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Road Transport Emissions from Biofuel Consumption in the UK

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Executive Summary

The amount of biofuels consumed by road transport in the UK is growing, driven by national Renewable Transport Fuel Obligation (RTFO) targets and EU Biofuels Directive targets aimed at accelerating growth in the share of fuel derived from renewable sources in order to meet commitments aimed at tackling climate change by reducing CO_2 emissions and to ensure the security of energy supplies. The RTFO will require 5% by volume of all UK fuel sold on forecourts to come from a renewable source by 2010. The EU Biofuels Directive includes 'reference' biofuel targets of 5.75% of energy content by 2010, with a conditional target of 10% set for 2020. In response to this, by June 2008, consumption of biofuels in the UK had reached 1.34% of all petrol sales and 4.19% of all biodiesel sales in volume terms.

There are several different types of biofuel products that are currently or could be made available. While there are any number of combinations of types of biofuels that could be used to achieve the same overall biofuel consumption and carbon reduction targets, each one could have a different impact on air quality and emissions of other greenhouse gases because emissions of these pollutants depend on the type of biofuel and the strength of mixtures with conventional petrol and diesel fuels in which they are consumed.

This study has reviewed the effects of different types of first-generation biofuels on exhaust emissions of air quality and non-CO_2 greenhouse gas pollutants. The effects of second-generation biofuels were not considered. Through a review of the literature, scaling factors representing the change in emissions of the regulated pollutants nitrogen oxides (NO_x), particulate matter (PM), hydrocarbons (HCs) and carbon monoxide (CO) relative to their emissions from conventional petrol and diesel fuels have been developed for different strengths of bioethanol, different strengths of transesterified biodiesel (e.g. Rapeseed Methyl Ester (RME) biodiesel), pure virgin plant oil biodiesel and biogas. Where possible, quantitative estimates were also made for certain non-regulated pollutants such as methane (CH_4), nitrous oxide (N_2O), benzene and 1,3-butadiene. This information is required for biofuel consumption to be accounted for in the National Atmospheric Emissions Inventory (NAEI).

Using these scaling factors, the NAEI road transport emissions forecasting model was used to predict future UK road transport emissions of NO_x, PM, non-methane volatile organic compounds (NMVOCs) and CO for seven different biofuel uptake scenarios. The seven scenarios were all based on the same assumption of increasing overall biofuel consumption rates in the UK in terms of volume or energy content consistent with the Renewable Transport Fuel Obligation for 2010 and the EU conditional target for 2020, but they differed in terms of mix of different types of biofuels used in the UK to meet these targets. The scenarios were:

- **'Realistic' Scenario 1**, involving the same uptake rates of low strength bioethanol and biodiesel
- '**Bioethanol Favoured' Scenario 2**, initially favouring the uptake of low strength bioethanol and eventually supplemented with low strength RME-biodiesel
- **'Bioethanol Only' Scenario 3**, initially favouring the uptake of low strength bioethanol and eventually supplemented with high strength E85 bioethanol, with no biodiesel at all.
- **'Biodiesel Favoured' Scenario 4**, initially favouring the uptake of low strength RME- biodiesel and eventually supplemented with low strength bioethanol
- **'Biodiesel Only' Scenario 5**, initially favouring the uptake of low strength RME-biodiesel and eventually supplemented with pure RME-biodiesel, with no bioethanol at all.
- **'Biodiesel Only' Scenario 6**, initially favouring the uptake of low strength RME-biodiesel and eventually supplemented with pure virgin plant oil-biodiesel, with no bioethanol at all.

- **'Realistic' with biogas consumption by HDV Scenario 7**, involving the same uptake rates of low strength bioethanol and biodiesel, but with 10% of the biodiesel consumed by HDVs replaced with biogas.

The biofuel scenario (Scenario 1) involving equal uptake of bioethanol and RME-biodiesel (referred to as the more 'Realistic' scenario) is expected to lead to the following percentage changes in emissions in 2020, relative to the basecase predictions assuming no biofuel uptake (a negative value indicates a decrease in emissions):

NOx	**0.5%**
PM	**-16.8%**
NMVOCs	**-7.8%**
CO	**-22.9%**

Across the whole range of scenarios studied, the changes in emissions relative to the base case would be within the following ranges for all future years:

NOx	**-2% to +2%**
PM	**-19% to +9%**
NMVOCs	**-10% to +6%**
CO	**-23% to +3%**

The majority of the scenarios lead to a decrease or no change in emissions. The only scenario that could potentially lead to increased emissions is one concentrated on the uptake of pure virgin plant oil biodiesel.

The impacts of biofuels on non-regulated pollutants are generally more uncertain and depend on biofuel scenario. Overall, air toxic emissions are likely to be reduced, but there could be some scenarios that lead to increases in emissions of benzene and acetaldehyde. Biogas consumption could lead to an increase in methane emissions, though road transport is a very small contributor to UK emissions of this greenhouse gas so the overall impact on future UK emissions of methane is expected to be very small.

The emission scaling factors developed in this study have high levels of uncertainty and in some cases even the directional change in emissions is not certain, especially for the non-regulated pollutants. Further research on emission effects is required on high strength fuel blends if these are likely to become more popular in the UK, e.g. flexible fuelled vehicles (FFVs) that can run on both conventional petrol and high strength bioethanol. Most tests on biodiesel emissions have to date been based on heavy duty vehicles with older engines. Further emission tests are required on diesel light duty vehicles and vehicles, engines and technologies relevant to the UK fleet to improve the reliability of the biodiesel emission scaling factors.

The study has been based on hypothetical assumptions about the future mix of biofuels that could penetrate fuel sales in order to predict the range of possible outcomes on emissions that might ensue. From the emission ranges given above, it is evident that NO_x emissions from road transport are not likely to be sensitive to the mix of biofuels sold, but emissions of PM, NMVOCs and CO could be. The study has indicated that to more accurately account for biofuel uptake in the NAEI there will be a need for annual statistics to be made available on the volumes and strengths of each type of biofuel sold in the UK. At the moment, such data are lacking with the only data gathered being in terms of total volume of bioethanol and biodiesel released for sale, as provided by HM Revenue & Customs, rather than by type of biofuel or mixture strength. It is recognised that the nature of the biofuel supply industry may make this data collection difficult and may require periodic surveys of suppliers to break down the total volume-based figures collected by HMRC.

Contents

1 Introduction

Renewable energy has a critical role to play in meeting Europe's two key energy policy challenges:

- tackling climate change – by displacing consumption of fossil fuels with energy sources that overall emit much less carbon; and
- ensuring secure energy supplies - by reducing our dependence on imported fossil fuels

The European Commission has proposed that 15% of all the UK's energy (electricity, heat and transport) should come from renewables by 2020. Part of this is expected to be achieved by the uptake of biofuels in the transport sector. Sales of biofuels in the UK are being driven by two main initiatives. The EU Biofuels Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport came into force in 2003 (OJ, 2003) requiring Member States to set indicative targets for the use of biofuels in the transport sector by 2005 and 2010. The Directive includes 'reference' targets of 2% biofuel use by 2005 and 5.75% of energy content by 2010. A conditional target of 10% has been set for 2020. The UK government has set a Renewable Transport Fuel Obligation (RTFO) that from April 2008, places an obligation on fuel suppliers to ensure that a certain percentage of their aggregate sales is made up of biofuels (http://www.dft.gov.uk/pgr/roads/environment/rtfo/). The effect of this will be to require 5% by volume of all UK fuel sold on UK forecourts to come from a renewable source by 2010. The 5% by volume target represents the maximum biofuel content allowed by European Specifications to be sold on the forecourts as standard petrol or diesel. The UK is considering setting higher levels post-2010.

In response to these policy drivers, consumption of biofuels in the UK has been rising rapidly in recent years. Current data from HM Revenue & Customs showed that the total quantities of bioethanol and biodiesel released for consumption in 2007 reached 153 and 347 million litres, respectively (June 2008 bulletin on hydrocarbon oil duties at www.uktradeinfo.co.uk/index.cfm?task=bulloil). This represents 0.64% of total petrol sales and 1.36% of total diesel sales in 2007 on a volume basis. This compares with figures of 0.39% and 0.70% of petrol and diesel sales, respectively, in 2006. Consumption of biofuels has been growing very rapidly during 2008 and by June 2008 bioethanol reached 1.34% of all petrol sales and biodiesel reached 4.19% of all biodiesel sales.

Biofuel is a generic rather than a specific description. Biofuels for road transport encompass petrol replacements used in spark-ignition engines, usually ethanol, although butanol is also being pursued, and biodiesel. Biogas is an alternative biofuel used in transport. There is a variety of biofuel feedstocks and these can be broadly categorized as **first generation** and **second generation** biofuels. First generation biofuels are produced from biomass such as sugar or starch crops (e.g. maize and wheat) for bioethanol and animal fats and plant oils for biodiesel using processes that are currently available and economic to run. First-generation biodiesel is usually trans-esterified vegetable oils (e.g. rape seed, sunflower oil etc) or pure vegetable oils (either neat or waste). Second generation biofuels refer to a range of fuels under development and include bioethanol from lignocellulosic biomass feedstocks such as wood and straw, biobutanol, Fischer-Tropsch diesel and hydrogen. They are not yet commercially available, but offer a wider range of feedstocks including, for example, agricultural and forestry waste and their introduction is thought to be necessary in order to meet the more challenging EU conditional target of 10% share of biofuels by 2020. Biogas can be produced from any organic feedstock that is suitable for anaerobic digestion

In the transport sector, biofuels can be used in their pure form or, more commonly as a blend with fossil-fuel based petrol and diesel. At present, biofuels are typically sold in the UK as 5% blends, though this cannot always be assumed. There are particular reasons why blends of 5% or less are more common-place. EU Directive 2003/30/EC on the promotion of biofuels includes a requirement for Member States to ensure specific labelling at sales points. This specifies a labelling scheme where more than 5% biofuel is supplied. No additional labelling is required for biofuels less than 5% in strength. The requirement of specially labelled pumps means filling stations require separate tanks for fuels containing >5% biofuel. The associated infrastructure costs mean that the "readily accessible" biofuels will most frequently be those with <5% biofuel. Another reason is that both modern diesel and petrol fuelled vehicles have fuel systems which include a computer controlled fuel metering system to the injectors. In terms of rheological and thermodynamic properties, a 5% biofuel mineral oil derivative mix behaves sufficiently similarly to the pure diesel or petrol fuel that no adaptation of the engine is required. However, for vehicles running on very high percentages of biofuel the differences are sufficient to require the vehicle's fuelling map to be changed for optimum performance. This makes it very difficult to switch between the two types of fuel. This would be a barrier to the use of high percentage biofuels by drivers who move around the country, given the very small number of high percentage biofuel filling stations. A further barrier to the use of high percentage biofuels is that manufacturers often provide a warranty that is only valid provided that <5% biofuel mixtures are used.

High strength blends of bioethanol (e.g. 85% ethanol/petrol, known as E85) are used extensively in some parts of the world, but this fuel is more of a niche fuel in Europe, mainly in Sweden. So-called flexible fuelled vehicles (FFVs) are on the market that can run on both normal petrol and E85 using just one fuel tank. On these vehicles, the engine can adapt automatically the ignition timing and mixture strength using an ethanol/gasoline sensor. E85 is not currently used widely in the UK.

The wide variety of biofuel feedstocks from so many diverse sources has drawn much attention to their social, economic and environmental costs of production and usage. The Defra website alone has a number of recent reports and reviews in areas that have examined the impacts of biofuel production on biodiversity, deforestation, land use, overall greenhouse gas emissions and on food and commodity prices (see http://www.defra.gov.uk/environment/climatechange/uk/energy/renewablefuel/index.htm). However, these reports generally make only passing reference to impacts on air quality and emissions at the point of consumption. The most detailed assessment was a chapter on air quality in a major review carried out by AEA for Defra on the environmental sustainability of international biofuels production and use (AEA, 2008). This chapter was written by one of the authors of this report from the National Atmospheric Emissions Inventory programme (NAEI), but gave only a qualitative assessment on the directional change in exhaust emissions from a vehicle using different biofuels.

To account for consumption of biofuels in the UK's emissions inventory for road transport and the effect of their uptake on air quality requires a quantitative assessment on the effects of biofuels on exhaust emissions for types of biofuels used in the UK. A scoping study on estimating emissions from biofuel consumption provided an initial set of emission change factors for some biofuels, but it also pointed out that accounting for biofuels in the inventory is severely constrained by information on the types and strengths on biofuel blends sold in the UK (AEA, 2007a). The quantities of different strength blends sold in the UK is information necessary for the inventory because of the non-linearity between emission rates for many air quality and non-CO_2 greenhouse gases and the strength of biofuels mixed with conventional petrol and diesel fuels. The HM Revenue & Customs are currently the only source of national statistics on sales of biofuels in the UK, but provides only the total volume of bioethanol and biodiesel released for consumption in the UK from tax revenues collected, with no information on types of biofuels, feedstocks and the strengths of mixtures in which the fuels were ultimately consumed. Lack of data in this area partly reflects the complex biofuel production and supply chain that currently operates in the UK as a cottage industry, making collection of more detailed national statistics on biofuel consumption difficult.

This report gives a quantitative review of vehicle exhaust emission factors, focusing on types of biofuels that are believed to be used in the UK. The review expands on the assessment of biofuel emission factors made in the NAEI's initial scoping study and builds on the more recent and comprehensive, but qualitative review undertaken for Defra on biofuel exhaust emissions of air quality pollutants (AEA, 2008). The focus is on the regulated pollutants, nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC, and the subset of species that excludes methane, known as non-methane volatile organic compounds, NMVOCs) and where information is known, on the non-CO_2 greenhouse gases, methane (CH_4) and nitrous oxide (N_2O) and other air toxics that might be affected by biofuel consumption relative to conventional fossil fuels.

The impact of biofuel consumption on future UK emissions from the road transport sector is quantified for the regulated pollutants for a number of different biofuel uptake scenarios that represent the range of outcomes in terms of consumption of different types of biofuels expected within the same overall trend in UK biofuel uptake rates consistent with current EU legislation and national objectives. A qualitative assessment of the impacts on the inventory of non-CO_2 greenhouse gases and other air toxic emissions is also given. Some of the uptake scenarios investigated represent extreme ranges of potential biofuel consumption patterns, for example where the overall biofuel growth strategy is based solely on bioethanol consumption or solely on biodiesel consumption or an equal mix of both. The scenarios are based on first-generation biofuels currently available. The uptake of second-generation biofuels has not been considered because of the lack of information on the effect of these fuels on emissions, though it is recognized that in the longer term, the penetration of these fuels can be expected. A biogas scenario is also included.

In the absence of figures on projected consumption of specific types of biofuels that will overall ensure that EU legislation and national biofuels obligations will be met, this approach will at least indicate the maximum range of potential outcomes on national road transport emissions expected from the future market penetration of biofuels in the UK and the likely benefits or disbenefits on air quality that will ensue.

The study considers only the impacts on emissions at the point of consumption, i.e. in terms of direct tailpipe emissions from vehicles, and not emissions over the full fuel-cycle including land-use changes, production, supply and distribution of the fuels. It is recognized that for the non-CO_2 greenhouse gases this is inadequate for an overall assessment of the climate change impacts of biofuel consumption where tailpipe emissions of pollutants like CH_4 and N_2O at point of consumption are likely to be small compared with emissions at other parts of the fuel production and supply chain. But the primary aim of the study is to consider the implications to the road transport sector of the national emissions inventory. For the air quality pollutants, the impact of biofuels on tailpipe emissions at the point of consumption is much more relevant as this will have greater influence on emissions of NO_x, PM, CO and other air toxics in urban areas and the attainment of air quality objectives for the protection of human health. Having said this, air quality pollutant emissions at other stages of the fuel chain should not be ignored, for example emissions from forest burning, carried out in parts of the world for land clearance, agricultural processes and fuel distribution. As well as affecting local air quality, these processes can affect regional air pollution and formation of secondary pollutants such as ozone. Considering fuel-cycle emissions is outside of the scope of this study.

2 Effect of Biofuels on Vehicle Emissions

With a few notable exceptions, studies have shown that running a vehicle on biofuels has a varied, and quite often a relatively small effect on exhaust emissions compared with emissions from a petroleum-based fuel. In many cases, there has been conflicting evidence even on the directional change in emissions. This partly reflects the variety of factors influencing emissions and the variability in exhaust emissions from the same type of vehicle running on the same type of fuel. Measured emission rates from a given vehicle depend on the condition of the vehicle, the manufacturer's engine management systems, vehicle design and the way it is driven, so much so that the effect of fuel composition can often be within the emission uncertainty and variability.

The small effect of biofuels on exhaust emissions also reflects the quality of fuel that vehicles and engines have demanded for some years now in fleets in many parts of the world. Motor fuels in Europe are highly refined products and made to within tight specifications. Biofuels must meet equally tight standards and therefore there is little scope for biofuel specifications to be so different from specifications for petroleum-based fuels that it would affect emissions substantially. Bioethanol and biodiesel are virtually sulphur-free, but sulphur levels in conventional, petroleum-based petrol and diesel are also now very low.

The following sections consider different types of biofuels in turn and how these affect emissions. The review is based on the assessment carried out in the previous biofuel sustainability study for Defra (AEA, 2008), using the same literature sources, but a more quantitative interpretation is given. The reports that were assessed were mainly of European and North American origin, but several of these were themselves reviews of information and research carried out in South America, parts of Asia and Australia as well as Europe and North America.

2.1 EMISSIONS FROM BIOETHANOL CONSUMPTION

Bioethanol is mainly used around the world in low strength blends with petroleum-based gasoline (5-25%). In some regions, it is used at very high strengths (85%) or even in pure, undiluted form. Types of bioethanol are usually referred to as Exx where xx refers to the percentage content by volume of bioethanol in the fuel.

2.1.1 Low-medium strength bioethanol blends (E5-E25)

These are the most common forms of bioethanol used in Europe (E5) and North America (E10). Current European Fuel Quality Directive 2003/30/EC sets limits of 5% ethanol in petrol permitted to be sold in filling stations without using separate, dedicated tanks and re-labelling the pumps. At this strength, vehicles behave similarly to the way they run on pure, conventional petrol and in Europe manufacturers' car warranties are currently valid for running on bioethanol blends up to 5%. In Europe, a conditional target of 10% has been set for the energy content share of biofuels in overall EU petrol and diesel consumption by 2020, subject to amendment of the Fuel Quality Directive, so this may lead to a rise in strengths of bioethanol blends sold. In the U.S., car manufacturers already provide warranties for vehicles running up to 10% ethanol strength.

Five major studies which addressed the effects of bioethanol blends on exhaust emissions were reviewed in this work:

JRC (Ispra, 2006).
GAVE (TNO, Netherlands, 2004).
AVL (Sweden, 2005).
AEA (Harwell, UK, 2002)
Kojima and Johnson (2005)
Yacobucci 2006 (CRS for the U.S. Congress, 2006).

These studies showed a high degree of variability in the effect of low strength bioethanol blends on emissions and the available literature does not always present a consistent picture. The pollutants CO and PM are the only pollutants that show a clear downward trend in emissions from E5-E10 compared with fossil-fuel based petrol, indicating positive benefits of bioethanol. Results for hydrocarbons are mixed, with some studies showing significant reductions and others showing significant increases in emissions, though the majority of studies do suggest a decrease in emissions. Results for NO_x are also mixed, but overall probably suggest no change or a very small change in emissions. Where measurements have been made, the studies consistently show a reduction in PM emissions for biofuels relative to petrol, but since emissions of PM from petrol engines are normally very small compared with those from diesel vehicles, the apparent benefits of E5-E10 are not significant.

Where benefits are most likely to be shown are in emissions from older generation cars and 2-stroke vehicles (e.g. mopeds and motorcycles and small cars). These vehicles do not have emission control systems and exhibit significantly higher CO emissions. PM emissions from 2-stroke engines can be high because of the burning of lubricating oil in the engines, so for these vehicles running on E5-E10 brings real benefits. The presence of oxygen in the fuel assists more complete combustion.

Studies have consistently shown reductions in air toxics like benzene and 1,3-butadiene. For benzene, this will in part be because of partial displacement of this component of petroleum-based petrol.

One pollutant which shows a significant increase in emissions when switching to E5-E10 is acetaldehyde. Although emitted in very small quantities, and largely controlled by catalytic converters, emissions can increase 5 fold for E10. Acetaldehyde is considered a toxic air pollutant as defined by the U.S. Clean Air Act and is one of the precursor volatile organic compounds involved in ground-level ozone formation. It is emitted through incomplete oxidation of ethanol in the engine. Acetaldehyde is also a precursor to peroxy acetyl nitrate, known as PAN, another ingredient of photochemical smog formed in stagnant air in warm summer climates causing eye irritation and respiratory problems.

There is evidence to suggest that methane emissions are reduced by switching to bioethanol, though emissions of methane from normal petrol-driven vehicles are very low anyway. There is no evidence to suggest bioethanol has any effect on exhaust emissions of N_2O.

As well as emissions from the exhaust due to incomplete combustion, hydrocarbons are also emitted from petrol vehicles due to evaporation of fuel vapour from the fuel tank and the vehicle’s fuel delivery system, a process that depends on the vapour pressure of the fuel, ambient temperature conditions and whether the car is fitted with a carbon canister device for evaporative emission control. Fuel quality regulations in Europe and North America set maximum limits on the vapour pressure of petrol that can be sold during the summer months so as to reduce evaporative emissions which can be significant in hot climates. However, adding small quantities of ethanol to petrol (from 0 to 10% by volume (v/v)) has the effect of increasing the vapour pressure of the fuel making it difficult for refiners to meet the fuel quality limits. The European Union is currently considering this issue with a view to possibly relaxing the 60 kPa limits on summer RVP (Reid Vapour Pressure) for bioethanol fuel blends in order to encourage the uptake of stronger blends, up to E10, in Europe by amendment to the Fuel Quality Directive. The potential increase in evaporative emissions during the summer months that would occur by this step will be largely mitigated by the continual fitting of carbon canister control devices and fuel injection systems on the vast majority of the European car fleet by 2020. A recent modelling study by AEA for the Department for Transport estimated that increasing fuel RVP from 60 to 68 kPa during the summer months as a means of promoting the uptake of 10% bioethanol would increase total hydrocarbon emissions in Europe by 0.7% in 2010 and 0.35% in 2020 during the summer due to the increase in evaporative emissions from vehicles (AEA 2007b).

Medium strength blends of bioethanol such as E25 are not commonly used in Europe. Evidence on how bioethanol of strengths of around 25% affect emissions could not be found, but there is no clear indication that, qualitatively, the effects on exhaust emissions are any different to those of the weaker blends. However, one key difference will be the impact on evaporative emissions. Further increasing the ethanol content of petrol above around 10% actually reduces fuel vapour pressure of the mixture, so that for blends of this strength, the vapour pressure will be no higher than for the petroleum-based petrol. For this reason, one would not expect any significant change in evaporative losses from vehicles. Measurements have shown that the vapour pressure of ethanol blended petrol peaks at around 10% and decreases thereafter with increasing ethanol content.

2.1.2 High strength bioethanol blends (E85)

High strength bioethanol blends such as E85 are used extensively worldwide, though not in as significant amounts as low strength blends. Brazil is the main exception where a substantial part of the fleet runs on E85 and even neat ethanol. E85 is more of a niche fuel in Europe (mainly in Sweden) and in the U.S. Standard car engines can run on bioethanol blends up to about 20% without any noticeable difference in performance, but cannot run on E85 without engine re-tuning and other adaptations. In the U.S. and Sweden, so-called flexible fuelled vehicles (FFVs) are on the market that can run on both normal petrol and E85 using just one fuel tank. On these vehicles, the engine can adapt automatically the ignition timing and mixture strength using an ethanol/gasoline sensor.

The necessary re-tuning of the engine, different physical characteristics of neat ethanol compared with petrol and different behaviour during cold starts probably explains why the effects of E85 on emissions appears to be quite different to that of low strength blends. Research on emissions from vehicles running on E85 is not conclusive but studies in the U.S. Auto/Oil Air Quality Research programme, quoted in the review of Kojima and Johnson (2005) for the World Bank, tends to suggest little overall effect on CO and total HC emissions, but reductions in NO_x emissions. This is contrary to trends observed by low strength bioethanol blends. There are also significant reductions in toxics like benzene and increases in acetaldehyde emissions. Research suggests that the mix of organic compounds in the hydrocarbons emitted from E85 is different to those emitted from pure petrol, such that even if total hydrocarbon emissions are unaffected, their ozone forming potential is lower. PM emissions are lower for E85. It has to be said that these conclusions are based on fairly old vehicle technologies and further research is required to confirm the trends for more modern vehicle technologies with abatement systems characterised by much lower emissions.

2.1.3 Emission scaling factors for bioethanol blends

Based on the available literature where quantitative information was given on the effects of bioethanol relative to petroleum-based petrol, the scaling factors shown in Table 2.1 are estimated for E5-E15 blends and E85. These represent change factors for exhaust emissions of each pollutant relative to emissions from petroleum-based ultra-low sulphur petrol commonly sold in the UK. They are assumed to apply to all types of petrol vehicles over all drive cycles in the absence of further information.

For the low strength blends, up to E15, the effects are assumed to be linear with strength of the blend, with the effects becoming greater as the ethanol volume content increases. For the high strength E85 blends, the scaling factors are much more uncertain estimates because of lack of quantitative information on vehicles representative of the UK fleet. For example, the evidence from the U.S. of there being a reduction in NO_x was largely based on tests on old cars running on re-formulated gasoline. Thus, we have made a cautionary assumption that on modern petrol vehicles, converting to E85 has no effect on NO_x. A similar assumption is made for CO and HC emissions as even though there is evidence for a reduction in emissions of these pollutants, other studies have suggested at there being no change. For PM, the scaling factor for E85 is estimated assuming some decrease would be expected. For benzene, 1,3-butadiene and methane emissions, an approximately linear reduction in emissions is assumed to be extended from the low strength blends to E85 due to displacement of the hydrocarbons in the petrol giving rise to their emissions from incomplete combustion.

Evaporative emissions of VOCs from cars are calculated in inventories from equations relating emissions to fuel vapour pressure (RVP) and ambient temperature conditions. It is assumed that for E5-E15, the RVP of the fuel is increased by 10 kPa in summer months, so there is an increase in evaporative emissions of HCs relative to the base fuel. As the bioethanol strength further increases, the RVP decreases, so for E85 bioethanol, it is assumed that the RVP is reduced to the same level as for the base fuel and hence there is no increase in evaporative emissions.

Table 2.1 Emission scaling factors for different blends of bioethanol relative to base petrol (ULSP)

	HC	CO	NO_x	PM
E5	0.975	0.9	1.0	0.8
E10	0.95	0.8	1.0	0.6
E15	0.925	0.7	1.0	0.4
E85	1.0	1.0	1.0	0.8

	Benzene	1,3-butadiene	Acetaldehyde	CH_4	N_2O
E5	0.9	0.925	2.5	0.925	1.0
E10	0.8	0.85	5.0	0.85	1.0
E15	0.7	0.775	7.5	0.775	1.0
E85	0.1	0.2	10	0.2	1.0

2.2 EMISSIONS FROM BIODIESEL CONSUMPTION

Biodiesel is used both in dilute (5-10%) blends with petroleum-based diesel and in neat form. It can be obtained from esterification of vegetable oils and animal fats or consumed as virgin plant oil. Feedstocks vary around the world with the most common vegetable oils being rapeseed oil (common in Europe for rapeseed methyl ester, RME), soybean oil (common in the U.S. for soybean methyl ester, SME), sunflower oil and palm oil.

Five major studies which addressed the effects of biodiesel blends on exhaust emissions were reviewed in this work:

USEPA (2002)
JRC (Ispra, 2006).
GAVE (TNO, Netherlands, 2004
Kojima and Johnson (2005)

As for bioethanol, these studies showed a high degree of variability in the effect of biodiesel on exhaust emissions and the available literature does not always present a consistent picture. The majority of studies have been carried out on heavy duty diesel vehicles or engines, emissions from which vary significantly with duty cycle. The US Environmental Protection Agency (USEPA) carried out a comprehensive analysis on emission test results for a variety of biodiesel products based on studies made predominantly in the U.S. (USEPA, 2002). The other studies and reviews on the impacts of biodiesels on emissions that were examined all referred to the USEPA study and come to consistent conclusions.

The available information indicates that emissions from light duty vehicles might respond differently to biodiesel than emissions from heavy duty vehicles for some pollutants and that emissions from virgin plant oil are different from esterified vegetable oils.

Unlike for vehicles running on petrol, evaporative emissions are not a concern for diesel-fuelled vehicles. This is because diesel fuel is much less volatile than petrol so the propensity of fuel vapour to be emitted from the vehicle by evaporation is much lower.

2.2.1 Biodiesel from esterified oils

Research has consistently shown a reduction in hydrocarbon and CO emissions from diesel vehicles running on biodiesel from esterified oils. This is not surprising given that biodiesel contains a significant amount of oxygen in the fuel (~10% by weight (w/w)) thus helping to oxidise unburnt fuel. The most serious emission and air quality problems associated with diesel are NO_x and PM emissions. For these pollutants, the effects observed have not been so consistent even in terms of directional change, but have tended to suggest a small increase in NO_x and a decrease in PM emissions relative to petroleum-based diesel. Emissions of toxics such as polyaromatic hydrocarbons show a fairly consistent decreasing trend in emissions.

From analysis of a large body of data, the USEPA developed relationships between the emission change factor (as a percentage change relative to base diesel) and the percentage of esterified oil-based biodiesel in the blend, up to 100 % (i.e. neat biodiesel), for each pollutant. Different equations were available for both RME and SME types of biodiesel. The USEPA report points out that no tests had been carried out on the effects of biodiesel on vehicles equipped with advanced systems like particulate traps and exhaust gas recirculation, so these change factors may not be applicable to these vehicles. However, the report states that they have no reason to believe that the impacts of biodiesel on emissions from these more modern vehicles will be any different to those from older vehicles.

Another point to note is that the number of studies on the effects of biodiesel on emissions from light duty diesel vehicles (such as cars and vans) are much fewer than the number of studies on heavy duty vehicles and the USEPA report acknowledges that it cannot say for certain that the trends observed above, based on heavy duty engines, will apply to light duty vehicles. The information in the USEPA and JRC reports hint at conflicting evidence on even the directional change in emissions from light duty vehicles. The apparent anomalies might be real due to differences in test cycles used or might be statistically less significant owing to the smaller number of tests on light duty vehicles. The issue is, however, relevant to much of Europe where a high proportion of light duty vehicles run on diesel and suggests further research is required on light duty vehicle emissions running on biodiesel.

The JRC is continuing research in this area in Europe and tests continue to show a variation in emission effects. In the UK, Ricardo is examining the effect of biodiesel on new diesel technologies associated with emerging Euro 6 vehicles (post–2010 standards). It is too early to come to conclusions, but some differences in emissions between biodiesel and diesel have been observed. The composition of particulate matter emitted from diesel exhausts could be significantly different between biodiesel and diesel due to the potentially different chemical composition of the fuels. The impact this could have on health responses to PM exposure is not known.

The USEPA study also examined emissions data for biodiesel produced from different types of feedstocks and found these showed different effects. For example, animal fat-based esterified diesel blends showed more beneficial effects on PM emissions than rapeseed and soybean oil-based diesel blends. The animal fat-based blends also showed less negative effects on NO_x emissions than did the rapeseed and soybean oil-based diesel blends which acted similarly.

These studies have suggested that overall air toxic emissions are reduced when biodiesel is added to conventional diesel, but the situation for individual types of air toxics is not so clear. Emissions of PAH species are generally reduced, but benzene emissions might be increased.

2.2.2 Virgin plant oil

Virgin plant oil (without esterification) can also be used in pure form or blended with petroleum-based diesel fuel. Fuel blends can be used in unmodified engines whereas pure virgin plant oil generally requires some engine conversions using retrofit systems for the vehicle to run. Such conversions and engine re-calibrations can affect emissions and these factors may partly explain the different change effect trends shown for virgin plant oil compared with esterified oils.

The effects of virgin plant oil on exhaust emissions are varied and not always consistent. These fuels were excluded from the detailed analysis by the USEPA because of the far fewer studies undertaken. These fuels have less superior physical and combustion properties than the esterified versions and may also be of variable quality. Vehicles running on these fuels tend to show less beneficial impacts than ester-basted fuels with the possible exception of NO_x where it may show some benefits. The report by JRC suggests large increases in CO and HC emissions. The situation is not clear for PM with both increases and decreases in emissions from virgin plant oil observed.

2.2.3 Emission scaling factors for biodiesel blends

The USEPA report gives equations relating the emission change factor for different pollutants (CO, HC, NO_x and PM) to the percentage content of esterified oil-based biodiesel in the blend. The equations are based on correlations observed between emissions from heavy duty vehicles and engines and the biodiesel content of the fuel. The correlations indicate that all pollutants decrease with increasing biodiesel content except NO_x which increases. For RME biodiesel blends, the equations are in the functional form:

% change in emissions = 100 x exp[(A x (% biodiesel))-1]

with values of A given for each pollutant; %v/v refers to the percent by volume of RME biodiesel in the fuel.

These equations were used to calculate the scaling factors shown in Table 2.2 for 5%, 10%, 15% and 100% RME-biodiesel blends, referred to as B5-B100. These represent change factors for exhaust emissions of each pollutant relative to emissions from petroleum-based ultra-low sulphur diesel commonly sold in the UK. They are assumed to apply to **heavy duty vehicles**.

Based on consideration of evidence given in the USEPA and JRC reports, a corresponding set of scaling factors was estimated for **light duty vehicle emissions** shown in Table 2.3. The assumptions made here is that the change in emissions of CO and HC from LDVs for a given strength of biodiesel up to 15% is half as much as the change in emissions of these pollutants from HDVs for the same strength of biodiesel. For NO_x, it is assumed no change in emissions occurs for LDVs (i.e. the scaling factor is 1.0). For PM, the change in emissions from LDVs for a given strength of biodiesel up to 15% is assumed to be twice as much as the change in emissions of these pollutants from HDVs for the same strength of biodiesel. For 100% RME-biodiesel, the scaling factors for LDVs are assumed to be the same as for HDVs.

In the absence of further information, these change factors are assumed to apply over all drive cycles.

As stated earlier, the trend in emissions from diesel vehicles running on 100% virgin plant oil is quite different to those observed for esterified oils. The USEPA report notes that the emission correlations developed for esterified oils do not apply to virgin plant oils and in general the virgin plant oils show less beneficial effects for CO, HC and PM emissions. This evidence was substantiated in the JRC report. Based on these reports, the scaling factors in Table 2.4 are proposed for LDVs and HDVs running on virgin plant oil. The factor for PM is very uncertain, but is assumed to be the same as for CO and HC indicating an increase in emissions relative to conventional diesel on the basis of incomplete combustion. Clearly further measurements are needed in this area of emissions for virgin plant oils.

For the non-regulated pollutants, it is at best only possible to make qualitative statements on the effects of biodiesel. These are summarised in Table 2.5 for esterified and virgin plant oil biodiesel where a √ symbol indicates a reduction in emissions relative to conventional diesel, a X symbol indicates an increase in emissions and a O symbol indicates no effect. Emissions of overall toxics from virgin plant oil biodiesel are not known and cannot be even qualitatively assessed.

Table 2.2 Emission scaling factors for different blends of rapeseed methyl ester (RME) biodiesel relative to base diesel (ULSD):

Heavy duty vehicles:

RME	HC	CO	NO_x	PM
B5	0.95	0.98	1.00	0.98
B10	0.89	0.96	1.01	0.95
B15	0.84	0.94	1.01	0.93
B100	0.31	0.66	1.08	0.62

Table 2.3 Emission scaling factors for different blends of rapeseed methyl ester (RME) biodiesel relative to base diesel (ULSD):

Light duty vehicles:

RME	HC	CO	NO_x	PM
B5	0.97	0.99	1.00	0.95
B10	0.95	0.98	1.00	0.91
B15	0.92	0.97	1.00	0.86
B100	0.31	0.66	1.08	0.62

Table 2.4 Emission scaling factors for pure virgin plant oil (VPO) biodiesel relative to base diesel (ULSD): all vehicles

VPO	HC	CO	NO_x	PM
100%	1.5	1.5	1.00	1.5

Table 2.5 Directional change in emissions of non-regulated pollutants from esterified and virgin plant oil biodiesel relative to emissions from petroleum-based fuels

	All toxics	Benzene	1,3-butadiene	PAHs	CH_4	N_2O
RME	√	X	O	√	O	O
VPO	-	X	X	O	O	O

√ indicates a likely decrease in emissions relative to petroleum-based fuel (i.e. a beneficial effect)
O indicates weak effect or no clear trend, with equal evidence for increase and decrease in emissions relative to petroleum-based fuel (i.e. no clear effect)
X indicates a likely increase in emissions relative to petroleum-based fuel (i.e. negative effect)

2.3 EMISSIONS FROM BIOGAS CONSUMPTION

Biogas is not widely used as a transport fuel, but it finds greater popularity in some parts of the world, for example, in Sweden, where there are several thousand cars and buses running on biogas. In other countries and regions, including the UK, vehicles running on biogas remain a niche area.

Biogas is derived from renewable sources such as sewage, landfills and agricultural waste materials and depending on the source the composition of raw biogas differs greatly. Raw biogas from landfills contains 30-70% methane, the remainder being mixtures of air, water vapour, hydrogen, carbon monoxide and potentially other impurities. Raw biogas from agricultural waste contains around 65-85% methane, with carbon dioxide being the other main constituent, but there may also be trace levels of sulphur compounds such as hydrogen sulphide (H_2S). Because of these variations in methane content and other impurities, the use of biogas in modern vehicles usually requires the upgrading of the raw biogas to natural gas qualities in which case the emission impacts of biogas compared with other fuels become largely similar to those of natural gas (CNG).

The review carried out for the GAVE programme in the Netherlands gives the most comprehensive overview of the impacts of biogas as a transport fuel on emissions (GAVE, TNO, Netherlands, 2004). The recent report by AEA on the environmental sustainability of international biofuels production and use (AEA, 2008) summarised in qualitative terms the main conclusions drawn from the GAVE review indicating the directional change in exhaust emissions for vehicles running on biogas relative to petrol and diesel shown in Table 2.6 and the following paragraphs.

Table 2.6 Directional change on emissions from biogas relative to emissions from petroleum-based fuels (taken from AEA, 2008)

	HC	CO	NO_x	PM	CH_4	PAHs
Relative to petrol	√	√	√	O	XX	√
Relative to diesel	√	√	√	√√	XX	√√

Notes:
√√ indicates evidence strongly showing a consistent decrease in emissions relative to petroleum-based fuel (i.e. a beneficial effect)
√ indicates a likely decrease in emissions relative to petroleum-based fuel (i.e. a beneficial effect)
O indicates weak effect or no clear trend, with equal evidence for increase and decrease in emissions relative to petroleum-based fuel (i.e. no clear effect)
XX indicates evidence showing a consistent increase in emissions relative to petroleum-based fuel (i.e. a negative effect)

Biogas can be used in passenger cars of the type normally run on petrol with stoichiometric spark-ignition engines and a three-way catalyst for emission control. Emissions are much the same as when the vehicle is run on conventional CNG and for the regulated pollutants (NO_x, CO and HCs) are equal or better than emissions from when the vehicle is run on petrol. Methane will account for the major part of the hydrocarbons emitted and this has both ozone forming and greenhouse gas implications as discussed below. Methane is more difficult to control over a catalyst exhaust after-treatment system than other hydrocarbons and generally requires special palladium-based catalyst systems to achieve acceptable methane emissions. This can lead to long-term durability problems of the emission control system. Traces of sulphur compounds such as H_2S in the raw biogas must be removed to retain catalyst efficiency for reducing pollutant emissions over prolonged periods.

Like CNG, biogas can be used to fuel large vehicles with compression ignition engines that would normally run on diesel and have found applications in, for example, bus fleets in cities around the world in countries such as Sweden. As indicated in Table 2.6, biogas shows emission benefits to all the air quality pollutants compared with conventional diesel, including NO_x, PM and unregulated toxic pollutants such as the polyaromatic hydrocarbons (PAHs). These are similar to the benefits shown by CNG relative to diesel-fuelled vehicles. However, quoting a European overview of biogas as a transport fuel (Landahl, 2003), the GAVE review suggested even benefits to PM, CO and HC emissions from a bus running on biogas relative to CNG, but possible deterioration in NO_x emissions. Why this is the case is not clear, but, possibly being based on a single study, may reflect differences in the composition of the biogas used in the tests compared with the CNG perhaps in terms of methane content and traces of impurities. Therefore, it is probably unwise to generalise any statistically significant differences in pollutant emissions between biogas and conventional CNG until further tests are carried out for a range of biogas sources.

Another feature of biogas, which also applies to CNG, is the potential negative impact it could have on future NO_x control catalyst technology used on diesel vehicles. This again relates to the properties of methane that make it a poor HC reducing agent necessary for efficient regeneration of the NO_x storage catalyst system.

The impacts of biogas on greenhouse gas emissions from vehicles are the same as for CNG. The major component of the HC emissions is methane itself, so the potentially higher methane emissions from biogas consumption need to be accounted for when comparing the overall greenhouse gas emission impacts of utilising this fuel as a replacement for conventional petrol and diesel. The potential for leakage of methane during the biogas distribution, storage and refuelling stages of the supply chain also needs to be considered in the overall assessment of greenhouse gas emissions from the usage of biogas as a transport fuel.

In the UK, biogas is, at least in the short term, likely to find application as a replacement for diesel to power heavy duty vehicles, especially captive fleets such as urban buses which are more amenable to refuelling via a simple centralised fuelling depot system than a nationwide fuel supply infrastructure which other vehicles would require. The biogas-favoured scenario modelled in this study was based on the uptake of biogas to power heavy duty vehicles normally running on diesel, therefore a set of biogas emission scaling factors was required. These were developed from information in the GAVE report. Table 2.7 shows change factors for biogas exhaust emissions of each pollutant relative to emissions from petroleum-based ultra-low sulphur diesel commonly sold in the UK.

Table 2.7 Emission scaling factors for biogas emissions from heavy duty vehicles relative to base diesel (ULSD)

	HC	CO	NO_x	PM	NMVOCs	CH_4
Biogas	0.65	0.83	0.5	0.3	0.065	5.0

The scaling factors for CO and HC are based on the assumption that biogas reduces emissions relative to diesel, but the reduction is only half the amount shown by pure RME-biodiesel. For HC, this implies a scaling factor of 0.65. However, in the case of biogas, the majority of the HC are emitted as methane. Assuming that 90% of the HC emitted from biogas is as methane and using information on the methane content of normal diesel HC emissions, then this implies a factor of 5 increase in methane exhaust emissions from an HDV running on biogas relative to diesel. The remaining hydrocarbons emitted are referred to as non-methane volatile organic compounds (NMVOCs), a group of compounds reported explicitly in emission inventories and one of the pollutants targeted in the National Emissions Ceilings Directive. The above assumptions therefore lead to the conclusion that total NMVOC emissions from biogas consumption are reduced by a scaling factor of 0.065 relative to normal diesel (i.e. a 93.5% decrease).

It should be noted that apart from biogas, methane is a very minor component of the hydrocarbons emitted from petrol, diesel, bioethanol and biodiesel consumption so that the change in HC emissions discussed above in relation to other biofuels can be taken to mean the change in NMVOC emissions as far as the emissions inventory for this pollutant is concerned.

The scaling factors for NO_x and PM emissions from biogas in Table 2.7 are based on data for CNG emissions from heavy duty vehicles which suggest around a 70% reduction in emissions relative to base diesel, and information from GAVE which suggests that reductions in NO_x emissions for biogas are better than for RME-diesel, but not as low as for CNG.

3 Biofuel Uptake Scenarios Modelled

This study has investigated the impact of biofuel consumption on future UK emissions of NO_x, PM, NMVOCs and CO from the road transport sector for seven different biofuel uptake scenarios using the emission scaling factors presented in Section 2. Each of the seven scenarios meet the same requirements in terms of the overall volume uptake of biofuels consistent with the 2010 national objective set in the RTFO and the 2020 conditional target set by the EU. These imply a 5% biofuels by volume target for 2010 rising at a linear rate each year to reach 15% biofuels by volume target for 2020, the latter being consistent with the EU conditional target of 10% by energy content. The difference between each of the seven scenarios is the mix of different biofuels used to reach the target.

Some of the scenarios are quite extreme, by strongly favouring a particular type of biofuel, but are chosen deliberately to illustrate the maximum range of outcomes in terms of future emissions of air quality pollutants that can be expected within an overall strategy to boost consumption of biofuels consistent with current UK objectives and EU targets. All the scenarios are based on consumption of first-generation biofuels reviewed in Section 2 although it is recognised that second-generation biofuels might be necessary to meet the more ambitious EU conditional target for 2020.

3.1 SCENARIO 1 – "REALISTIC" SCENARIO

This scenario assumes equal uptake rates of bioethanol displacing normal petrol and RME-biodiesel displacing normal diesel. In other words, by 2010, 5% of volume of petrol sold is bioethanol (as E5) and 5% of volume of diesel sold is RME-biodiesel (as B5). By 2020, 15% of volume petrol sold is bioethanol (as E15) and 15% of volume diesel sold is RME-biodiesel (as B15). The scenario is referred to as 'Realistic' simply because it implies moderate uptake of both low strength blends of bioethanol and biodiesel with neither being strongly favoured. The scenario, however, takes into account the overall growth in diesel consumption relative to petrol consumption as a result of the increased penetration of diesel cars into the fleet implied in the base emission projections of the NAEI. Hence, overall more biodiesel than bioethanol would have to be sold to meet this requirement. This scenario assumes a higher Reid Vapour Pressure (RVP) of the low strength bioethanol fuel relative to the petrol fuel it is displacing and hence an increase in evaporative emissions occurs during the summer months.

3.2 SCENARIO 2 – "BIOETHANOL FAVOURED" SCENARIO

This scenario assumes that the biofuel targets are met initially by the sale of 15% bioethanol (E15) only and once the sale of E15 reaches 100% of all petrol sales (i.e. saturates the petrol market, which it must very quickly to maintain the overall biofuel target), then further growth of biofuel sales are met through sale of 15% RME-biodiesel to achieve the correct overall biofuel target. Again, the scenario takes into account the overall growth in diesel consumption relative to petrol consumption as a result of the increased penetration of diesel cars into the fleet implied in the base emission projections of the NAEI.

Because of the assumed near linearity in the change factors for emissions with strength of bioethanol and biodiesel in the 5-15% range, the scenario can be represented in the model in terms of percentage sales of 15% blends (E15 and B15) and the associated impacts these blends have on emissions as shown in Table 3.1 for this scenario. In reality, the overall sales of biodiesel could be met by a mixture of sales of B5, B10 and B15 at rates required to meet the overall biofuel volume equivalence defined by the sales of B15 given in Table 3.1. This scenario assumes a higher Reid Vapour Pressure (RVP) of the low strength bioethanol fuel relative to the petrol fuel it is displacing and hence an increase in evaporative emissions occurs during the summer months.

Table 3.1: Consumption-equivalence of 15% bioethanol and 15% RME-biodiesel as percentages of overall petrol and diesel sales necessary to meet definitions of Scenario 2 used in emission model

	2010	2015	2020
Sales of E15 as % of all petrol sales	71%	100%	100%
Sales of B15 as % of all diesel sales	0%	44%	100%

3.3 SCENARIO 3 – "BIOETHANOL ONLY" SCENARIO

This scenario assumes that the biofuel targets are met solely by the sale of bioethanol in all years. No biodiesel is consumed. It is assumed that this is initially met by the sale of 15% bioethanol (E15), but once the sale of E15 reaches 100% of all petrol sales (i.e. saturates the petrol market, which it must very quickly to maintain the overall biofuel target), then further growth of biofuel sales are met through sale of 85% bioethanol (E85) to achieve the correct overall biofuel target. Again, the scenario takes into account the overall growth in diesel consumption relative to petrol consumption as a result of the increased penetration of diesel cars into the fleet implied in the base emission projections of the NAEI. In the initial years, when E15 is sold, this scenario assumes a higher Reid Vapour Pressure (RVP) of the low strength bioethanol fuel relative to the petrol fuel it is displacing and hence an increase in evaporative emissions occurs during the summer months. But once E15 saturates the petrol market and E85 is sold, the RVP of this fuel reduces back to the same level as the petrol fuel it is displacing and so no increase in evaporative emissions occurs during the summer months relative to the basecase.

The scenario is represented in the model in terms of percentage sales of 15% and 85% blends (E15 and E85) as shown in Table 3.2 for this scenario.

Table 3.2: Consumption-equivalence of 15% bioethanol and 85% bioethanol as percentages of overall petrol sales necessary to meet definitions of Scenario 3 used in emission model. No biodiesel is sold in this scenario

	2010	2015	2020
Sales of E15 as % of all petrol sales	71%	0%	0%
Sales of E85 as % of all petrol sales	0%	29%	47%
Sales of biodiesel as % of all diesel	0%	0%	0%

3.4 SCENARIO 4 – "BIODIESEL FAVOURED" SCENARIO

This scenario assumes that the biofuel targets are met initially by the sale of 15% RME-biodiesel (B15) only and once the sale of B15 reaches 100% of all diesel sales (i.e. saturates the diesel market, which it will eventually to maintain the overall biofuel target), then further growth of biofuel sales are met through sale of 15% bioethanol to achieve the correct overall biofuel target. Again, the scenario takes into account the overall growth in diesel consumption relative to petrol consumption as a result of the increased penetration of diesel cars into the fleet implied in the base emission projections of the NAEI.

Because of the assumed near linearity in the change factors for emissions with strength of bioethanol and biodiesel in the 5-15% range, the scenario can be represented in the model in terms of percentage sales of 15% blends (E15 and B15) and the associated impacts these blends have on emissions as shown in Table 3.3 for this scenario. In reality, the overall sales of bioethanol could be met by a mixture of sales of E5, E10 and E15 at rates required to meet the overall biofuel volume equivalence defined by the sales of E15 given in Table 3.3. This scenario assumes a higher Reid Vapour Pressure (RVP) of the low strength bioethanol fuel relative to the petrol fuel it is displacing and hence an increase in evaporative emissions occurs during the summer months.

Table 3.3: Consumption-equivalence of 15% RME-biodiesel and 15% bioethanol as percentages of overall diesel and petrol sales necessary to meet definitions of Scenario 4 used in emission model

	2010	2015	2020
Sales of B15 as % of all diesel sales	63%	100%	100%
Sales of E15 as % of all petrol sales	0%	17%	100%

3.5 SCENARIO 5 – "BIODIESEL ONLY" SCENARIO (RME)

This scenario assumes that the biofuel targets are met solely by the sale of biodiesel in all years. No bioethanol is consumed. It is assumed that this is initially met by the sale of 15% RME-biodiesel (B15), but once the sale of B15 reaches 100% of all diesel sales (i.e. saturates the diesel market, which it will eventually to maintain the overall biofuel target), then further growth of biofuel sales are met through sale of 100% RME-biodiesel (B100) to achieve the correct overall biofuel target. Again, the scenario takes into account the overall growth in diesel consumption relative to petrol consumption as a result of the increased penetration of diesel cars into the fleet implied in the base emission projections of the NAEI.

The scenario is represented in the model in terms of percentage sales of 15% and 100% blends (B15 and B100) as shown in Table 3.4 for this scenario.

Table 3.4: Consumption-equivalence of 15% RME-biodiesel and 100% RME-biodiesel as percentages of overall diesel sales necessary to meet definitions of Scenario 5 used in emission model. No bioethanol is sold in this scenario

	2010	2015	2020
Sales of B15 as % of all diesel sales	63%	0%	0%
Sales of B100 as % of all diesel sales	0%	17%	24%
Sales of bioethanol as % of all petrol	0%	0%	0%

3.6 SCENARIO 6 – "BIODIESEL ONLY" SCENARIO (VPO)

This scenario assumes that the biofuel targets are met solely by the sale of biodiesel in all years. No bioethanol is consumed. It is assumed that this is initially met by the sale of 15% RME-biodiesel (B15), but once the sale of B15 reaches 100% of all diesel sales (i.e. saturates the diesel market, which it will eventually to maintain the overall biofuel target), then further growth of biofuel sales are met through sale of 100% virgin plant oil (B100) to achieve the correct overall biofuel target. This scenario is therefore the same as Scenario 5 except that 100% virgin plant oil is favoured instead of 100% RME-biodiesel. Again, the scenario takes into account the overall growth in diesel consumption relative to petrol consumption as a result of the increased penetration of diesel cars into the fleet implied in the base emission projections of the NAEI.

The scenario is represented in the model in terms of percentage sales of 15% and 100% blends (B15 and B100) as shown in Table 3.5 for this scenario.

Table 3.5: Consumption-equivalence of 15% RME-biodiesel and 100% Virgin Plant Oil as percentages of overall diesel sales necessary to meet definitions of Scenario 6 used in emission model. No bioethanol is sold in this scenario

	2010	2015	2020
Sales of B15 as % of all diesel sales	63%	0%	0%
Sales of B100 as % of all diesel sales	0%	17%	24%
Sales of bioethanol as % of all petrol	0%	0%	0%

3.7 SCENARIO 7 – "REALISTIC" SCENARIO WITH BIOGAS CONSUMPTION BY HDVs

This scenario is the same as Scenario 1 except that 10% of the energy that would have been consumed by heavy duty vehicles (hence distance travelled) using RME-biodiesel is consumed using biogas instead. Hence, by 2010, 5% of volume of petrol sold is bioethanol (all as E5) and 5% of volume of diesel sold is RME-biodiesel (all as B5) for light duty vehicle consumption, but 4.5% of diesel consumed by heavy duty vehicles is RME-biodiesel (all as B5) and a remaining 0.5% of diesel that would have been consumed by heavy duty vehicles is displaced with biogas. By 2020, 15% of volume petrol sold is bioethanol (all as E15) and 15% of volume diesel sold is RME-biodiesel (all as B15) for light duty vehicle consumption, but 13.5% of diesel consumed by heavy duty vehicles is RME-biodiesel (all as B15) and a remaining 1.5% of diesel that would have been consumed by heavy duty vehicles is displaced with biogas.

As for Scenario 1, this scenario assumes a higher Reid Vapour Pressure (RVP) of the low strength bioethanol fuel relative to the petrol fuel it is displacing and hence an increase in evaporative emissions occurs during the summer months.

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4 Road Transport Emissions Modelling Methodology and Assumptions

The methodology, assumptions and emission factors used for calculating and forecasting future emissions from road transport are given in methodology annex to the Greenhouse Gas Inventory report (Choudrie et al, 2008, see http://www.airquality.co.uk/archive/reports/cat07/0804161424_ukghgi-90-06_annexes_UNFCCCsubmission_150408.pdf) and in the report by Murrells and Hobson (2006).

The baseline emissions projections comprised of currently agreed emission standards, which included standards up to Euro 5 and 6 for Light Duty vehicles, and up to Euro V for Heavy Duty vehicles.

Both the baseline and the scenario emissions projections used the July 2004 Central traffic forecasts for Great Britain from the Department for Transport (DfT), which are given in “The Future of Transport - White Paper CM 6234". The figures are for 2010, 2015, and 2025 originating from Integrated Transport Economics and Appraisal Division’s NTM-FORGE model. Diesel car sales are assumed to grow to 42% by 2010.

Note that the version of the basecase assumptions used for the road transport emission projections in this study is referred to as the “July 2007 basecase”. Since this study was completed, the basecase has been updated to take into account more recent traffic projections data from DfT, higher diesel car penetration rates, the inclusion of provisional Euro VI standards for heavy duty vehicles and the London Low Emission Zone. That version (“April 2008 basecase”) was not used for this study.

5 Results of Biofuel Scenario Emission Projections

The biofuel emission scaling factors and uptake rates defined in Sections 2 and 3 were used in the NAEI road transport emissions forecasting model to calculate emissions of NO_x, PM, NMVOCs and CO for each vehicle class for years up to 2020. For the non-CO_2 greenhouse gases and other air quality pollutants, a qualitative assessment was given of the impacts of each scenario on their emissions.

5.1 EMISSION PROJECTIONS OF NO_x, PM, NMVOCs AND CO

The results of the road transport emission projections modelled for the basecase (no biofuels) and for each of the seven biofuel scenarios are summarised in Tables 5.1 to 5.4 for the pollutants NO_x, PM, NMVOCs and CO, respectively. These show the emissions for each scenario in 2010, 2015 and 2020 in kilotonnes/year, the change in emissions for each scenario relative to the base in ktonnes and the percentage change in emissions for each scenario relative to the base. A negative change indicates a decrease in emissions relative to the scenario. Further details on the emissions for each scenario broken down by vehicle type are provided in Appendix 1.

For NO_x, all the biofuel scenarios have very little effect on overall emissions. All the scenarios except the biogas scenario lead to a very small increase in emissions. In 2010, these range from an increase of 1.2 ktonnes for the biodiesel favoured scenarios (S4-S6) to a decrease of 2.7 ktonnes for the 'realistic with biogas' scenario (S7). In relative terms, the effects range from +0.3% to –0.7% of total road transport emissions predicted in 2010. As the uptake rate of biofuels increases further into the future, the impacts increase to +1.6% to –2.2% of total road transport emissions predicted in 2020. By this time, it is the RME-biodiesel only scenario (S5) which leads to the largest increase in NO_x as a result of the impact of pure RME-biodiesel on emissions from LDVs and HDVs. The beneficial effect of biogas on NO_x emissions from diesel vehicles leads to Scenario 7 showing the largest decrease in emissions by 2020. The 'more realistic' scenario (S1) involving equal uptake rates of low strength bioethanol and biodiesel blends leads to a 0.2 to 0.5% increase in road transport NO_x emissions from 2010 to 2020.

For PM, the effects of biofuels are more significant and all scenarios show beneficial outcomes except the scenario involving uptake of pure virgin plant oil biodiesel (S6). In 2010, the effects range from a decrease of 2.1% in emissions for the bioethanol favoured scenarios (S2 and S3) to a decrease of 7.1% for the biodiesel favoured and 'only' scenarios (S4-S6). By 2020, the range of outcomes between the different scenarios becomes much larger. The extreme 'biodiesel only scenario' involving the uptake of pure virgin plant oil leads to a 8.9% increase in PM emissions, reflecting the negative impact of this fuel on diesel vehicle emissions shown in Table 2.4. On the other hand any scenario that involves the widespread uptake of low strength blends of RME-biodiesel (S1, S2 and S4) in the fleet by 2020 leads to almost 17% reduction in predicted PM emissions for that year, although in absolute terms the reduction in PM emissions (-0.9 ktonnes) does not become significantly larger than in 2010 because the base level emissions have decreased so much by 2020 with the penetration of lower emitting vehicles in the fleet. The widespread (high) uptake of low strength blends of RME-biodiesel combined with uptake of low strength blends on bioethanol (as achieved by 2020 in S1, S2, S4 and S7) is actually more beneficial to PM than lower uptake rates of pure RME-biodiesel (S5) as this leads to only a 6.7% reduction in overall PM emissions. The most beneficial scenario is the 'realistic with biogas' scenario (S7) leading to an 18.5% reduction by 2020. The 'more realistic' scenario (S1) involving equal uptake rates of low strength bioethanol and biodiesel blends leads to a 4.8 to 16.8% decrease in road transport PM emissions from 2010 to 2020.

For NMVOCs, the effect of the biofuels on emissions is similar to the effects on PM, although they are generally smaller in magnitude. All scenarios show beneficial outcomes except again the scenario involving uptake of pure virgin plant oil biodiesel (S6). In 2010, the effects range from a decrease of

Table 5.1: Projected emissions of NO_x from UK road transport for different biofuel uptake scenarios. The change in emissions refers to changes relative to the basecase emissions for that year and a negative number indicates a decrease in emissions.

UK NOx	Emissions				Change in emissions				% Change in emissions		
	2010	2015	2020		2010	2015	2020		2010	2015	2020
	ktonnes	ktonnes	ktonnes		ktonnes	ktonnes	ktonnes				
Base	390.80	259.11	211.02								
Scenario 1 - Realistic	391.45	259.98	212.14		0.65	0.87	1.12		0.2%	0.3%	0.5%
Scenario 2 - Bioethanol favoured	390.80	259.68	212.14		0.00	0.58	1.12		0.0%	0.2%	0.5%
Scenario 3 - Bioethanol only	390.80	259.11	211.02		0.00	0.00	0.00		0.0%	0.0%	0.0%
Scenario 4 - Biodiesel favoured	392.02	260.41	212.14		1.23	1.30	1.12		0.3%	0.5%	0.5%
Scenario 5 - Biodiesel only (esterified)	392.02	262.02	214.45		1.23	2.92	3.43		0.3%	1.1%	1.6%
Scenario 6 - Biodiesel only (virgin plant oil)	392.02	259.11	211.02		1.23	0.00	0.00		0.3%	0.0%	0.0%
Scenario 7 - Realistic + 10% HDVs with biogas	388.12	255.55	206.43		-2.68	-3.56	-4.59		-0.7%	-1.4%	-2.2%

Table 5.2: Projected exhaust emissions of PM from UK road transport for different biofuel uptake scenarios. The change in emissions refers to changes relative to the basecase emissions for that year and a negative number indicates a decrease in emissions.

UK PM	Emissions				Change in emissions				% Change in emissions		
	2010	2015	2020		2010	2015	2020		2010	2015	2020
	ktonnes	ktonnes	ktonnes		ktonnes	ktonnes	ktonnes				
Base	18.13	9.65	5.50								
Scenario 1 - Realistic	17.26	8.66	4.58		-0.87	-0.99	-0.92		-4.8%	-10.2%	-16.8%
Scenario 2 - Bioethanol favoured	17.75	8.73	4.58		-0.38	-0.92	-0.92		-2.1%	-9.5%	-16.8%
Scenario 3 - Bioethanol only	17.75	9.61	5.43		-0.38	-0.05	-0.07		-2.1%	-0.5%	-1.3%
Scenario 4 - Biodiesel favoured	16.83	8.56	4.58		-1.30	-1.09	-0.92		-7.1%	-11.3%	-16.8%
Scenario 5 - Biodiesel only (esterified)	16.83	9.13	5.13		-1.30	-0.52	-0.37		-7.1%	-5.4%	-6.7%
Scenario 6 - Biodiesel only (virgin plant oil)	16.83	10.34	5.99		-1.30	0.68	0.49		-7.1%	7.1%	8.9%
Scenario 7 - Realistic + 10% HDVs with biogas	17.18	8.58	4.48		-0.94	-1.07	-1.02		-5.2%	-11.1%	-18.5%

Table 5.3: Projected emissions of NMVOCs from UK road transport for different biofuel uptake scenarios. The change in emissions refers to changes relative to the basecase emissions for that year and a negative number indicates a decrease in emissions.

UK NMVOCs	Emissions			Change in emissions			% Change in emissions		
	2010	2015	2020	2010	2015	2020	2010	2015	2020
	ktonnes	ktonnes	ktonnes	ktonnes	ktonnes	ktonnes			
Base	71.03	51.52	48.19						
Scenario 1 - Realistic	69.74	49.07	44.44	-1.28	-2.45	-3.74	-1.8%	-4.8%	-7.8%
Scenario 2 - Bioethanol favoured	70.06	49.38	44.44	-0.97	-2.14	-3.74	-1.4%	-4.1%	-7.8%
Scenario 3 - Bioethanol only	70.06	51.52	48.19	-0.97	0.00	0.00	-1.4%	0.0%	0.0%
Scenario 4 - Biodiesel favoured	68.88	48.36	44.44	-2.15	-3.15	-3.74	-3.0%	-6.1%	-7.8%
Scenario 5 - Biodiesel only (esterified)	68.88	48.62	43.95	-2.15	-2.89	-4.24	-3.0%	-5.6%	-8.8%
Scenario 6 - Biodiesel only (virgin plant oil)	68.88	53.61	51.26	-2.15	2.10	3.07	-3.0%	4.1%	6.4%
Scenario 7 - Realistic + 10% HDVs with biogas	69.32	48.31	43.31	-1.71	-3.20	-4.88	-2.4%	-6.2%	-10.1%

Table 5.4: Projected emissions of CO from UK road transport for different biofuel uptake scenarios. The change in emissions refers to changes relative to the basecase emissions for that year and a negative number indicates a decrease in emissions.

UK CO	Emissions			Change in emissions			% Change in emissions		
	2010	2015	2020	2010	2015	2020	2010	2015	2020
	ktonnes	ktonnes	ktonnes	ktonnes	ktonnes	ktonnes			
Base	626.52	405.18	387.67						
Scenario 1 - Realistic	577.19	344.11	298.73	-49.33	-61.07	-88.95	-7.9%	-15.1%	-22.9%
Scenario 2 - Bioethanol favoured	523.75	315.72	298.73	-102.77	-89.46	-88.95	-16.4%	-22.1%	-22.9%
Scenario 3 - Bioethanol only	523.75	405.18	387.67	-102.77	0.00	0.00	-16.4%	0.0%	0.0%
Scenario 4 - Biodiesel favoured	624.06	386.15	298.73	-2.46	-19.03	-88.95	-0.4%	-4.7%	-22.9%
Scenario 5 - Biodiesel only (esterified)	624.06	400.00	379.87	-2.46	-5.18	-7.81	-0.4%	-1.3%	-2.0%
Scenario 6 - Biodiesel only (virgin plant oil)	624.06	412.81	399.16	-2.46	7.62	11.48	-0.4%	1.9%	3.0%
Scenario 7 - Realistic + 10% HDVs with biogas	577.04	343.83	298.32	-49.48	-61.35	-89.36	-7.9%	-15.1%	-23.1%

1.4% in emissions for the bioethanol favoured scenarios (S2 and S3) to a decrease of 3.0% for the biodiesel favoured and 'only' scenarios (S4-S6). This represents a decrease of around 1-2 ktonnes NMVOCs. By 2020, the range of outcomes between the different scenarios becomes larger. The extreme 'biodiesel only scenario' involving the uptake of pure virgin plant oil leads to a 6.4% increase in NMVOC emissions, reflecting the negative impact of this fuel on diesel vehicle emissions shown in Table 2.4. On the other hand any scenario that involves the widespread uptake of low strength blends of RME-biodiesel combined with bioethanol blends in the fleet by 2020 (S1, S2, S4 and S7) or else the 'biodiesel only scenario' involving uptake of pure RMS-biodiesel (S5) leads to around 8-9% reduction in predicted NMVOC emissions for that year. The most beneficial scenario is again the 'realistic with biogas' scenario (S7) leading to a 10% reduction by 2020. The 'more realistic' scenario (S1) involving equal uptake rates of low strength bioethanol and biodiesel blends leads to a 1.8 to 7.8% decrease in road transport NMVOC emissions from 2010 to 2020.

For CO, the effects of the biofuels on emissions is particularly beneficial for the scenarios involving the uptake of low strength blends of bioethanol, but all scenarios show beneficial outcomes except again the scenario involving uptake of pure virgin plant oil biodiesel (S6). In 2010, the effects range from a decrease of 0.4% in emissions for the biodiesel favoured scenarios (S4-S6) to a decrease of 16% for the bioethanol scenarios. By 2020, the range of outcomes between the different scenarios becomes larger. The extreme 'biodiesel only scenario' involving the uptake of pure virgin plant oil leads to a 3% increase in CO emissions, reflecting the negative impact of this fuel on diesel vehicle emissions shown in Table 2.4. On the other hand, any scenario that involves the widespread uptake of low strength blends of bioethanol combined with low strength blends of RME-biodiesel in the fleet by 2020 (S1, S2, S4 and S7) leads to around 23% reduction in predicted CO emissions for that year. The 'biodiesel only scenario' involving uptake of pure RMS-biodiesel (S5) leads to only a 2% reduction in CO. The 'more realistic' scenario (S1) involving equal uptake rates of low strength bioethanol and biodiesel blends leads to a 7.9 to 22.9% decrease in road transport CO emissions from 2010 to 2020. The addition of biogas to the 'more realistic' scenario (S7) as a replacement for 10% of the biodiesel leads to little further benefits to CO emissions.

The impacts on emissions discussed above refer to total UK emissions from road transport. The model was also used to focus on effects of biofuels on emissions in just urban areas. For all pollutants except CO, the percentage changes in emissions in urban areas, whether negative or positive, were of smaller or similar magnitude to the changes in total UK emissions in all areas. For CO, the effects of biofuels on emissions in urban areas was slightly larger than over the whole of the UK. The differences reflects the relative contributions made by different types of vehicles in different areas.

The same results for the percentage changes in emissions, summarised in Tables 5.1 to 5.4 grouped by pollutant and broken down by biofuel scenario, are shown in Table 5.5 grouped by biofuel scenario and broken down by pollutant. This makes it easier to see the different impacts a particular biofuel scenario has on different pollutants. From this table, it can be seen that:

- The **'Realistic' Scenario 1**, involving the same uptake rates of low strength bioethanol and biodiesel, has a very small negative impact on NO_x and leads to reductions in PM, NMVOCs and CO emissions. The effects are more significant on PM and CO increasing to 17% and 23%, respectively, by 2020.

- The '**Bioethanol Favoured' Scenario 2**, initially favouring the uptake of low strength bioethanol and eventually supplemented with low strength RME-biodiesel, has a very small negative impact on NO_x and initially has a significant beneficial effect on CO and smaller beneficial effects on PM and NMVOCs before converging with the situation for Scenario 1 with more significant beneficial effects on PM.

- The **'Bioethanol Only' Scenario 3**, initially favouring the uptake of low strength bioethanol and eventually supplemented with high strength E85 bioethanol, with no biodiesel at all, has no effect on NO_x, initially has a significant beneficial effect on CO and smaller beneficial effects on PM and NMVOCs until the introduction of E85 reduces the initial benefits gained leading to virtually no overall effects (<1.5%).

- The **'Biodiesel Favoured' Scenario 4**, initially favouring the uptake of low strength RME-

Table 5.5: Percentage change in projected emissions of NO_x, PM, NMVOCs and CO from UK road transport for different biofuel uptake scenarios relative to the basecase. A negative number indicates a decrease in emissions.

		% Change in emissions		
		2010	2015	2020
Scenario 1 - Realistic	**NOx**	**0.2%**	**0.3%**	**0.5%**
	PM	**-4.8%**	**-10.2%**	**-16.8%**
	NMVOCs	**-1.8%**	**-4.8%**	**-7.8%**
	CO	**-7.9%**	**-15.1%**	**-22.9%**
Scenario 2 - Bioethanol favoured	**NOx**	**0.0%**	**0.2%**	**0.5%**
	PM	**-2.1%**	**-9.5%**	**-16.8%**
	NMVOCs	**-1.4%**	**-4.1%**	**-7.8%**
	CO	**-16.4%**	**-22.1%**	**-22.9%**
Scenario 3 - Bioethanol only	**NOx**	**0.0%**	**0.0%**	**0.0%**
	PM	**-2.1%**	**-0.5%**	**-1.3%**
	NMVOCs	**-1.4%**	**0.0%**	**0.0%**
	CO	**-16.4%**	**0.0%**	**0.0%**
Scenario 4 - Biodiesel favoured	**NOx**	**0.3%**	**0.5%**	**0.5%**
	PM	**-7.1%**	**-11.3%**	**-16.8%**
	NMVOCs	**-3.0%**	**-6.1%**	**-7.8%**
	CO	**-0.4%**	**-4.7%**	**-22.9%**
Scenario 5 - Biodiesel only (esterified)	**NOx**	**0.3%**	**1.1%**	**1.6%**
	PM	**-7.1%**	**-5.4%**	**-6.7%**
	NMVOCs	**-3.0%**	**-5.6%**	**-8.8%**
	CO	**-0.4%**	**-1.3%**	**-2.0%**
Scenario 6 - Biodiesel only (virgin plant oil)	**NOx**	**0.3%**	**0.0%**	**0.0%**
	PM	**-7.1%**	**7.1%**	**8.9%**
	NMVOCs	**-3.0%**	**4.1%**	**6.4%**
	CO	**-0.4%**	**1.9%**	**3.0%**
Scenario 7 - Realistic + 10% HDVs with biogas	**NOx**	**-0.7%**	**-1.4%**	**-2.2%**
	PM	**-5.2%**	**-11.1%**	**-18.5%**
	NMVOCs	**-2.4%**	**-6.2%**	**-10.1%**
	CO	**-7.9%**	**-15.1%**	**-23.1%**

biodiesel and eventually supplemented with low strength bioethanol, has a very small negative impact on NO_x, and initially has a small beneficial effect on PM and NMVOCs and a very small effect on CO before converging with the situation for Scenario 1 with more significant beneficial effects on PM and CO.

- The **'Biodiesel Only' Scenario 5**, initially favouring the uptake of low strength RME-biodiesel and eventually supplemented with pure RME-biodiesel, with no bioethanol at all, would lead to slightly stronger, but still very small negative impact on NO_x, and reductions in PM, NMVOCs and CO emissions. The effects are more significant on PM and NMVOCs, reaching up to 9%.

- The **'Biodiesel Only' Scenario 6**, initially favouring the uptake of low strength RME-biodiesel and eventually supplemented with pure virgin plant oil-biodiesel, with no bioethanol at all, would lead to no effects on NO_x, and negative effects on PM, NMVOCs and CO. The negative impacts would be stronger on PM and NMVOCs, reaching up to 9%.

- The **'Realistic' with biogas consumption by HDV Scenario 7**, involving the same uptake rates of low strength bioethanol and biodiesel, but with 10% of the biodiesel consumed by HDVs replaced with biogas, has a small beneficial impact on NO_x and leads to reductions in PM, NMVOCs and CO emissions that are slightly stronger than in the same scenario (S1) without biogas. The effects are more significant on PM and CO increasing to 18% and 23%, respectively, by 2020. Introducing biogas uptake mostly improves the reductions in emissions of NO_x, NMVOCs and PM.

5.2 EFFECTS ON NON-CO_2 GREENHOUSE GAS EMISSIONS

The study considered the impact of biofuels on exhaust emissions of methane and nitrous oxide, but no quantitative estimates of the impacts on projected emissions were made for these pollutants.

Methane emissions are expected to be reduced by biofuel scenarios involving the uptake of bioethanol, but there is no indication there would be any effect through uptake of biodiesel. Overall, the uptake scenarios involving bioethanol and biodiesel (S1-S6) would lead to a reduction in methane emissions, but this has not been quantified. The situation is different for the scenario involving biogas where a significant increase in methane emissions would be expected from the heavy duty vehicles running on this fuel due to the estimated five-fold increase that biogas is considered to have on methane emissions relative to the same vehicle running on diesel, but again this effect has not be quantified. It should be noted, however, that road transport makes a small contribution to methane emissions compared with other sources, currently around 7 kilotonnes, about 0.3% of the UK total emissions of methane in 2006. Methane emissions from road transport are predicted to decrease to around 4 ktonnes by 2020. As a very rough estimate, the increase in methane emissions caused by consumption of biogas in Scenario 7 would lead to a less than 2% increase in methane emissions from road transport.

Data on N_2O emissions from biofuel consumption by transport is severely lacking, but there is no evidence that biofuels would have any effect on N_2O emissions.

5.3 EFFECTS ON EMISSIONS OF OTHER AIR TOXICS

The study considered the impact of biofuels on exhaust emissions of air toxics such as benzene, 1,3-butadiene, PAHs and acetaldehyde, but no quantitative estimates of the impacts on projected emissions were made for these pollutants.

Consumption of bioethanol could lead to a significant reduction in benzene emissions, but consumption of biodiesel could lead to an increase in emissions of benzene. However, emissions of benzene from petrol vehicles outweigh the emissions from diesel vehicles, so in a situation where there were comparable uptake rates of bioethanol and biodiesel (e.g. as in the "Realistic" Scenario 1), one would expect an overall decrease in benzene emissions.

The situation for 1,3-butadiene is similar to benzene with significant reductions from consumption of bioethanol, but consumption of certain types of biodiesel could lead to an increase in emissions of 1,3-butadiene, though perhaps only with virgin plant oil biodiesel and not with esterified biodiesel. The overall impact of biofuels on 1,3-butadiene emissions is not so clear.

The impact of bioethanol on emissions of PAHs is not clear, but there is evidence that PAH emissions from biodiesel are reduced relative to conventional diesel.

Emissions of acetaldehyde are increased significantly from bioethanol consumption relative to its emissions from conventional petrol, possibly by as much as five-fold for even low strength blends such as E10. Emission estimates of this pollutant are not made explicitly by the NAEI. The latest VOC speciation inventory suggests that emissions from petrol vehicles make up about 25% of UK emissions of acetaldehyde directly emitted by sources. However, it has to be understood that acetaldehyde is a major intermediate VOC species produced in the atmospheric oxidation of many other VOCs. Hence, the direct emissions of acetaldehyde from vehicle exhausts will contribute much less to the concentrations of this species in the atmosphere. Furthermore, previous ozone modeling work for Defra on the potential impacts of increased acetaldehyde emissions from vehicle exhausts in Europe following the uptake of bioethanol as a road fuel showed that the effects on predicted ozone concentrations in the UK would be very small (Murrells et al, 2008).

6 Summary and Conclusions

This study has reviewed the effects of different biofuels on exhaust emissions of air quality and non-CO_2 greenhouse gas pollutants. Through a review of the literature, scaling factors representing the change in emissions of regulated pollutants NO_x, PM, HCs and CO relative to their emissions from conventional petrol and diesel fuels have been developed for different strengths of bioethanol, different types of biodiesel and biogas. Where possible quantitative estimates also made for certain non-regulated pollutants such as CH_4, N_2O, benzene and 1,3-butadiene.

Using these scaling factors, the NAEI road transport emissions forecasting model was used to predict future UK road transport emissions of NO_x, PM, NMVOCs and CO for seven different biofuel uptake scenarios. The seven scenarios were all based on the same assumption of increasing overall biofuel consumption rates in the UK in terms of volume or energy content consistent with the Renewable Transport Fuel Obligation for 2010 and the EU conditional target for 2020, but they differed in terms of mix of different types of biofuels used in the UK to meet these targets. The scenarios included one involving an equal mix of low strength bioethanol and transesterified biodiesel blends, arguably the most likely uptake pathway, and more extreme pathways favouring or exclusively involving bioethanol or different types of biodiesel. One scenario also involved the modest uptake of biogas for powering heavy duty vehicles. Thus, with uncertainty in the actual biofuel pathway that the UK will follow, this approach indicates the range of potential outcomes on emissions of key air quality pollutants that will occur.

The biofuel scenario (Scenario 1) involving equal uptake of bioethanol and RME-biodiesel (referred to as the more 'Realistic' scenario) is expected to lead to the following percentage changes in emissions in 2020, relative to the basecase predictions assuming no biofuel uptake:

NOx	**0.5%**
PM	**-16.8%**
NMVOCs	**-7.8%**
CO	**-22.9%**

A negative value indicates a decrease in emissions.

Across the whole range of scenarios studied, the changes in emissions relative to the base case would be within the following ranges for all future years:

NOx	**-2% to +2%**
PM	**-19% to +9%**
NMVOCs	**-10% to +6%**
CO	**-23% to +3%**

The majority of the studies lead to a decrease or no change in emissions. The only scenario that could potentially lead to increased emissions is one concentrated on the uptake of pure virgin plant oil biodiesel.

The impacts of biofuels on non-regulated pollutants are generally more uncertain and depend on biofuel scenario. In general, strategies favouring bioethanol would benefit benzene, 1,3-butadiene and methane emissions, but lead to higher acetaldehyde emissions. Strategies favouring biodiesel would benefit PAHs, but could lead to increased emissions of benzene and 1,3-butadiene. Strategies favouring biogas would benefit PAHs and probably benzene and 1,3-butadiene, but would lead to higher methane emissions. Overall, air toxic emissions are likely to be reduced. Although the increase in methane and acetaldehyde emissions per vehicle look very significant for biogas and bioethanol consumption, respectively, the overall impact on future UK emissions (methane) or air quality (acetaldehyde) are expected to be very small.

The emission scaling factors developed in this study have high levels of uncertainty and in some cases even the directional change in emissions is not certain, especially for the non-regulated pollutants. This reflects the fact that the majority of studies are based on low-strength blends where the emission effects are subtle and also the variability in vehicle emissions with drive cycle, vehicle type and technology and quality of the base petrol and diesel fuels used in the tests. Although the effects on emissions might be stronger for high strength blends or pure biofuels, there have been fewer repeat tests reported in the literature on vehicles and fuels probably relevant to the UK fleet. To run a vehicle on high strength biofuel blends usually requires engine re-tuning or other vehicle adaptations and this adds further uncertainty to the overall effects of the biofuel on emissions when the changes more reflect the adaptation strategy of the vehicle or engine manufacturer than the fuel *per se*. Further research on emission effects is required in this area if these high strength fuel blends are likely to become more popular in the UK, e.g. flexible fuelled vehicles (FFVs).

The study also found that most tests on biodiesel emissions were based on heavy duty vehicles with older engines. Further emission tests are required on diesel light duty vehicles and vehicles, engines and technologies relevant to the UK fleet to improve the reliability of the biodiesel emission scaling factors.

The study has been based on hypothetical assumptions about the future mix of biofuels that could penetrate fuel sales in order to predict the range of possible outcomes on emissions that might ensue. From the emission ranges given above, it is evident that NO_x emissions from road transport are not likely to be sensitive to the mix of biofuels sold, but emissions of PM, NMVOCs and CO could be. The study has indicated that to more accurately account for biofuel uptake in the inventory there will be a need for annual statistics to be made available on the volumes and strengths of each type of biofuel sold in the UK. At the moment, such data are lacking with the only data gathered being in terms of total volume of bioethanol and biodiesel released for sale, as provided by HM Revenue & Customs, not by type of biofuel or mixture strength. It is recognised that the nature of the biofuel supply industry may make this data collection difficult and may require periodic surveys of suppliers to break down the total volume-based figures collected by HMRC.

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Appendices

CONTENTS

Road transport emission projections for biofuel scenarios: NO_x (Base and Scenarios 1-3)

		Basecase			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	115.01	77.26	69.44	71.04
HGV	Rigid	55.25	35.27	28.75	28.60
ALL HGV		170.25	112.52	98.19	99.64
Buses		25.59	17.74	13.87	11.89
Motorcycles		1.04	0.73	0.40	0.35
All DERV		302.73	217.64	177.26	167.42
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**390.80**	**259.11**	**211.02**	**201.19**

		Scenario 1 - Realistic			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	115.39	77.77	70.13	71.75
HGV	Rigid	55.43	35.50	29.04	28.88
ALL HGV		170.82	113.27	99.17	100.64
Buses		25.68	17.85	14.00	12.01
Motorcycles		1.04	0.73	0.40	0.35
All DERV		303.38	218.51	178.38	168.53
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**391.45**	**259.98**	**212.14**	**202.30**

		Scenario 2 - Bioethanol favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	115.01	77.60	70.13	71.75
HGV	Rigid	55.25	35.42	29.04	28.88
ALL HGV		170.25	113.02	99.17	100.64
Buses		25.59	17.81	14.00	12.01
Motorcycles		1.04	0.73	0.40	0.35
All DERV		302.73	218.22	178.38	168.53
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**390.80**	**259.68**	**212.14**	**202.30**

		Scenario 3 - Bioethanol only			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	115.01	77.26	69.44	71.04
HGV	Rigid	55.25	35.27	28.75	28.60
ALL HGV		170.25	112.52	98.19	99.64
Buses		25.59	17.74	13.87	11.89
Motorcycles		1.04	0.73	0.40	0.35
All DERV		302.73	217.64	177.26	167.42
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**390.80**	**259.11**	**211.02**	**201.19**

Road transport emission projections for biofuel scenarios: NO_x (Scenarios 4-7)

		Scenario 4 - Biodiesel favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	115.73	78.03	70.13	71.75
HGV	Rigid	55.59	35.62	29.04	28.88
ALL HGV		171.32	113.65	99.17	100.64
Buses		25.75	17.91	14.00	12.01
Motorcycles		1.04	0.73	0.40	0.35
All DERV		303.95	218.95	178.38	168.53
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**392.02**	**260.41**	**212.14**	**202.30**

		Scenario 5 - Biodiesel only (esterified)			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	55.23	42.82	36.89
	All Cars	146.49	94.52	74.95	69.10
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	33.33	23.65	20.08
	All LGV	47.42	34.77	24.87	21.29
HGV	Artic	115.73	78.29	70.78	72.42
HGV	Rigid	55.59	35.74	29.31	29.15
ALL HGV		171.32	114.03	100.09	101.57
Buses		25.75	17.97	14.13	12.12
Motorcycles		1.04	0.73	0.40	0.35
All DERV		303.95	220.56	180.69	170.65
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**392.02**	**262.02**	**214.45**	**204.42**

Scenario 6 - Biodiesel only (virgin plant oil)					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	115.73	77.26	69.44	71.04
HGV	Rigid	55.59	35.27	28.75	28.60
ALL HGV		171.32	112.52	98.19	99.64
Buses		25.75	17.74	13.87	11.89
Motorcycles		1.04	0.73	0.40	0.35
All DERV		303.95	217.64	177.26	167.42
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**392.02**	**259.11**	**211.02**	**201.19**

Scenario 7 - Realistic, with 10% HDV biogas					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	84.94	39.29	32.13	32.21
	DERV	61.56	54.50	42.01	36.19
	All Cars	146.49	93.79	74.14	68.40
LGV	Petrol	2.10	1.44	1.22	1.21
	DERV	45.32	32.89	23.20	19.70
	All LGV	47.42	34.33	24.42	20.91
HGV	Artic	113.44	75.15	66.59	68.13
HGV	Rigid	54.49	34.30	27.57	27.42
ALL HGV		167.93	109.45	94.17	95.56
Buses		25.24	17.25	13.30	11.40
Motorcycles		1.04	0.73	0.40	0.35
All DERV		300.05	214.08	172.67	162.84
All Petrol		88.07	41.46	33.76	33.77
All Vehicles		**388.12**	**255.55**	**206.43**	**196.62**

Road transport emission projections for biofuel scenarios: PM (Base and Scenarios 1-3)

		Basecase			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.86	0.76	0.75	0.77
	DERV	4.33	2.14	0.95	0.50
	All Cars	5.19	2.91	1.70	1.27
LGV	Petrol	0.02	0.02	0.02	0.02
	DERV	8.67	4.16	1.59	0.73
	All LGV	8.69	4.18	1.61	0.75
HGV	Artic	2.19	1.14	0.96	0.99
HGV	Rigid	0.97	0.47	0.34	0.34
ALL HGV		3.16	1.61	1.30	1.33
Buses		0.40	0.25	0.19	0.17
Motorcycles		0.68	0.70	0.70	0.70
All DERV		16.57	8.17	4.03	2.73
All Petrol		1.55	1.48	1.47	1.49
All Vehicles		**18.13**	**9.65**	**5.50**	**4.22**

		Scenario 1 - Realistic			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.69	0.46	0.30	0.31
	DERV	4.13	1.94	0.82	0.43
	All Cars	4.82	2.40	1.12	0.74
LGV	Petrol	0.02	0.01	0.01	0.01
	DERV	8.27	3.77	1.37	0.63
	All LGV	8.28	3.79	1.38	0.64
HGV	Artic	2.14	1.09	0.89	0.92
HGV	Rigid	0.95	0.45	0.32	0.32
ALL HGV		3.09	1.54	1.21	1.23
Buses		0.39	0.24	0.18	0.16
Motorcycles		0.68	0.70	0.70	0.70
All DERV		15.88	7.49	3.57	2.45
All Petrol		1.38	1.17	1.01	1.01
All Vehicles		**17.26**	**8.66**	**4.58**	**3.47**

		Scenario 2 - Bioethanol favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.49	0.30	0.30	0.31
	DERV	4.33	2.01	0.82	0.43
	All Cars	4.82	2.32	1.12	0.74
LGV	Petrol	0.01	0.01	0.01	0.01
	DERV	8.67	3.90	1.37	0.63
	All LGV	8.68	3.91	1.38	0.64
HGV	Artic	2.19	1.10	0.89	0.92
HGV	Rigid	0.97	0.46	0.32	0.32
ALL HGV		3.16	1.56	1.21	1.23
Buses		0.40	0.24	0.18	0.16
Motorcycles		0.68	0.70	0.70	0.70
All DERV		16.57	7.72	3.57	2.45
All Petrol		1.18	1.01	1.01	1.01
All Vehicles		**17.75**	**8.73**	**4.58**	**3.47**

		Scenario 3 - Bioethanol only			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.49	0.72	0.68	0.70
	DERV	4.33	2.14	0.95	0.50
	All Cars	4.82	2.86	1.63	1.20
LGV	Petrol	0.01	0.02	0.02	0.02
	DERV	8.67	4.16	1.59	0.73
	All LGV	8.68	4.18	1.61	0.75
HGV	Artic	2.19	1.14	0.96	0.99
HGV	Rigid	0.97	0.47	0.34	0.34
ALL HGV		3.16	1.61	1.30	1.33
Buses		0.40	0.25	0.19	0.17
Motorcycles		0.68	0.70	0.70	0.70
All DERV		16.57	8.17	4.03	2.73
All Petrol		1.18	1.44	1.40	1.42
All Vehicles		**17.75**	**9.61**	**5.43**	**4.15**

Road transport emission projections for biofuel scenarios: PM (Scenarios 4-7)

		Scenario 4 - Biodiesel favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.86	0.68	0.30	0.31
	DERV	3.95	1.84	0.82	0.43
	All Cars	4.81	2.53	1.12	0.74
LGV	Petrol	0.02	0.02	0.01	0.01
	DERV	7.91	3.58	1.37	0.63
	All LGV	7.93	3.60	1.38	0.64
HGV	Artic	2.10	1.06	0.89	0.92
HGV	Rigid	0.93	0.44	0.32	0.32
ALL HGV		3.02	1.50	1.21	1.23
Buses		0.39	0.23	0.18	0.16
Motorcycles		0.68	0.70	0.70	0.70
All DERV		15.28	7.16	3.57	2.45
All Petrol		1.55	1.40	1.01	1.01
All Vehicles		**16.83**	**8.56**	**4.58**	**3.47**

		Scenario 5 - Biodiesel only (esterified)			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.86	0.76	0.75	0.77
	DERV	3.95	2.01	0.86	0.46
	All Cars	4.81	2.77	1.61	1.23
LGV	Petrol	0.02	0.02	0.02	0.02
	DERV	7.91	3.90	1.45	0.66
	All LGV	7.93	3.92	1.47	0.68
HGV	Artic	2.10	1.07	0.87	0.90
HGV	Rigid	0.93	0.44	0.31	0.31
ALL HGV		3.02	1.51	1.18	1.20
Buses		0.39	0.23	0.17	0.16
Motorcycles		0.68	0.70	0.70	0.70
All DERV		15.28	7.65	3.66	2.48
All Petrol		1.55	1.48	1.47	1.49
All Vehicles		**16.83**	**9.13**	**5.13**	**3.97**

Scenario 6 - Biodiesel only (virgin plant oil)					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.86	0.76	0.75	0.77
	DERV	3.95	2.32	1.06	0.57
	All Cars	4.81	3.09	1.81	1.33
LGV	Petrol	0.02	0.02	0.02	0.02
	DERV	7.91	4.51	1.79	0.82
	All LGV	7.93	4.53	1.81	0.84
HGV	Artic	2.10	1.23	1.07	1.11
HGV	Rigid	0.93	0.51	0.38	0.38
ALL HGV		3.02	1.75	1.45	1.49
Buses		0.39	0.27	0.21	0.19
Motorcycles		0.68	0.70	0.70	0.70
All DERV		15.28	8.85	4.52	3.06
All Petrol		1.55	1.48	1.47	1.49
All Vehicles		**16.83**	**10.34**	**5.99**	**4.55**

Scenario 7 - Realistic, with 10% HDV biogas					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	0.69	0.46	0.30	0.31
	DERV	4.13	1.94	0.82	0.43
	All Cars	4.82	2.40	1.12	0.74
LGV	Petrol	0.02	0.01	0.01	0.01
	DERV	8.27	3.77	1.37	0.63
	All LGV	8.28	3.79	1.38	0.64
HGV	Artic	2.10	1.04	0.83	0.86
HGV	Rigid	0.93	0.43	0.29	0.29
ALL HGV		3.02	1.47	1.12	1.15
Buses		0.39	0.23	0.17	0.15
Motorcycles		0.68	0.70	0.70	0.70
All DERV		15.81	7.41	3.48	2.36
All Petrol		1.38	1.17	1.01	1.01
All Vehicles		**17.18**	**8.58**	**4.48**	**3.37**

Road transport emission projections for biofuel scenarios: NMVOCs (Base and Scenarios 1-3)

		Basecase			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	35.49	21.86	19.38	19.37
	DERV	4.56	5.57	6.13	6.38
	All Cars	40.06	27.43	25.51	25.74
LGV	Petrol	0.65	0.47	0.42	0.42
	DERV	5.77	4.86	4.69	4.91
	All LGV	6.42	5.32	5.11	5.33
HGV	Artic	10.36	9.47	9.58	9.95
HGV	Rigid	4.20	3.51	3.41	3.47
ALL HGV		14.56	12.98	12.99	13.42
Buses		1.71	1.63	1.61	1.66
Motorcycles		8.28	4.15	2.97	2.90
All DERV		26.61	25.03	25.42	26.37
All Petrol		44.42	26.48	22.77	22.68
All Vehicles		**71.03**	**51.52**	**48.19**	**49.05**

		Scenario 1 - Realistic			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	35.36	21.54	18.85	18.87
	DERV	4.44	5.27	5.64	5.87
	All Cars	39.80	26.81	24.49	24.73
LGV	Petrol	0.65	0.46	0.40	0.40
	DERV	5.61	4.60	4.32	4.52
	All LGV	6.26	5.06	4.72	4.92
HGV	Artic	9.81	8.46	8.05	8.36
HGV	Rigid	3.98	3.14	2.86	2.91
ALL HGV		13.79	11.60	10.91	11.28
Buses		1.62	1.45	1.35	1.39
Motorcycles		8.28	4.15	2.97	2.90
All DERV		25.46	22.92	22.22	23.05
All Petrol		44.28	26.15	22.23	22.17
All Vehicles		**69.74**	**49.07**	**44.44**	**45.22**

		Scenario 2 - Bioethanol favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	34.55	21.14	18.85	18.87
	DERV	4.56	5.37	5.64	5.87
	All Cars	39.11	26.52	24.49	24.73
LGV	Petrol	0.63	0.45	0.40	0.40
	DERV	5.77	4.69	4.32	4.52
	All LGV	6.40	5.13	4.72	4.92
HGV	Artic	10.36	8.80	8.05	8.36
HGV	Rigid	4.20	3.26	2.86	2.91
ALL HGV		14.56	12.06	10.91	11.28
Buses		1.71	1.51	1.35	1.39
Motorcycles		8.28	4.15	2.97	2.90
All DERV		26.61	23.63	22.22	23.05
All Petrol		43.46	25.75	22.23	22.17
All Vehicles		**70.06**	**49.38**	**44.44**	**45.22**

		Scenario 3 - Bioethanol only			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	34.55	21.86	19.38	19.37
	DERV	4.56	5.57	6.13	6.38
	All Cars	39.11	27.43	25.51	25.74
LGV	Petrol	0.63	0.47	0.42	0.42
	DERV	5.77	4.86	4.69	4.91
	All LGV	6.40	5.32	5.11	5.33
HGV	Artic	10.36	9.47	9.58	9.95
HGV	Rigid	4.20	3.51	3.41	3.47
ALL HGV		14.56	12.98	12.99	13.42
Buses		1.71	1.63	1.61	1.66
Motorcycles		8.28	4.15	2.97	2.90
All DERV		26.61	25.03	25.42	26.37
All Petrol		43.46	26.48	22.77	22.68
All Vehicles		**70.06**	**51.52**	**48.19**	**49.05**

Road transport emission projections for biofuel scenarios: NMVOCs (Scenarios 4-7)

		Scenario 4 - Biodiesel favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	35.49	21.88	18.85	18.87
	DERV	4.34	5.12	5.64	5.87
	All Cars	39.83	27.00	24.49	24.73
LGV	Petrol	0.65	0.47	0.40	0.40
	DERV	5.48	4.47	4.32	4.52
	All LGV	6.13	4.94	4.72	4.92
HGV	Artic	9.32	7.95	8.05	8.36
HGV	Rigid	3.78	2.95	2.86	2.91
ALL HGV		13.11	10.90	10.91	11.28
Buses		1.54	1.37	1.35	1.39
Motorcycles		8.28	4.15	2.97	2.90
All DERV		24.46	21.86	22.22	23.05
All Petrol		44.42	26.50	22.23	22.17
All Vehicles		**68.88**	**48.36**	**44.44**	**45.22**

		Scenario 5 - Biodiesel only (esterified)			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	35.49	21.86	19.38	19.37
	DERV	4.34	4.92	5.11	5.31
	All Cars	39.83	26.79	24.49	24.68
LGV	Petrol	0.65	0.47	0.42	0.42
	DERV	5.48	4.30	3.91	4.10
	All LGV	6.13	4.76	4.33	4.51
HGV	Artic	9.32	8.37	7.98	8.29
HGV	Rigid	3.78	3.11	2.84	2.89
ALL HGV		13.11	11.48	10.82	11.19
Buses		1.54	1.44	1.34	1.38
Motorcycles		8.28	4.15	2.97	2.90
All DERV		24.46	22.14	21.18	21.98
All Petrol		44.42	26.48	22.77	22.68
All Vehicles		**68.88**	**48.62**	**43.95**	**44.66**

Scenario 6 - Biodiesel only (virgin plant oil)					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	35.49	21.86	19.38	19.37
	DERV	4.34	6.03	6.87	7.15
	All Cars	39.83	27.90	26.25	26.51
LGV	Petrol	0.65	0.47	0.42	0.42
	DERV	5.48	5.27	5.26	5.51
	All LGV	6.13	5.73	5.68	5.92
HGV	Artic	9.32	10.26	10.74	11.15
HGV	Rigid	3.78	3.81	3.82	3.89
ALL HGV		13.11	14.07	14.55	15.04
Buses		1.54	1.76	1.81	1.86
Motorcycles		8.28	4.15	2.97	2.90
All DERV		24.46	27.13	28.49	29.56
All Petrol		44.42	26.48	22.77	22.68
All Vehicles		**68.88**	**53.61**	**51.26**	**52.24**

Scenario 7 - Realistic, with 10% HDV biogas					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	35.36	21.54	18.85	18.87
	DERV	4.44	5.27	5.64	5.87
	All Cars	39.80	26.81	24.49	24.73
LGV	Petrol	0.65	0.46	0.40	0.40
	DERV	5.61	4.60	4.32	4.52
	All LGV	6.26	5.06	4.72	4.92
HGV	Artic	9.54	7.97	7.30	7.59
HGV	Rigid	3.87	2.96	2.60	2.65
ALL HGV		13.41	10.92	9.90	10.24
Buses		1.58	1.37	1.23	1.26
Motorcycles		8.28	4.15	2.97	2.90
All DERV		25.04	22.16	21.09	21.89
All Petrol		44.28	26.15	22.23	22.17
All Vehicles		**69.32**	**48.31**	**43.31**	**44.06**

Road transport emission projections for biofuel scenarios: CO (Base and Scenarios 1-3)

		Basecase			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	472.76	287.03	277.76	291.27
	DERV	15.00	18.45	20.45	21.29
	All Cars	487.77	305.48	298.21	312.57
LGV	Petrol	7.42	5.52	5.49	5.72
	DERV	34.35	35.39	37.31	39.56
	All LGV	41.77	40.91	42.81	45.28
HGV	Artic	25.88	24.22	24.62	25.59
HGV	Rigid	10.09	8.62	8.42	8.58
ALL HGV		35.98	32.84	33.04	34.17
Buses		4.93	4.35	4.28	4.38
Motorcycles		56.07	21.61	9.33	8.44
All DERV		90.26	91.02	95.09	99.40
All Petrol		536.26	314.16	292.59	305.44
All Vehicles		**626.52**	**405.18**	**387.67**	**404.83**

		Scenario 1 - Realistic			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	425.49	229.63	194.43	203.89
	DERV	14.85	18.08	19.84	20.65
	All Cars	440.34	247.70	214.27	224.54
LGV	Petrol	6.68	4.42	3.85	4.01
	DERV	34.00	34.68	36.19	38.37
	All LGV	40.69	39.10	40.04	42.38
HGV	Artic	25.37	23.25	23.15	24.06
HGV	Rigid	9.89	8.27	7.91	8.06
ALL HGV		35.26	31.52	31.06	32.12
Buses		4.83	4.18	4.02	4.12
Motorcycles		56.07	21.61	9.33	8.44
All DERV		88.95	88.46	91.11	95.26
All Petrol		488.24	255.65	207.61	216.34
All Vehicles		**577.19**	**344.11**	**298.73**	**311.60**

		Scenario 2 - Bioethanol favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	371.58	200.92	194.43	203.89
	DERV	15.00	18.20	19.84	20.65
	All Cars	386.59	219.12	214.27	224.54
LGV	Petrol	5.84	3.86	3.85	4.01
	DERV	34.35	34.92	36.19	38.37
	All LGV	40.18	38.78	40.04	42.38
HGV	Artic	25.88	23.58	23.15	24.06
HGV	Rigid	10.09	8.39	7.91	8.06
ALL HGV		35.98	31.97	31.06	32.12
Buses		4.93	4.24	4.02	4.12
Motorcycles		56.07	21.61	9.33	8.44
All DERV		90.26	89.32	91.11	95.26
All Petrol		433.49	226.40	207.61	216.34
All Vehicles		**523.75**	**315.72**	**298.73**	**311.60**

		Scenario 3 - Bioethanol only			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	371.58	287.03	277.76	291.27
	DERV	15.00	18.45	20.45	21.29
	All Cars	386.59	305.48	298.21	312.57
LGV	Petrol	5.84	5.52	5.49	5.72
	DERV	34.35	35.39	37.31	39.56
	All LGV	40.18	40.91	42.81	45.28
HGV	Artic	25.88	24.22	24.62	25.59
HGV	Rigid	10.09	8.62	8.42	8.58
ALL HGV		35.98	32.84	33.04	34.17
Buses		4.93	4.35	4.28	4.38
Motorcycles		56.07	21.61	9.33	8.44
All DERV		90.26	91.02	95.09	99.40
All Petrol		433.49	314.16	292.59	305.44
All Vehicles		**523.75**	**405.18**	**387.67**	**404.83**

Road transport emission projections for biofuel scenarios: CO (Scenarios 4-7)

		Scenario 4 - Biodiesel favoured			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	472.76	272.14	194.43	203.89
	DERV	14.72	17.89	19.84	20.65
	All Cars	487.49	290.03	214.27	224.54
LGV	Petrol	7.42	5.23	3.85	4.01
	DERV	33.70	34.33	36.19	38.37
	All LGV	41.13	39.56	40.04	42.38
HGV	Artic	24.91	22.76	23.15	24.06
HGV	Rigid	9.72	8.10	7.91	8.06
ALL HGV		34.63	30.87	31.06	32.12
Buses		4.74	4.09	4.02	4.12
Motorcycles		56.07	21.61	9.33	8.44
All DERV		87.80	87.17	91.11	95.26
All Petrol		536.26	298.98	207.61	216.34
All Vehicles		**624.06**	**386.15**	**298.73**	**311.60**

		Scenario 5 - Biodiesel only (esterified)			
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	472.76	287.03	277.76	291.27
	DERV	14.72	17.39	18.77	19.54
	All Cars	487.49	304.43	296.53	310.82
LGV	Petrol	7.42	5.52	5.49	5.72
	DERV	33.70	33.37	34.25	36.31
	All LGV	41.13	38.89	39.74	42.03
HGV	Artic	24.91	22.84	22.60	23.49
HGV	Rigid	9.72	8.13	7.73	7.87
ALL HGV		34.63	30.97	30.33	31.36
Buses		4.74	4.10	3.93	4.02
Motorcycles		56.07	21.61	9.33	8.44
All DERV		87.80	85.84	87.28	91.23
All Petrol		536.26	314.16	292.59	305.44
All Vehicles		**624.06**	**400.00**	**379.87**	**396.67**

Scenario 6 - Biodiesel only (virgin plant oil)					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	472.76	287.03	277.76	291.27
	DERV	14.72	19.99	22.92	23.86
	All Cars	487.49	307.02	300.68	315.14
LGV	Petrol	7.42	5.52	5.49	5.72
	DERV	33.70	38.35	41.82	44.34
	All LGV	41.13	43.87	47.31	50.06
HGV	Artic	24.91	26.25	27.60	28.68
HGV	Rigid	9.72	9.34	9.44	9.61
ALL HGV		34.63	35.59	37.03	38.29
Buses		4.74	4.72	4.80	4.91
Motorcycles		56.07	21.61	9.33	8.44
All DERV		87.80	98.64	106.57	111.40
All Petrol		536.26	314.16	292.59	305.44
All Vehicles		**624.06**	**412.81**	**399.16**	**416.84**

Scenario 7 - Realistic, with 10% HDV biogas					
ktonnes		**2010**	**2015**	**2020**	**2025**
Cars	Petrol	425.49	229.63	194.43	203.89
	DERV	14.85	18.08	19.84	20.65
	All Cars	440.34	247.70	214.27	224.54
LGV	Petrol	6.68	4.42	3.85	4.01
	DERV	34.00	34.68	36.19	38.37
	All LGV	40.69	39.10	40.04	42.38
HGV	Artic	25.27	23.07	22.88	23.77
HGV	Rigid	9.86	8.21	7.82	7.97
ALL HGV		35.13	31.28	30.70	31.74
Buses		4.81	4.14	3.98	4.07
Motorcycles		56.07	21.61	9.33	8.44
All DERV		88.80	88.18	90.70	94.83
All Petrol		488.24	255.65	207.61	216.34
All Vehicles		**577.04**	**343.83**	**298.32**	**311.17**

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