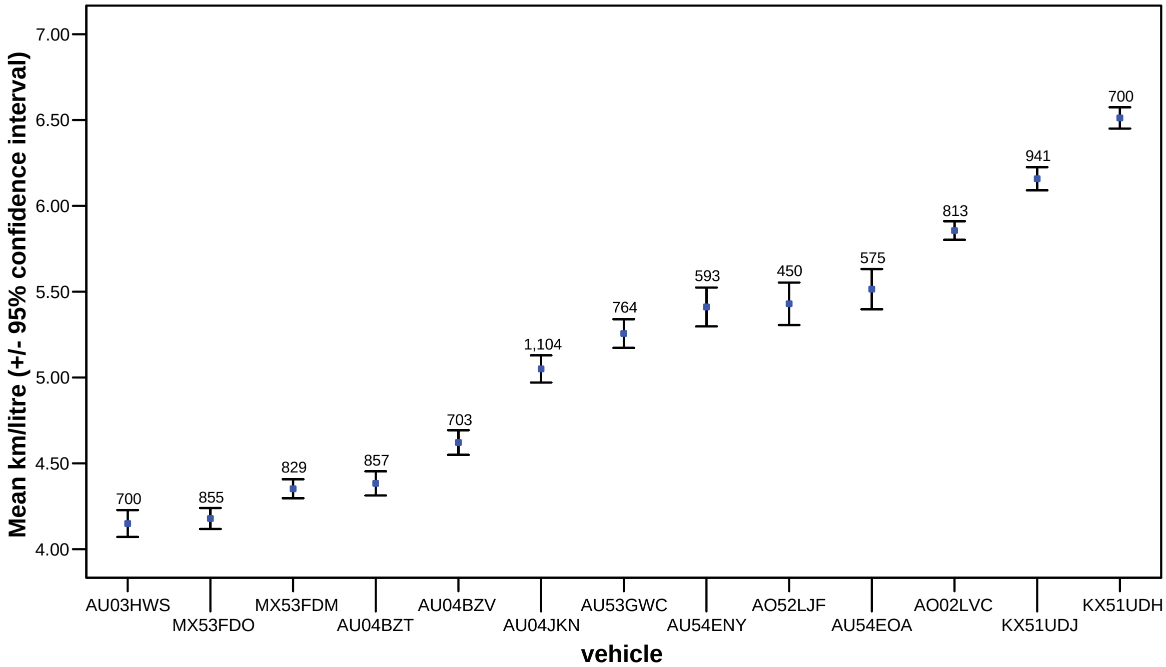



**Fig 2. Baseline fuel economy data of selected fleet vehicles with anomalies removed (numbers above the error bars are sample sizes, n).**

This fleet approach is complimented with more accurate fuel metering on 2 to 3 specific vehicles. Accurately metered fuel use data is recorded during an on road test circuit repeated using the same driver on each outing, and keeping as best as possible to similar speeds on each repeat lap and for each fuel test.

We are not aware of any similarly thorough study of vehicle fuel economy for a vehicle fleet. Most often, overall fuel use is quoted and compared to a previous period with allowance for variation in total distance travelled. The analysis above identifies many issues that are observed in trying to understand fuel economy in detail and sets a standard for fuel economy measurement where sufficient data are available from an automated fuel monitoring system.

**Baseline Energy & $CO_2$ per km**

The figures for baseline greenhouse gas emissions life cycle emissions for mineral diesel are based on $CO_2$ equivalent greenhouse gas emission intensities reported in accepted literature of 87.4 $gCO_{2equivalent}$ / $MJ_{fuel}$ (JEC 2007[1]). This assumes full combustion and includes fuel distribution related emissions as well as extraction, refining and processing related emissions.

Energy intensity of the diesel is given in supplier's specifications sheets but also bomb calorimeter tests have been carried out in our laboratories to substantiate these. Typically the energy intensity of diesel is 43.1 MJ $kg^{-1}$. This is equivalent to 35.8 MJ $litre^{-1}$ (density 0.832 kg $litre^{-1}$ at 15C°). Therefore for the purposes of this evaluation the baseline greenhouse gas emissions per litre of ULS diesel combusted would be equivalent to 3.13kg $CO_{2equivalent}$.

Average fuel economy of the selected fleet vehicles is Mean 5.12 km $litre^{-1}$ (± St.deviation 1.33).

This equates to Mean Average 611g $CO_{2equivalent}$ $km^{-1}$ (St. dev 158).

**Baseline NOx and Smoke emissions**

Due to the evaluation methodology, the collection of baseline emission test results is ongoing throughout the trials, so a contiguous 'before' baseline data set is not presentable or useful for evaluation purposes until after all tests are conducted and analysed. See explanation for Indicator 10 & 11.

**Baseline public awareness survey results**

These data are interesting in that while approximately two-thirds of respondents had heard of biodiesel, only about one-third were aware that biodiesel was being used in buses and taxis in Norwich. The proportions are reversed for the two questions 1A and 1B.

1 Well-to-wheels analysis of future automotive fuels and power trains in the European context European Commission Joint Research Centre, CONCAWE & EUCAR – European Council for Automotive Research and Development. March 2007.

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Norwich City | 264 | 32.7 | 32.7 | 32.7 |
| | Greater Norwich | 544 | 67.3 | 67.3 | 100.0 |
| | Total | 808 | 100.0 | 100.0 | |

**Q1A. Have you heard of bio diesel before?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 552 | 68.3 | 68.3 | 68.3 |
| | No | 256 | 31.7 | 31.7 | 100.0 |
| | Total | 808 | 100.0 | 100.0 | |

**Q1B. Did you know that Bio Diesel was currently being used in buses and taxis in Norwich?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Yes | 214 | 26.5 | 38.8 | 38.8 |
| | No | 338 | 41.8 | 61.2 | 100.0 |
| | Total | 552 | 68.3 | 100.0 | |
| Missing | System | 256 | 31.7 | | |
| Total | | 808 | 100.0 | | |

**Q1C. How did you find out bio diesel was being used in public transport in Norwich?**

| | | Frequency | Percent | Valid Percent | Cumulative Percent |
|---|---|---|---|---|---|
| Valid | Ad on bus | 25 | 3.1 | 11.7 | 11.7 |
| | Ad in taxi | 6 | .7 | 2.8 | 14.5 |
| | In local press | 64 | 7.9 | 29.9 | 44.4 |
| | In national newspaper | 54 | 6.7 | 25.2 | 69.6 |
| | By word of mouth | 26 | 3.2 | 12.1 | 81.8 |
| | Other way | 28 | 3.5 | 13.1 | 94.9 |
| | Can't recall | 11 | 1.4 | 5.1 | 100.0 |
| | Total | 214 | 26.5 | 100.0 | |
| Missing | System | 594 | 73.5 | | |
| Total | | 808 | 100.0 | | |

Table 1

### C1.3 Building the business-as-usual scenario

At the level of an individual vehicle there is no business as usual scenario – either the bus operates on standard ultra low sulphur diesel fuel or it operates on the trial blend of biodiesel with the measured impact.

A business as usual scenario could be developed in terms of assuming that a proportion of the fleet might have switched to some form of biodiesel blend if the SMILE measure had not been in place. However, in reality this appears to encourage / support the users in getting this far.

## C2 Measure results

### C2.1 Economy

As we discuss at length in C1.2, there is no change in cost that we can specifically identify when changing from ULSD to a biodiesel blend. There are many cost factors that may influence decision-making but these will be specific to particular situations and cannot be generalised.

### C2.2 Energy

A consequence of the delays in establishing the biodiesel supply chain has meant that we have been unable to collect fuel economy data for biofuel blends to the same degree of accuracy as has been the case for the fleet running on ULSD. Also, as discussed in Section B4, the fuel meter we have had fitted to one bus has not proved sufficiently accurate to provide meaningful fuel economy information in real-time.

However, we have acquired several weeks' data for fleets running on B5 and B20 a part of this Measure and have been able to compare the overall fuel economy per vehicle with that for ULSD under similar conditions. There are, as expected, fluctuations from vehicle to vehicle but we observe no significant change overall in fuel economy (see below).

We have also run a new Scania Euro IV bus of the Anglian fleet on B100 and observed the change in fuel economy compared to B0 (ULSD) [this bus is only warrantied for B0 to B5 and for B100]. While the data is not as extensive as we would like, indications are that fuel economy drops by up to 10 per cent when the vehicle is running on B100 compared to operation on ULSD. This drop is consistent with the change in energy per litre of Argent biodiesel relative to ULSD (see below).

In Figure 3 below we plot the fuel economy for twelve buses of First Group fleet running first on ULSD, then on B5 (as discussed above) and finally on B5 after exhaust retrofit with SCR (selective catalytic reduction) to reduce NO emissions as part of Measure 6.2. As we found above, there are variations from bus to bus but no significant trend in fuel economy. We conclude that there is no significant change in fuel economy either on moving from ULSD to B5 or after retrofitting with SCR. This latter result is gratifying and shows that measures to reduce exhaust emissions seem to have no adverse impact on fuel economy.

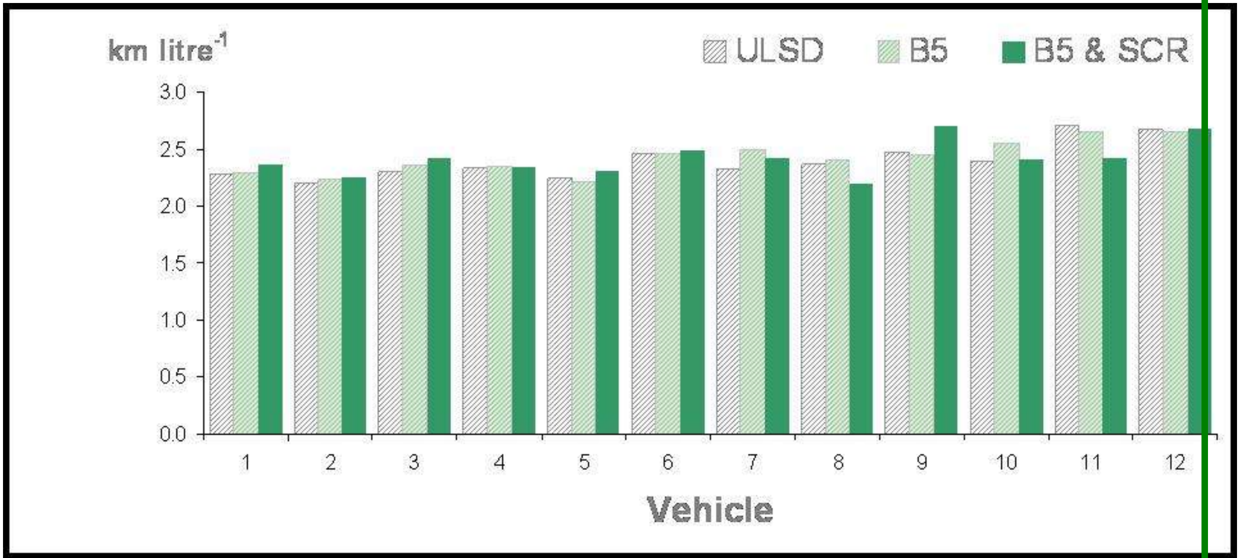
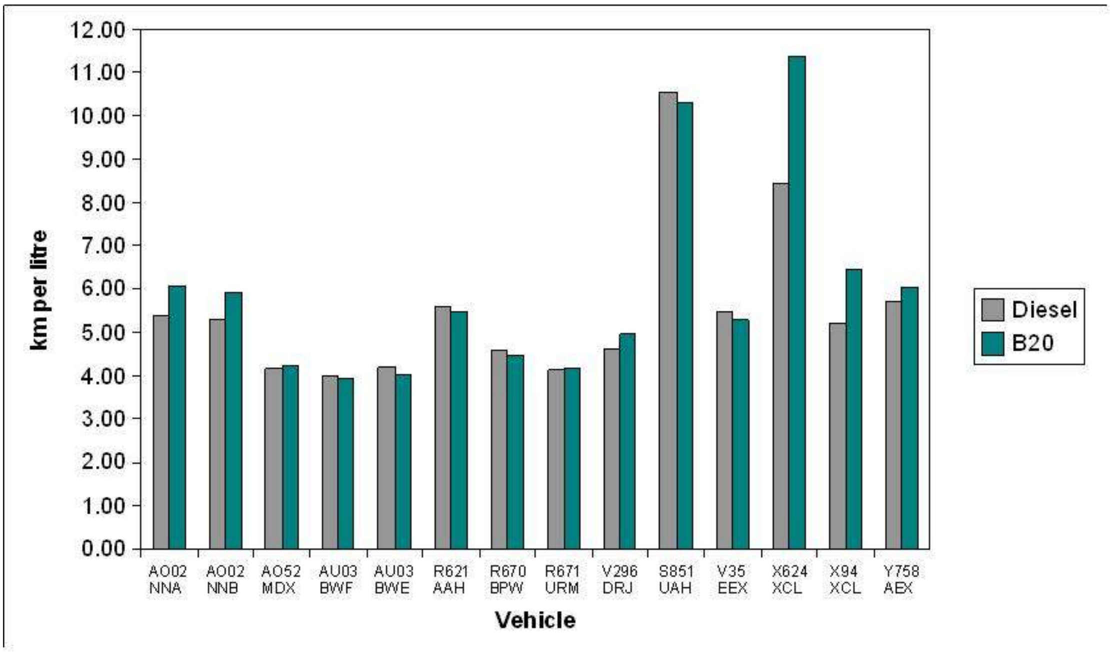



**Fig 3. Fuel economy data for twelve First Bus vehicles running on ULSD, then on B5 and finally on B5 after retrofitting with SCR (selective catalytic reduction) to reduce exhaust emissions.**

In Figure 4 below we show fuel economy data for vehicles from CPS Fuels fleet that were running on a B20 blend for nearly six months in 2006. These data are compared with the same period in 2006 when the vehicles were running on ULSD. In this manner we hope to eliminate or at least minimise seasonal variations in fuel economy.

As expected the data are variable from vehicle to vehicle but there is no indication of any reduction in fuel economy in going from B0 (ULSD) to B20. Statistically, there is no overall change, but there is possible indication of a slight increase in fuel economy at B20. Given the manner in which the data were collected (comparing one year with the same period in the previous year) we do not feel confident in suggesting that fuel economy is higher for B20 than for ULSD. However, we are confident that these data are consistent with no change.




Graph of fuel tanker fuel economy over periods April 17th 2006 to Sept 30th 2006 (Diesel) compared to April 17th 2007 to Sept 30th 2007 (B20 blend). Fuel economy calculated from mass balance: the cumulative total distance driven in the period divided by cumulative total fuel attributed as used by each vehicle over the period.

**Fig 4. Fuel economy data for CPS vehicle fleet for April to September 2006 (B20) compared with the same period in 2006 (ULSD).**

Overall, our results indicate that fuel economy does not change in going from ULSD to B20. This result is not rigorous across a range of different vehicle types, but is consistent with the modest change in energy density per litre at this level (approx two per cent lower in B20 relative to ULSD [based on a ten per cent reduction for B100 – see next section]). A two per cent change will be very difficult to observe given all the influences on fuel economy that our analysis of the ULSD data (above) reveal.

We would like to collect more data to substantiate the apparent ten per cent reduction in fuel economy for B100 relative to ULSD (see above) but this drop is very consistent with the ten per cent drop in energy per litre for Argent B100 relative to ULSD.

However, for operational reasons we will not recommend use of B100 except for trials. As we note below in the section on Baseline NOx and smoke emissions, B20 is the highest blend of Argent biodiesel with ULSD that can be safely used through the year even in cold weather. Also, if there is a ten per cent reduction in fuel economy for B100, this equates to a ten per cent increase in fuel costs for the operator relative to ULSD which is unsustainable. We would like to collect more data on B50, but as we note below, B20 seems to provide an optimal combination of reduced greenhouse gas emissions, possible reduction in NO emissions with no drop in fuel economy.

## C2.3 Energy & Environment

Energy

The net calorific value of Argent B100 biodiesel we measure in the bomb calorimeter is 36.7 MJ $kg^{-1}$. This is equivalent to 32.3 MJ $litre^{-1}$ (density 0.88 kg $litre^{-1}$ at 15C°). In other words, the energy density per litre of Argent biodiesel is ten per cent less than that of ULSD. This trend is consistent with the change in fuel economy per litre we have observed for B100 compared to ULSD for a Scania Euro IV bus (see above).

***$CO_2$ emissions***

In respect of greenhouse gas emissions, use of B20 biodiesel would generate a significant reduction in $CO_2$ emissions of around 600 tonnes per annum across the Anglian Bus fleet. As noted above, the accepted $CO_2$ emissions per MJ of ULSD is 87.4g. We have not yet completed the full life-cycle and carbon footprint analysis of Argent biodiesel as it has been difficult to obtain some of the necessary data. However, Argent Energy have had to perform an approximate analysis in order to comply with the requirements of the UK RTFO (Renewable Transport Fuels Obligation) and suggest a figure of around 14 g/MJ. This is 16 per cent of the emissions for ULSD and is a very large reduction because of the source of the input material in their process – used oil.

Pro rata, this figure would imply a 17 per cent reduction in greenhouse gas ($CO_2$e) emissions for B20 compared to ULSD. Anglian Bus use approximately 100,000 litres of fuel each month. If this were to be B20 (with similar fuel economy to ULSD) then annual greenhouse gas savings would be around 600 tonnes.

The ghg saving from the biodiesel in the B5 fuel used by First Bus will not be as large, as it comes primarily, probably, from virgin oils. We do not have the make up of this fuel but the published response of Greenergy and Harvest Energy (First suppliers) to the UK RTFO (Renewable Transport Fuels Obligation) indicates that the ghg saving for the B100 fuel would be in excess of 50 per cent. In this case, knowing that there is no observable change in fuel economy, we would exceed a 2% well to wheel reduction in ghg emissions for the First fleet using B5.

***NOx and Smoke emissions***

We present here preliminary analysis of real-time exhaust emissions measurement of NO from an Anglian Optare Solo Euro III, Mercedes 4.2 litre engine bus fitted with Horiba gas analysis equipment.

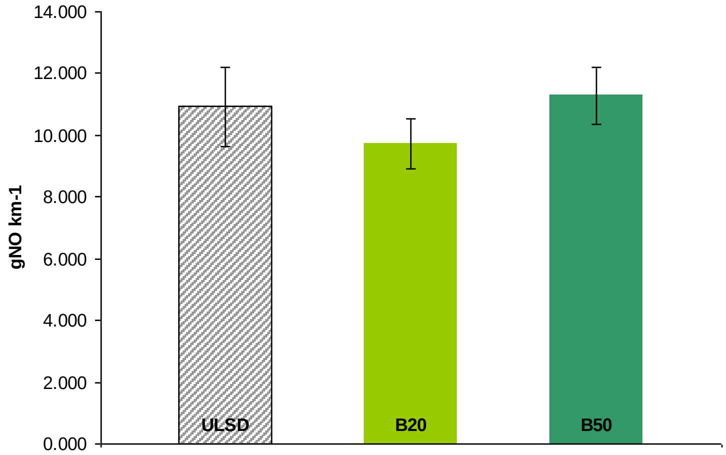



**Fig 5. NO emissions per km measured on an Anglian Optare Solo Euro III bus (Mercedes 4.2 litre engine) with the exhaust fitted with Horiba gas analysis equipment to enable real-time monitoring of exhaust emissions. Here we present the average of emissions over particular parts of a specified route for diesel (ULSD) and for B20 and B50 blends of ULSD with biodiesel. The error bars represent one standard deviation.**

In such real-time monitoring there are inevitably more variables than in the laboratory engine testing that is the norm. However, these real-time studies represent real-life situations and therefore represent the situations that will be encountered in cities such as Norwich.

We have chosen a route near the Anglian Bus depot that simulates a route through the Norwich low-emission zone and have measured NO emissions per km for a portion of this route over several laps for ULSD and for B20 and B50 biodiesel blends. NO is emitted from the vehicle exhaust and is oxidised to $NO_2$ very rapidly in the atmosphere. $NO_2$ is the pollutant that is measured and controlled in the Castle Meadow Low Emission Zone.

We have only been able to collect these data at weekends because the demand for buses is too great during the working week and none are available for such trials. The data are the average over usually several weekend's testing.

Although there is overlap within the errors, we seem to find a consistent but small reduction in NO emissions when changing from a pure diesel ULSD fuel to B20 but a small increase on going to B50.

These data for B20 are consistent with the data from the United States noted above and suggest that there will be no effective change in NO emissions (and hence in atmospheric $NO_2$) when changing from a B0 (ULSD) to a B20 biodiesel blend. This result is important because B20 is a widely used blend in continental Europe and is a likely choice for fleet operators that may wish to use a higher biodiesel blend than B5. While biodiesel from used oil throws down precipitates in cold weather below around 10C (which is why storage facilities must be heated in cold weather to maintain the fuel temperature above this level), a B20 blend is likely to be viable all the year round irrespective of the source of the biodiesel. Of course, we cannot confirm that these results will apply to other vehicles and other engines.

We have also collected comparison data for a similar Optare Solo bus using an Autologic gas analyser where sample exhaust is collected from the exhaust and fed to the analyser. This method is not so precise as use of the Horiba gas analyser which is mounted into a flange that is welded into the exhaust manifold. However, it is more flexible as no permanent fixtures are necessary to the vehicle exhaust system which reduces cost and downtime considerably (it was necessary to have a special exhaust part modified and the flange inserted by our laboratories at the University of East Anglia; together with the fitting procedure on the bus, this proved to be a time consuming and expensive process).

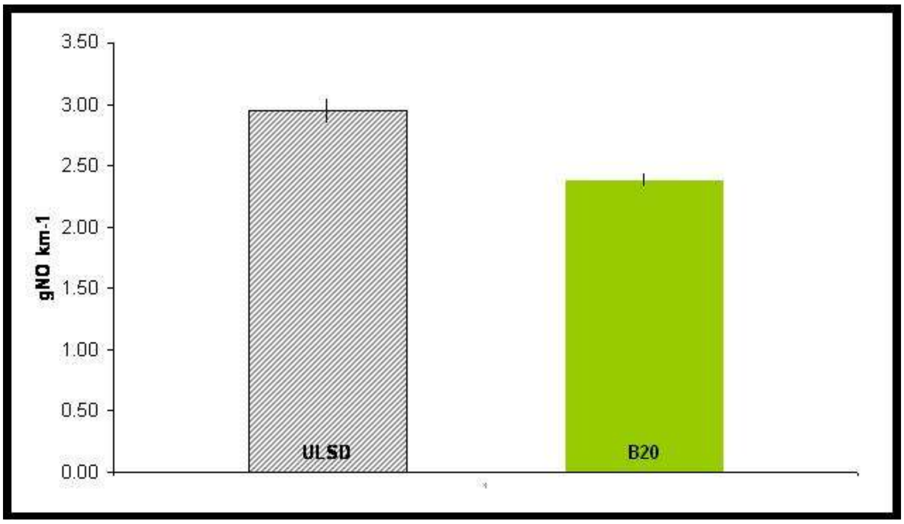



**Fig 6. NO emissions per km measured on an Anglian Optare Solo Euro III bus (Mercedes 4.2 litre engine) using Autologic gas analysis equipment. Here we present the average of emissions integrated over a specified route for diesel (ULSD) and for B20 blend of ULSD with biodiesel. The error bars represent one standard deviation.**

Rather than monitor emissions for specific portions of a route that simulates city driving in and near Castle Meadow in Norwich (the site of the Low Emission Zone, Measure 6.2) as was shown above in Figure 5, the NO emissions measured with the Autologic analyser have been integrated for the whole route and the data shown are averages over several laps. Nevertheless, the data are very analogous that that from the use of the Horiba analyser (above) in indicating a reduction in NO emissions from B0 (ULSD fossil diesel) to B20.

We seem to have established (for this particular make of vehicle at least) a slight reduction in NO emissions for B20 relative to B0 (ULSD). Although this result is very interesting and reassuring with regard to use of vehicles in the Norwich Low Emission Zone, we cannot be sure that this result will apply equally to other kinds and makes of vehicles either in the Anglian Bus fleet or in other bus fleets. We are willing to suggest, given the data collected to date, that, for B20 at least, there is no change in NO emissions (and hence in background $NO_2$) relative to ULSD.

Within one standard deviation, the data for B50 in Figure 5 is identical that that for ULSD but emissions certainly seem to have risen relative to B20 and just possibly relative to ULSD. We have not operated these Optare vehicles on blends higher than B50, but have recently operated a newer Euro IV Scania bus on B100. This vehicle is warrantied only for B0 to B5 and for B100 and hence we can only obtain a comparison between B0 and B100. These data are still under analysis and will be reported in a final report but preliminary indications are that there is a small increase in NO emissions for B100 relative to B0, ULSD. If confirmed, this result would be consistent with the trend observed for the Optare Euro III vehicle with a Mercedes engine for B0 to B50.

We conclude, therefore that up to B20, fuel economy and NO emissions are no worse than for operation with B0. For higher biodiesel blends, there are indications that fuel economy may reduce by a few per cent (as expected because of the lower volumetric energy density of biodiesel compared to ULSD) and that NO emissions may increase modestly. A B20 blend might therefore be an optimum compromise between $CO_2$ saving, fuel economy and NO emissions.

We have made some analyses of smoke emissions but these have not been evaluated at this stage. All the literature indicates that smoke emissions from biodiesel use are likely to be lower than for ULSD and hence we do not anticipate any problems in this regard. Smoke is not an identified problem from vehicle exhausts in Norwich.

## C2.4 Transport

There are no specific impacts or changes.

## C2.5 Society

Overall, this is an encouragingly high proportion of people who are aware of what is being done as part of this CIVITAS measure and provides a positive reflection of the impact of local publicity and dissemination activities. We note that the local press is the principal vehicle via which people have become aware of this activity, closely followed by national newspapers. Advertisements on buses and word of mouth are also important vehicles for promoting awareness.

These results can probably be generalised and used whatever the Measure being promoted.

**Q1a. Have you heard of bio diesel before?**

| | Area | | |
|---|---|---|---|
| | Before | After | Difference |
| Yes | 552<br>68.3% | 595<br>73.9% | 5.6% |
| No | 256<br>31.7% | 210<br>26.1% | -5.6% |
| Total | 808<br>100.0% | 805<br>100.0% | |

**Table 2**

**Q1b. Did you know that bio diesel was currently being used in buses and taxis in Norwich?**

| | Area | | |
|---|---|---|---|
| | Before | After | Difference |
| Yes | 214<br>38.8% | 258<br>43.4% | +4.6% |
| No | 338<br>61.2% | 337<br>56.6% | -4.6% |
| Total | 552<br>100.0% | 595<br>100.0% | |

Q1c. How did you find out that bio diesel was being used in public transport in Norwich?

| | BEFORE TOTAL | Greater Norwich | Inner Area (Norwich City) | Total |
|---|---|---|---|---|
| Ad on bus | 25 | 27 | 21 | 48 |
| | 11.7% | 15.3% | 25.9% | 18.6% |
| Ad in taxi | 6 | 3 | 2 | 5 |
| | 2.8% | 1.7% | 2.5% | 1.9% |
| In local press | 64 | 76 | 25 | 101 |
| | 29.9% | 42.9% | 30.9% | 39.1% |
| In national newspaper | 54 | 15 | 7 | 22 |
| | 25.2% | 8.5% | 8.6% | 8.5% |
| By word of mouth | 26 | 28 | 14 | 42 |
| | 12.1% | 15.8% | 17.3% | 16.3% |
| OTHER | 28 | 28 | 12 | 40 |
| | 13.1% | 15.8% | 14.8% | 15.5% |
| Total | 214 | 177 | 81 | 258 |
| | 100% | 100.0% | 100.0% | 100.0% |

**Table 3**

We believe that the use of a renewable fuel such as Argent Energy biodiesel that is known to be made from waste oils and cannot be linked to issues of food-versus-fuel or deforestation will be very acceptable to most sectors of society. We have not specifically examined this aspect but from other work where Argent biodiesel has been involved we have received encouraging responses.

## C3 Achievement of quantifiable targets

| No. | Target | Rating |
|---|---|---|
| 1 | 30% + well to wheel reduction in ghg emissions for B100 trial | *** |
| 2 | 2% + well to wheel reduction in ghg emissions for B5 trial | *** |
| 3 | Compliance with Euro IV emission standards | ** |
| 4 | Positive public opinion | * |
| 5 | Take up of biodiesel within other vehicle fleets | * |
| | | |

**NA = Not Assessed 0 = Not achieved ★ = Substantially achieved (> 50%)**

**★★= Achieved in full ★★★= Exceeded**

## C4 Up-scaling of results

There is unlikely to be significant up-scaling of use of biodiesel in the vehicle fleets within this Measure for the reasons explained at length above (C1.2). However, as a direct result of this Measure, Norfolk and Norwich are now very likely to take the lead in the UK in the use of low-carbon vehicles, probably biomethane powered, for bus and other fleet operations. If this happens it will be as a direct result of the contact via this Measure with Malmo and observation of their success with gas-powered and biomethane powered bus fleets.

## C5 Appraisal of evaluation approach

Satisfactory

## C6 Summary of evaluation results

The key results are as follows:

- **Key result 1** – The energy content per litre of Argent biodiesel is approximately ten per cent lower than for ULSD. In proportion, this will scale to a two per cent reduction for B20 and a 0.5 per cent reduction for B5.
- **Key result 2** – Up to B20, fuel economy and NO emissions are no worse than for operation with B0 (ULSD). For higher biodiesel blends, there are indications that fuel economy may reduce by a few per cent (as expected because of the lower volumetric energy density of biodiesel compared to ULSD - for B100, the indications are that fuel economy is approximately ten per cent less than for ULSD which scales very closely with the reduction in energy content per litre for Argent biodiesel compared to ULSD.) and that NO emissions may increase modestly. A B20 blend might therefore be an optimum compromise between $CO_2$ saving, fuel economy and NO emissions. This means that operation of buses in Norwich with B20 fuel will not cause any problems in respect of the Low Emission Zone and that B20 is a cleaner fuel (when greenhouse gas emissions are also considered) than ULSD.
- **Key result 3** – In respect of greenhouse gas emissions, use of B20 biodiesel would generate a significant reduction in $CO_2$ emissions of around 600 tonnes per annum across the Anglian Bus fleet.

# D Lessons learned

## D1 Barriers and drivers

### D1.1 Barriers

- **Barrier 1 –** Vehicle manufacturer’s representatives in the UK did not generally approve the use of biodiesel above 5% blends in their vehicles at the start of the measure. This is a result of experience of poor quality, substandard biodiesel in the past, or cautiousness through lack of awareness and industry inertia. We have relied on the cooperation of our partners to have the confidence to trial blends above 5% as this project required as it has not been possible to obtain any modification of protocols from vehicle makers. We have found that vehicle distributors in the UK have been very reluctant to agree to biodiesel blends above 5% being used even if similar vehicles in continental Europe may be running on high blends or even on pure biodiesel.

- **Barrier 2 -** The awareness of the logistics needed to conduct a biodiesel trial with vehicle fleets that do not own onsite fuel storage facilities. This was something that was overlooked in the initial budgeting of the measure.

- **Barrier 3** – The UK Bus Service Operators Grant structure prevents biodiesel being used in (public funded) supported bus services because the method of payment is through a fuel duty rebate. Biodiesel attracts less fuel duty, so bus operators receive less in rebate if they use this fuel on supported routes.

- **Barrier 4** – Fuel Quality. This has been a particular issue in this Measure but one that has been successfully tackled and solved. Waste vegetable oil based biodiesel is one of the most sustainable biodiesel fuels produced, but getting the required quality standard is vital especially for bus operators. The original partner, Global Commodities, was, at project inception, the biggest manufacturer of biodiesel in the UK and made product from used oil. The company claimed that its product complied with EN14214 biodiesel standard. It became clear as the project got underway that this was not the case and the product was not acceptable to our other partners. The Measure was obliged to set up a biodiesel laboratory for testing product quality. We learned during the Measure that several users of product from Global had experienced some major problems with the fuel – especially filter blockages and knowledge of this had created a negative perception of biodiesel in the region. Smaller producers, usually without good technical processing expertise, experience and a high level of investment in quality processing technology, pre-treatment techniques will fail to achieve the EN14214 standard, specifically for parameters such as water content. We have been able to achieve supply of high quality biodiesel from used oil from Argent Energy in Scotland and use of this product has created confidence across the supply chain and with fleet users. We have also worked with a small local producer to help improve quality, especially water content. Biofuel production from virgin oils will avoid many of these problems but will not achieve such a significant reduction in $CO_2$ emissions because of the greenhouse gas emissions during crop growth. We wished, in this Measure, to demonstrate the potential for use of biodiesel from used oil.

- **Barrier 5** – Storage and distribution of higher biodiesel blends. While biofuels including biodiesel are being introduced at low blends into fuel supplies at the pump across European and other countries, this action requires no new facilities for storage or distribution. In the case of the higher blends of interest in this Measure, however, facilities for storage, blending and distribution are required. Few fuel suppliers have these facilities and investment is costly for a low margin business. This is a significant barrier to the use of higher biodiesel blends on a wide scale, but this Measure has overcome this barrier in Norfolk and the East of England.

- **Barrier 6** – Complexity of real-time emissions measurement. Undertaking real-time monitoring on service buses brings several problems and barriers to overcome that are not apparent until work begins. Because of service demands, vehicles may not be available at the time scheduled which can set back progress. The electronic data gathering system is particularly complex in the manner in which it integrates with the engine-management system and poses many technical and logistical problems. The company that is pre-eminent in this field which we have used to provide our hardware and software found several problems in the work which added to cost and to time spent. Finally, we need to use a bus and availability of drivers at weekends – the only time this work could be done because of service demands during weekdays – is unreliable. There has been a big increase in bus numbers during this project so that drivers and buses are fully committed. Sometimes, at weekends, there are no drivers available.

- **Barrier 7** – Problems in obtaining data for lifecycle analysis; we had access to all of Global's data but this is more difficult with Argent which is several hundred kilometres away.

## D1.2 Drivers

- **Driver 1** – The cost of fossil-fuel diesel has increased and may set to increase in the long term even though there is a significant drop in late 2008. This will be an incentive for fleet operators to subsidise fuel costs by using slightly cheaper biodiesel blends. However, the price of biodiesel is also rising as production increases and input costs increase. Also, distributors tend to equalise costs where biodiesel is potentially cheaper so that there may not, in reality, be a price incentive for biodiesel use, except in the case of smaller suppliers of biodiesel that may not be EN14214 compliant.

- **Driver 2 -** EU and US policy signals and mandates are stimulating markets for biodiesel production, though not necessarily with the environmental benefits achievable in the Measure. However, these mandates are driving fuel suppliers to blend at low levels consistent with the mandates (e.g. 2.5 per cent biodiesel in the UK from 2008) and are discouraging the use of higher biodiesel blends. So this is a driver for biofuel use but a barrier towards use of higher biodiesel blends (see Barrier 5 above).

- **Driver 3** – Climate change has become a significant presence and issue in the UK media and in political and economic debate. Businesses, organisations and individuals are becoming more aware of the message about lowering their carbon footprint. Businesses are using this fact as a marketing tool to promote themselves and biodiesel’s ‘green fuel’ tag has been used as way fleet operators can capitalise on this added PR and marketing opportunity.

# D2 Participation of stakeholders

- **Stakeholder 1 -** Anglian Bus. This company has been very cooperative and helpful despite the problems experienced by small businesses in being a partner in an EU project such as this. The provision of bank guarantees presents a major financial disincentive. Without a guarantee, there is a very long wait for receipt of funds. The filling in of financial reporting forms is complex and difficult for a small business for which the priority must always be running the business. The company has been aware that involvement in the project may take some management time but can stimulate new thinking and innovation and can also provide important publicity and awareness benefits.

- **Stakeholder 2** – Global Commodities. This company caused major problems because of the poor quality of the biodiesel provided. We were unable to work with them to improve the quality. In retrospect, this was probably the result of cash flow problems that resulted in the sudden decision to go into administration in 2006. Another small company but a very difficult outcome to the partnership with Anglian Bus.
- **Stakeholder 3** – CPS Fuels Ltd. There was a very positive relationship with this small company that was very keen to develop a new business stream. We were both surprised and very disappointed when the takeover of this company was announced out of the blue.
- **Stakeholder 4** – Argent Energy Ltd. This company has been very helpful. They already have markets for all their product with major fuel companies but were willing to supply our project with quite modest volumes and have been helpful in supplying information.
- **Stakeholder 5** – Pace Petroleum. This company was approached after the takeover of CPS Fuels Ltd as is was the only company that seemed to offer the appropriate combination of location and scale. Pace took several months to decide to become involved which was frustrating given the delays we had already experienced but, once the decision was made, have been helpful and cooperative.
- **Stakeholder 6** – First Bus. As has been noted above, there were problems at the start of the project in supplying First with biofuel blend but towards the middle of the project they changed fuel suppliers to be able to fuel buses with B5. This was a very positive move and we have found them to be helpful in supplying information.

## D3 Recommendations

- **Recommendation 1 -** B20 is a recommended biodiesel blend for fleet operators because our work in this Measure indicates that this blend has an optimal combination of properties: it will remain useable in the coldest weather; fuel economy seems to be unchanged relative to ULSD; and NOx emissions seem to be lower than for ULSD in the road testing we have undertaken.
- **Recommendation 2** – Norwich and Norfolk pursue the ambition of becoming the UK’s leading authority in the use of low-carbon fleet vehicles.
- **Recommendation 3** – Since the inception of the project the understanding of possible indirect effects of biofuels has been transformed. Since the publication of two papers in Science in February 2008, the UK Renewable Fuels Agency (which did not exist when the project began) has published the Gallagher Report on the Indirect Effects of Biofuels and the UK Government has accepted its recommendation to slow down the mandate and to sharpen focus in future years on second-generation biofuels. Further action on biofuels must be based on knowledge and expertise of these complex issues and ideally should focus on second-generation fuels that do not create potential displacement effects.
- **Recommendation 4** – Where possible the use of waste oil, as in this measure, provides the optimum solution for biofuel use in transport applications. However, the volume of fuel that can be sourced from such sources is limited and requires further review, which is beyond the scope of a city-level investigation such as this. In Norwich we have been very interested to learn about the use of biogas by Malmo, and have made serious efforts (which continue) to promote CNG and biogas fuel for heavy vehicles in the UK.

## D4 Future activities relating to the measure

The introduction of low-carbon (biomethane or possibly hybrid) fleet vehicles in Norwich and Norfolk.

In addition to the specific Measure objectives, a particular benefit of the collaboration between different countries and cities in the CIVITAS project is that Norwich can learn from other cities' experience with renewable fuels of several types. This measure has been active, in particular, in working with Malmo and other CIVITAS cities (e.g. Stockholm) in learning about biogas as a transport fuel and, as a consequence, has been able also to tap into expertise in the UK on gas-powered vehicles. Several presentations have been made on gas-powered transport in Norwich as part of CIVITAS dissemination activities and, in November 2008, Norfolk County Council, in collaboration with this Measure, organised an event in Norwich for regional cities and other partners about the potential for biogas-powered fleet vehicles at which there was a keynote presentation from Malmo. There is now great interest and enthusiasm for introducing low-carbon vehicle fleets in Norfolk that has arisen specifically as a result of this Measure.

More widely, as a result of the expertise on biodiesel that has been gained as a result of this Measure, and the supply chain that has been established, a new market for biodiesel has potentially been established in the UK which is for heating oil. There are over one million homes in the UK and Ireland that are not connected to the natural gas supply and that use oil for heating. Trials, supported by the UK oil heating industry, are now underway to demonstrate that blends of thirty per cent or higher of biodiesel in kerosene or gas oil heating oil can function effectively as lower carbon heating oil in existing boiler systems. The potential $CO_2$ saving from this application is at least one million tonnes a year in the UK. There is great interest in this project from across the EU. It could not have happened without the benefit of the expertise gained in this Measure.