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Scenarios for the cost effective deployment of biofuel in the UK road transport sector in 2020

‘Biofuels Modes Project 3’

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AEA reference	ED56675- Final Report - Issue Number 5
Contact details	John Norris AEA Gemini Building Fermi Avenue Harwell Didcot OX11 0QR t: 0870 190 6439 f: 0870 190 6944 e: john.norris@aeat.co.uk AEA is a business name of AEA Technology plc AEA is certificated to ISO9001 and ISO14001
Author	John Norris, Dan Rapson, and Paul Scott
Approved By	Sujith Kollamthodi
Signed	
Date	2nd August 2011

Executive summary

Overview

The use of biofuels in the transport sector is an important part of the UK's plan to comply with the 2020 renewable energy targets set out in the European Union's Renewable Energy Directive (RED) and the 2020 targets for improving the greenhouse gas (GHG) intensity of transport fuels set out in the Fuel Quality Directive (FQD). Beyond 2020 and through to 2050, biofuels could potentially play an increasingly important role in helping to decarbonise the transport sector.

To realise the potential of biofuels to reduce emissions from transport in the most cost-effective way, the Department for Transport (DfT) has recognised that modifications to, and innovations in the UK supply infrastructure and in the capacity of the UK vehicle fleet to use biofuels may be required.

This project was commissioned to focus on identifying the most cost effective ways for deploying biofuels in the road transport sector to meet the 2020 RED and FQD targets.

Approach

The project built on the cost effectiveness modelling framework developed as part of a separate study assessing cost effectiveness scenarios for deployment options across the UK transport sector to 2020 and 2050. The project comprised the following key steps:

- Review of the biofuel deployment options for road transport developed in the previous study;
- Refinement of these options to fit with the objectives specific to this study;
- Modification of the cost-effectiveness model to meet the objectives specific to this study;
- Development of final scenarios;
- Analysis of findings and conclusions;

The biofuel deployment options considered can be grouped into four broad scenarios:

- **Scenario 1 "Mainstream":** The biofuels capability of all new mainstream vehicles changes;
- **Scenario 2 "Depots":** The biofuels capability of the mainstream road transport fleet does not change, but there is selective use of high-strength biofuel blends by captive vehicle fleets;
- **Scenario 3 "Combined":** A combination of Scenarios 1 and 2, but also including the introduction of E85 for flex-fuel cars;
- **Scenario 4 "Advanced":** Protection grades for petrol and diesel remain at E5 and B7 but are supplemented by the use of drop-in fuels.

Possible options for increasing the deployment of biofuels in the UK road transport sector by 2020 were considered in the context of these scenarios. Thirteen specific scenarios were modelled, and their contributions to RED and FQD targets were calculated (the former taking into account the RED Directive's double counting of some biofuels). The latter was based on the key assumption that the fossil fuel baseline GHG intensity would be 86.4 gCO_2e/MJ, meaning the 6% reduction for the FQD target gave a target GHG intensity of 81.2 gCO_2e/MJ. The first of these involves increasing the FAME content of standard diesel fuel from the 5% baseline figure, the value specified in the RTFO, to 7%, the limit specified in EN590:2009. Because this affects mainstream fuel and is within existing fuel specifications and vehicle capabilities, it is labelled "Mainstream 0".

Key findings

- The overarching conclusion is that the UK needs to use a multiplicity of contributing measures to achieve the RED and FQD targets by 2020 rather than a straightforward approach focused on the high usage of a single type of biofuel.
- Meeting the 10% RED target is easier than meeting the 6% FQD target. Typically a group of options having a 10% biofuel energy content (i.e. meeting the RED target) generates around a

5% reduction in GHG intensity (i.e. goes five sixths of the way towards meeting the FQD target).

- Using only first generation biofuels (FAME, bioethanol and biomethane), the study has shown that only scenarios that combine most of the options available meet the 10% RED level; but none of these meet the FQD 6% reduction in GHG intensity.

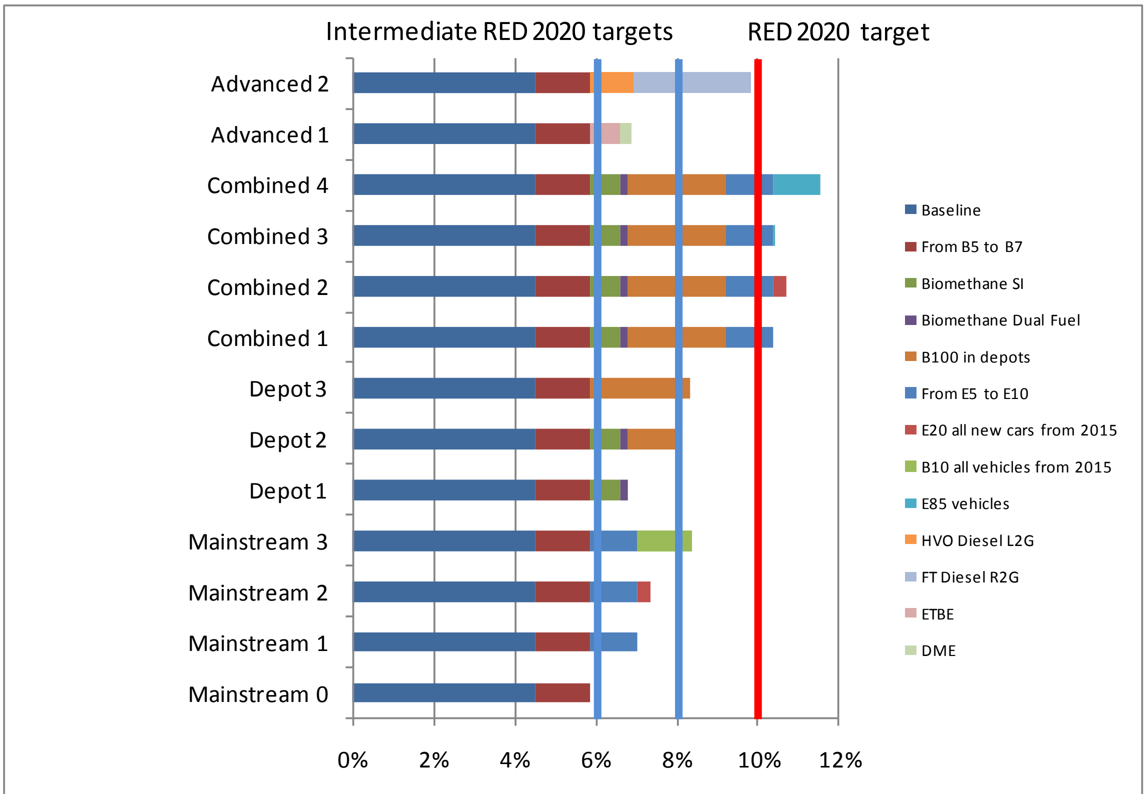
- The 6% FQD target is met when a multiplicity of options utilising first and second generation biofuels are combined.

- The analyses reported above were conducted on the basis of only limited improvements in life-cycle GHG emissions for biofuels between now and 2020 and no improvements in the life-cycle emissions associated with fossil fuel production. Either sufficient reductions in the GHG intensity of fossil fuels through improvements in production and refining processes, or reductions in the GHG emissions from the production of FAME and bioethanol, could be combined with a multiplicity of options utilising first generation biofuels to meet both the RED and FQD targets.

Key findings for deployment scenarios

A brief description of the options that comprise the thirteen scenarios studied, their contributions to the RED and FQD targets, and their cost effectiveness (expressed both in £/GJ bioenergy, and £/tonne CO_2e abated) are given in the table overleaf.

The figure below shows these graphically, illustrating how the various options, listed in the legend on the right hand side of the figure, combine to generate the RED savings tabulated overleaf.



Contribution of options comprising scenarios to meeting the RED target in 2020

Summary of scenarios considered and headline figures

Scenario name	Detail	Contribution to RED (percentage points)	Contribution to FQD (percentage points)	Cost Effectiveness £/GJ	Cost Effectiveness (£/tonne CO_{2e} abated)
Mainstream 0	Baseline (E5 +B5) All vehicles begin using B7	5.87%	2.80%	£7/GJ	£131/tCO_2e
Mainstream 1	Baseline (E5 +B5) All vehicles using B7/E10	7.02%	3.40%	£5/GJ	£101/tCO_2e
Mainstream 2	Baseline (E5 +B5) All vehicles using B7/E10 All new cars to market are E20 compliant by 2015; in addition E15 available at 30% of pumps in 2020 (i.e. Replaces premium)	7.36%	3.58%	£5/GJ	£105/tCO_2e
Mainstream 3	Baseline (E5 +B5) All vehicles using B7/E10 All new diesel vehicles begin using B10 from 2015	8.33%	4.01%	£6/GJ	£109/tCO_2e
Depot 1	Baseline (E5 +B5) All vehicles begin using B7 By 2015, 2% of new LCV and coaches in captive fleets, and 4% of rigid trucks and buses, are SI vehicles with 95% of their fuel coming from biomethane. And by 2015, 2% of new articulated trucks in captive fleets are dual fuel using 65% biomethane, 35% diesel.	6.78%	3.18%	£6/GJ	£113/tCO_2e
Depot 2	Baseline (E5 +B5) All vehicles begin using B7 Biomethane options as for Depot 1 B100 for 20% of depot fuelled vehicles that are B100 compatible	8.00%	3.75%	£7/GJ	£121/tCO_2e
Depot 3	Baseline (E5 +B5) All vehicles begin using B7 B100 for 40% depot fuelled vehicles that are B100 compatible	8.30%	3.92%	£7/GJ	£132/tCO_2e
Combined 1	All four options in Depot 4 and Both options in Mainstream 1:	10.35%	4.91%	£6/GJ	£114/tCO_2e
Combined 2	All four options in Depot 4 and Both options in Mainstream 1: Plus: E20 in all new cars by 2015	10.69%	5.09%	£6/GJ	£114/tCO_2e
Combined 3	All four options in Depot 4 and Both options in Mainstream 1: Plus: E85 in 5% of new cars by 2020	10.41%	4.94%	£6/GJ	£114/tCO_2e
Combined 4	All four options in Depot 4 and Both options in Mainstream 1: Plus: E85 in all new cars by 2020	11.49%	5.51%	£6/GJ	£120/tCO_2e
Advanced 1	Both options in Depot 1 and Maximum amount of ETBE and DME available used	7.49%	3.36%	£4/GJ	£96/tCO_2e
Advanced 2	Both options in Depot 1 and Maximum amount of FT diesel, from both L2G and R2G scenarios Plus maximum amount of HVO diesel (L2G) used	9.84%	4.27%	£6/GJ	£100/tCO_2e

Key findings on barriers from a biofuel and vehicle capability perspectives

It is clear from the analysis that the nature of the barriers to deployment vary depending on the type of biofuel. These can be sub-divided into the first generation fuels (FAME, bioethanol and biomethane) and advanced biofuels. The size of the contribution from the first generation fuels follows the order above, with FAME likely to contribute the most, and biomethane the least.

FAME

- The introduction of sustainability criteria as specified in the Renewable Energy Directive will reduce the amount of FAME available, most notably from oil seed rape and soya, but also from palm.
- The central supply scenario indicates that around 99 PJ of FAME will be available for road transport use in 2020. (Corresponding figures for the high and low supply scenarios are 107 PJ and 46 PJ respectively.)
- Around 70% of this would be used if standard diesel became the B7 biodiesel blend for the central supply scenario. (This figure would be 65% for the high supply scenario, but for the low supply scenario B7 would use more FAME than would be available, by 150%).
- These restrictions on the availability of FAME mean that choices need to be made, e.g. between providing high-strength FAME blends for depot fuelled vehicles, increasing the standard diesel grade above a 7% blend (B7), or using vegetable oil feedstocks to make hydrogenated vegetable oil (HVO) diesel in preference to FAME biodiesel.
- The recommended option from this analysis is to use the any remaining FAME supply in depot fuelled vehicles capable of using B100 fuel (for the central scenario this would result in 40% of the available vehicles using B100).

Bioethanol

- The potential future supply of bioethanol exceeds the projected consumption that would occur if the standard petrol/ethanol blend was E10. Indeed, this would only consume around 32% of the available bioethanol for the central supply scenario. (This figure would be 31% for the high supply scenario, but for the low supply scenario E10 would use more bioethanol than would be available, by a factor of around two.)
- To increase consumption above this using E20 or E85 blends would require new vehicles (not currently in the fleet) and the options investigated contribute only little additional consumption by 2020.
- One reason for this small impact is that it will take time for vehicles capable of using higher bioethanol blend strengths to become a marked proportion of the fleet.
- The recommended option is to encourage accelerated uptake of flex-fuel (E85 capable) vehicles because some vehicles are already available thereby making a larger impact possible by 2020 (relative to options using E15 or E20 blends), and this is the third most cost effective way of using bioethanol, and could become an important biofuel use beyond 2020.
- In conjunction with the need to develop the vehicle capability, which is a significant challenge for vehicle manufacturers, these vehicles would also require the widespread availability of two petrol grades by 2020.

Biomethane

- Biomethane occupies an interesting position: because of its current low usage and because it can only be used in specially-adapted vehicles, its use is vehicle constrained.
- The scenarios investigated (which included both dedicated spark ignition biomethane vehicles, and dual fuelled vehicles) contribute only little by 2020, but could be vital in decarbonising road transport beyond this date.

- For gaseous fuels such as biomethane, and also the advanced biofuel DME, there are likely to be operational barriers to uptake, including resistance to alternative fuel technologies.
- Notwithstanding, it is recommended that the use of biomethane in depot fuelled vehicles is encouraged.

Advanced biofuels

- Drop-in replacement diesels (e.g. HVO diesel and Fischer-Tropsch (FT) diesel) have the advantage of being totally compatible with current vehicles.
- FT diesel has the potential to provide around a sixth of the FQD target, with this being new diesel, i.e. not competing with other feedstocks. However, for this fuel the availability of sufficient production capacity is also likely to be a barrier.
- The restrictions on the availability of vegetable oils, and therefore on FAME supply, means that using vegetable oil feedstocks to make HVO diesel would reduce the volume of FAME biodiesel available. Additionally, the availability of sufficient production capacity may prove a barrier.
- Other advanced fuels such as bio-ETBE and biobutanol are significantly more compatble with current vehicles than bioethanol. However, the future use of all of these fuels is anticipated to be supply-limited between now and 2020, due to production capacity constraints.

Key findings on barriers from a biofuel and vehicle capability perspectives

Whilst collecting information on how the further deployment of biofuels could contribute to meeting the RED and FQD targets for road transport in 2020, the study team also found other barriers to using higher percentage biofuel blends. Some of these barriers are technological challenges, whilst others are more focussed on approaches and policies. These barriers also need to be considered in order for the UK to successfully meet the targets. The key findings are as follows:

- The users of biofuels are not willing to pay a significant premium for these types of fuels, i.e. the economics of using higher biofuel blends needs to commercially attractive.
- Vehicle manufacturers require a long term plan/policy that is adhered to because of the time required to design, develop and introduce a new vehicle (or engine) to the market and the duration of the production run that is required to make the whole cycle economically viable.
- Because vehicles are manufactured for European and global markets there should be a harmonised approach across Europe rather than bespoke country-specific biofuel strategies.
- Each vehicle’s development cycle requires significant engineering input, and so vehicle manufacturers do not want gradual increases in permitted biofuel blend concentration limits. Bold, but technologically viable, step changes that last for at least a decade would be preferred.
- In addition to being able to overcome the economic and engineering challenges, increased biofuel usage also requires users to be able to buy the fuel, i.e. the biofuel distribution and supply infrastructure needs to be in place.

Conclusions

The findings from this study indicate that sustainable biofuels potentially have a very important future role to play in decarbonising the transport sector between now and 2020 and that they can be used to control GHG emissions from road transport. First generation biofuels (especially FAME, bioethanol and, to a lesser extent, biomethane) will be key in meeting the 2020 RED 10% renewable energy target, and the FQD 6% reductions in GHG emissions (relative to 2010) target. However, the detailed analysis indicates that whilst these first generation biofuels could meet the RED target, they alone are unlikely to meet the FQD target in 2020: this will require further contributions from advanced biofuels, most probably bio-ETBE and FT diesel, or significant increases in the GHG emissions reductions from first generation biofuels.

Notwithstanding the findings from this study that both targets can be met, there are a number of barriers that need to be overcome before the predicted quantities of fuels can be delivered and used in road transport. It is anticipated that steps will be required to encourage the development of, and to accelerate the use of, biofuels in road transport.

The overarching conclusion is that both targets can be met, but will require the use of a multiplicity of contributing measures to achieve the RED and FQD targets by 2020 rather than a straightforward approach focused on the high usage of a single type of biofuel. It is recommended that the findings from this study should be used to inform the development of a UK strategy for meetings these 2020 targets.

Glossary

ACEA	The European Automobile Manufacturers Association
ATOC	Association of train operating companies
Bxx	Biodiesel blend containing xx% of biodiesel and (100-xx)% of fossil fuel derived diesel
CI	Compression ignition
DECC	Department for the Environment and Climate Change
DERV	Diesel engined road vehicle
DUKES	Digest of UK Energy Statistics
Exx	Bioethanol blend containing xx% of biodiesel and (100-xx)% of fossil fuel derived petrol
FAME	Fatty acid methyl ester
FT	Fischer Tropsch
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
GVW	Gross vehicle weight
HGV	heavy goods vehicle (one whose GVW is greater than 3.5 tonnes)
HVO	Hydrogenated vegetable oil
LCV	Light commercial vehicles (commonly called vans)
MAN	German commercial vehicle maker
NNFCC	National Non-Food Crop Centre
RED	Renewable energy directive (Directive 2009/28/EC)
RFA	Renewable Fuels Agency
RSSB	Rail Standards and Safety Board
RTFO	Renewable transport fuels obligation
SI	Spark ignition
TTW	Tank to wheel
UKPIA	UK Petroleum Industry Association
WTT	Well to tank
WTW	Well to wheel

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1 Introduction

The use of biofuels in the transport sector is an important part of the UK's plan to comply with the target in the Renewable Energy Directive (RED), requiring 15% of its total final energy demand to be met with energy from renewable sources by 2020. In particular the Directive includes a further sub-target for 10% of transport fuels (by energy content) to be delivered from renewable sources by 2020, and it is anticipated that this will be achieved mainly through the use of biofuels. Furthermore, the Fuel Quality Directive (FQD) requires a reduction in the GHG intensity of transport fuels, and it is anticipated that this reduction will be met through the increased use of biofuels and reduced venting and flaring from oil extraction. The Fuel Quality Directive specifies that the GHG intensity of transport fuels must decrease by a minimum of 6% by 2020 compared to 2010 levels.

First generation biofuels are currently limited to 7% blends for biodiesel and 5% blends for bioethanol in petrol (although for bioethanol a recent amendment to the FQD allows separate blends of up to 10%). Second generation / advanced biofuels offer greater potential for reducing GHG emissions, but would need to be on-stream in the near future in order to help achieve the RED and FQD targets by 2020.

The Department for Transport (DfT) has recognised the need to understand more about the potential ways in which biofuels might contribute to the targets in these two Directives, both in terms of potential contributions from specific options across road transport, and the relative cost effectiveness of these options.

This project was therefore commissioned to look into these issues, building on the substantial work undertaken in three related studies, known as the 'Biofuels Modes' projects.

Collectively, the four projects aim to provide an assessment of the possible contribution that could be made to meeting the UK's climate change targets and other policies, through increased uptake of bioenergy in the transport sector. This overall programme of work will be used to investigate if any modes of transport should be prioritised for deployment of biofuels, taking into account cost effectiveness considerations and the potential for maximising bioenergy deployment and GHG emissions savings.

The project is one of four interdependent projects commissioned by the DfT under a programme of work referred to as the Biofuels "Modes" projects. These projects are summarised in Table 1.1 below.

Table 1.1 Aims and content of the Biofuels 'Modes' programme

Details	Content	Relationship
Assessment of the existing UK infrastructure capacity and vehicle fleet capability for the use of biofuels (Modes Project 0). Carried out by AEA with support from Energy Crops Company	This work determined the current infrastructure and vehicle fleet capabilities in terms of biofuel compatibility. It provided DfT with an evidence based audit of the current situation regarding both the use of biofuels, and the current capability to use biofuels (i.e. a baseline position).	Provided baseline for Modes Project 2
Development of illustrative scenarios describing the quantity of different types of bioenergy potentially available to the transport sector in 2020, 2030 and 2050 (Modes Project 1). Carried out by E4tech with support from AEA	The project provided three **illustrative** scenarios describing the quantity of different types of bioenergy potentially available to the transport sector over time. It was not intended to provide a detailed forecast of the total amount of sustainably-sourced bioenergy that will be available to the transport sector. Rather, a set of illustrative but credible scenarios for the availability of sustainably-sourced bioenergy in the transport sector to 2020 and 2050.	Provided the feedstock supply scenarios used in Modes Projects 2 and 3

Details	Content	Relationship
Assessing cost-effectiveness scenarios for biofuel deployment options across the UK transport sector to 2020 and to 2050 (Modes Project 2) Carried out by AEA, with input from E4tech and FiveBarGate.	The overarching aim of this project was to inform Government analysis of the potential options for the cost-effective deployment of available sustainable bioenergy resources within the UK transport sector, in order to inform decisions on how to meet EU Climate Change and Renewable Energy goals for 2020 and 2050.	Contained the bulk of the programme effort – and included the development of the main cost-effectiveness model
Scenarios for the cost-effective deployment of biofuel in the UK road transport sector in 2020 (Modes Project 3) Carried out by AEA.	This project focussed specifically on the road transport sector, looking at deployment scenarios up to 2020. The DfT will use this work to help inform UK policy development in this area regarding: • The achievement of 2020 transport sector renewable energy targets under the Renewable Energy Directive (RED) • The target of a 6% reduction in greenhouse gas intensity of transport fuels under the amended Fuel Quality Directive Modes 3 develops detailed quantified options that illustrate how biofuels could be used cost-effectively to achieve 6%, 8%, and 10% biofuels use (by energy content) in the road transport sector by 2020; and 5%, 6% and 7% reductions in GHG intensity of transport fuels by 2020.	Builds on Modes Project 2, looking in more detail at the Road sector.

This project, known as 'Modes Project 3' focuses on the road transport sector in more detail, specifically looking at biofuel deployment scenarios up to 2020 in order to meet RED and FQD commitments.

1.1 Project aims and objectives

In order for the UK to comply with the 2020 targets sets out in the RED and FQD, the amount of biofuels used in the road transport sector needs to increase significantly between now and 2020.

The majority of current vehicles operating in the UK today are only compatible with biofuel blend strengths of E10 for petrol-engined vehicles and B7 for diesel-engined vehicles. Related research carried out by AEA for 'Modes Project 0' *(Assessment of the existing UK infrastructure capacity and vehicle fleet capability for the use of biofuels),* indicated that around 84% of the existing UK petrol car fleet and petrol van fleet is able to run on a maximum blend strength of E10 (100% can run on E5), whilst 100% of existing UK diesel road transport fleet (cars, vans, HGVs, buses and coaches) is able to run on B7 biodiesel.

The current capability of the fleet means that it will not be possible to meet the RED, and possibly the FQD targets, without the introduction of new vehicles that are capable of using higher strength biofuel blends beyond E10 and/or B7. The aim of this study was to investigate possible options for achieving various levels of biofuels deployment (6%, 8%, and 10% energy content in transport fuels) and various levels of GHG savings (5%, 6%, and 7% reductions in GHG intensity against 2010 baseline levels) by 2020, with a focus on identifying the most cost effective options.

While cost effectiveness is an important part of the overall objectives, understanding the extent to which potential deployment options can take the UK towards the RED and FQD targets (and the potential balance between the two) differentiates this study from Modes 2.

The project builds on work carried out in the Modes 0, Modes 1, and Modes 2 projects, and analysis has been carried out to quantify the cost per tonne of CO_2 abated and the cost per GJ of biofuel deployed for the various options. As part of the Modes 2 study, a comprehensive biofuels cost effectiveness model was developed in order to support the research programme. For the purposes of this separate study on the RED and FQD targets, a modified version of this cost effectiveness model was developed and was used to support the analysis required for this project.

1.2 Structure of this report

As already noted, this project has built on the outputs of the three other related Modes projects. Between them, these projects have involved the consideration of a large amount of data and information sources. The reports for each of these projects summarise the various research streams undertaken, the construction of the cost effectiveness model, and the key data inputs and assumptions involved. This report therefore avoids duplication of elements contained in the other projects, and so summarises key points or refers readers across to the other projects where appropriate.

This report has been designed to enable readers to quickly gain a high-level appreciation of the process that the project team went through in carrying out the research, and to present the findings and discussion of the key drivers in the most straightforward manner. Readers looking to gain a deeper understanding of the underlying data, assumptions and approaches that have informed this work, are referred to the final reports for the other Modes studies.

With these requirements in mind, the report is structured as follows:

Section 2 – Overview of approach

- providing contextual understanding in the context of the other studies, especially the Modes 2 study;
- highlighting the modifications undertaken to develop the Modes 3 version of the biofuels cost effectiveness model;
- specific data considerations;
- the role industry stakeholders played in the study; and
- the approach taken to identifying possible deployment options.

Section 3 – Results and discussion

- overview of the key parameters used in the cost effectiveness modelling;
- the deployment options and scenarios considered;
- the initial findings from the work; and
- assessment of the sensitivity of results to key input parameters such as biofuel prices and Greenhouse Gas (GHG) intensity of fuels.

Section 4 – Conclusions and recommendations

The deeper consideration of some of the issues considered in the course of the work – for example, the possible constraints on deployment options due to supply constraints, are summarised in the supporting Appendices.

2 Overview of Approach

The project required the following key steps:

- Review of Modes 2 biofuel deployment options for road transport;
- Refinement of these options to fit with Modes 3 objectives;
- Modification of the cost-effectiveness model to meet Modes 3 objectives;
- Refinements to the model and underpinning assumptions;
- Development of final scenarios;
- Analysis of findings and conclusions;

A significant amount of the work needed to develop the modelling framework was completed in the Modes Project 2. This section will therefore provide information on the additional tasks needed to refine the Modes 2 research in order to deliver the Modes 3 outcomes. For detail of the original work, please refer to the Modes 2 final report. This section outlines the approach taken in completing the additional tasks for Modes 3 only. Additional detail is provided in supporting appendices where necessary.

2.1 Additional data sources feeding into this study

Several additional sources were consulted to inform the work in Modes 3:

- Further direct discussions with vehicle manufacturers and industry groups to inform the refinement of deployment options;
- The RED and the FQD policy documents;
- Relevant fuel standards for road transport, which are:
  - Road diesel – EN590 for bulk, and EN14214 for FAME biofuel
  - Road petrol – EN228 for bulk and EN15736 for ethanol

Where relevant to the discussion, these sources are referred to as footnotes throughout the report.

2.2 Scope

This project focused purely on biofuel deployment within the road transport sector in the period between 2011 and 2020. The vehicle types included in the analysis were as follows:

- Passenger cars
- Light Commercial Vehicles
- Heavy Goods Vehicles
- Passenger Carrying Vehicles (Buses and Coaches)

The following fuels were considered (where they are sustainable[1] and appropriate within the 2020 timeframe):

[1] Sustainable as defined in Renewable Energy Directive.

- Single counted under RED[2]
  - first generation bioethanol and biodiesel (including high blends), excluding biodiesel from waste and residues;
  - hydrogenated vegetable oil;
  - dimethyl ether (DME, 1,2-dimethoxyethane);
- Double counted under RED (single counted under the FQD)
  - first generation biodiesel (including high blends) from waste and residues;
  - biogas (including biomethane);
  - lignocellulosic ethanol;
  - synthetic diesel / biomass-to-liquids;
  - upgraded pyrolysis oil

As with the Modes 2 project, the DfT required that work should be undertaken to assess the monetised costs and benefits of deploying biofuels across the road transport sector – critical in order to produce an assessment of cost effectiveness. In the main, this work was undertaken during the development of the cost effectiveness model produced in Modes 2. There was, however, the need to reconfirm certain data points and assumptions around the introduction of specific types of biofuels. In most cases this amounted to further one-to-one discussions with contacts at vehicle manufacturers and industry bodies, but further information was also gathered through the stakeholder workshop and a presentation to the SMMT working group.

The specification for the project also included a task (as in Modes 2) to identify step changes in the level of bioenergy take-up for each road vehicle type that significantly alters the assessment of cost effectiveness. However, the contribution of infrastructure costs to the overall cost effectiveness of biofuel deployment options was found to be low in the Modes 2 project, and it was assumed that marginal capital and operating costs for vehicles compatible with high strength biofuel blends do not change between now and 2020. These two factors mean that there are unlikely to be an step changes that significantly influence the results of the analysis.

2.3 Stakeholder consultation

As with the Modes 0, Modes 1, and Modes 2 projects, a key part of this study has been consultation with stakeholders. Discussions with industry, NGO, and governmental stakeholders have again been critical in ensuring that the best available data and information was captured. Direct one-to-one discussions were held where necessary. A full stakeholder list is given in Appendix 1.

The stakeholder group, who had been contacted as part of the earlier studies, was sent some outline information on the Modes 3 project shortly after the project began. This was in advance of the second workshop for the studies, where an overview of the Modes 3 work was presented as it stood at that time (February 2011).

Feedback collected from stakeholders in relation to presentations given on the modelling, and on the initial findings of the Modes 3 work, was useful in shaping the Modes 3 approach. When presented with the early findings of Modes 3, the stakeholder group made particular comments regarding the potential usefulness of the work.

AEA was also invited to present the key findings and assumptions from the study at the SMMT's 'Light Duty Vehicle Powertrain Working Group'. This included vehicle manufacturers and Tier 1 component suppliers, and provided further input on the options and timeframes being considered.

2.4 Key differences to the Modes 2 study

As for the Modes 2 project, this study used a range of complex data sources to build a common analytical framework that allowed assessments of cost effectiveness to be carried out. Specifically, the requirement was to assess the cost effectiveness (in terms of costs per tonne of CO_2e saved and costs per GJ of bioenergy used) of deploying different forms of bioenergy in each mode of transport.

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[2] Pure plant oil was scoped out as this is not a fuel that can be routinely used in road vehicles, it needs to be processed to make FAME or HVO

The spreadsheet model built for the Modes 2 project was developed as a supporting analytical tool to complement the detailed qualitative and quantitative analysis undertaken throughout this project. In particular, the spreadsheet model was designed to allow the results of the other tasks to be presented in such a way as to make the assessment of the most cost-effective split between modes flexible to a change in the input assumptions. The model includes three main modules that together can be used to define supply and deployment options for the use of biofuels in the transport sector. The three main modules are as follows:

- Fuel supply module;
- Fuel allocation module;
- Fuel deployment, vehicle stock and cost effectiveness module.

The detailed functionality of the model is described in the Modes 2 summary report. For the Modes 3 project, the model required some important modifications, to enable it to assess deployment options in the context of 2020 RED and FQD targets. These modifications are summarised in Table 2.1 below.

Table 2.1 Modifications to the Modes 2 model for Modes 3

Aspect of model	Modes 2 model	Modes 3 model
Scope	Road, rail, sea and air modes	Road transport only – dissagregated into the different the different vehicles types (cars, vans, rigid and articulated trucks, buses and coaches), and according to depot or forecourt fuelling.
Timeframe	2010 – 2050 in 5 year intervals	2010 – 2020 in one year intervals
Key focus	Cost effectiveness of scenarios involving different transport modes	Predictions of scenario performance in 2020 against: • 10% energy targets under RED • 6% GHG Intensity target under FQD
Additional functionality	N/A	Double counting of biofuels from waste streams, residues, non-food cellulosic and lignocellulosic material

The two key changes required were to the time intervals considered, and the need to reflect the double counting of certain types of biofuels.

The Modes 2 model works on the basis of five-year intervals between data points, but the need in the Modes 3 project for a greater level of resolution to cover the shorter study period meant that annual data points were needed. This was particularly important in order to reflect the change to sustainability criteria coming in 2017.

A feature of the RED is to encourage the use of biofuels which give additional benefits, including the benefits of diversification offered by biofuels made from waste, residues, non-food cellulosic material, ligno-cellulosic material and algae. To support this, the contribution from biofuels produced from these renewable sources is double counted relative to the contribution from other biofuels.[3]

2.5 Options and scenarios to illustrate biofuel deployment to achieve RED/FQD targets

Following discussions with the DfT, it was agreed that individual options would be put together under four broad scenarios, with a number of variations to each scenario investigated:

[3] See Article 21 (2) of Directive 2009/28/EC, the Renewable Energy Directive

- **Scenario 1 "Depots":** The biofuels capability of the mainstream road transport fleet does not change, but there is selective use of high-strength biofuel blends by captive vehicle fleets;
- **Scenario 2 "Mainstream":** The biofuels capability of all new mainstream vehicles changes;
- **Scenario 3 "Combined":** A combination of Scenarios 1 and 2, but also including the introduction of E85 for flex-fuel cars;
- **Scenario 4 "Advanced":** Protection grades for petrol and diesel remain at E5 and B7 but are supplemented by the use of drop-in fuels.

Possible options for increasing the deployment of biofuels in the UK road transport sector by 2020 were considered in the context of these scenarios. This identified a list of 23 (plus the current RTFO baseline) possible options that would be compatible with the 2020 road transport timeframe for modelling.

The cost effectiveness model was then used to determine:

- The potential contribution each could make towards the RED and FQD targets
- The cost effectiveness of each individual option

Under each of the four scenarios it became clear that there were several combinations of options that could be assessed to determine their contributions to meeting the targets, in order to determine and present the most cost effective ones.

The formation of these into sub-scenarios was undertaken, based on an assessment of progress towards the 6%, 8% and 10% RED target levels, and 5%, 6% and 7% FQD target levels. It is important to note that some combinations are mutually exclusive, and also that some combinations will be supply constrained. For example, the option under the depot fuelled scenario, involving the use of B100 in vehicles with the capability to use this type of fuel is limited by the supply of FAME rather than the availability of suitable vehicles.

2.6 Sensitivity analysis

Sensitivity analysis was carried out to understand the extent to which the key drivers of cost effectiveness and supply affect the results when assumptions are altered. The following aspects were identified as important drivers of the final results:

- Price of biofuels;
- Vehicle costs;
- GHG intensity of fuels;
- The potential availability of advanced (2G) biofuels.

The Modes 2 project showed that fuel distribution and supply infrastructure costs, while important at the implementation level, are a relatively small proportion of the overall costs of any biofuel deployment scenario. Infrastructure costs were therefore not considered in this work.

3 Results and Discussion

3.1 Consideration of the potentially available biofuels in relation to RED and FQD targets

An initial piece of analysis concerned the consideration of the potential availability of biofuels in relation to the RED and FQD targets. A starting point for this research was the Modes Project 1 assessment of the availability of bioenergy for the UK transport sector. This provided three **illustrative** scenarios (high, central (or medium) and low) for the potential availability of feedstocks that can be used to produce biofuels. For Second Generation options, two availability scenarios were constructed – a 'Low Second Generation' deployment (L2G) case, and a 'Rapid Second Generation' deployment (R2G) case. These central feedstock supply scenarios were combined with the calculations used in the Modes 2 model to estimate the quantities of each type of fuel likely to be available to the UK transport sector between 2011 and 2020.

When calculating the contribution towards meeting the RED's target the Directive specifies that the contribution from the fuels derived from some feedstocks is double counted. The fuels that have some component of double counting in 2020 are FAME and HVO (because of the tallow and used cooking oil sources), biomethane, FT diesel and DME. The proportion of double counting varies year by year within the model as the relative contributions from different feedstocks vary. For 2020 the amount of doubly counted biofuel (as a percentage of the biofuel supplied) is as summarised below.

FAME, HVO	12% of biofuel is doubly counted[4]
Biomethane and DME	100% of biofuel is doubly counted
FT diesel	100% of biofuel is doubly counted[5]

A full explanation of this process is contained in Appendix 2. The headline findings and their implications on the Scenario modelling for Modes 3 are as follows:

1. The potential supply of biofuels to the UK transport sector under the central supply scenario is sufficient to meet the 2020 RED target, and the FQD target. However, meeting the FQD target will be more challenging than meeting the RED target. (This does not include any further restriction in supply that may be introduced to combat the risk of Indirect Land Use Change[6].)
2. FAME biodiesel and bioethanol are anticipated to be the most significant types of biofuels deployed in the UK road transport sector. However, the supply of neither is sufficient to meet the RED target (nor the FQD target) on its own.
3. Meeting both the RED and FQD targets will require combinations of biofuels, e.g. FAME + bioethanol + 2-G drop-in fuels + others.
4. Biomethane appears very attractive in terms of its potential contribution towards meeting the RED target (due in part to its contribution counting as double since the feedstocks used to produce this fuel originate from waste residues, and in part from the large potential quantity available), but its current use in road transport is minimal.
5. Whilst the RED target is clearly defined, the FQD target will not be fully quantified until the specification of the baseline GHG intensity value against which reductions in greenhouse gas emissions are measured is confirmed by the European Commission. This study has assumed the 6% reduction is against a baseline figure of 86.4 gCO_2e/MJ, i.e. the target is 81.2 gCO_2e/MJ by 2020. Uncertainties mean that the baseline could fall anywhere in the range between 86.4 gCO_2e/MJ and 83.8 gCO_2e/MJ (the latter being the default figure quoted in the Fuel Quality Directive). These figures are discussed further in Appendix 2 (section entitled: Contribution of the potentially available biofuels to meeting FQD targets) where their origins, and the basis for selecting the assumed figure are detailed. Both targets could be affected if an amendment to address indirect land use change is proposed by the Commission[6].

[4] FAME produced from Used Cooking Oil and Tallow are double counted
[5] FT diesel is produced from Wood Energy Crops (93%) and Municipal Waste (7%), both sources are double counted
[6] At time of writing the European Commission is considering options to address the Indirect Land Use Change impacts of biofuels and is expected to report on whether further action is needed, with Impact Assessments, by July 2011. If the RED and FQD are sustainability standards, or emissions calculation methodology, are amended this could change the volumes of biofuel that meet sustainability standards, or the reported emissions savings from these biofuels.

3.2 Assessment of individual options

The contribution towards meeting RED and FQD targets, and the cost effectiveness of the individual options, has been evaluated using the Modes 3 cost effectiveness model. Cost effectiveness was calculated relative to a baseline where the standard fuels comprise B5 and E5 blends. The options (summarised in Table 3.1 below) investigated changing FAME, bioethanol or biomethane blends, together (as appropriate) with changing the biofuel capability of a proportion, or all, new vehicles. In addition, options associated with the supply of advanced biofuels were also assessed. The main constraints associated with these options are also shown.

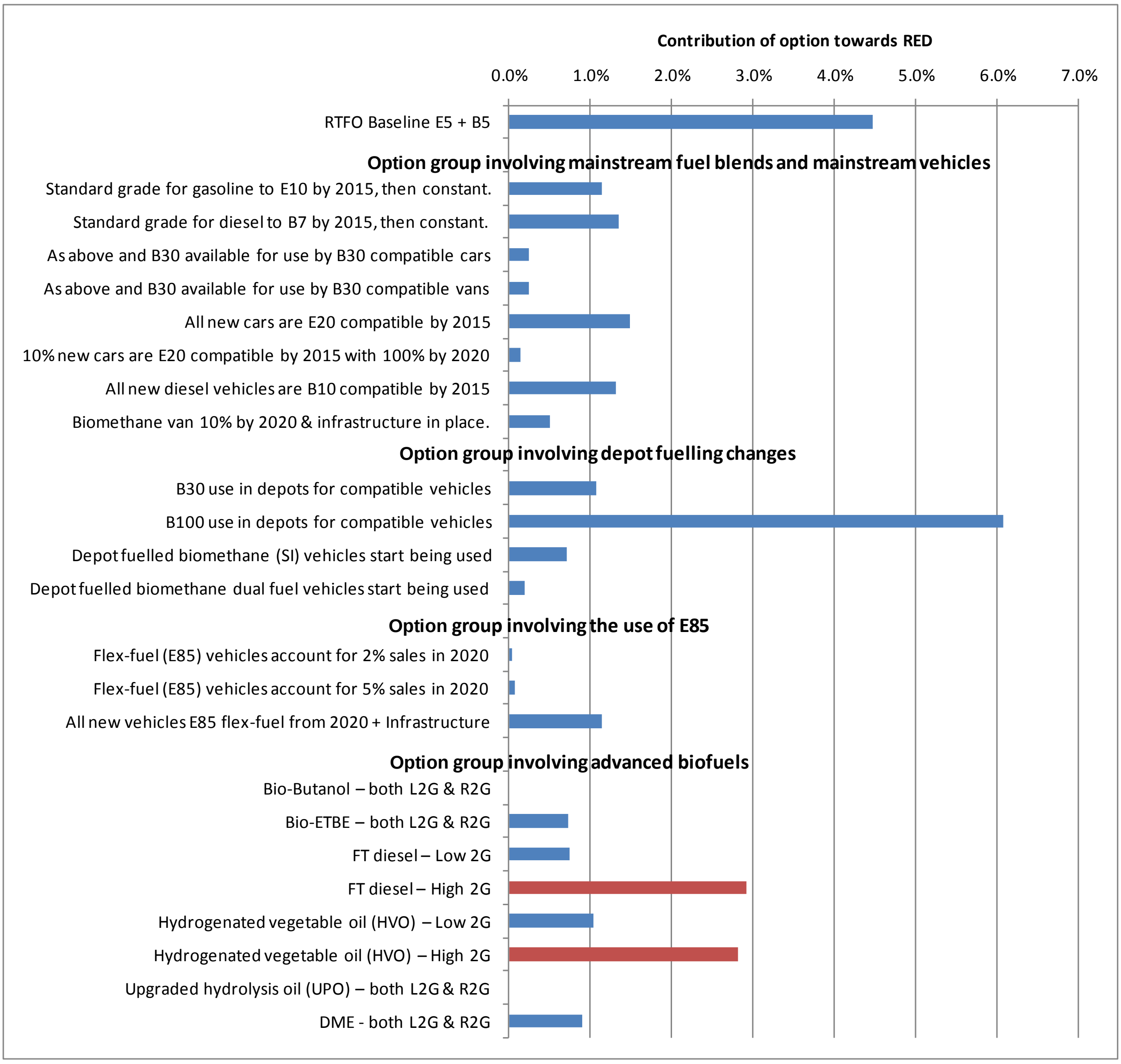
Table 3.1 Options and scenarios modelled in the Modes 3 study

Scenario type	Options	Main constraint
Mainstream	Changing mainstream fuel to E10 by 2015	None
	Changing mainstream fuel to B7 by 2015	None
	Use of B30 via forecourts for capable cars	Relatively low numbers of cars which can use B30
	Use of B30 via forecourts for capable vans	Relatively low numbers of vans which can use B30
	Requiring all new petrol cars to be E20 compatible by 2015	Currently no such vehicles, no E20 blend infrastructure
	Requiring 10% of new petrol cars to be E20 compatible by 2015	
	Requiring all diesel vehicles to be B10 compatible by 2015	Currently many vehicles, whilst B7 compatible, are not B10 compatible
	10% of all new vans run on biomethane (SI) by 2020	Currently very few vehicles available, no biomethane infrastructure.
Depot	B30 FAME blend available for 100% of depot fuelled vehicles that can use this blend	Potential operator risk aversion and lack of interest in changing fuel in the absence of compelling commercial reasons (linked to concerns about longevity of policy)
	B100 FAME blend available for 40% of depot fuelled vehicles that can use this blend	FAME availability Potential operator risk aversion and lack of interest in changing fuel in the absence of compelling commercial reasons (linked to concerns about longevity of policy)
	Depot fuelled biomethane SI vans, rigid trucks, buses and coaches start being used	Number of vehicles capable of using biomethane
	Depot fuelled biomethane/diesel dual fuelled articulated trucks start being used	Number of vehicles capable of using biomethane
Combined And E85 options	2% new vehicle sales are flex-fuel (E85) capable vehicles by 2020.	Currently only a few flex-fuel vehicles models available, very limited/negligible E85 infra-structure
	5% new vehicle sales are flex-fuel (E85) capable vehicles by 2020.	
	All new vehicle sales are flex-fuel (E85) capable vehicles by 2020.	
Advanced fuels	Biobutanol	Negligible fuel available by 2020
	BioETBE	Lack of both vehicle development/assessment and infrastructure
	FT Diesel (a drop-in diesel) both low and rapid-2G	Production facility capacity and

	scenarios	technological maturity
	Hydrogenated vegetable oil (HVO) (a drop-in diesel) both low and rapid-2G scenarios	Feedstock availability (and hydrogenation plant capacity)
	Upgraded Pyrolysis Oil	Negligible fuel available by 2020
	Bio-DME	Lack of both vehicle development/assessment and infrastructure

Figures 3.1 and 3.2 show the contributions of each option toward the RED and FQD targets, respectively. The performance of the grouped scenarios is considered in Section 3.3. The individual cost effectiveness results for the options considered are tabulated in Appendix 4. It is important to note that these options are shown in isolation of each other. For B100 use in depots for compatible vehicles, this assumes a 100% of the compatible vehicles use B100. However, when this option is combined with options, fuel supply becomes a constraint. This reduces the contribution from this option in the scenarios, and is discussed further under the scenarios analysis in Section 3.3.

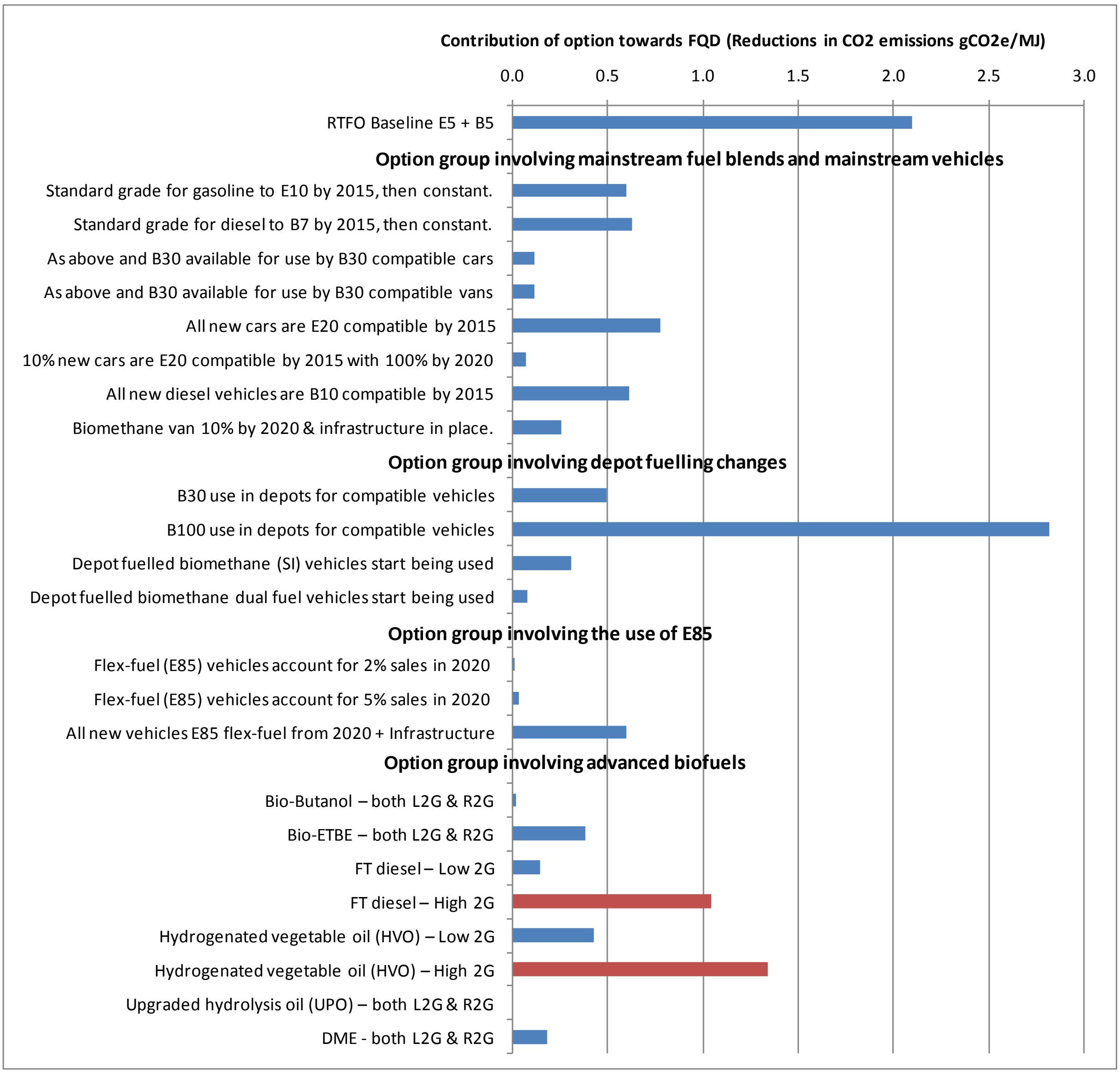
Figure 3.1 Data for each individual option discussed towards meeting the 10% RED target[7]



[7] Note how the individual options shown in this figure may be larger than in the scenarios. This arises because of additional fuel supply constraints which occur when combining some scenarios. The options affected are B100 use in depots for compatible vehicles, and HVO options where the supply of sustainable vegetable oil limits the total availability of FAME and HVO.

In both Figures 3.1 and 3.2, the blue bars were calculated using the central fuel supply scenario, and the low 2G fuel supply scenario for advanced biofuels. The red bars were calculated again using the central fuel supply scenario, but the rapid 2G fuel supply scenario for advanced biofuels.

Figure 3.2 Data for each individual option towards meeting the FQD target (which requires a reduction of 6% (5.18 g CO_2e/MJ) relative to the GHG intensity of the actual fuel mix used in 2010 in the EU).



3.2.1 Options within the 'Mainstream' scenarios

These options consider the impact of changing the standard fuel grades, whereby the biofuel content of petrol and/or diesel is increased above 5%. These fuels are assumed to be supplied through both depots and forecourts.

Main findings

Increasing the bioethanol content of standard grade fuel to 10% (E10) would consume around a further 17% of the anticipated bioethanol available, over and above the 17% of bioethanol supply used to produce E5. (For the central supply scenario this would leave 72 PJ for other options, and for the high supply scenario it would leave 73 PJ for other options. However, for the low supply scenario there would only be sufficient bioethanol for standard grade petrol fuel to contain 4.3% bioethanol, see Table A2.1 of Appendix 2.) The marginal cost effectiveness for going from E5 to E10 would be

£73/tonne of CO_2e abated and £4/GJ bioenergy deployed. The costs of increasing the bioethanol blend strength to 10% would mainly be due to the difference in price between bioethanol and petrol rather than vehicle-related costs, as the vast majority of new vehicles are already E10 compatible.

Similarly, increasing the FAME content of the standard grade diesel to B7 by 2015 is a relatively cost effective option (compared to other FAME options), which could be implemented within the current fuel specification and vehicle capability.

It should be noted that some light duty vehicles are already B30 compatible. Options for supplying B30 to these existing vehicles were considered. The analysis indicated that these vehicles would not use a significant amount of B30, and this option would be a relatively expensive means of using some of the limited amount of FAME available. (Cost effectiveness was £188/tonne CO_2e abated and £10/GJ bioenergy deployed for B30 cars, and £209/tonne CO_2e abated and £11/GJ bioenergy deployed for B30 vans, relative to around £140/tonne CO_2e abated and £7/GJ bioenergy deployed for B100 depot fuelled vehicles, see Table A4.3 in Appendix 4.) The reasons for this poorer cost effectiveness is the relatively large investment required in establishing a network of B30 infra-structure, serving only a small fraction of the fleet, relative to the more focussed investment in depots where a higher proportion of the fleet can use the high biofuel blend. For this reason, these options were not built in to the scenarios considered in section 3.3.

The two options considered that use E20 also perform well in terms of cost-effectiveness. The first option involves an ambitious change to all petrol vehicles being E20 compatible by 2015, whereas the second option assumes that all petrol vehicles become E20 compatible by 2020 (ramping up from 10% in 2015). This is likely to be a more realistic option, but would produce a lower progress towards the RED target – around 0.1% bioenergy deployment compared to around 1.5% deployment under the more ambitious option. In practice these options would also require changing the current fuel distribution and supply infrastructure to make E20 available for those vehicles that can use it. The cost effectiveness of this latter option was £84/tonne CO_2e abated and £4/GJ of bioenergy deployed.

A final ambitious option investigated the contribution towards the RED and FQD targets if sales of vans that can use biomethane reached 10% by 2020. The maximum contribution that these vehicles could make towards the RED and FQD targets would occur if the vehicles were fuelled solely using biomethane. In this scenario, the additional vehicle costs over and above standard diesel vehicles diminish the cost effectiveness of this option, though it still compares favourably to all FAME options, including increasing the standard blend from B5 to B7, and the use of B100 blend in depots. (A key reason for this is the lower price for biomethane, at around 72% that of FAME, offsetting higher capital investment costs). In practice, such an increase in (bio)methane compatible vans is most likely to be accompanied by fuelling from the natural gas grid. Currently, this would be fossil fuel, not biofuel, although by 2020 the proportion of biomethane will increase, it is unlikely to exceed a few percent of total gas supply. This reduces the potential contribution this ambitious option would be able to deliver by a further 90%. Another challenge is the provision of the necessary fuel supply infrastructure, which would be more challenging than introducing a higher strength ethanol or biodiesel blend, due to the requirements of dispensing gaseous fuels. However, if these barriers could be overcome, the model shows that this could make a valuable 0.5% contribution towards meeting the RED target.

3.2.2 Options within the 'Depot' scenarios

From the apportioning of vehicle fuel supplied via depots and forecourts, the opportunities for the use of bioethanol through depots is judged to be small, and has not been considered further (i.e. the proportion of petrol cars that refuel at on-site depots is very small). Rather, it is options involving FAME biodiesel blends and biomethane that are deemed to be feasible deployment options at depots.

The standard grade presumed for diesel vehicles was B5 (this is the baseline, business as usual scenario which meets the RTFO requirement of 5% biofuel content, by volume, by obligated suppliers, and assuming this is split equally between petrol and diesel fuel streams).

As part of this study, further work was undertaken to gain a better understanding of the relative proportions of vehicles fuelled at depots and on forecourts. This is summarised in Appendix 3.

Main findings

Increasing the FAME content of standard grade diesel fuel to 7% (B7) by volume will consume around 70% of the anticipated FAME available in the central supply scenario, leaving around 34 PJ for other options. (The high supply scenario would leave 42 PJ for other options, whilst in the low supply scenario there would only be sufficient sustainable vegetable oil for standard grade diesel fuel to contain 5.0% FAME, see Table A2.1 of Appendix 2.) The other options considered involve either using B30 or B100 blends for depot fuelled (captive) fleets. These would consume the remaining quantities of FAME. It is appreciated that there are currently vehicles in the fleet that can use these blends and they build on this existing capability, and so they do not involve new vehicle models becoming available.

In terms of cost effectiveness, the model calculates that using B100 in captive fleets would cost £132/tonne of CO_2e abated and £7/GJ bioenergy deployed, whilst the options involving B30 in either captive fleets, or for forecourt fuelled vehicles cost around £381/tonne of CO_2e abated and £19/GJ bioenergy deployed. The use of B100 is more cost effective principally because a greater amount of bioenergy is consumed for every litre of fuel used compared to B30, whilst operating costs for B100 and B30 vehicles are similar.

The limit on what could be achieved, when only vehicle compatibility constraints are considered is calculated assuming the use of B100 in depots for any vehicle that can use it, and B7 standard grade for those that cannot use B100. This would potentially use 84 PJ of bioenergy, far in excess of what is likely to be available in the period to 2020. The FAME supply (for the central supply scenario) would all be used if 40% of the depot fuelled B100 capable vehicles used B100, and the remaining 60%, plus all those vehicles that cannot use B100, used the B7 standard grade. This was the option investigated. If B100 was supplied in 25% of compatible depot-fuelled vehicles in 2020, this would both be more feasible from the perspective of both fuel supply and vehicle operator uptake.

Relative to options regarding the use of high strength bioethanol blends or biomethane, the use of FAME biodiesel in these options would create a marked impact on meeting the RED and FQD targets in 2020 because compatible vehicles are already in the fleet.

However, discussions with a key manufacturer of heavy duty vehicles that are currently B100 compatible, has indicated their intention to change the type of fuel system technology used in their engines, moving from unit fuel injectors (which can use B100) to common rail fuel systems (which are limited to B7). This change will be made in order to meet the forthcoming Euro VI air pollutant emissions regulations. All heavy duty vehicles sold from 1st September 2015 will need to meet the Euro VI regulations, and whilst it is not clear that all manufacturers will follow the same technological route, there is a risk that in future the biofuels compatibility of new heavy duty vehicles will decrease.

For biomethane options, the current vehicle parc capabilities to use this fuel are low, there is limited availability of new biomethane-compatible vehicle models and there is a negligible level of biomethane distribution and supply infrastructure in place to support vehicle use. These factors mean that significant deployment of this fuel in the UK road transport fleet would be difficult to achieve by 2020. The options considered assumed that 4% of all new buses and rigid trucks, and 2% of all new light commercial vans and coaches operating in captive fleets, use biomethane from 2015. Sales were assumed to ramp up to this figure from 2011, and then remain stable. It was assumed that the biomethane vehicles actually use 95% biomethane and 5% petrol. For articulated trucks it was assumed that by 2015 2% of new vehicle sales into captive fleets had a dual fuel capability (using 65% biomethane, 35% diesel). Even with these ambitious assumptions regarding sales of methane vehicles and the assumption that 100% of the methane they use is biomethane (none of it being fossil-methane) it was found that biomethane could only make a small contribution to meeting the RED and FQD targets by 2020.

The Modes 3 model indicates that depot-fuelled dedicated biomethane, or dual-fuelled, vehicles are relatively cost effective at around £80/tonne CO_2 abated and £6/GJ bioenergy deployed. This is more cost effective than increasing the FAME content of standard grade diesel fuel from B5 to B7 (£131/tonne CO_2 abated and £7/GJ bioenergy deployed). An option involving forecourt fuelled biomethane vans also predicted a small, but cost effective, contribution to meeting both the RED and FQD targets for 2020.

For reasons related to infrastructure and behaviour, it is likely that the introduction of biomethane fuelled vehicles to captive fleets would be the more easily implemented route compared to setting up facilities for biomethane-powered vehicles to refuel at garage forecourts. However, it should be appreciated that the potential contribution of this fuel to meeting the RED and FQD targets in 2020 is small. Furthermore, in March 2011 the UK Department of Energy and Climate Change published the "Renewable Heat Incentive". This contains feed-in tariff rates (Chapter 6) of 6.5 p/kWh for the use of renewable energy sources (such as biomethane) to provide heat energy for buildings and industry. This converts to £18.06/GJ. This value for biomethane under the RHI is higher than the methane price assumed in the Modes 3 model (£14.78/GJ). Consequently, it is anticipated that the RHI tariff will preferentially promote the injection of biomethane into the gas grid to be used as a supply of heat energy rather than used as a road fuel, because this provides the highest commercial return to the producers. For biomethane to be economically attractive to its producers as a transport fuel, incentives at a similar financial level would need to be introduced.

3.2.3 E85 Options

The 'Combined' scenario group is made up of options from across the 'Depot' and 'Mainstream' scenarios. In this scenario the study team focused on those options that, when combined, could meet the 10% RED deployment target. These options were also the only means found that were capable of getting close to the 6% FQD target.

This group of options also included the impact of introducing vehicles which are E85 compatible. It focused on passenger cars because this vehicle group uses the majority of the petrol supplied in the UK. In terms of technological innovation, E85 vehicles are widely used in Sweden within the EU, and in other countries around the world. Consequently, it is clear that some of the large volume passenger car manufacturers already sell vehicles that can run on E85. However, it is also notable that some large volume passenger car manufacturers do not offer E85 compatible vehicles. Hence it appears there are manageable technical barriers to the use of E85, but that technological maturity is manufacturer-dependent.

The E85 options were based on either low or high penetration rates of sales of the existing flex-fuel vehicles alongside current models which can only use bioethanol blends up to E10, or that all new vehicles from 2020 will be E85 compatible (e.g. as flex-fuel vehicles). The options considered were as follows:

- Flex-fuel (E85) vehicles account for 5% of new petrol car sales in 2020.
- All new petrol cars from 2020 are flex-fuel; 30% of retail refuelling stations supply E85 by 2020.

The introduction of vehicles compatible with blends higher than E10 (e.g. E20 or E85) are further options for using more of the available ethanol. However, all these options are characterised by some common challenges:

- there are very few, or no, vehicles in the current fleet compatible with these fuels;
- the availability of new vehicles compatible with these fuels is low; and
- there is virtually no high blend strength fuelling infrastructure in place.

Main findings

The analysis indicated that each of these high ethanol blend options could only make a small contribution to both targets by 2020. However, the Modes 2 study showed that they could contribute more significantly in the longer term (beyond 2020), when there has been time for new models that can use bioethanol blends above 10% to penetrate the fleet.

For the scenario where flex-fuel vehicles increase from zero to account for 5% of petrol vehicle sales in 2020, the cost effectiveness (relative to the E5 RTFO baseline) is £80/tonne CO_2e abated and £4/GJ of bioenergy deployed. However, the contribution of this scenario to the RED target is only 0.07% more than if all petrol fuelled vehicles used E10. For scenarios where flex-fuel vehicle sales account for 2% or 100% of petrol vehicle sales in 2020, their contributions to the RED target are 0.03% and 1.15% respectively (scaling with the fraction of new vehicle sales).

Another important aspect is the potential benefit that would occur from the different blend options. Relative to a vehicle using a standard E10 blend, vehicles using E20 and E85 provide additional bioethanol consumption of 100% and 750% respectively per vehicle. Therefore, modelling the impact of a constant percentage of new vehicle sales having a biofuel capability greater than E10 always shows E85 vehicles as leading to the largest change.

A further aspect to be considered is the potential availability of bioethanol. If all the bioethanol available in 2020 were used in the standard grade fuel, this would be equivalent to an E31.5 blend for the central feedstock supply scenario. The figures for the low and high feedstock supply scenarios are equivalent to E4.6 and E31.8 blends respectively. The contributions these could make in terms of progress towards the 10% RED target are illustrated in Figure A2.1 in Appendix 2. Therefore if all vehicles were E85 compatible in 2020, there would not be sufficient bioethanol available to use this capability. If 29% of the fuel sold was E85, with the remaining 71% being the E10 blend, this scenario would use all the bioethanol projected to be available in the central scenario. The impact of different supply assumptions (from Modes 1) are shown in Table A2.1 of Appendix 2. Essentially there is little difference between the central and high supply scenarios (1PJ); however the low supply scenario would mean that considerably less bioethanol would be available, with the possibility of having insufficient bioethanol to meet even E5.

The analysis suggests that in order to gain the largest benefit with the fewest challenges, the car industry should be encouraged to increase the production of E85 flex fuel vehicles. This is becoming an established technology, and the infrastructure can be made available, as evidenced by the importance of E85 in Sweden. A key barrier to achieving this at present is the current UK fuel duty structure, which taxes by volumes of liquid fuels. The lower energy density of ethanol means that vehicles using E85 typically require 30–35% more fuel relative to petrol. Leaving aside the issue of the maturity of the refuelling infrastructure, the current fuel duty system means this would lead to a 30–35% increase in the amount of duty paid by the owner of a flex fuel vehicle to travel the same distance.

3.2.4 ‘Advanced’ biofuel options

Within this group there are drop-in diesel replacements, e.g. Fischer-Tropsch (FT) diesel, Hydrogenated Vegetable Oil (HVO) diesel and Upgraded Pyrolysis Oil (UPO), along with advanced fuels such as biobutanol, bio-DME, and bio-ETBE. Bio-ETBE is a petrol-like fuel which is made from bioethanol, the majority of which is classified as a first generation biofuel.

For all these biofuels (except DME) a common theme is that they are more compatible with the current road vehicle fleet than ethanol or FAME. Consequently, in terms of vehicle capabilities these fuels could potentially contribute markedly towards reaching the RED and FQD targets by being added to base fossil fuel **in addition to** the blending in of bioethanol or FAME. However in terms of the current fuel specifications the limit on oxygen content in petrol means that although the maximum permitted concentrations of ethanol is 10% (v/v) and of ethers is 22% (v/v) having both at these maximum values in a single fuel blend is not possible. Hence for the above to happen there would need to be a change in the fuel specification in Annex I of Directive 2009/30/EC to allow the combination of 10% ethanol and significant quantities of ETBE.

A further barrier limiting the uptake of both bioethanol and bioethanol-derived ETBE, or FAME and HVO are supply quantities, either because of limited raw bio-feedstocks or other key feedstocks (e.g. hydrogen for hydrogenation) or limited production capacity (e.g. for the hydrogenation of vegetable oils).

The options considered involving these fuels (which are considered to be capable of having a significant impact by 2020) are:

- Bio-ETBE – which can be blended with petrol.
- FT diesel – which can be blended with road diesel.
- Hydrogenated vegetable oil (HVO) – which can be blended with road diesel.
- DME – which can be used in dedicated vehicles unblended.

Biobutanol and UPO are predicted to not to be available in any significant quantities by 2020 – and therefore are not considered further.

For FT diesel, values for both the low 2G and rapid 2G scenarios are included. For HVO only the low 2G scenario is included as the rapid 2G scenario would compete with FAME for feedstock.

These were included as illustrative additional options so that the impact of advanced fuels can be appreciated. There will of course be further scenarios possible where advanced fuels are combined with some of the other 1G options discussed previously.

Main Findings

There has been some research on the use of ETBE in SI vehicles (cars) which most probably applies equally to bio-ETBE. The JCAP II[8] study used up to 8% ETBE in vehicles for up to 40,000 km, and tested materials compatibility with blends containing up to 17% ETBE. It concluded "There is no problem with the use of ETBE 8% blended fuel for gasoline vehicles in-use". In Europe some of the "ethanol" is added as ETBE, though it is hard to obtain definitive figures regarding the ethanol:ETBE ratio. Consultation with vehicle manufacturers has indicated they have little knowledge on its potential performance, despite how, on paper, it appears less challenging than bioethanol[9]. Hence, there appears to be little pull from manufacturers requesting that ETBE is made available.

The use of increased quantities of ETBE is very cost effective: from the analysis carried out in this study, bio-ETBE has a cost effectiveness indicator of £3/tonne of CO_2e abated and <£0.5/GJ bioenergy deployed, relative to £73/tonne CO_2e, and £4/GJ bioenergy deployed, for changing from E5 to E10 standard grade. However, there are other aspects to be considered for this option:

- The currently proposed fuel specification for petrol (EN228) would limit the quantity of ETBE that could be added to an E10 blend to 3.7%. This could be increased if the ethanol content was reduced, or the specification was revised.
- A blend of 30% ETBE (a hypothetical high-strength blend) would only contain around 10% bioenergy content because four of the six carbon atoms in each bio-ETBE molecule are fossil fuel derived, with only two from renewable sources. Hence ETBE is a somewhat "diluted" biofuel.

For HVO, feedstocks used to produce this fuel are the same as for FAME. The supply of HVO and FAME is limited by the availability of these feedstocks, and an increase in HVO supply means a decrease in FAME supply. Also, the production of HVO would require production facilities that currently do not exist, and provides a small benefit in cost effectiveness (£120/tonne CO_2e abated and £6/GJ bioenergy deployed for HVO R2G relative to £131/tonne CO_2e abated and £7/GJ bioenergy deployed for FAME used as B100 for depot fuelled vehicles). However, there are advantages of using vegetable oils to make HVO vs FAME, namely a small GHG savings, with HVO generating 52.1 kg CO_2e/GJ relative to FAME's 54.7 kg CO_2e/GJ (around a further 5% GHG intensity saving) but and a larger advantage in terms of fleet capability and infrastructure – with the HVO drop-in fuel being immediately usable in all diesel-engined vehicles and compatible with existing fuel supply infrastructure.

The synthesis of FT Diesel creates new biodiesel beyond that available from FAME and HVO diesel fuels produced from vegetable oils. The low 2G projected supply of 2.4 PJ of FT diesel to road transport would lead to a 0.2% FQD saving (relative to the 6.0% target, i.e. 0.14 kg CO_2e/GJ saving), and a 0.4% contribution to meeting the RED target. However, for the Rapid-2G option, 19 PJ leads to a 1.2% FQD saving (1.04 kg CO_2e/GJ saving), and a 1.6% contribution to meeting the 10% RED target. This is a significant potential contribution.

DME is made from waste streams and therefore provides a double benefit for the RED. It also provides a high carbon saving, because it has the lowest carbon footprint of all the renewable biofuels. However, it requires modified vehicles. If all the DME available was used in road transport, it is predicted to contribute 0.9% towards the 10% RED target having taken into account its double credit, and a 0.2% FQD saving (0.18 kg CO_2e/GJ saving). These are relatively small contributions, and unlikely to lead to a significant change relative to the baseline scenario.

[8] Reported in 5th JCAP Conference Gasoline WG Report, 2007, available from http://www.pecj.or.jp/english/jcap/jcap2/pdf/5th/1-2_koseki.pdf
[9] This arises because the attention of manufacturers' R&D teams has been focussed on meeting CO_2 targets, preparing for Euro 6 emissions targets for new models in 2014, and simply remaining competitive and viable in tough trading conditions.

3.3 Assessment of cost effective deployment possibilities for the four Scenarios

The possible options for increasing the deployment of biofuels to the UK road transport sector by 2020 have been considered in the context of the four overarching scenarios described in Section 2.5.

Some of the options which were analysed have not been carried forward into these deployment scenarios (due to their low benefit levels in relation to the targets). These included introducing B30 on retail refuelling forecourts for those vehicles that have the capability to use B30 and biomethane van sales reaching 10% by 2020 with sufficient refuelling infrastructure to support this in place.

The contribution that each of the groups of options within the four scenarios can make to the RED and FQD target levels, and their levels of cost effectiveness, are summarised in Table 3.2 below.

Cost effectiveness is considered with respect to each unit of bioenergy consumed, and against each unit of CO_2e abated, i.e. the cost effectiveness in terms of contributing to both the RED and the FQD targets (the same as was used in the Modes 2 project). Detailed tables showing the cost effectiveness of each individual option, which also contain GHG abatement potential and energy deployment figures, are given in Appendix 4. Sensitivity analysis has also been undertaken against the key drivers of these results – this is discussed in Section 3.5.

Figures 3.3 and 3.4 illustrate graphically the potential progress towards RED and FQD targets that each of these groupings would achieve.

Before listing the options that might be used for depot fuelled vehicles, an option "Mainstream 0" is introduced. In this option the FAME concentration is standard diesel fuel increases from the 5% required by the RTFO (the assumed baseline FAME concentration throughout this study) to 7% as is permitted within the fuel standard EN590:2009. Its importance arises because of limitation in FAME supply. These make a smaller percentage of B100 depot fuelling possible when B7 is the standard fuel that if the standard fuel was B5. Prioritising the order in which the fame is preferentially used is important when assessing cost effectiveness, and to avoid double counting.

Table 3.2 Summary of scenarios considered and headline figures

Scenario name	Detail	Contribution to RED (percentage points)	Contribution to FQD (percentage points)	Cost Effectiveness £/GJ	Cost Effectiveness (£/tonne CO_{2e} abated)
Mainstream 0	Baseline (E5 +B5) All vehicles begin using B7	5.87%	2.80%	£7/GJ	£131/tCO_2e
Mainstream 1	Baseline (E5 +B5) All vehicles using B7/E10	7.02%	3.40%	£5/GJ	£101/tCO_2e
Mainstream 2	Baseline (E5 +B5) All vehicles using B7/E10 All new cars to market are E20 compliant by 2015; in addition E15 available at 30% of pumps in 2020 (i.e. Replaces premium)	7.36%	3.58%	£5/GJ	£105/tCO_2e
Mainstream 3	Baseline (E5 +B5) All vehicles using B7/E10 All new diesel vehicles begin using B10 from 2015	8.33%	4.01%	£6/GJ	£109/tCO_2e
Depot 1	Baseline (E5 +B5) All vehicles begin using B7 By 2015, 2% of new LCV and coaches in captive fleets, and 4% of rigid trucks and buses, are SI vehicles with 95% of their fuel coming from biomethane. And by 2015, 2% of new articulated trucks in captive fleets are dual fuel using 65% biomethane, 35% diesel.	6.78%	3.18%	£6/GJ	£113/tCO_2e
Depot 2	Baseline (E5 +B5) All vehicles begin using B7	8.00%	3.75%	£7/GJ	£121/tCO_2e

Scenario name	Detail	Contribution to RED (percentage points)	Contribution to FQD (percentage points)	Cost Effectiveness £/GJ	Cost Effectiveness (£/tonne CO_{2e} abated)
	Biomethane options as for Depot 1 B100 for 20% of depot fuelled vehicles that are B100 compatible				
Depot 3	Baseline (E5 +B5) All vehicles begin using B7 B100 for 40% depot fuelled vehicles that are B100 compatible	8.30%	3.92%	£7/GJ	£132/tCO_2e
Combined 1	All four options in Depot 4 and Both options in Mainstream 1:	10.35%	4.91%	£6/GJ	£114/tCO_2e
Combined 2	All four options in Depot 4 and Both options in Mainstream 1: Plus: E20 in all new cars by 2015	10.69%	5.09%	£6/GJ	£114/tCO_2e
Combined 3	All four options in Depot 4 and Both options in Mainstream 1: Plus: E85 in 5% of new cars by 2020	10.41%	4.94%	£6/GJ	£114/tCO_2e
Combined 4	All four options in Depot 4 and Both options in Mainstream 1: Plus: E85 in all new cars by 2020	11.49%	5.51%	£6/GJ	£120/tCO_2e
Advanced 1	Both options in Depot 1 and Maximum amount of ETBE and DME available used	7.49%	3.36%	£4/GJ	£96/tCO_2e
Advanced 2	Both options in Depot 1 and Maximum amount of FT diesel, from both L2G and R2G scenarios Plus maximum amount of HVO diesel (L2G) used	9.84%	4.27%	£6/GJ	£100/tCO_2e

Figure 3.3 Summary of deployment scenarios in relation to RED target levels

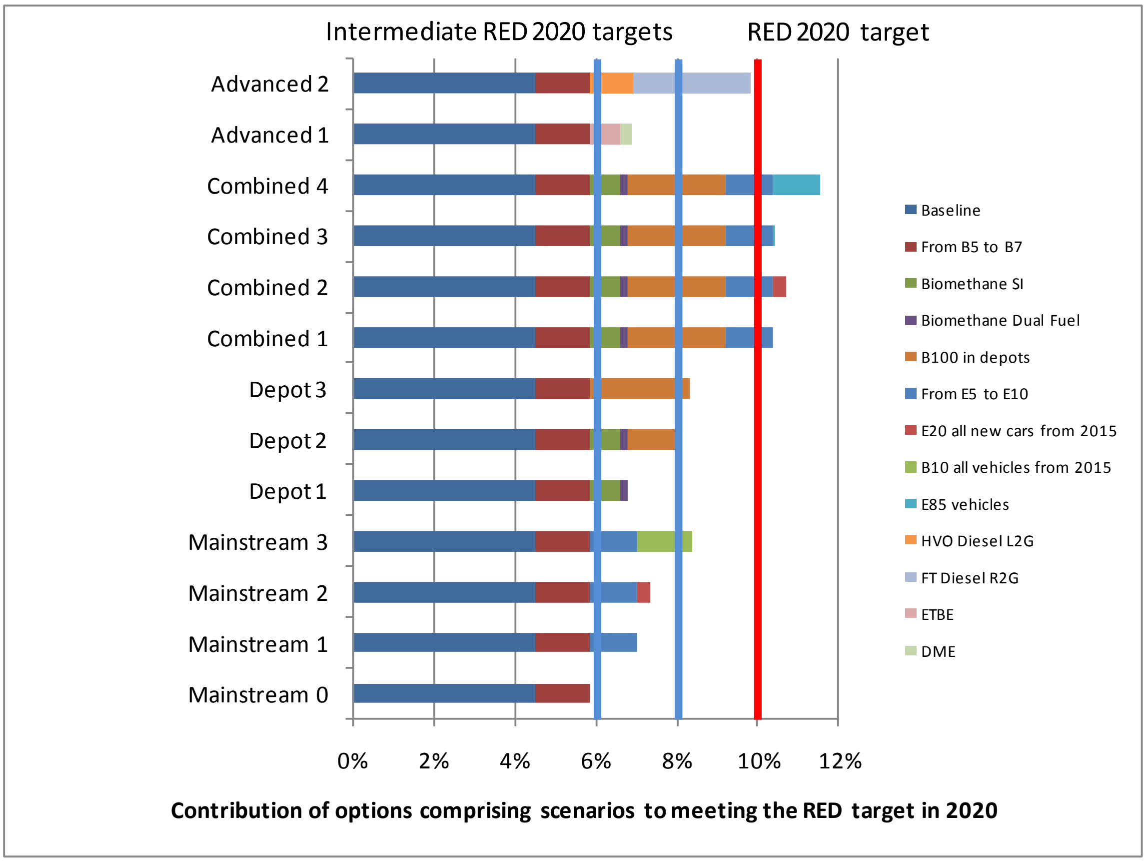
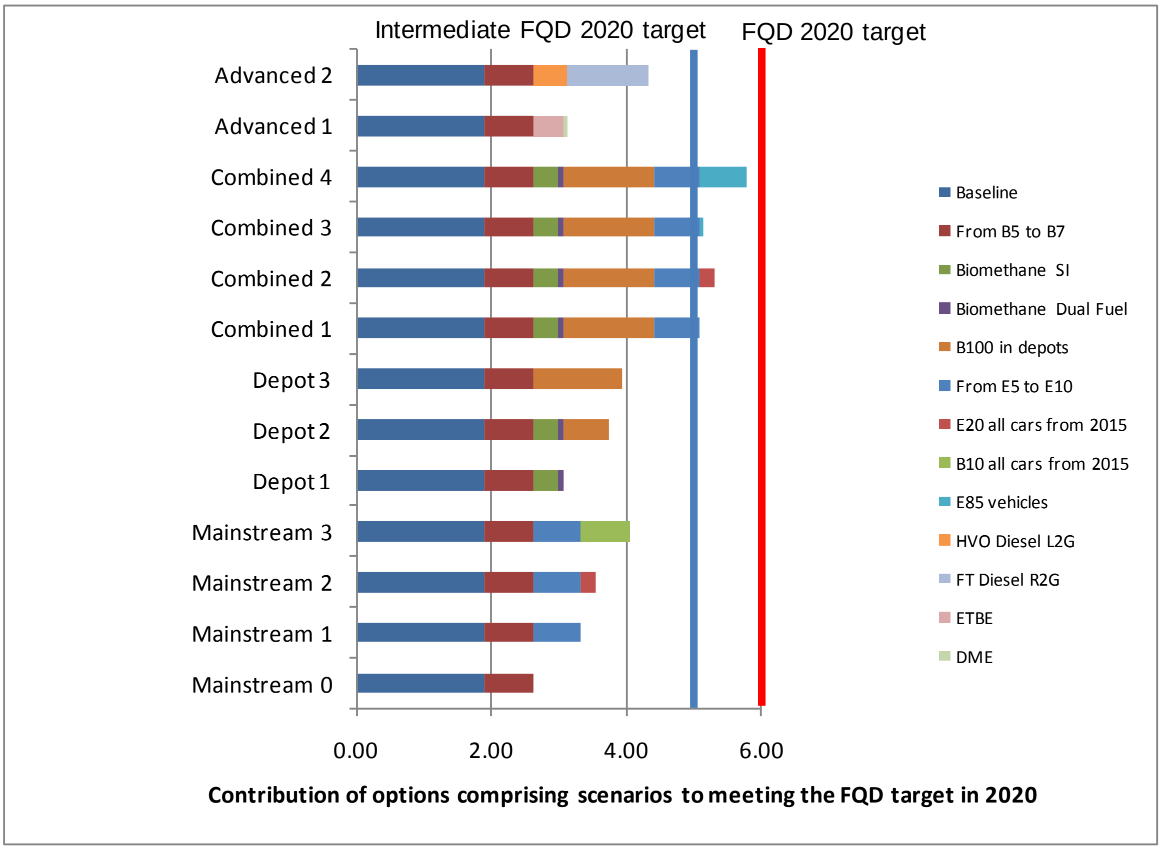


Figure 3.4 Summary of deployment scenarios in relation to FQD target levels



These charts highlight an important finding of this study; the deployment scenarios required to meet targets will require a combination of several options. For the FQD in particular, the combinations considered, involving first generation biofuels and ambitious (but realistic) vehicle capability changes, would not provide any means of reaching the target of a 6% reduction in GHG intensity. This highlights that there will likely be the need for some early introduction of advanced biofuels or the need to ensure that further reductions in the GHG emissions associated with the production of fossil fuels and biofuels occur between now and 2020.

Depot fuelling scenarios (i.e. involving vehicles in captive fleets) provide routes whereby all the FAME not used in the standard diesel fuel, and a small amount of biomethane could be used. Whilst these scenarios can exceed 8% deployment of bioenergy in transport fuels (getting close to the 10% RED target), the scenarios modelled did not quite reach a 4% GHG reduction target (two thirds of the FQD target).

All the mainstream scenarios assumed the standard diesel and petrol fuels would become B7 and E10 by 2020. In the scenario “Mainstream 3”, the majority of the additional FAME was used within the fleet by presuming all vehicles could use B10 by 2015. The cost effectiveness for this differs slightly relative to the B100 depot fuelling option (£129/tonne CO_2e abated (£7/GJ deployed) vs £133/tonne CO_2e abated (£7/GJ deployed)for the B100 depot option). However, this mainstream scenario contributes less towards reaching the RED or FQD targets because not all the FAME is used. However, Mainstream 3 is closer to the targets than the options involving E20, because the latter can only be used in passenger cars, whereas B10 could be used by diesel vehicles across all modes of road transport.

In the combined scenarios, again it is assumed the standard fuels would become B7 and E10 by 2020, all available FAME is used by supplying B100 to around 40% of the depot fuelled vehicles, and the sales of biomethane vehicles for use in depots starts becoming significant. These five options, when combined with the baseline (scenario “Combined 1”) generate levels of deployment slightly above the 10% RED target, and slightly more than 5% GHG savings relative to the 6% target.

If the options involving E20 cars (Combined 2) or E85 cars (modelled as flex-fuel vehicles in Combined 3 and Combined 4) are included, further progress towards meeting the 6% target is seen. As expected the scenarios involving “all new vehicles being E85 flex-fuel by 2020” generate the most progress, but this option is calculated by the model to be more expensive (see Appendix 3 Table 3.4).

As noted above, no combination involving first generation biofuels and ambitious (but realistic) vehicle capability changes were found to reach the FQD target. **However,** broadly independent of these scenarios, are options involving advanced biofuels (the principal exception is the production of HVO which would reduce the FAME supply because it uses the same biofuel feed-stock. Also, currently, there is an ethanol/ETBE/butanol trade off that is required to keep the overall oxygen content of petrol within the 3.7% limit specified in Directive 2009/30 (FQD)). The scenario “Advanced 1” considers the contribution DME and bio-ETBE might make, whilst scenario “Advanced 2” considers the use of drop-in diesel fuels. To avoid the potential of double counting, HVO was not included in scenario Advanced 2.

Supplementing scenario “Combined 4” with **either** bio-ETBE **or** DME + FT Diesel (L-2G production scenario) would reach the 6% FQD target, and also generate 12% biofuel deployment by energy (taking deployment beyond the 10% RED target). However, this would require increasing the oxygen content limit (currently 3.7% m/m) specified in the FQD (Directive 2009/30/EC). The FT Diesel (Rapid-2G production scenario) generates a further 1% GHG saving beyond the FQD target and would be permitted within the current diesel fuel specifications.

The cost effectiveness of the scenarios (shown in Table 3.2) results from the combination of options, weighted by the bioenergy used, or CO_2e abatement they generate. It should be remembered that the vast majority of scenarios involve the B5 and E5 baseline, the additional increased biofuel usage associated with using B7 and E10 as the standard fuels, and the use of additional FAME within depot fuelled vehicles. These options alone virtually meet the 10% RED target, and are close to a 5% reduction in GHG intensity. Other options are then added to these. The cost effectiveness of the “Combined N” options is dominated by the large options common to all. Consequently, the cost effectiveness of the four Combined scenarios differ only a little. A more detailed assessment of the cost effectiveness of individual options is found in the tables in Appendix 4.

3.4 Barriers and implementation considerations for the Scenario groups

In addition to considerations of the potential of each scenario to meet the RED/FQD targets, and respective cost effectiveness, it is important to note the main barriers that are likely to be faced in any attempt to pursue them. These are shown in Table 3.3 below, along with a view on possible further considerations regarding their implementation.

Table 3.3 Summary of barriers and implementation considerations for each scenario group

Scenario Grouping	Vehicle/Infrastructure constraints, barriers and required changes
Mainstream 0	None This option would achieve 5.9% towards RED and so falls short of the 6% lower target level of interest to DfT. Other scenarios therefore required to go beyond 6%. This option would achieve 2.5% towards FQD and so falls short of the 5% lower target level of interest to DfT
Depot 1	Either dual-fuel artic trucks or SI rigid trucks would provide the additional 0.13% required to meet a 6% RED target level. Significant vehicle changes and infrastructure requirements. Support/incentivisation for biomethane introduction. Competition with use in other sectors (RHI subsidy level).
Depot 2	Biomethane as above + B100 would be available that are compatible and standard B7 for others. This would involve having two biodiesel grades available, which may be a problem for some depots, but which is being done at others surveyed. 20% depot fuelling is minimum required to reach RED 8% intermediate target
Depot 3	N.B. 100% depot fuelled vehicles unlikely to be possible as this will be constrained by FAME supply In the central supply scenario 40% uptake of depot fuelled B100 capable vehicles would consume all the FAME available beyond B7 in the standard grade. In the high supply scenario this rises to a 50% uptake before all the available FAME has been allocated. . (This scenario is less demanding than requiring **all** depot fuelled vehicles that are capable of using B30 to actually us it.) As for Depot 3 this would involve having two biodiesel grades available, which may be a problem for some depots, but which is being done at others surveyed. The data in Figures 3.1 and 3.2 assume the central supply scenario and 40% uptake of depot fuelled B100 vehicles, i.e. consumption of all available FAME within the central supply scenario. This “Depot” scenario is the best of the four, but even this scenario which exceeds 8% bioenergy deployment does not quite reach 4% towards the 6% FQD target There is the likelihood that in future the biofuels compatibility of new heavy duty vehicles will decrease. Currently around 65% of the largest trucks can use B100. A key manufacturer has indicated the fuel system technology used in their engines will change to meet the forthcoming Euro VI air pollutant emissions regulations. This will apply to all heavy duty vehicles sold from 1st September 2015, and will mean this company’s trucks will go from being B100 compatible to being limited to B7.
Mainstream 1	None by 2020.
Mainstream 2	Would require two petrol grades in 2020. This would either require switching premium blend tanks to the higher biofuel blend, or adding new tank and fuel delivery capacity, a barrier to introduction. Vehicle changes are required for E20 use. Significant challenge for passenger car manufacturers and would require widespread availability of two petrol grades in 2020.
Mainstream 3	Would likely require two diesel grades in 2020. Vehicle changes are required for B10 use. Significant challenge for passenger car manufacturers and would require widespread availability of two diesel grades in 2020.
Combined 1	As for Depot 4 + standard grades become B7 and E10 by 2020. Few vehicles not compatible with this.
Combined 2	As for Depot 4 + standard grades become B7 and E10 by 2020. Forecourts require B7, E10 and E20 pumps. . This would either require switching premium blend tanks to the higher biofuel blend, or adding new tank and fuel delivery capacity, a barrier to introduction. Vehicle changes are required for E20 Challenging for vehicle manufacturers and would require widespread availability of two petrol grades in 2020.
Combined 3	As for Depot 4 + standard grades become B7 and E10 by 2020. Forecourts require B7, E10 and E85 pumps. Vehicle changes are required for E85 Would require widespread availability of two petrol grades in 2020, E85 and standard E10 grade. The current UK fuel duty structure, which taxes by volumes of liquid fuels, penalises the lower energy

Scenario Grouping	Vehicle/Infrastructure constraints, barriers and required changes
	density of ethanol leading to a 30–35% increase in the amount of duty paid by the owner of a flex fuel vehicle to travel the same distance.
Combined 4	As for Depot 4 + standard grades become B7 and E10 by 2020. Forecourts require B7, E10 and E85 pumps. Vehicle changes are required for E85. Also, the current UK fuel duty structure, which taxes by volumes of liquid fuels, penalises the lower energy density of ethanol leading to a 30–35% increase in the amount of duty paid by the owner of a flex fuel vehicle to travel the same distance.
Advanced 1	Required ETBE is to be available. Current barrier caused by fuel oxygen content limit in fuel specification leads to there needing to be a trade off between the ethanol / butanol / ETBE concentrations Only limited experience on compatibility of ETBE with current SI vehicles as many manufacturers have not given much consideration to ETBE yet.
Advanced 2	Drop-in fuels can be mixed with base fuel. There are large uncertainties associated with the rate of development of the technologies for drop-in fuel production. These are linked to associated costs, projected rate of return, and the national economic climate

3.5 Sensitivity analysis

3.5.1 Prices of biofuels

The price, or more accurately differences in price, between different biofuels and the fossil fuels they are replacing has a significant impact on the cost effectiveness (as measured in £/GJ, or in £/tCO_2e abated).

A sensitivity assessment was undertaken in which the price of oil was varied. This changes the marginal costs, but leaves the marginal bioenergy consumption and GHG emissions unaffected. Hence both measures of cost effectiveness are changed by the same proportion. Figure 3.5 and Figure 3.6 show the cost effectiveness (£/GJ bioenergy and £ /tonne CO_2 abated) calculated using the central and high oil price settings within the model for options involving five different biofuels. The two graphs have similar forms, especially regarding the relative size of cost effectiveness indicators for the two fuel supply scenarios.

Figure 3.5 The sensitivity of the oil price on the cost effectiveness of deploying bioenergy for options involving different biofuels

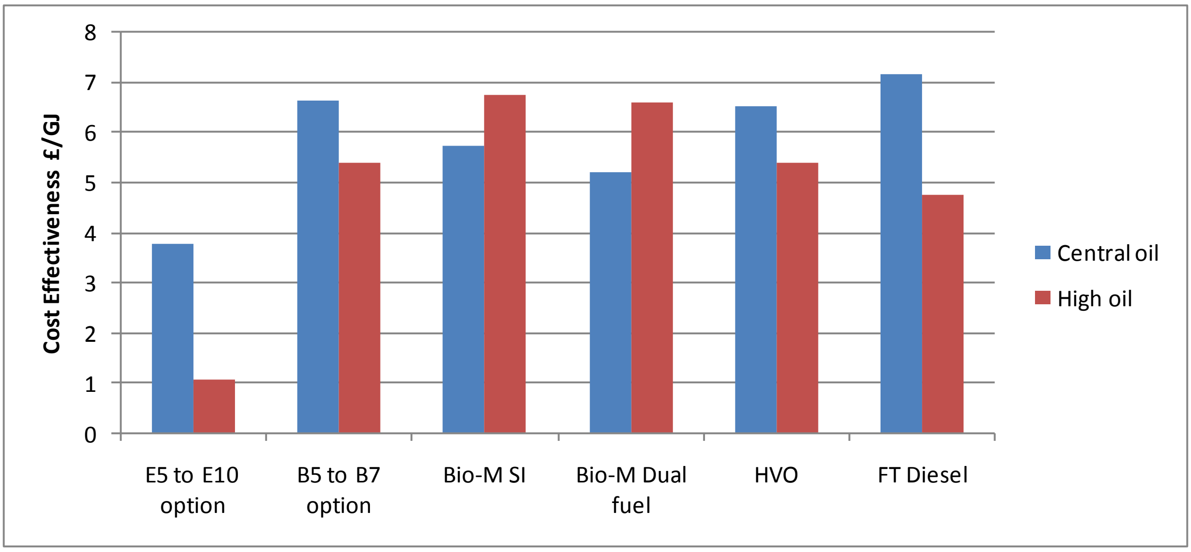
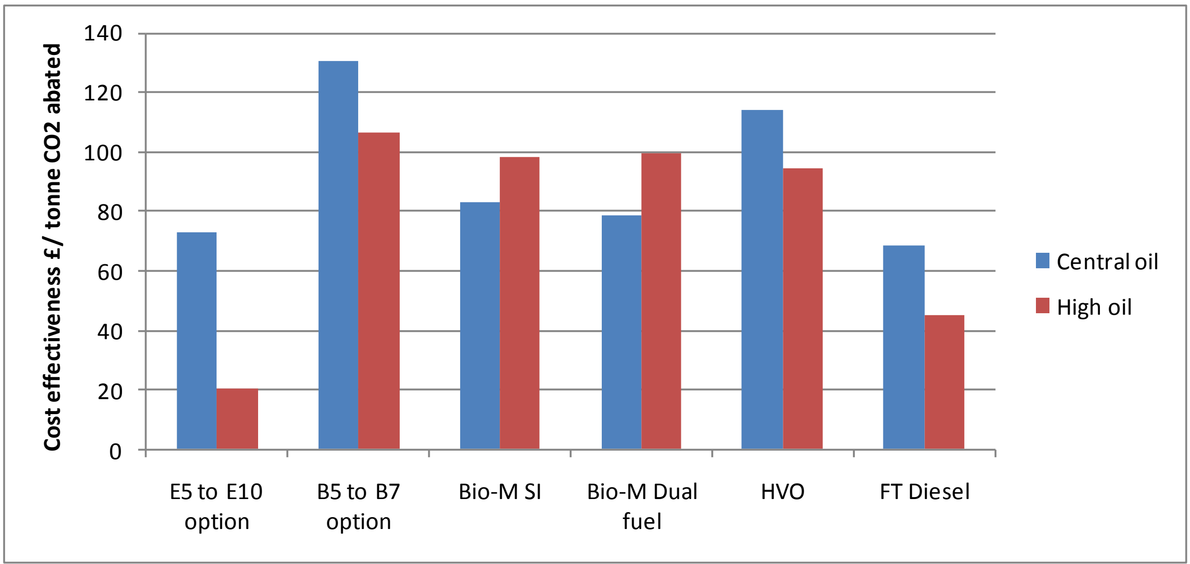


Figure 3.6 The sensitivity of the oil price on the cost effectiveness of reducing CO_2e emissions for options involving different biofuels



For bioethanol, FAME and the two drop-in diesel fuels, as the cost of the fossil fuel replaced increases there is a **smaller** marginal cost increase when using the biofuel replacements. This causes the high oil price scenario to have lower marginal costs per GJ of bioenergy deployed (varying from a 70% reduction for bioethanol to 17% for HVO).

Under the high oil price scenario the biomethane price also is modelled to increase from its originally very small value **more rapidly** than the fossil fuel price rises. Consequently, the cost effectiveness analysis for the biomethane options indicate a higher cost per GJ (by around 20%) for the high oil price scenario.

3.5.2 Additional maintenance costs for vehicles running on higher blends

The cost effectiveness modelling assumes that additional maintenance costs for vehicles running on higher blend biofuels do not vary in the future. This is probably a pessimistic assumption because changes in the materials used, and in the additive packages added to biofuel containing base fuels, are both likely to lead to improvements in the durability of vehicles, and reductions in maintenance costs in the future. Specific examples might be due to corrosion of HDV fuel tanks and microbial growth. For the former, in the future there could be either a move away from steel based fuel tanks, or towards coating the inside of the tanks. This would reduce maintenance costs relative to the current situation where vehicles that were not designed to take biofuels, but are in the vehicle parc, do suffer some deleterious effects when using biofuel blends. For the latter, it is known that microbial growth can be an issue, leading, for example, to the blocking of fuel filters. In the future it could be anticipated that research and development will lead to the addition of small quantities of effective biocides that reduce this challenge. In terms of this project, however, it was anticipated that the additional maintenance costs for vehicles using higher blend biofuels will not vary much between now and 2020; significant reductions in maintenance costs are only likely to occur after 2020.

3.5.3 Sensitivity to GHG emissions for the fossil fuels

In 2020, around 85–90% of the fuel used in the road transport sector will still be fossil fuels. The GHG emissions from the production, refining and combustion of these fuels are the major portion of road transport GHG emissions. The overall well to wheel (WTW) emissions can be expressed as the sum of the well to tank (WTT) and tank to wheel (TTW) emissions. A change in the Well to Tank (WTT) GHG emissions associated with producing fossil fuels, would impact on the progress towards the more demanding FQD target (though do nothing relative to the RED target). Such changes might include reductions in flaring and venting at oil production facilities, or reductions in the energy required to crack and reform the crude oil into end products. No change in the TTW figure is anticipated since the elemental composition of fuel is not anticipated to change significantly.

The WTW, and component WTT and TTW, CO_2 emissions for petrol and diesel that have been used in this study are tabulated below (Table 3.4), together with the impact of a 5% change in the WTT component, to reflect changes in flaring, venting and refining.

Table 3.4 WTW and TTW for petrol and diesel

Fuel	WTW CO_2 emissions	WTT CO_2 emissions	TTW CO_2 emissions	Impact of 5% WTT reduction on CO_2 emissions
Petrol	83.19	9.81	73.38	0.49 gCO_{2eq}/MJ
Diesel	88.97	15.72	73.25	0.79 gCO_{2eq}/MJ

When these changes are weighted by the projected diesel:petrol road fuel usage in 2020 this would produce a 0.69 gCO_2e/MJ reduction in GHG emissions. Given the assumed FQD target of a 5.2g gCO_2e/MJ reduction[10] this is a potential modest contribution to the reaching the target.

3.5.4 Sensitivity to GHG emissions for manufacturing the biofuels

Table A2.4 in Appendix 2 contains data on the GHG savings for the different biofuels. These range from 93% for DME and FT diesel to 59% for FAME. (All values must be at least 50% from 2017 onwards in order to quality as sustainable biofuels.) The stakeholder consultation indicated that some of the projected 2020 improvements in GHG savings could be conservative.

An illustration of the impact of changing the GHG emissions savings from the biofuels is shown below. In this illustration all available FAME is used, and has an average GHG emission saving of 70% and the standard petrol uses a blend of E10 with average emissions saving from the ethanol of 80%. The Modes 3 model was re-run using modified GHG savings as given in Table 3.5.

Table 3.5 Impact of GHG savings improvements from biofuels

	Petrol	Diesel
Fossil fuel reference GHG emissions (gCO_2e/MJ)	83.19	88.97
GHG emissions for average biofuel (gCO_2e/MJ)	30.88	36.91
GHG savings relative to fossil fuels used in baseline case	62.9%	58.5%
More ambitious GHG savings relative to fossil fuels	80.0%	70%
Change in GHG emissions calculated by model (gCO_2e/MJ)	0.33*	0.66**

* using E10 in the standard petrol grade

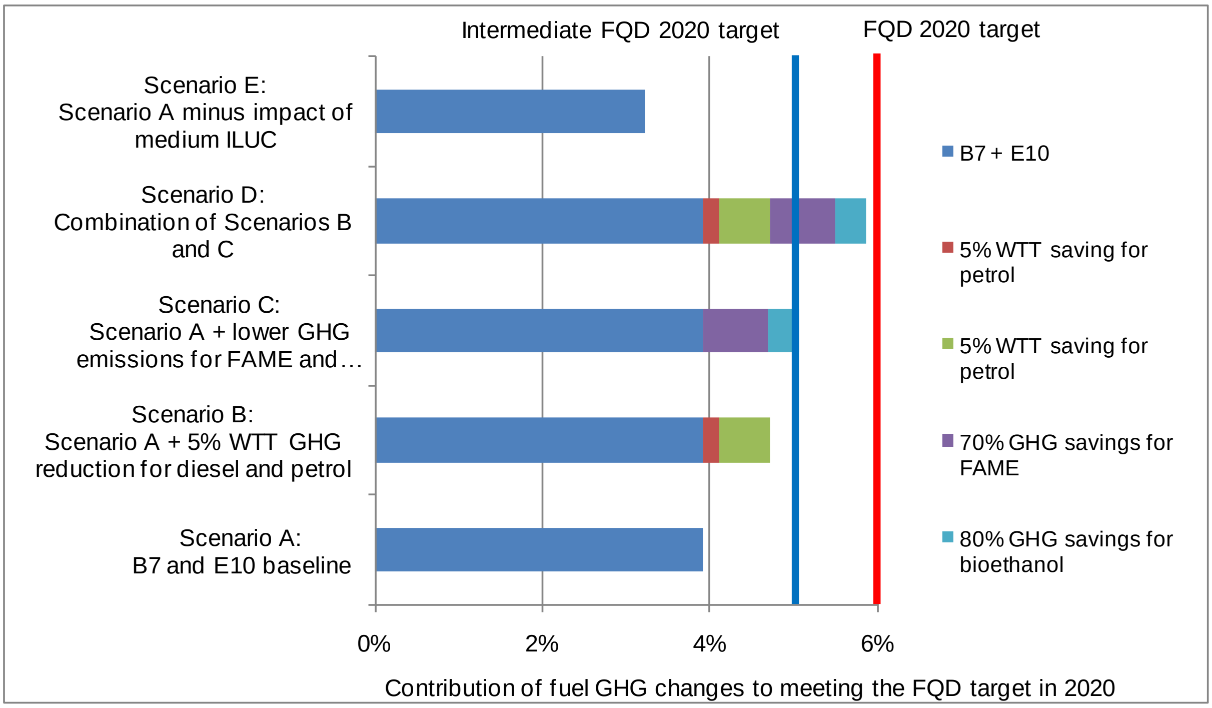
** using 99 PJ of FAME

Together these would contribute a further 1.0 gCO_2e/MJ reduction in the GHG emissions. This would make a sizeable contribution to reaching the 5.2 gCO_2e/MJ reduction required to meet 6% FQD target. Investment in improving GHG savings could also mean that more FAME production reached the sustainability criteria, and was therefore available for use in road transport, further positively contributing towards meeting the FQD target.

Figure 3.7 below shows the effect of the contribution towards meeting the 2020 FQD target of the possible changes in WTT emissions for petrol and diesel, the possible improvements in the GHG savings for all of the FAME available, and bioethanol used in E10, when combined with using B7 and E10 as the standard fuel blends.

[10] The figure of 81.2 gCO_2e /MJ is derived from a 6% reduction from a 2010 baseline GHG emissions figure of 86.4 gCO_2e/MJ

Figure 3.7 Additional progress towards targets from GHG savings improvements from biofuels



ILUC effects

At present GHG emissions due to indirect land use change (ILUC) are not included in the calulation of GHG emissions savings required by RED, although it is possible that this could change[6]. The inclusion of ILUC would lead to the following changes:

- the reduced GHG savings would affect the cost effectiveness (in £/tonne CO_2e abated)
- would reduce the contribution to the FQD target reported by each litre of fuel to which the ILUC factor applied.
- the reduced GHG savings could mean some fuel supply routes (e.g. from palm and soya) would fail the EU sustainablility criteria, and consequently the quantities of qualifying biofuels could decrease.

The study team assessed the sensitivity of the results to the inclusion of an ILUC emissions factor on the cost effectiveness, based on the ILUC GHG factors developed for sensitivity analysis in the Modes 2 study. The three ILUC options available within the Modes 2 and 3 models are:

- No ILUC
- Medium ILUC (10 gCO_2e/MJ for land based crops) and
- High ILUC (35 gCO_2e/MJ for land based crops).

All the data presented in this report up to this point has used the “No ILUC” option.

When the medium and high ILUC emissions estimates were used in the Modes 3 model these led to smaller GHG savings, relative to the equivalent “No ILUC” baseline, as tabulated overleaf (Table 3.6). The ratio of the increase in GHG emissions for the medium and high ILUC emissions estimates follows the ratio 10 gCO_2e/MJ to 35 gCO_2e/MJ as might be anticiapated for each biofuel scenario.

Table 3.6 Increase in CO_2e emissions associated with the Medium and High ILUC emissions estimates

	Increase in GHG emissions (i.e. impact on FQD target)	
	Medium ILUC estimates	High ILUC estimates
FAME – impact from 99 PJ FAME usage	0.56 gCO_2e/MJ	1.96 gCO_2e/MJ
Bioethanol – impact from using E10 as the standard grade petrol	0.23 gCO_2e/MJ	0.80 gCO_2e/MJ

Together these would contribute a 0.8 gCO_{2eq}/MJ increase in the GHG emissions compared to the baseline, offsetting some of the other contributions to the reaching the FQD target.

It is likely that inclusion of an ILUC factor would affect the supply of biofuels, as a greater proportion would not meet the GHG saving criteria.

3.5.5 Availability of biofuels

1G biofuels

For mainstream fuels, such as FAME, bioethanol and biomethane, there are three biofuel supply scenarios: low, central and high (see Table A2.1 of Appendix 2 for values). All of the data reported to date has used the central biofuel supply scenario.

The options considered for bioethanol and biomethane only use a fraction of the available biofuel in road transport by 2020 (though this may not be the situation beyond 2020 where supply constraints may become relevant). Hence, relative to the central supply scenario the only impact on the ability to meet the RED and FQD targets in 2020 would be if the low supply scenario applied for bioethanol, because this would give insufficient bioethanol to meet the E5 standard fuel option.

For FAME the situation is different and many options provide the potential for using more than the available amount of FAME. Consequently, changes in biofuel availability have a direct impact on the potential to meet the RED and FQD targets in 2020. The projected energy supply in 2020 for the three supply scenarios for FAME is as tabulated below (and shown in Table 3.7):

Table 3.7 Projected energy supply in 2020 for the three supply scenarios for FAME

	High biofuel supply	Central biofuel supply	Low biofuel supply
Absolute	106.8 PJ	99 PJ	46.2 PJ
Relative	108.2%	100%	46.8%

Hence the research findings suggest that FAME and HVO use is likely to be supply constrained rather than constrained by vehicle or infrastructure compatibility, but there is a risk that overall volumes will be significantly lower than modelled.

Advanced biofuels

It is projected that some advanced biofuels will contribute minimally to meeting the 2020 RED and FQD targets. Consequently, there is only a very low sensitivity to meeting the targets for these fuels.

At the stakeholder workshops it was noted by several participants that the availability of some advanced biofuels was towards the low end of the credible range. Therefore, two advanced biofuel scenarios were generated giving a low 2G (L2G) and rapid 2G (R2G) development scenarios. If it is assumed that the quantities of drop-in fuels used match the amount available, then the sensitivity to meeting the 2020 RED and FQD targets is as shown in Table 3.8.

Table 3.8 Sensitivity of using advanced biofuels to meeting the 2020 RED and FQD targets

Fuel	Sensitivity	Comments	Supply Constraints
DME	Very low	Only anticipated to make a small contribution to biofuel supply in 2020. Therefore doubling or halving the supply leads to little impact on progress towards meeting the RED and FQD targets.	Production technology maturity and capital investment
Biobutanol	Very low	Only anticipated to make a small contribution to biofuel supply in 2020. Therefore doubling or halving the supply leads to little impact on progress towards meeting the RED and FQD targets.	Production technology maturity
ETBE	Moderate	High uncertainty because the manufacturers have not thought much about using this fuel	Lack of demand for ETBE as a fuel, and probably scale-up challenges
FT diesel	High	This is a key potential fuel, supply ranges from 2.6 PJ for L2G to 21 PJ for R2G. The difference is approx 12% of the RED target, and a 1 g CO_2e/MJ contribution towards meeting the FQD target (14%)	Production technology maturity and capital investment
HVO diesel	Low	Looks large with values ranging from 13 PJ for BAU to 42 PJ for Rapid 2-G **but** this availability of HVO would lead to corresponding reduction[11] in FAME availability – which would compensate and lead to little net effect on the meeting of the targets.	Availability of feedstock and hydro-reformation capacity
UPO	Very low	Projected to contribute extremely little in 2020, therefore independent	Immature technology

3.5.6 Sensitivity in relation to the FQD target

A key assumption in the analysis presented is that the EC fossil fuel baseline GHG intensity has been set at 86.4 gCO_2e/MJ, leading to an FQD target GHG intensity of 81.2 gCO_2e/MJ. However, if the baseline value used was different, for example 83.8 gCO_2e/MJ then the FQD target would become 78.8 gCO_2e/MJ. In this case, the 6% reduction from the new baseline figure would be the same as an 8.8% reduction from the assumed 86.4 gCO_2e/MJ baseline figure. Given the combinations of different measures required to meet the 6% reduction target using a baseline of 86.4 gCO_2e/MJ, this further reduction would be even more challenging.

[11] It is not strictly a corresponding reduction because of different conversion efficiencies for producing FAME and HVO from the same feedstocks. However, using these different conversion efficiencies, weighted by the quantities of the feedstocks available in 2020, gives a difference of less than 1%. Therefore, treating the energy content of the FAME and HVO from the combined feedstocks as being equivalent is a reasonable approximation.

4 Conclusions and recommendations

The overarching conclusion is that the UK needs to use a multiplicity of contributing measures to achieve the RED and FQD targets by 2020 rather than a straightforward approach focused on the high usage of a single type of biofuel. In particular, the study has shown that only scenarios that combine most of the options available meet the 10% RED level; under none of the scenarios using only the first generation biofuels considered is it possible to meet the FQD 6% reduction in GHG intensity.

Whilst results indicate that a multiplicity of options utilising first and second generation biofuels is required to meet the FQD target, this analysis was conducted on the basis of only limited improvements in life-cycle GHG emissions for biofuels between now and 2020 and no improvements in the life-cycle emissions associated with fossil fuel production.

Consequently, the FQD 6% reduction in GHG intensity target can be met by augmenting the 'Combined' scenarios utilising much of the first generation biofuel with only one of the following options:

- introducing any one of the 'Advanced' options involving second generation fuels; or
- reducing the GHG intensity of fossil fuels through improvements in production and refining processes; or
- reducing the GHG emissions from the production of FAME and bioethanol.

4.1 Summary of conclusions and recommendations

- The analysis carried out in this study indicates there is likely to be a sufficient quantity of biofuels in 2020 to meet both RED and FQD target.
- It is likely to be more difficult to meet the FQD target than the RED target.
- In terms of individual fuels, the principal contributions to meeting these targets can be grouped as generally coming from FAME, bioethanol, advanced biofuels and biomethane. No single fuel alone can meet the targets in any plausible scenario, but the size of their contribution follows the order above, i.e. FAME is likely to contribute more than bioethanol, etc.
- Restrictions on the quantity of FAME available mean that choices need to be made, e.g. providing high-strength FAME blends for depot fuelled vehicles, or increasing the standard diesel grade above a 7% blend (B7), or using vegetable oil feedstocks to make HVO diesel in preference to FAME biodiesel.
- The potential future supply of bioethanol exceeds the projected consumption that would occur if the standard petrol/ethanol blend was E10. To increase consumption above this, using E20 or E85 blends, would require new vehicles not currently in the fleet, and the options investigated contribute only little additional consumption by 2020.
- Drop-in replacement diesels (e.g. HVO diesel and FT diesel) have the advantage of being totally compatible with current vehicles. Other advanced fuels such as bio-ETBE and biobutanol are significantly more compatble with current vehicles than bioethanol. However, the future use of all of these fuels is anticipated to be supply-limited between now and 2020.
- Biomethane occupies an interesting position; because of its current low usage and because it can only be used in specially-adapted vehicles, its use is vehicle constrained. Consequently, scenarios investigating its increased usage contribute only little by 2020, but could be vital in decarbonising road transport beyond this date.
- The sensitivity analysis shows that a modest contribution towards meeting the FQD target would occur if the well-to-tank GHG emissions of generating fossil fuel derived petrol and diesel were reduced. (This would not affect the meeting of the RED target.)

- The sensitivity analysis also shows that if the GHG emissions associated with producing FAME and bioethanol biofuels were reduced, this too would provide a modest contribution towards meeting the FQD target. (Again this would not affect the meeting of the RED target.)

- The FQD target is not finalised. The analysis from this study indicates how meeting a target derived from a 2010 baseline of 86.4 gCO_2e/MJ will be challenging.

The recommendations regarding the use of biofuels from vegetable oils and tallow, are, in order of preference:

- To increase the FAME content of standard fuel to B7 because all new vehicles are B7 compatible, the current fuel standard (EN590:2010) allows for 7% FAME in diesel, and this is the most cost effective option for deploying FAME in vehicles.
- Also, to use vegetable oil feedstocks to make HVO diesel because this is a drop-in replacement diesel fuel compatible with existing vehicles and infrastructure whose cost is slightly less per tonne CO_2e abated or GJ biofuel deployed.
- It is recommended any remaining FAME is used in depot fuelled vehicles, preferably B100 fuel, because this is a more cost effective option relative to using the B30 blend.

The recommended preferences for using bioethanol are the combination of the three options below:

- To use the maximum amount of bioethanol as ETBE because this is the most cost effective way of using bioethanol feedstock, and it appears to be compatible with current vehicles.
- To increase the bioethanol content of standard fuel to E10 because virtually all new petrol fuelled vehicles are compatible with E10, and this is the most cost effective option for using bioethanol directly in vehicles.
- To encourage the uptake of flex-fuel (E85 capable) vehicles because some vehicles are already available thereby making a large impact possible by 2020 (relative to options using E15 or E20 blends), and this is the third most cost effective way of using bioethanol, and could become an important biofuel use beyond 2020.

The recommendations for biomethane are based on there being a considerable quantity of bioenergy available, but currently there is low usage, limited numbers of vehicles available, and very poor infrastructure capabilities. The recommendations are:

- To encourage the uptake of depot fuelled dedicated biomethane fuelled vehicles, especially of use in urban environments, where in addition to GHG emissions abatement these vehicles provide pollution emissions abatement, improving local air quality.
- To encourage the uptake of depot fuelled dual fuel biomethane diesel vehicles for use on trunk routes where biofuel usage would be maximised.

The overall recommendations following from the above conclusions are:

1. The UK needs to use a multiplicity of contributing measures to achieve the RED and FQD targets by 2020 rather than a straightforward policy focused at the high usage of a single type of fuel. Eight specific recommendations regarding the currently available biofuels are given above. In addition, advanced biofuels need to be produced. This diversity of contributing measures needs to be taken into account when developing policies or supporting measures to ensure that the targets are met.

2. In terms of meeting the 2020 targets, and particularly the FQD target, either the GHG intensity of biofuels and/or fossil fuels will need to decrease, or the supply of advanced biofuels will need to increase.

3. Although high blend bioethanol usage is predicted to contribute only little to meeting 2020 targets, its potential for contributing in the future means that it should not be overlooked as a medium term option. The current availability of vehicles compatible with E85 fuel, and experience in Sweden, suggests that E85 flex fuel vehicles could have an important role to play. Vehicle manufacturers are positively engaging with these challenges and opportunities, and the UK government should keep abreast of ACEA's strategy for high blend bioethanol vehicles.

4. Similarly, although biomethane usage is predicted to contribute only little to meeting 2020 targets, its potential for contributing in the future means that it should not be overlooked as a medium term option. Experience in Italy provides evidence as to how (bio)methane fuelled vehicles can make a valuable contribution. It is very unlikely that (bio)methane fuelled vehicles will displace petrol fuelled SI vehicles, but nonetheless they could become an important part of the fleet mix.

This study has focussed on how the further deployment of biofuels could contribute to meeting the RED and FQD targets for road transport in 2020. However, whilst collecting this information the study team also researched barriers to using higher percentage biofuel blends. Some of the barriers are technological challenges, whilst others are more focussed on approaches and policies. These barriers also need to be considered in order for the UK to successfully meet the targets. The key points are as follows:

- The users of biofuels are not willing to pay a significant premium for these types of fuels, i.e. the economics of using higher biofuel blends needs to commercially attractive.
- Vehicle manufacturers require a long term plan/policy that is adhered to because of the time required to design, develop and introduce a new vehicle (or engine) to the market and the duration of the production run that is required to make the whole cycle economically viable.
- Because vehicles are manufactured for European and global markets there should be a harmonised approach across Europe rather than bespoke country-specific biofuel strategies.
- Each vehicle's development cycle requires significant development, and so vehicle manufacturers do not want gradual increases in permitted biofuel blend concentration limits. Bold, but technologically viable step changes that last for at least a decade would be preferred.
- In addition to being able to overcome the economic and engineering challenges, increased biofuel usage also requires users to be able to buy the fuel, i.e. the biofuel distribution and supply infrastructure needs to be in place.

Appendices

Appendix 1: Stakeholders

A list of those organisations contacted in relation to this work is shown below.

AA	IMechE
Abengoa	Inspectorate Ltd
ACFO	International Air Transport Association
Airbus	International Council of Clean Transportation
Airport Operations Association	Iveco Ltd
Allied Biodiesel Industries (UK)	Johnson Matthey
Argent	Joule Vert
Argicultural Industries Confederation	Low CVP
Association of Independent Crop Consultants	Lyondell
Association of Train Operating Companies	Mabanaft
ATOC	MAN
AUKOI	Murco
BA	National Grid
Bentley	NFU
Biomass Engineering Limited	NNFCC
bmi British Midland International	Petroplus
Boeing	PSA Peugeot Citroen
BP	REA
BP Biofuels UK Ltd	Renault
British Chamber of Shipping	Renewable Fuels Agency
British Ports Association	Ricardo
British Sugar	Rix biodiesel
British Transport Association	RMI PETROL RETAILERS ASSOCIATION
Climate Change Mitigation Team Defra	Road Haulage Association
Conoco Phillips	Rolls Royce
DAF	Royal Aeronautical Society
Daimler Chrysler	RSSB
DECC	Scania
DEFRA	Shell
Delphi Diesel Systems	SMMT
Denso	Society of British Aerospace Companies
EBB	Society of British Aerospace Manufacturers
eBio	Tata
Energy Saving Trust	Technology Strategy Board
Ensus	The Anaerobic Digestion and Biogas Association
First Group	Thomson Airways
Food & Environment Research Agency	Toyota
Ford Motor Company Ltd	UKPIA
Forestry Commission	UKSTBA
Freight Transport Association	Vauxhall
Friends of the Earth	Vireol plc
Frontier Agriculture	Virgin Atlantic Airways Ltd
Green Fuels Ltd	Volvo
Green Spirit Fuels	Volvo Trucks
Greenergy	Welsh Automotive Forum
Greenpeace	WRAP
Harvest Energy	WWF

Appendix 2: Quantities of biofuels potentially available and their contribution to meeting the RED and FQD targets

This Appendix looks in more detail at the maximum quantities of biofuels available (based on the Modes 1 central supply scenario and Modes 2 modelling), and their possible contributions towards meeting the RED and FQD targets.

The emphasis is on the types of fuel available (not the crops from which they are made), because the fuel specifications and vehicle capabilities are expressed in terms of maximum permitted quantities of ethanol and FAME (both quantified on a volume/volume basis).

Quantities of biofuels potentially available

The Modes 1 and Modes 2 projects were used to define the quantities of biofuels potentially available. In particular, the following datasets were important:

- Feedstock supply scenarios were taken directly from the Modes 1 project;
- Estimates of the maximum quantities of different biofuels that can be produced from each feedstock in the period between 2010 and 2020 were taken from the Modes 2 model.

These datasets provide for central, high and low, biofuel supply scenarios. For this project the fuels considered were:

- Bioethanol (for blending with fossil petrol);
- FAME (for blending with fossil diesel);
- Biomethane and DME for use with either modified spark ignition (petrol) vehicles or in combination with diesel in compression ignition engined vehicles; and
- Advanced biofuels that can be used instead of petrol or diesel.

The Modes 2 project identified that the amounts of biofuel available by 2020 under each supply scenario, would be as given in Table A2.1.

Table A2.1 Maximum amounts of biofuel available in 2020

	Biofuel supply availability (PJ) for each feedstock supply scenario		
Biofuel types	**Low**	**Central**	**High**
Bioethanol	16	109	110
FAME	46	99	107
Biomethane	82	83	93
DME	2	2	2
Biobutanol	0	0	0
ETBE (scaled by the same factors as bioethanol)	3	22	23
Drop in fuels		**Low 2G**	**Rapid 2G**
FT-Diesel		2	19
HVO-Diesel		12	38
UPO		0	0
Total supply availability		**329 PJ**	**392 PJ**

Quantities of biofuels available for deployment options

Scenarios for FAME

<u>FAME availability</u>	
The supply potential of FAME in 2020 is <u>99 PJ.</u>	
The RTFO baseline (i.e. using B5) would use:	46.4 PJ, (or 47.9 if this extended to rail use)
The current fuel specification (EN590, B7) would use:	65.0 PJ, (or 67.1 if this extended to rail use)
This leaves:	34.0 PJ FAME available for other options
Using all the FAME available in a standard grade would give 10.7% substitution, by volume.	
<u>Note</u>: HVO uses the same feedstock, i.e. increasing HVO availability decreases FAME availability.	

From the options considered those that involve the use of FAME, relative to a baseline scenario of using the B5 as the standard fuel, are:

Overall, the modest amount of unallocated FAME beyond the baseline scenario (around 51 PJ, or 5% of all diesel fuel usage) means that several of the options would require more FAME than is available. Hence, selection of feasible FAME scenarios involve **choosing between the options** rather than selecting all those deemed to be sufficiently cost effective.

Scenarios for bio-ethanol

<u>Bioethanol availability</u>	
The supply potential of bioethanol in 2020 is <u>109 PJ.</u>	
The RTFO baseline (i.e. using E5), would use:	17.3 PJ[12],
The current fuel specification (EN228, E7) would use:	24.2 PJ, (as above)
If future fuel specification permits E10, would use:	34.6 PJ
This leaves:	74.4 PJ FAME available for other options
Using all the bioethanol available in a standard grade would give a 31.5% substitution, by volume.	

Overall, the relatively large amount of unallocated bioethanol beyond the baseline scenario (around 92 PJ, or 17% of all petrol fuel usage) means that from bioethanol supply considerations **all** of the options considered could occur, using less bio-ethanol than all that is available by 2020. (However, some of these options may lead to supply difficulties in the future, e.g. if all new vehicles were required to be able to use E85 by 2020, then bioethanol consumption would rise rapidly after 2020 potentially outstripping supply.) Hence, the selection of feasible bioethanol scenarios involves **prioritising the options,** e.g. using cost effectiveness criteria, rather than choosing between options and considering the impact beyond 2020.

[12] This figure is around 37% of the FAME energy content despite it being for 5% volume replacement of petrol by bioethanol. This reduction is caused by the approximately 40% lower energy content/litre relative to petrol, and the ratio of the energy required from petrol to diesel ratio being around 1 to 2.

Scenarios for bio-methane

<u>**Bio-methane availability**</u>

The supply potential of biomethane in 2020 is <u>83 PJ</u>

Current baseline: The UK only uses a small amount of biomethane each year, 0.013 PJ per year[13]

Biomethane is not blended with petrol, hence no standard grade petrol would use any biomethane and the baseline situation is to presume that no bio-methane is used.

This leaves 83 PJ biomethane available for all options

Overall, as was the case for ethanol, the large amount of available biomethane means that from fuel supply considerations **all** of the options above could occur, using less biomethane than all that is available by 2020 and the selection of feasible biomethane scenarios involves **prioritising the options above,** e.g. using cost effectiveness criteria.

Whereas for FAME and bioethanol there are "advanced" biofuels which use the same raw materials, no advanced biofuels use biomethane as their feedstock. (DME uses wood and wood wastes as its principal feedstock, methanol being commonly referred to as wood alcohol.)

Scenarios for drop-in fuels and second generation fuels for 2020

The supply potential of advanced biofuels in 2020 is <u>36.5 PJ</u> for the central biofuel supply, Low 2G, scenario, rising to <u>80 PJ</u> for the central biofuel supply, Rapid 2G, scenario. Table A2.2 shows a break down of these totals.

Table A2.2 Summary of advanced fuels in the two supply scenarios.

Advanced biofuel	Central biofuel supply, Low 2G, scenario	Central biofuel supply, Rapid 2G, scenario
Biobutanol	0.0 PJ	0.0 PJ
Bio-ETBE (only biofuel component)	22.2 PJ	22.4 PJ
FT Diesel	2.4 PJ	19.1 PJ
HVO	11.9 PJ	38.3 PJ
UPO	0.0 PJ	0.0 PJ
DME	1.8 PJ	1.8 PJ

Contribution of the potentially available biofuels to meeting RED targets

The RED target is defined in terms of the share of **energy** supplied to the transport sector from renewable fuel sources. This differs from the Renewable Transport Fuel Obligation target, which is defined in terms of the **volume of fuel** supplied from renewable sources. As there is a difference between the energy content of biofuels relative to their fossil fuel equivalents on a volume basis, there is not a straight conversion between volume-based biofuel deployment targets and energy-based deployment targets. Consequently, to meet the RED target of 10% renewable energy content using a mixture of petrol and bioethanol would require a petrol/ethanol blend that contains 14.5% ethanol by volume. The difference for FAME is smaller: to meet the 10% energy-based RED target, FAME would need to make up 10.8% by volume of a diesel/biodiesel blend.

[13] Taken from doubling up RFA Quarterly report covering April 2010 – October 2010. This is an increase on the previous year, when the value was 0.008 PJ for the year.

The RED states that "for the calculation of the denominator only petrol, diesel, biofuels consumed in road and rail transport, and electricity shall be taken into account." Article 3 4 (a). The Modes 2 model predicts the liquid fuel component for road and rail transport will be 1,568 PJ. Consequently, 10% renewable content, by energy, is 156.8 PJ.

One subtle amendment to this calculation is given in Article 21 paragraph 2, which states that: "For the purposes of demonstrating compliance with national renewable energy obligations placed on operators and the target for the use of energy from renewable sources in all forms of transport referred to in Article 3(4), the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels."

In the Modes 3 model the biofuels from some sources are single counted, whereas those from others were double counted, as tabulated below

Fuels produced from the list below are single counted when calculating their contribution to the RED	**Fuels produced from the list below are doubly counted when calculating their contribution to the RED**
Wheat	Tallow
Corn	Used oil
Cassava	Micro algae
Sugar cane and beet	Woody energy crops
Rape seed	Straw
Soya bean	Municipal organic waste
Palm oil	Wet manure
Jatropha	

In 2020 this leads to the following amounts of doubly counted biofuel (as a percentage of the biofuel supplied) being calculated within the model as tabulated below.

Fuel	**% of fuel doubly counted**
Bioethanol	0%
Biobutanol	0%
ETBE	0%
FAME	12%
FT-Diesel	100%
HVO-Diesel	12%
UPO	0%
Biomethane	100%
DME	100%

The value of 0% may arise

- either because all the biofuel feedstocks contributing to the biofuel are single counted,
- or because in 2020 none of the fuel is modelled to be available, and consequently no double counting is relevant.

On this basis, the contribution from biomethane and DME is doubled, the contribution from bioethanol is singly counted, and the contribution from FAME is doubled for the quantity of the FAME that originates from used cooking oil and tallow, both waste products.

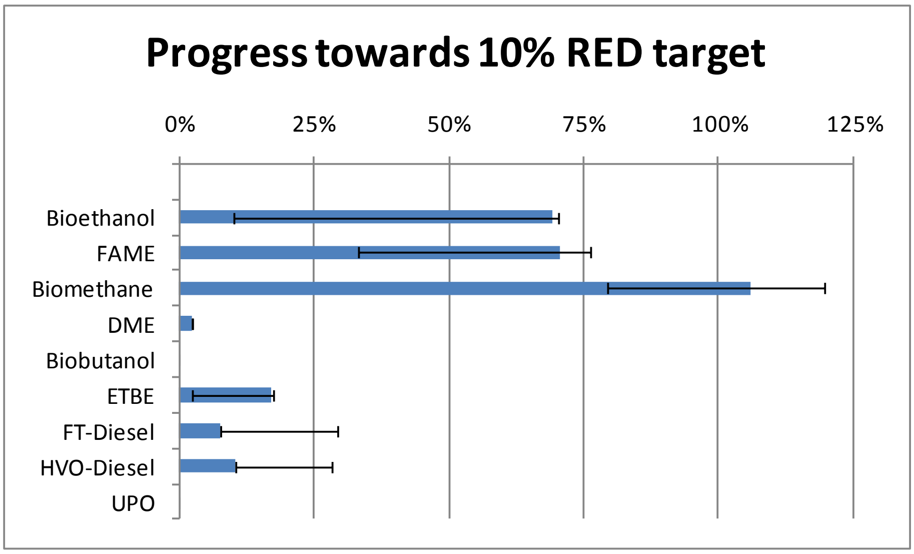
Using these factors, the theoretical maximum contributions to the RED target from the biofuels available under the central supply scenario (in both absolute and percentage terms) are given in Table A2.3.

Table A2.3 Energy supply from different biofuels in 2020 and the potential contribution to the RED target.

Fuels	Biofuel supply availability (PJ)	Energy content for RED accounting (PJ)	Percentage of RED 10% target
Bioethanol	109	109	**69.2%**
FAME	99	111	**70.6%**
Biomethane	83	166	**106.1%**
DME	2	4	**2.4%**
Biobutanol	0	0	**0.0%**
ETBE	22	22	**14.0%**
FT-Diesel	2	5	**3.0%**
HVO-Diesel	12	12	**7.6%**
UPO	0	0	**0.0%**
Total supply potential for 2020	**329**	**430**	**273%**

The theoretical maximum potential contributions to the RED target from each of the fuels included in Table 2 are plotted in Figure A3.1, such that the target is to achieve 100% of the RED target by 2020. The data shown are for the central supply scenario. For bioethanol, FAME and biomethane, the low and high supply scenarios are expressed as asymmetric error bars. The percentage change for ETBE is set to be the same as for bioethanol. For FT-diesel and HVO-diesel, the bars shown are for the central supply scenario with low 2G development, and the error bar to the right shows how this would increase according to the rapid 2G scenario.

Figure A2.1. Energy supply from different biofuels in 2020 and the potential contribution to the RED target



Comments on this figure:

- Using all of the available bioethanol or FAME alone would not meet the RED target but together they could exceed it by around 40%.
- Whilst the maximum supply of biomethane exceeds the RED target, the limit on its usage in road transport is not the supply of biofuel, but the capability of the existing fleet, the availability

and potential future deployment of new vehicles capable of using biomethane, and the immaturity of the infrastructure. Overall, the contribution from biomethane is expected to be small.

- The theoretical maximum contribution from advanced diesel-type biofuels is around 10% of the RED target (1% by total energy) for the low second generation (L2G) fuel supply scenario. This could rise to more than 20% of the RED target for the Rapid 2G (R2G) fuel supply scenario.
- Other biofuels such as ETBE and DME could also contribute to meeting the RED target. These fuels are theoretically capable of providing up to 20% of the bioenergy deployment required to meet the 2020 RED target.

Contribution of the potentially available biofuels to meeting FQD targets

Whilst the RED target specifies that 10% by energy content of transport fuels should be sourced from sustainable[14] renewable sources, the Fuel Quality Directive (FQD) requires a 6% reduction in the life-cycle GHG intensity of transport fossil fuels relative to a baseline figure. .

The EC has consulted on a baseline figure, and it appears likely that the value that will be used will be 86.4 gCO_{2eq} /MJ or a value close to this. The impact of changing to a lower baseline number is considered in the sensitivity analysis presented in Section 3.4 of the main report.

Key assumption

For the purposes of this study, the EC fossil fuel baseline GHG intensity has been set at 86.4 gCO_{2eq}/MJ. This means the 6% reduction for the FQD target would give a resultant GHG intensity of 81.2 gCO_{2eq}/MJ.

The methodology used in this study to quantify the effect on GHG intensity of deploying a specific quantity of a biofuel was to:

i. Consider the GHG emissions of the fossil fuel that the biofuel would replace;
ii. Subtract the life-cycle GHG emissions of the biofuel, and thereby calculate the reduction in GHG emissions relative to a baseline that is purely fossil fuel based.

A EUCAR, CONCAWE JRC lifecycle analysis, and other data that fed into the biofuels model developed for the Modes 2 project, give life-cycle (well-to-wheels) GHG emission factors of 88.97 and 83.19 gCO_{2eq}/MJ for diesel and petrol, respectively. The average of these, weighted by the diesel to petrol fuel use in 2010 gives baseline GHG emissions of 86.4 gCO_{2eq}/MJ. However, by 2020 the anticipated increased relative use of diesel fuel in transport, would give a weighted average of 87.0 gCO_{2eq} /MJ.

The GHG emissions for the various fossil fuels, and the biofuels that might replace them, are given in Table 4 below. The FQD introduces a mechanism for monitoring and reducing life cycle greenhouse gas emissions from production (well) to final use (wheel) (WTW) for different fuels. Reductions occur for biofuels dependent on their relative WTW greenhouse gas emissions relative to the fossil fuel they replace. Table 4 contains the WTW GHG emissions for fossil fuels, the first two columns, and the current WTW GHG emissions of biofuels that might replace them, the third and fourth columns, per unit energy. The reduction in GHG emissions, expressed as a percentage of the original fossil fuel GHG emissions, are given in the fifth column for each biofuel.

During the stakeholder consultation it was opined that the current biofuel WTW greenhouse gas emissions might be unduly pessimistic in the future. For example, by changing the feedstocks used to supply process energy, the greenhouse gas emissions from the manufacture of bioethanol could further reduce from providing a current reduction of 63% to a future reduction of 80%. These "stretched" reductions are given in the final column of Table 4 below, and are discussed further in the sensitivity analysis, detailed in Section 3.5 of the main report.

[14] as defined in the Directive. From 2017 this must lead to at least a 50% reduction in GHG emissions for its life cycle, relative to a fossil fuel equivalent.

Table A2.4 The GHG emissions for fossil fuels and biofuels

Fossil fuel	WTW[15] GHG intensity gCO_{2eq}/MJ	Replacement biofuels	WTW GHG intensity gCO_{2eq}/MJ	For FQD target, reduction in GHG intensity: Current	Stretched
Fossil fuel petrol	83.19	Bioethanol	30.88	63%	80%
		Biobutanol	34.84	58%	N/A
		ETBE	63.44	71%	80%
Fossil fuel Diesel	88.97	FAME	36.91	59%	80%
		FT-Diesel	6.15	93%	93%
		HVO-Diesel	34.31	61%	80%
		UPO	29.49	67%	N/A
Petrol or diesel		Biomethane	12.81	86%	86%
		DME	5.97	93%	93%

N/A used when fuel supply is so low that it is changing GHG intensity makes no difference.

For the maximum amounts of biofuels available in 2020 (given in Table 1) and the GHG emissions data (given in Table 4) the changes in GHG emissions are given in Table A2.5.

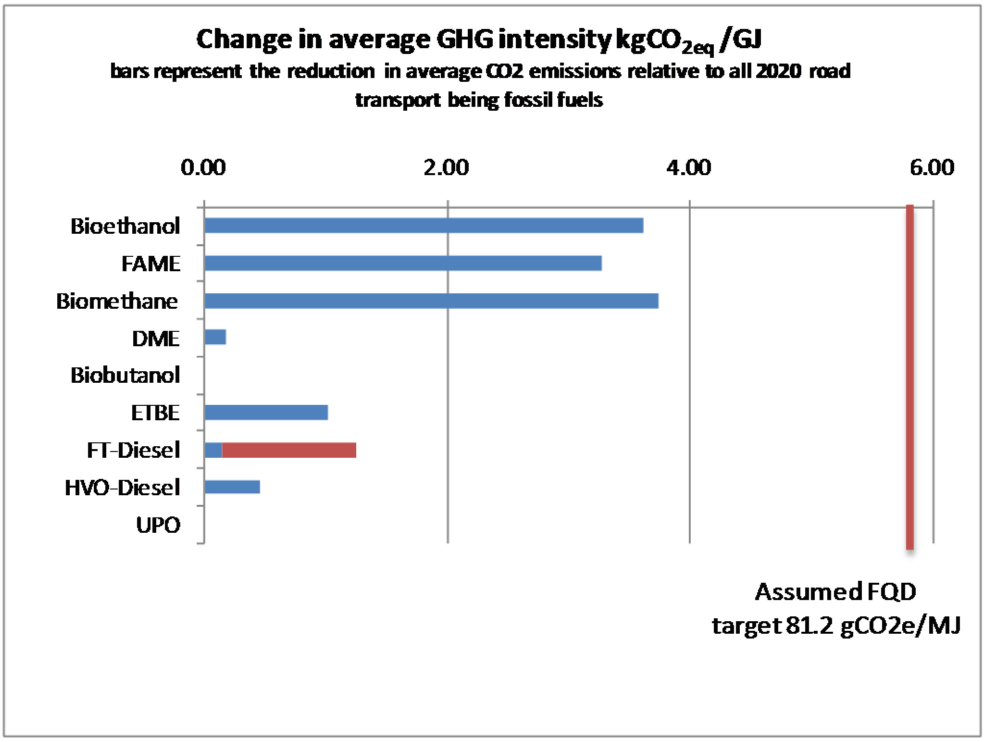
Table A2.5: Maximum potential energy supply from different biofuels in 2020 and the potential contributions to the FQD target.

Biofuel	Quantity of fuel available PJ	Change in average GHG intensity gCO_{2eq} /MJ	Number of MJ towards RED target for each MJ used	CO2 emissions reduction (g CO2/MJ)
Bioethanol	109	-3.67	1.000	52.31
FAME	99	-3.32	1.121[16]	52.06
Biomethane	83	-3.78	2.000	76.16
DME	2	-0.09	2.000	83.00
Biobutanol	0	0	0	0
ETBE	81	-1.03	0.333	19.75
FT-Diesel	2.6	-0.14	1.000	82.82
HVO-Diesel	13	-0.46	1.000	54.66
UPO	0	0	0	0
Total potential for 2020	**390**	**-12.49**		

The maximum theoretical contributions of the various biofuels to reducing the GHG emissions relative to the projected 2020 fossil fuel only starting point are shown in Figure A3.2. The maximum contribution each fuel could make to reaching the 81.2 gCO_{2eq} /MJ FQD target is also shown.

[15] WTW = Well to wheel, full life cycle analysis
[16] This is a weighted average because some feed stocks are double counted, whereas others are not.

Figure A3.2 Energy supply from different biofuels in 2020 and the potential contribution to the possible FQD targets



Comments on this figure:

- Using neither bioethanol nor FAME alone would meet the FQD target but together they could exceed it by around 20%.
- Whilst the maximum supply of biomethane towards the FQD target is similar to that for FAME and bioethanol, around 80% of the target. As was discussed in relation to meeting the RED target, the limit on its usage in road transport are barriers concerning the existing fleet, new vehicles and infrastructure. As before, the contribution from biomethane is expected to be small.
- The contributions of these three main first generation biofuels to the FQD target is less than their contributions to the RED target. It follows that meeting the FQD target will be more challenging than meeting the RED target.
- As was noted for the RED target, there is a sizeable potential contribution from advanced biofuels to meeting the FQD target, both those that could potentially replace petrol, and the drop-in diesel replacements.

Conclusions from considering the potentially available biofuels and the targets to be met

1. Whilst the RED target is unequivocally defined, the FQD target is not defined pending the definition of the fossil fuel baseline GHG intensity value from which reductions in greenhouse gas emissions are measured.
2. Based on findings from the Modes 2 study, the potential supply of biofuels to the UK transport sector under the central supply scenario is sufficient to meet the 2020 RED target, and probably the FQD target. Meeting the FQD target will be more challenging than meeting the RED target.

3. FAME biodiesel and bioethanol are anticipated to be the most significant types of biofuels deployed in the UK road transport sector. However, the supply of neither is sufficient to meet the RED target (nor the FQD target) on its own.
4. Meeting both the RED and FQD targets will require using combinations of biofuels, e.g. FAME + bioethanol + 2-G drop-in fuels + others.
5. Biomethane appears very attractive in terms of the supply against the RED target (due in part to its contribution counting as double since they originate from waste residues), but its current use in road transport is minimal. Also, there are both vehicle capability and infrastructure barriers to be overcome before its use becomes high.

Appendix 3 – Determination of the fuels supplied through depots and forecourts

In order to evaluate biofuel supply scenarios where depot fuelled vehicles are provided with different blends to that provided on filling station forecourts, the apportioning of fuel supplied to different vehicle types through depots has been estimated. A summary of the analysis is presented here with the details of how these conclusions were reached being given in Appendix 1.

Two different approaches were used:

Bottom up approach where the characteristics of each group of vehicles, its ownership and its usage were considered to derive the proportion of this vehicle group that it is estimated are depot fuelled, and

Top down approach using data from the Digest of UK Energy Statistics (DUKES) on the portion of inland deliveries of road fuel to forecourts, supermarkets and companies.

Conclusions from the bottom up approach

Petrol

To a first approximation it is assumed no petrol is supplied by depots because of the small number of petrol fuelled company cars, safety issues regarding the bunkering of petrol and the increasing use of fuel cards.

Diesel

A very significant bunkering of diesel occurs. The estimates of the fraction of fuel supplied at depots for the various different types of road vehicles which use diesel fuel is summarised in Table A3.1. Overall, this estimates that **34.5%** of diesel road fuel is supplied via depots.

Table A3.1 Summary of the bottom up analysis

Vehicle type	Estimate of fraction supplied at depots	Fraction of total diesel fuel used in 2008 (from national GHG emissions inventory
Cars	2%	34.1%
Vans	25%	22.5%
Artic trucks	80%	18.9%
Rigid trucks	45%	17.1%
Buses	90%	4.8%
Coaches	40%	2.6%
TOTALS		**100%**

Conclusions from the top down approach

The Digest of UK Energy Statistics (DUKES) contains the authoritative data on UK petroleum products[17]. Table 3.6 from this publication, “Commodity Balances for 2008”, contains data on inland deliveries of selected petroleum products. For 2008, the DUKES data indicates that for diesel (DERV), **37.6%** (i.e. 7,743 ktonnes) of a total of 20,614 ktonnes of fuel were delivered to depots. This figure compares reasonably well with the overall total of 34.5% from the bottom up analysis and indicates that the data in Table 6 is probably a slight underestimate. Overall, the data included in Table 6 forms an evidence-based starting point for the quantification of options involving depot fuelled vehicles.

[17] Data available from : http://www.decc.gov.uk/en/content/cms/statistics/publications/dukes/dukes.aspx

Appendix 4 – Performance of individual options against RED/FQD targets and cost effectiveness

Cost effectiveness results

The tables below summarise the individual cost effectiveness results for the options considered under each of the four overarching deployment scenarios.

The table lists the **marginal** costs, **marginal** bioenergy deployment and **marginal** GHG abatement relative to the baseline scenario. Each of these parameters is calculated over the lifetimes of vehicles. From these the cost effectiveness, both in units of £/GJ bioenergy deployed and £/tCO_2e abated, are calculated. Hence these are the marginal cost effectiveness values relating to the lifetime of the vehicle.

The baseline corresponds to a scenario with an evolving fleet that uses standard fuels containing 5% (by volume) of bioethanol or FAME (i.e. fuels meeting the RTFO targets) from 2014 onwards. For the calculations it is assumed that the biofuels are made from a realistic feedstock scenario appropriate to meeting this biofuel volume requirement.

The six columns on the right hand side of the table contain data for 2020 only. They list the bioenergy deployed (PJ) and the greenhouse gas abatement (ktCO_2e) in 2020 for each specific scenario relative to the baseline (i.e. assuming only E5 and B5 fuels were used). The contribution to meeting the RED target (%) and the well-to-wheel greenhouse gas intensity (gCO_2e) in 2020 are calculated, together with their change from the baseline value. From changes in the well-to-wheel greenhouse gas intensity, progress to meeting the FQD target can be calculated.

Table A4.1 Model Baseline

Description	Cost Effectiveness (£/GJ Bioenergy Deployed)	Cost Effectiveness (£/tCO2e Abated)	Costs (£m)	Bioenergy Deployment (PJ)	GHG Emissions (ktCO2e)	2020 Bioenergy Deployment (PJ)	2020 GHG Emissions (ktCO2e)	2020 RED (%)	2020 RED - Change from Baseline (%)	2020 GHG Emissions (gCO2/MJ)	2020 Change in GHG emissions from Baseline (gCO2/MJ)
Baseline	-	-	452,020	1,330	4,466,700	60	211,170	4.46%		84.90	

Table A4.2 Option Group Involving Changes to Depot Fuelling

Description	Cost Effectiveness (£/GJ Bioenergy Deployed)	Cost Effectiveness (£/tCO2e Abated)	Marginal Costs (£m)	Marginal Bioenergy Deployment (PJ)	Marginal GHG Abatement (ktCO2e)	2020 Bioenergy Deployment (PJ)	2020 GHG Abatement (ktCO2e)	2020 RED (%)	2020 RED - Change from Baseline (%)	2020 GHG Emissions (gCO2/MJ)	2020 Change in GHG emissions from Baseline (gCO2/MJ)
Depots use B30 for compatible LCVs; standard grade for incompatible LCVs	33	655	1,730	50	2,600	< 5	130	4.64%	0.18%	84.81	0.08
Depots use B30 for compatible rigid HGVs; standard grade for incompatible rigid HGVs	17	328	1,170	70	3,600	< 5	200	4.75%	0.28%	84.77	0.13
Depots use B30 for compatible coaches; standard grade for incompatible coaches	16	319	110	10	300	< 5	20	4.49%	0.03%	84.88	0.01
Depots use B30 for compatible buses; standard grade for incompatible buses	15	298	310	20	1,000	< 5	60	4.55%	0.09%	84.86	0.04
Depots use B30 for compatible articulated HGVs; standard grade for incompatible articulated HGVs	16	313	2,050	130	6,600	10	360	4.96%	0.50%	84.67	0.23
Depots use B100 for compatible rigid HGVs; standard grade for incompatible rigid HGVs	7	131	2,550	390	19,500	20	1,010	5.87%	1.41%	84.24	0.65
Depots use B100 for compatible articulated HGVs; standard grade for incompatible articulated HGVs	7	145	3,550	480	24,500	30	1,380	6.39%	1.92%	84.00	0.89
Depots use B100 for compatible coaches; standard grade for incompatible coaches	6	126	2,380	370	18,900	20	970	5.82%	1.36%	84.27	0.63
Depots use B100 for compatible buses; standard grade for incompatible buses	6	127	2,450	380	19,300	20	990	5.85%	1.38%	84.25	0.64
Biomethane LCVs (bi fuel) in captive fleets from 2015	7	106	160	20	1,500	< 5	110	4.65%	0.18%	84.82	0.08
Biomethane rigid HGVs (bi fuel) in captive fleets from 2015	6	81	330	60	4,100	< 5	240	4.86%	0.40%	84.73	0.17
Biomethane coaches (bi fuel) in captive fleets from 2015	4	57	10	< 5	200	< 5	10	4.48%	0.02%	84.89	0.01
Biomethane buses (bi fuel) in captive fleets from 2015	5	67	80	20	1,200	< 5	70	4.58%	0.12%	84.85	0.05
Biomethane articulated HGVs (dual fuel) in captive fleets from 2015	5	78	110	20	1,400	< 5	110	4.66%	0.19%	84.82	0.08

Table A4.3 Option Group Involving Changes to Mainstream Fuel Blends and Mainstream Vehicles

Description	Cost Effectiveness (£/GJ Bioenergy Deployed)	Cost Effectiveness (£/tCO2e Abated)	Marginal Costs (£m)	Marginal Bioenergy Deployment (PJ)	Marginal GHG Abatement (ktCO2e)	2020 Bioenergy Deployment (PJ)	2020 GHG Abatement (ktCO2e)	2020 RED (%)	2020 RED - Change from Baseline (%)	2020 GHG Emissions (gCO2/MJ)	2020 Change in GHG emissions from Baseline (gCO2/MJ)
Standard grade increases to E10 for petrol fuel by 2015, then remains constant	4	73	1,120	300	15,300	20	930	5.61%	1.14%	84.30	0.60
Standard grade increases to B7 for diesel fuel by 2015, then remains constant	7	131	1,910	290	14,600	20	970	5.82%	1.35%	84.27	0.63
B7 becomes standard grade diesel by 2015; B30 available for use by those cars that are B30 compatible (9%)	10	188	4,080	430	21,700	20	1,140	6.06%	1.59%	84.16	0.74
B7 becomes standard grade diesel by 2015; B30 available for use by those vans that are B30 compatible (20%)	11	209	4,550	430	21,800	20	1,150	6.06%	1.60%	84.15	0.74
All new cars to market are E20 compliant by 2015	5	91	1,900	400	20,700	20	930	5.61%	1.14%	84.30	0.60
All new cars to market are E20 compliant by 2015; in addition E15 available at 30% of pumps in 2020	5	89	2,050	440	23,000	20	1,200	5.95%	1.49%	84.12	0.78
10% of new cars to market are E20 compliant by 2015, rising to 100% by 2020; in addition E20 available at 30% of pumps in 2020	4	84	1,440	330	17,200	20	1,040	5.75%	1.28%	84.23	0.67
Biomethane van sales reach 10% by 2020	7	109	500	70	4,600	10	350	4.97%	0.50%	84.64	0.25

Table A4.4 Option Group Involving Use of E85 ('Combined')

Description	Cost Effectiveness (£/GJ Bioenergy Deployed)	Cost Effectiveness (£/tCO2e Abated)	Marginal Costs (£m)	Marginal Bioenergy Deployment (PJ)	Marginal GHG Abatement (ktCO2e)	2020 Bioenergy Deployment (PJ)	2020 GHG Abatement (ktCO2e)	2020 RED (%)	2020 RED Change from Baseline (%)	2020 GHG Emissions (gCO2/MJ)	2020 Change in GHG emissions from Baseline (gCO2/MJ)
Flex-fuel (E85) vehicles account for 2% sales in 2020 (low penetration)	4	76	1,210	310	16,000	20	950	5.64%	1.17%	84.28	0.61
Flex-fuel (E85) vehicles account for 5% sales in 2020 (high penetration)	4	80	1,330	320	16,800	20	980	5.67%	1.21%	84.27	0.63
All new vehicles from 2020 required to be flex-fuel, 30% of pumps E85 by 2020	6	113	4,510	770	40,000	40	1,850	6.75%	2.29%	83.70	1.20

Table A4.5. Option Group Involving Advanced Biofuels

Description	Cost Effectiveness (£/GJ Bioenergy Deployed)	Cost Effectiveness (£/tCO2e Abated)	Marginal Costs (£m)	Marginal Bioenergy Deployment (PJ)	Marginal GHG Abatement (ktCO2e)	2020 Bioenergy Deployment (PJ)	2020 GHG Abatement (ktCO2e)	2020 RED (%)	2020 RED - Change from Baseline (%)	2020 GHG Emissions (gCO2/MJ)	2020 Change in GHG emissions from Baseline (gCO2/MJ)
L2G Deployment of biobutanol	-	-	0	0	0	0	0	4.46%	0.00%	84.90	0.00
L2G Deployment of bioETBE	< 0.5	3	20	290	8,100	20	590	5.18%	0.72%	84.51	0.38
L2G deployment of FT diesel	7	68	210	30	3,100	< 5	220	5.21%	0.75%	84.75	0.14
L2G deployment of HVO diesel	7	114	1,050	160	9,200	10	670	5.51%	1.04%	84.47	0.43
L2G deployment of DME to rigid HGVs	18	186	540	30	2,900	< 5	150	4.84%	0.37%	84.79	0.11
L2G deployment of DME to buses	18	115	150	10	1,300	< 5	60	4.74%	0.28%	84.85	0.04
L2G deployment of DME to coaches	17	62	60	< 5	900	< 5	40	4.72%	0.25%	84.87	0.03
R2G deployment of FT diesel	6	73	1,540	250	21,200	20	1,610	7.39%	2.92%	83.86	1.04
R2G deployment of HVO diesel	6	120	3,260	500	27,200	40	2,070	7.29%	2.82%	83.56	1.34

AEA

The Gemini Building
Fermi Avenue
Harwell
Didcot
Oxfordshire
OX11 0QR

Tel: 0870 190 1900
Fax: 0870 190 6318

www.aeat.co.uk