European Commission

Impact of higher levels of bio components in transport fuels in the context of the Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998, relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC

Final report

October 2015

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Luxembourg: Publications Office of the European Union, 2017

PDF ISBN 978-92-79-68989-5 doi:10.2834/153655 ML-02-17-580-EN-N

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A report submitted to:
European Commission
Directorate-General for Climate Action
Unit C.2: Transport and Ozone
Brussels, B-1049

Ref: 340201/2014/692408/SER/CLIMA.C.2 under Framework Contract No CLIMA.C.2/FRA/2012/0013 LOT 1

A report submitted by ICF Consulting Limited

Date: 29 October 2015

Job Number: 088594

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Document Control

Document Title	Impact of higher levels of bio components in transport fuels in the context of the Direction 98/70/EC of the European Parliament and of the Council of 13 October 1998, relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC
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Executive summary

The overall objective of this study is to undertake an economic and environmental analysis of the impact of increasing the limits of the bio-content of petrol and diesel imposed by the FQD, and beyond 2020.[1] In particular, for specific biofuel blends identified in the study, the assessment considers both their positive and negative impacts associated with:

- Biofuels policies, market capacity, distribution of fuels, availability and origin of bio-content;
- Vehicle technology, in particular engine efficiency, tail pipe emissions, biofuel compatibility and fuel use in existing and future vehicle fleets and possible evolution of automotive technology;
- Air quality;
- Greenhouse gas emissions;
- Effect on the refinery sector; and
- Any impact on the current market shares of the fuel mix (diesel vs. petrol) and possible induced changes in Europe.

The findings of this work will provide input to the Commission when considering implications of increasing the bio-content level in transport fuels.[2]

The following presents a summary of the key findings from the study.

Biofuel policies and market capacity

Biofuel consumption is almost fully policy driven, with large variations between Member States

At the EU level, the main drivers are the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). The RED sets a binding 10% target (energy content) for renewable energy in transport in 2020; the FQD sets a reduction target for the GHG intensity of fuels of 6%, in 2020. The FQD also defines blending limits for FAME and ethanol (Chapter 1, Section 1.3.2.2), limiting the share of FAME in diesel to 7 vol% (6.4% energy content) and the share of ethanol in petrol to 10 vol% (6.8% energy content).[3] Both directives define sustainability criteria that biofuels have to meet to count towards both targets, the RED furthermore regulates that biofuels from waste and residues count double towards the 10% target. Recently, the Indirect Land Use Change (ILUC) Directive (Chapter 1, Section 1.3.2.3) has been adopted by the Council at second reading and is likely to enter into force in late 2015. Under this Directive there will be a cap on the contribution that biofuels from food crops and some energy crops can make to targets in the RED at 7%[4] of transport energy. Member States will also be required to set a target for advanced biofuels with a reference value of 0.5%. Furthermore, the multiplication factors for electricity from renewable sources are increased, from 1 to 2.5 for the energy consumed in electrified rail transport, and from 2.5 to 5 for renewable electricity use in road transport.

At the Member State level, by 2014, almost all, with the exception of Latvia, Cyprus and Estonia, had implemented biofuel obligations (quotas) for fuel suppliers (Chapter 1, Section 1.3.3.1). However, the level of these obligations varies significantly between countries, from an average target of less than 3% in Croatia and Greece, to 7% or higher in France, Poland and Slovenia. The majority of Member

[1] Taking also into account certain recent policy developments such as the 2030 framework for climate and energy policies including COM(2014) 15 final

[2] The objective of the study in not an impact assessment or exploration of concrete alternative policy options but an assessment of the implications of (hypothetical) changes to the blending limits in the current fuel specification

[3] These limits are termed B7 and E10 respectively, with the letter referring to either biodiesel or ethanol and the number referring to the vol% limits.

[4] In the remainder of this document, all biofuel shares will be expressed in terms of energy content, unless explicitly indicated (vol%, to indicate a share in volume)

States are relying on blending or GHG reduction obligations to increase supply and demand of biofuels to meet their 2020 targets. This has reduced the need to also provide financial incentives. As such, only approximately half of EU Member States have implemented tax incentives (Chapter 1, Section 1.3.3.2), which differ based on the blend type (e.g., six Member States offer incentives for blends within the blending limit; while others focus on high blends), and incentive level.

There is still a lot of potential to further increase biofuel sales within the current blend limits defined by the FQD (B7, E10)

The FQD blending limits have not been an issue in many Member States yet, as most biofuel obligations are still below these limits (Chapter 1, Section 1.4.3.1). The average share of biodiesel in diesel in 2013 was 5.2%, which is still well below the blend limit B7, which equates to 6.4% FAME in energy content. However, this average encompasses Member States, such Austria, Bulgaria, Denmark, France, Poland and Portugal, who already consume more biodiesel than B7, as well as several Member States that can still add two or more percent of FAME to their diesel within the limit. Consequently, biodiesel sales can be increased within the current blending limits. For ethanol, shares are still relatively limited in almost all Member States. Currently, most Member States only have E5 petrol grades on their market; the average ethanol content in the EU is 3.4%, compared to the 6.8% limit of E10. There is still a lot of potential to further increase ethanol sales within the current blending limits, if all Member States would introduce E10. However, only three Member States (Finland, France and Germany) have introduced it so far. To increase blending levels to FQD limits or introduce a new higher blend such as E10, Member States will be required to provide additional incentives or to increase the obligations (Chapter 1, Section 1.3.4.1).

Policy uncertainties result in a lack of clarity about how demand for biofuels will develop throughout the EU until 2030.

The Indirect Land Use Change (ILUC) Directive, which enters into force in the second half of 2015 will have implications for future Member State biofuel policies and biofuel demand (Chapter 1, Section 1.6.1). The ILUC provisions will encourage the biofuel sector to move from biofuels from food crops to biofuels from waste, residues, ligno-cellulosic biomass, algae, etc. This shift towards double-counting biofuels,[5] as well as the increased contribution of electricity from renewable sources towards the target, could result in lower biofuel consumption than that expected in Member State National Renewable Energy Action Plans (NREAPs).

However, the extent of these two effects is uncertain, as the ILUC Directive leaves room for Member States to continue to support food-based biofuels (it only restricts their counting towards the RED target), and the cap does not apply to the FQD. Furthermore, Member States may set a national target for advanced biofuels lower than the 0.5%,[6] provided this decision is well-founded.

Beyond 2020, there is even more uncertainty as the EU's 2030 energy and climate package does not yet provide details about renewable energy in transport policies for 2030, although the Commission's proposal (COM (2014) 15 final)[7] does state that first generation biofuels should have a limited role in decarbonising the transport sector. In the recent Energy Union Package, it was announced that the Commission will propose a new Renewable Energy Package in 2016-2017, which will include a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU renewable energy target is met cost-effectively.

From the EU Energy Roadmap 2050 (COM(2011) 885/2) and the EU White Paper 'Roadmap to a Single European Transport Area' (COM(2011) 144), it can be concluded that, when these documents were prepared in 2011, an increase of biofuels use had been expected to contribute to longer term EU and Member State climate goals.

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[5] Advanced biofuels and other waste biofuels are double counted towards the 10% target for renewable energy in transport in 2020 (a feature which already applied in the RED).

[6] A sub-target for advanced biofuels with a reference value of 0.5% has been introduced in the ILUC Directive.

[7] A policy framework for climate and energy in the period from 2020 to 2030; COM (2014) 15 final.

Fuel distribution impacts

The introduction of higher blends will require ‘protection grades’, but this will have cost implications for fuel distributors

When new blends or fuel grades such as E20 or B10 are to be introduced on the fuel market, they cannot just replace the current E5/E10 or B7, as a large share of the current vehicle fleet is not compatible with these new fuels. The current blends need to remain available throughout the EU as ‘protection grades’ for many years, until the non-compatible vehicles are phased out of the market (Chapter 1, Section 1.4.4).

The stakeholders in the fuel market (i.e., fuel suppliers, distributors and owners of retail stations) will then have the following options:

a. introduce the new blend by replacing an existing fuel grade that they offer;

b. invest in expanding the existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics, and add the new blend to their existing portfolio; or

c. not introduce the new blend, i.e. maintain their current fuel grade portfolio, and wait until market demand for the new blend is sufficient to warrant replacing one of their existing fuel grades

The cost and benefits of these three options, and therefore the optimal choice for a specific stakeholder, may depend on the specific situation of the filling station: the number of grades they sell and their market shares, whether or not they have the (physical and financial) possibilities to expand their infrastructure (e.g., invest in new (subsurface) fuel tanks, pumps, fuel piping, etc.). Since fuel markets in different Member States can have various ownership structures, ranging from Germany, Greece, Italy which are dominated by a limited number of major companies, to Poland and the UK where independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales, consideration is required for potential market distortion effects (Chapter 1, Section 1.4.4.1). For example, if one retailer has the opportunity to add a new blend with limited cost, a smaller competitor, with one fuel grade and insufficient means to invest, will likely lose market share to the larger competitor.

Higher biofuel blends may cause a number of technical issues that need to be resolved before roll-out, to ensure fuel quality and prevent technical issues in the fuel supply chain.

Higher ethanol blends can cause issues in tank systems through the supply chain from depot to petrol station (Chapter 1, Section 1.4.5.2). Costs to resolve these issues increase with increasing shares of ethanol.

Aging of higher FAME blends may lead to fuel quality control issues throughout the fuel chain, such as filter plugging, corrosion, durability problems and deposit formation (Chapter 1, Section 1.4.5.2). The aging rate is strongly dependent on storage conditions, and so could be compounded by a low uptake by the market, for example if a higher FAME blend is introduced at service stations with low throughput, or if there are not sufficient compatible vehicles available. Research in this area has been limited to date, so further research is required to understand and possibly resolve these issues before roll-out.

Information provision and strategic price setting will be important to encourage customers to buy higher biofuel blends.

Consumer acceptance and willingness to buy is crucial to successfully introducing a new biofuel blend or fuel grade at filling stations successfully (Chapter 1, Section 1.4.6.1). The different experiences with introducing E10 in Finland, France and Germany illustrate that consumer acceptance is important: in Germany, low consumer acceptance proved to be a significant barrier, resulting in much lower market shares, while Finland and France were the opposite as extensive effort was made to list E10 compatible vehicles, clearly label pumps and actively inform consumers using promotional literature.

The higher price of biofuels results in a higher price of fuels that contain higher biofuel shares (‘high blends’), but this does not have to be a barrier to the sales of high blends (Chapter 1, Section 1.4.6.3).

Effective biofuel policies such as a biofuel obligation or tax incentives can provide sufficient incentives for fuel suppliers to sell these fuels despite the higher cost.

Biofuel availability and origin

Even with a 7% cap on first generation biofuels (ILUC Directive) in 2030, the maximum potential of the current blending limits (B7/E10) could still be achieved by these biofuels only.

In 2013, only 43% of the EU's biodiesel production capacity was actually used, along with 44% of biopetrol capacity (mainly ethanol) (Chapter 1, Section 1.6.2.2). More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, while 44% of the biopetrol production capacity located in France, Germany and the UK. Current European biodiesel production capacity is already sufficient to meet the 2020 demand, as predicted by the NREAPs. EU Biopetrol capacity can only meet 80% of the supply that Member States expect for 2020; however, since Member States are likely to use imports to fill the gap, the current capacity can be considered sufficient to meet the (remaining) demand (Chapter 1, Section 1.6.2.2).

Due to the current uncertainties regarding EU and Member State policies after 2020, projecting the demand for biofuels in 2030, at this point in time, is highly uncertain. However, based on EU-forecasts for road transport energy demand in 2030, it is estimated that if the current FAME and ethanol blend levels (B7 and E10) still apply in 2030, they would allow blending of 11.8 million tonnes (Mton) FAME and 7.0 million tonnes of oil equivalent (Mtoe) ethanol. The ILUC Directive places a 7% cap on the contribution that first generation biofuels[8] can make to RED targets; however, this would still equate to about 20.3 Mtoe of biofuels. Consequently, the maximum potential of the current blending limits (B7/E10) could still be achieved, without exceeding the ILUC cap. (Chapter 1, Section 1.6.3.2).

Current EU biopetrol production is first generation; advanced[9] biopetrol generation capacity still very limited. Current biodiesel production capacity can be used to produce FAME from plant oils and from waste and residues, but not for advanced biodiesel production.

Without policies for 2030, such as a cap on biofuels from food crops and a target for advanced biofuels, first generation will continue to dominate and there is continued uncertainty about whether more advanced routes will reach large-scale, commercial application in the future, and by when they could be expected. In the EU, the developments of advanced biofuel processes are supported by EU-level R&D funding (e.g., Horizon 2020 and the NER 300 programmes, the European Biofuels Technology Platform (EBTP)), but the R&D route from smaller scale to large scale application can take many years and even decades (Chapter 1, Section 1.6.3).

Biofuels are more costly than fossil fuels, and will remain more costly at least until 2025/2030 and possibly even longer.

The cost of biofuels that consumers have to pay, the retail prices, typically consist of cost of the biofuels itself (incl. cost of feedstock, oil price, production and distribution), taxes and excise duties. Import tariffs can also impact the cost of biofuels. It is estimated that the cost of rapeseed FAME is approximately 65% higher than that of conventional diesel. Similar ratios were found for the cost of ethanol from EU wheat or sugar beet, compared to petrol. In practice, prices of biofuels and fossil fuels vary significantly over time, but it is predicted by that biofuels will remain more costly at least until 2025/2030 (Chapter 1, Section 1.6.5). Advanced biofuels are more expensive than conventional biofuels, and this is expected to remain the case in the future.

[8] First generation biofuels refer to the fuels that have been derived from food crops.

[9] Advanced biofuels are those produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams.

Development of possible biofuel scenarios to 2030

Four hypothetical scenarios were developed to describe the potential development of biofuel demand to 2030. These scenarios form the basis of the analysis into air quality, carbon emissions, refinery and fuel supply impacts

There is still significant uncertainty about biofuel policy development to 2030, both at the EU and Member State level. The development of biofuel demand is therefore difficult to predict. However, based on findings from the analysis, four hypothetical scenarios have been developed (Chapter 1, Section 1.7.3):

- The Base Case scenario assumes that the energy content of biodiesel (FAME/HVO) and ethanol in 2013 (i.e., 5.2% and 3.4%, respectively), will not change through 2030.
- Scenario A assumes a full use of the biofuel blend limits of FAME and ethanol in the EU by 2020, and assumes there is no need for Member States to resort to higher blends; i.e., the blending limits remain constant at B7 and E10 through 2030.
- Scenario B assumes further growth of FAME and ethanol demand in the EU beyond 2020, and accommodates that with an introduction of B10 and E20 from 2020 onwards. B7 and E10 would remain available throughout the EU as protection grades, at least until 2030.
- Scenario C assumes an even stronger growth of FAME and ethanol demand in the longer term (2025-2030) than scenario B. Limitations due to biofuel availability also apply in this scenario, but these are assumed to be resolved after 2025. It assumes that B10 and E25 are introduced from 2020 onwards, B7 and E10 would remain available throughout the EU as protection grades, at least until 2030. In addition, a standard for B30 will be introduced, to be used in captive fleets only.

These scenarios form the basis for the analysis conducted into the potential impacts of higher biofuels on air quality, carbon emissions, the refinery sector, and fuel supply.

Vehicle technology

Increased use of higher biofuel blends would not impede future engine technology and some blends may be helpful in enhancing technology performance.

With the aim of improving fuel economy, petrol engine technology is expected to progress along two pathways in the future: 1) increased turbocharger boost with engine downsizing; and 2) use of very high compression ratios (Chapter 2, Section 2.3.1). Both engine trends will continue to value higher octane fuels, which could provide engine efficiency benefits, and ethanol's high latent heat of vaporisation, which could contribute to lower combustion temperatures and, therefore, potentially reduce NOx emissions.

Light and heavy duty diesel engine technology is expected to progress along a path of increased turbocharge boost, coupled with further engine downsizing (Chapter 2, Section 2.4.1). However, fundamental changes in diesel combustion technology are not expected in the 2030 timeframe. As such, current diesel fuel properties will be suitable for future diesel engines.

Regardless of the approach to improve petrol and diesel engine technology in the future, there will be no change in the impact of biofuel blends relative to their impact on current engines.

By 2020, the increased use of high ethanol blends is possible in petrol vehicles, with some technical issues.

Most post-2003 vehicles are E10 tolerant (i.e., they have no efficiency advantage from the higher octane value of ethanol, but they will not have safety or performance issues with this fuel. However, they cannot use higher blend levels (e.g., E20), and warranties may not include higher blends). However, for pre-2003 vehicles, which will likely comprise between 1.3 to 6.8% of the 2020 EU light duty fleet, fuel leaks or fuel system corrosion could occur (Chapter 2, Section 2.3.3.4). This could be addressed by upgrading fuel system gaskets and elastomers for costs of <200 Euros, but there may be a small number of vehicles requiring hardware changes. There are no public data on affected models and the EU would need to work with auto-manufacturers to identify affected vehicles, related upgrade costs and affected populations in 2020.

Manufacturers suggest that most post-2011 vehicles are E20 tolerant; however, precise numbers of non-E20 tolerant vehicles still in the market by 2020 are not available.[10] An E20 tolerant vehicle will not receive the efficiency benefit of the higher octane rating, without engine optimisation. It is assumed that the costs of optimisation will be small for naturally aspirated engines and under Euro 50 for turbocharged engines, if the changes are incorporated in the design stage.[11] This approach will affect future manufacturer product plans as engines will need to be modified. A lead time of 4 to 5 years will be required for manufacturers to design such engines (Chapter 2, Section 2.3.3.4).

Although B7 presents no technical issues, B10 and B30 FAME diesel blends are more problematic. Concerns also exist about the use of FAME blends with plug-in vehicles.

B7 (i.e., 7 vol%) is the current level of the FAME blend limit and is the default requirement for vehicle technology; as such, all EU diesel vehicles can run on B7. The introduction of B10 could lead vehicles with duty cycles having short trip lengths and many cold starts daily to experience significant oil dilution issues. This issue could be addressed by improved monitoring of engine oil and more frequent oil change intervals (i.e., reduced from current levels of 25,000 to 30,000 km to less than 20,000 km). In addition, the use of B10 during winter months may need to be prohibited (Chapter 2, Section 2.4.2).

Oil dilution and cold storage problems are heightened when using B30 (Chapter 2, Section 3.2). As such, vehicle manufacturers suggest that it may not be suitable to be placed in the market, but only to be used in “captive” fleets, where measures can be implemented, such as an oil dilution monitoring programme, and careful oversight of fuel quality. It is unclear if any hardware changes to the fuel system are needed for modern (post-2010) vehicles to use B30.

Concerns exist about the oxidation stability of FAME when used in plug-in vehicles where the tank fuel can be used over several months if the vehicle is operated primarily in electric mode. However, further research into this issue is required as plug-in diesels have entered the market only in 2014.

Irrespective of the hypothetical scenarios explored in this study, it is considered that the introduction of new, higher biofuel blends require fully compatible vehicles, which will be developed and sold once the technical specifications of these blends are confirmed.

The introduction of vehicles fully compatible for higher blends first requires agreement on fuel specifications (in the CEN), which are then included in the FQD and type approval regulation. Vehicle manufacturers can then develop and optimise vehicles for this new fuel standard, and introduce these on the market. The market penetration rate of these fully compatible vehicles determines the potential (maximal) growth of sales of these higher blends, and therefore provides a boundary condition to the consumption of these biofuels. Once the first fully compatible vehicles enter the market, it will take more than 20 years before the entire vehicle fleet will be compatible with the new blends.

Vehicle emissions

Biofuel blends (E10, E20, B7, B10 and B30) will have mostly positive emission benefits.

Based on a review of literature, ethanol blends will result in emission reductions ranging from 5-20% of regulated pollutants (carbon monoxide (CO); particulate matter (PM), hydrocarbons (HC)) and air toxics (benzene) when compared to current engines using E0 fuel (Chapter 2, Section 2.3.3.1 and Section 2.5.1). However, emissions for nitrogen oxides (NOx) could be slightly higher (~1%), as well as aldehyde emissions, especially in vehicles that are not optimised for the higher blends.

[10] Since it is likely that there will be a significant proportion of the vehicle fleet that is not E20 tolerant during the 2020 to 2030 timeframe, a protection grade (e.g., E5, E10) will be required. The rate of fleet renewal determines how long the protection grade has to be available. However, it is possible that even after 15 years, 15% of the vehicle fleet will still be incompatible with E20 (Chapter 1, Section 1.5.3).

[11] For non-E20 tolerant vehicles, optimisation costs will be significantly more; consequently, an E10 protection grade will be required.

Similarly, the use of B7, B10 or B30 will reduce emissions of HC, CO, PM and particulate number (PN), but literature indicates that NOx emissions will increase by a few percentage points (Chapter 2, Section 2.4.3.2 and Section 2.5.2).

Vehicle emissions testing indicates that pollutant emissions from E10, E20, B7, B10 and B30 are significantly lower than Euro 6 exhaust emission limits for passenger cars.

A limited vehicle emissions testing programme was conducted on single Euro VI compliant petrol and diesel vehicles, to the World Harmonized Light Vehicles Test Cycle (WLTC). Both vehicles were not optimised to the biofuel blends tested. For E10 and E20, total hydrocarbon (THC), PM and PN were 80% lower than Euro 6 emissions limits, while non-methane hydrocarbon (NMHC) was over 70% lower (Chapter 2, Section 2.3.3.1). CO and NOx vary between 50-70% and 18-46%, respectively, below Euro 6 emission limits.

For all biodiesel blends (B7, B10 and B30), CO, PM and PN were approximately >80%, >75% and >95% lower, respectively, than the Euro 6 exhaust emission limits (Chapter 2, Section 2.4.3). However, NOx emissions were over 7 times greater than Euro 6 limits, due to issues associated with the test cycle. Euro 6b limits are based on the New European Driving Cycle (NEDC), while the study tests were conducted using the Worldwide harmonized Light duty driving Test Cycle (WLTC). The test results are directionally similar to results from other studies which have compared NOx emissions from NEDC against other test cycles, such as WLTC and Real Driving Emissions (RDE). Overall, although the vehicle tests represent a small sample size, the results for NOx indicate a broader issue that warrants further investigation.

Air quality impacts

The introduction of higher biofuel blends will not detrimentally impact air pollution from the refinery sector

Modelling of refinery sector emissions was conducted for each of the four hypothetical biofuel scenarios (i.e., Base Case, and Scenarios A, B, and C). Refinery emissions of air pollutants (SOx, NOx, NMVOC, CO and PM) are expected to decline by 30-55% from 2010/2013 levels reported by the European Environment Agency (Chapter 3, Section 3.3.2). These declines are directly linked to reduced refinery throughput, and associated lower fuel consumption in the Base Case and higher biofuel scenarios (Chapter 1, Section 1.7.3), even though biorefinery production will likely offset some of the air pollution reduction due to refinery throughput reduction. The refinery sector accounts for only a small fraction of pollutant emissions when compared to vehicle tailpipe emissions.

Compared to current biofuel blending levels, the use of higher biofuel blends will not negatively impact air pollution from vehicle tailpipe emissions.

Modelling results indicate that regardless of the blending ratio (E10, E20, E25, B7, B10 or B30), vehicle tailpipe emissions compared to a Base Case using current biofuel blending levels, do not negatively impact air pollution (Chapter 3, Section 3.4.2). Pollutant emissions of THC, NMHC, CO, and PM will decline with higher blends. In 2030, light duty vehicles (LDV) emissions of these pollutants across each biofuel scenario (A, B and C) were on average 3%, 3%, 6% and 8%, respectively, lower than the Base Case. For NOx, emissions were on average 1% higher than the Base Case in 2030. CO_2 emissions for Scenarios A, B and C were the same as the Base Case in 2020, and 0.2% lower in 2030. For heavy duty vehicles (HDV), the trends were similar, although no declines in CO_2 were noted through 2030.

Moving to higher ethanol blends does not mean increases in the ethanol waiver (Annex III of the Fuel Quality Directive (FQD); 2009/30/EC), rather the required waiver (in kPa) gradually declines out to and beyond 30 volume % ethanol

Annex III of the Fuel Quality Directive (FQD; 2009/30/EC) sets out allowed vapour pressure (VP) waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. For a given base petrol, the blend vapour pressure (VP) peaks at an ethanol concentration of around 5% and then steadily declines as its concentration increases, initially sharply to about 10% concentration and then more slowly (Chapter 3, Section 3.5.6). Consequently, raising ethanol content from 0 to 5%

has a marked upward impact on blend VP, but increasing concentrations further actually lowers blend VP; e.g., based on calculations, from 68 kPa at 5% to 67.8 kPa at 10% and 66.8 kPa at 30%. Thus, going to higher ethanol concentrations beyond 5% does not cause increased pressure on petrol blend VP; rather the effect is to gradually reduce the vapour pressure waiver effect.

Higher ethanol blends will not result in adverse evaporative emissions impacts in petrol

An assessment of literature indicates that there would be no appreciable adverse evaporative emissions impacts from raising ethanol concentration in petrol (Chapter 3, Section 3.5.2). Studies indicate that diurnal, refuelling and hot-soak emissions were unaffected by higher ethanol content in petrol. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but not within the E10 to E25 range. Any reduction in VP from blends above E5 was noted to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

Greenhouse gas emissions impacts

Higher biofuel blending scenarios yield GHG benefits compared to the Base Case scenario, regardless of assumptions related to the emission factors for biofuels and ILUC emissions

The greenhouse gas (GHG) impact analysis of three hypothetical scenarios for higher bio blends suggests that these can yield benefits compared to the base case scenario. The estimated benefits are dependent on a) reducing the carbon intensity of biofuels over time as a result of improvements made in the supply chain of biofuels, b) expanded use of waste-based feedstocks, particularly for FAME and HVO production and c) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030, including for ethanol, biodiesel, and renewable diesel (Chapter 4, Section 4.4). Assuming a reduction in the carbon intensity emission factors of biofuels over time and excluding indirect land use change (ILUC) GHG emissions, the analysis (Chapter 4, Section 4.5) yields an estimated reduction in the range of 7.1 to 9.4% for the three higher blend limits and use scenarios in 2030. However, if no reductions in the carbon intensity of biofuels are assumed over time, and the emission factors as set out in current legislation are used, including default carbon intensity values for biofuels (included in FQD Annex IV) and indirect land use change factors (in the ILUC Directive), the analysis yields GHG emission reductions between 0.8 to 1.5% compared to the base case scenario.

Refining and fuel supply impacts

The fuel supply outlook in the Base Case incorporates further dieselisation[12], which will increase the strain on EU refining by lowering refinery throughputs and utilisations

The Base Case projection assumes EU petrol demand (including any biofuel content) dropping by 25% and 44% in 2020 and 2030, respectively, from 2011 levels (around 87,000 ktoe/yr (2 million bbl/d)). In contrast, EU diesel demand (including any biofuel content) is assumed to rise by 7% and 8% in 2020 and 2030, respectively, from the average demand levels seen between 2007 and 2013 (i.e., 205,000 ktoe/yr (4.2 million bbl/d)) (Chapter 5, Section 5.4.1).

In many refineries, the yield ratio of petrol to diesel is close to 1:1. In contrast, the Base Case scenario predicts an EU diesel to petrol demand ratio of 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis), which further exacerbates the yield and economic strain on European refineries through 2030 (Chapter 5, Section 5.4.1). In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. The continuing dieselisation trend (petrol demand decline with diesel demand increase) embodied in the Base Case scenario, and the associated increased strain on European refinery yields contributes to reduced refinery throughputs in the 2020 and 2030 Base Case model results. European refining throughputs decline to around 10 million bbl/d in 2030 compared to 11.9 million bbl/d in 2012, while at the same time necessitating higher petrol exports in order to enable diesel production. As a result, the Base Case scenario

[12] A continued decline in the ratio of petrol to diesel demand

projection is for petrol exports to be around 60% higher in 2020 and 2030 than they were in 2013, and for diesel/gasoil imports to double versus 2013 by 2020 and then triple by 2030.

Increases in biofuel demand will have a greater impact on refineries than the projected reduction in road fuel demand

Higher biofuel demand (as described by the three hypothetical scenarios) will have a greater impact on refineries than the projected reduction in road fuel demand in the Base Case. Specifically, by 2020, the EU mineral road fuels production could fall by 104,000 ktoe/yr (4.4%) from its 2014 level due to the Base Case fuel supply outlook, and by an additional 124,000 ktoe/yr (5.5%) due to higher biofuel demand (Chapter 5, Section 5.6.4). By 2030, mineral road fuels production could fall by 203,000 ktoe/yr (8.6 per cent) from its 2014 level due to Base Case assumptions, and, due to increasing biofuel demand, could fall by an additional:

- 209,000 ktoe/yr (9.7 per cent) in Scenario A;
- 240,000 ktoe/yr(11.1 per cent) in Scenario B; and
- 293,000 ktoe/yr (13.5 per cent) in Scenario C.

Higher biofuel supply and demand in the EU will have adverse impacts on the EU and Non-EU refining sectors in terms of throughputs

EU biopetrol and/or biodiesel supply was assumed to increase as needed in higher biofuel scenarios in order to prevent significant increases in EU biofuels imports (Chapter 5, Section 5.4.1). This has resulted in EU biofuel supply increases being entirely biodiesel in 2020 for all Scenarios (i.e., 0.2 mb/d) and predominantly biodiesel in the 2030 (i.e., as high as 0.5 million bbl/d under 2030 Scenario C).

Because the European industry operates with a petrol/diesel imbalance which is projected to worsen under the Base Case scenario, a primary impact of higher biofuel demand is to reduce diesel/gasoil imports into the EU such that the bulk of the refinery impacts are projected to be felt in regions outside the EU. Higher biofuel supply and use in the EU has adverse impacts on the EU and Non-EU refining sectors in terms of throughputs and margins. Implied further closures in 2030 due to the higher biofuel demand in Scenario A could be over 0.4 million bbl/d globally of which 0.08 million bbl/d occur in the EU. In comparison, for Scenario C, over 0.6 million bbl/d could be closed globally of which 0.2 million bbl/d could occur in the EU. However, the split of impacts between EU and Non-EU refining regions is dependent on Base Case assumptions (Chapter 5, Section 5.4.2.2). For example, if the 2030 Base Case outlook comprises higher demand for petrol in the EU, then a greater proportion of the total refinery throughput reductions and implied closures due to higher biofuels would occur in the EU.

The impact on refining margins in the EU, compared to the Base Case, will be small

In 2020, a reduction in margins on the order of 2-7% is estimated, while in 2030 a change of +2% to -4% is predicted for the higher biofuel scenarios compared to the Base Case (Chapter 5, Section 5.4.2, Section 5.6.3). For example, for gross margins, which vary between refineries, the absolute impact is a reduction of 7 $¢/bbl in 2020 for all Scenarios (compared to a base case margin of 3.93 US$/bbl) and 11 $¢/bbl in Scenario A, 13 $¢/bbl in Scenario B and 16 $¢/bbl in 2030 for Scenario C (compared to a base case margin of 3.83 US$/bbl) (Chapter 5, Section 5.6.3)

The underlying causes for the reduction in margins (Chapter 5, Section 5.4.1), include the projected continuing overall demand decline in Europe, (most notably for petrol), under the Base Case scenario,[13] and the relative margins on petrol oriented refineries dropping significantly between 2020 and 2030. This is because of a projected global slowing in petrol demand growth by 2030 in which the projected EU reduction plays an important role.

[13] The analysis assumes that EU refinery utilisations will drop from the 80% range in 2020 to approximately 70% in 2030 – with clear implications for further Base Case scenario closures by 2030. These closures were left implied in the results although clearly a 70% level is unsustainable; therefore the Base Case scenario implies significant closures before considering the added effects of higher biofuels. If the analysis had assumed further closures in the 2030 cases then the expected margins would be somewhat higher.

Consumer prices will increase as the biofuel energy share rises

The increase in consumer prices may be 2.3 €¢/l in 2020 (2 per cent) and, in 2030:

- 4.8 €¢/l (4 per cent) in Scenario A;
- 5.0 €¢/l (4.1 per cent) in Scenario B; and
- 5.8 €¢/l (4.8 per cent) in Scenario C.

Consumer prices are comprised of mineral road fuel wholesale prices, biofuel wholesale prices and the EU average current fuel duty and Value Added Tax. Mineral road fuel wholesale prices are 55.2 €¢/l for an 85 $/bbl crude oil price and biopetrol and biodiesel wholesale prices, which are weighted by their respective share in total biofuels, could be 91.9 €¢/l in 2020, rising to 97.8 €¢/l in 2030. Including taxes, the average price at the pump is 121.5 €¢/l in 2020 and 121.1 €¢/l in 2030. The difference in biofuel and mineral road fuel prices drives the consumer price increase as the biofuel share increases from the baseline, as laid out above. (Chapter 5, Section 5.6.2).

Higher crude oil prices would narrow the differential between mineral road fuel and biofuel prices and would make smaller the increase in consumer prices. At 124 $/bbl crude price, consumer prices increase by 1.0 €¢/l in 2020 across all scenarios and, in 2030, by 2.0 €¢/l in Scenario A; by 1.8 €¢/l in Scenario B and 1.9 €¢/l in Scenario C.

Study objectives

The overall objective of this study is to undertake an economic and environmental analysis of the impact of increasing the limits of the bio-content of petrol and diesel imposed by the FQD, and beyond 2020.[14] In particular, for specific biofuel blends identified in the study, the assessment considers both their positive and negative impacts associated with:

- Air quality and the resultant impact on human health;
- Market capacity, availability and origin of bio-content;
- Automotive technology, in particular engine efficiency, tail pipe emissions, biofuel compatibility and fuel use in existing and future vehicle fleets and possible evolution of automotive technology;
- Effect of an increase of the bio content in fuel on its overall carbon footprint (Life Cycle Assessment);
- Effect on the refinery sector and distribution of fuels;
- Competiveness of specific sectors or Member State fuel industry; and
- Any impact on the current market shares of the fuel mix (diesel vs. petrol) and possible induced changes in Europe.

The findings of this work will input to the Commission when considering implications of increasing the bio-content level in transport fuels.[15]

Overview of report

This is the Final Report of the study which presents the findings of in the following Chapters:

Chapter 1: Markets – current state and future trends

Chapter 2: Implications for automotive technology

Chapter 3: Effects on air quality and implications for vapour pressure

Chapter 4: Impacts on greenhouse gas (GHG) emissions

Chapter 5: Impacts on refining and fuel supply

This report has been developed by ICF, CE Delft, EnSys Energy and Vivid Economics. The work has involved close co-operation with DG CLIMA throughout the study and has included an industry stakeholder workshop in September 2015.

[14] Taking also into account certain recent policy developments such as the 2030 framework for climate and energy policies including COM(2014) 15 final

[15] The objective of the study in not an impact assessment or exploration of concrete alternative policy options but an assessment of the implications of (hypothetical) changes to the blending limits in the current fuel specification

1 Markets – current state and future trends

Abbreviations/acronyms

Advanced biofuels	
B7	Diesel containing up to 7% v/v
BOB	blendstock for oxygenate blending
BTL	biomass to liquid
CEN	European Committee for Standardization
E10	Ethanol blend containing up to 10% v/v
EC	European Commission
EN228	current standard including the fuel specification of petrol
EN590	current standard including the fuel specification of diesel
EU28	all 28 Member States of the European Union
FAME	fatty acid methyl esther
FQD	Fuel Quality Directive
Fungible biofuels	biofuels with fuel characteristics so close to fossil fuels that no blending limits should be taken into account
GHG	greenhouse gas emissions
HVO	hydrotreated vegetable oil
ILUC	indirect land use change
RED	Renewable Energy Directive

Country codes

EU28	EU-28
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark

EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovak Republic
UK	United Kingdom

1.1 Summary

Chapter 1 of the report provides an overview of the current biofuel market in the EU: the key policies, current status of consumption and production, biofuel blends and feedstock for the biofuels. Based on the current status and expected policy developments, the potential developments until 2030 are discussed.

Integrating these findings with the results from Chapter 2 of this report, three hypothetical scenarios are derived for the development of biofuels for the period to 2030. These will be used as a basis for the assessment of potential impacts of higher biofuel blend walls, in the remainder of this report.

1.1.1 Policy incentives and uncertainties

Biofuel consumption in Member States is almost fully policy driven. At the EU level, the main drivers are the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). The RED sets a binding 10% target (energy content) for renewable energy in transport in 2020; the FQD sets a reduction target for the GHG intensity of fuels of 6%, in 2020. The FQD also defines blending limits for FAME and ethanol, limiting the share of FAME in diesel to 7 vol% (6.4% energy content) and the share of ethanol in petrol to 10 vol% (6.8% energy content). Both directives also define sustainability criteria that biofuels have to meet to count towards both targets and the RED furthermore regulates that biofuels from waste and residues count double towards the 10% target. As required by the RED, Member States submitted National Renewable Energy Action Plans (NREAPs) to the Commission, which outlined indicative trajectories towards the 2020 targets, as well as an outlook of the expected biofuel volumes and types in 2020. In 2012 the European Commission proposed a Directive amending the RED and FQD to address the issue of indirect land use change (ILUC). The Directive has now been adopted by the Council at second reading and is likely to enter into force in late 2015. Under this Directive there will be a cap on the contribution that biofuels from food crops and some energy crops can make to targets in the RED at 7% of transport energy. Member States will also be required to set a target for advanced biofuels with a reference value of 0.5%[16]. Furthermore, the multiplication factors for electricity from renewable sources are increased, from 1 to 2.5 for the energy consumed in electrified rail transport, and from 2.5 to 5 for renewable electricity use in road transport.

By 2014, almost all Member States, with the exception of Latvia, Cyprus and Estonia, had implemented biofuel obligations (quotas) for fuel suppliers. However, the level of these obligations varies significantly between countries, from an average target of less than 3% in Croatia and Greece, to 7% or higher in France, Poland and Slovenia (in 2014). In addition, tax incentives for biofuels are provided in approximately half of EU Member States.

The FQD blending limits have not been an issue in many Member States, as most biofuel obligations are still below these limits. However, various options to go beyond the B7 and E10 limits have been implemented: E10 has been introduced in three Member States (Finland, France and Germany), B8 has been allowed in France (although it is not yet being sold), fungible (drop-in) biofuels such as HVO, whose properties are very similar to fossil diesel, are blended and incentives for E85 are in place in some Member States (at least in France and Finland).

In this study, it is assumed that the EU policies provide the drivers and boundary conditions for the future growth of biofuels in the EU. The potential impact of developments in the sustainability criteria on biofuel supply and demand has been taken into account, however, other than GHG implications (Chapter 4), environmental and social effects of increasing biofuel volumes have not been assessed in detail in this study.

[16] In this text, all biofuel shares are expressed in terms of energy content, unless otherwise specified as vol% (volume content)

1.1.2 Current status of the market

In 2013, 13.6 Mtoe biofuel was consumed in the EU, which represented a share of 4.6% of the EU's petrol and diesel consumption (in energy content). 79% of this was biodiesel, mostly FAME, while 20% was biopetrol. Biofuel shares varied significantly between Member States: where Estonia had a share of only 0.4% in road transport fuel sales, Sweden achieved a 9% share with both a blending obligation and tax incentives in place.[17]

The 2013 EU-average share of biopetrol in petrol was 3.4%, which leads to the conclusion that there is still a lot of potential to further increase ethanol sales within the current blending limits: if all Member States were to introduce E10 and the ethanol content would then be increased to the maximum level allowed, i.e. to 6.8% (energy content, representing 10 vol%), the EU-wide ethanol share can increase by at least 2.9% (equivalent to over 1,600 ktoe of ethanol) without having to resort to higher blend[18]. This can be achieved either by providing specific incentives for E10 and ethanol consumption, or by gradually increasing the obligations and thus encouraging the fuel suppliers to introduce and actively market E10.

Even though all Member States but two (Estonia and Latvia, 2013 data) have switched to B7 as the standard diesel grade, FAME sales can be increased within the current blending limits by at least 1.2% (equivalent to over 3,000 ktoe of FAME): the 2013 EU-average share of biodiesel in diesel was 5.2%, whereas the share allowed by B7 is 6.4%[19]. Note that B7 diesel may contain between 0 and 7 vol% FAME, so having B7 on the market does not automatically imply that 7 vol% of FAME is added.

In line with the consumption of biofuel in the EU, the production of biofuel has increased sharply since 2004. The production capacity installed in the EU is significantly higher than production itself. In 2013, only 43% of the EU's biodiesel production capacity was actually used, 44% of biopetrol capacity (ethanol, mainly). More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, 44% of the production capacity of biopetrol is located in France, Germany and the UK. The 2013 biodiesel production capacity is already sufficient to meet the 2020 demand as set out in the NREAPs. The European biopetrol capacity is not yet sufficient to supply the bioethanol that the Member States expect for 2020, but this gap may be filled with ethanol imports from outside the EU. In 2012, about 15% of the EU's biofuel consumption was produced from wastes and residues (most recent data), the rest was mainly produced from rapeseed and other oils, and sugar beet and grains.

Almost all Member States, with the exception of Cyprus, Hungary, Latvia, Malta and Slovakia, are likely to need higher blends for FAME, a large share of double counting biofuels or some other solutions (HVO, FAME in non-road modes) if they are to achieve the biodiesel shares given in their NREAPs in 2020. Results for petrol are quite different: many Member States do not expect to use the full blending potential of E10 in 2020. Portugal and Slovenia only use a quarter and one third of the E10 blending potential, respectively. These differences are not due to technical reasons but rather due to differences in Member State policy strategies and ambitions. However, the NREAPs were drafted prior to the ILUC decision, and the impact of the new legislation on the Member States plans and policies is not yet known.

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[17] Note that the more recent biofuel consumption data are for 2013, and the blending obligations data mentioned above are for 2014. Furthermore, blending obligations may also include double counting of biofuels from waste and residues, where these are only counted once in the actual consumption data.

[18] The actual room to increase ethanol sales will in fact be higher than 2.9%, since ethanol is also sold as ETBE and in E85 blends. However, as data of the EU-wide sales of ETBE and E85 are not available, this effect cannot be quantified.

[19] The actual room to increase FAME sales will be higher than the 1.2% given here, since the biodiesel sales data also include HVO (to which the B7 limit does not apply) and some of the FAME is sold as high blends (B10, B30) in captive fleets. As more specific data of the sales of biodiesel are not available, these effects cannot be quantified.

1.1.3 The potential impacts of introducing higher biofuel blends

The introduction of higher blends such as E20 or B10 requires so-called 'protection grades' remaining available, E10 or B7, as only part of the vehicle fleet will be compatible with the new blends (see Chapter 2, Section 2.3.3.4 for an in-depth discussion on vehicle compatibility). All stakeholders in the fuel market, i.e. fuel suppliers, distributors and owners of retail stations will then have to introduce the new blend either by replacing an existing fuel grade that they offer or by adding the new blend to their existing portfolio; where the latter option would require more significantly investments in expansion of existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics.

Fuel markets in different Member States can have various ownership structures, with some (e.g., Germany, Greece, and Italy) largely dominated by a limited number of major companies, and others (e.g., Poland, UK) much more fragmented. In the latter, independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales. This has implications for the introduction of a new blend, since a successful roll-out requires the active involvement of many different stakeholders. In both cases, introducing a new blend may lead to negative economic impacts on the smaller retailers, as they will have fewer resources to invest. These effects have, however, not yet been quantified or assessed.

Introducing a higher biofuel blend may cause a number of technical issues in fuel distribution and at service stations that need to be resolved to ensure fuel quality and prevent technical issues in the fuel supply chain. For higher FAME blends, these are mainly related to quality control and aging. For higher ethanol blends, technical issues may occur due to corrosion. Costs to resolve these issues increase with increasing shares of ethanol. A number of non-technical issues and barriers were also identified, for example consumer acceptance and willingness to buy the higher blends is an important prerequisite to a successful introduction.

Most petrol vehicles manufactured after 2003 are E10 tolerant, i.e. they can drive on E10 without technical or safety issues, but do not receive any fuel efficiency benefit. However, between 1.3 to 6.8% of the 2020 EU light duty fleet may not be compatible to E10, and thus could be susceptible to fuel leaks or fuel system corrosion. This would have to be addressed by retrofitting, or government incentives (scrappage schemes). From 2011 onwards, a majority of cars made in the EU are E20 tolerant; and all diesel vehicles can run on B7. These vehicles have, however, not been specifically designed for blends higher than the current blending limits B7 and E10, and warranties may not include higher blends. The introduction of new, higher biofuel blends is therefore considered to require vehicles specifically designed and optimised for these higher blends, i.e. be fully compatible with these blends. These can be developed and sold once the technical specifications of these blends are decided on.

The introduction of vehicles fully compatible with higher blends first requires agreement on fuel specifications (in the CEN), and then inclusion in the FQD and type approval regulation. Vehicle manufacturers can then develop and optimise vehicles for this new fuel standard, and introduce these on the market. The process for developing a new CEN standard and then for vehicle manufacturers to optimise vehicles for this new fuel standard is estimated to take about 4 years. Once the first fully compatible vehicles enter the market, it will take more than 20 years before the entire vehicle fleet will be fully compatible with the new blends. This time needed for fleet renewal will determine the need to maintain protection grade fuels for non-compatible vehicles.

Vehicle manufacturers and fuel suppliers recommend that some biofuel blends, notably FAME blends above B10, can best be used in captive fleets only, as they require closer quality monitoring of both fuels and vehicles. There is little data on EU-wide fuel sales in captive fleets, and so a rough estimate (used in the scenario development in this study) would be 25%.

1.1.4 Development of biofuel demand to 2030

There is still significant uncertainty about biofuel policy development to 2030, both at the EU and Member State level. The development of biofuel demand is therefore difficult to project.

The recent adoption of the ILUC Directive[20] (Directive 2015/1513) and potential future developments of the sustainability criteria for biofuels could be a strong driver for advanced biofuels (produced from woody and ligno-cellulosic wastes and residues and other non-food feedstock), if Member States set sub-targets for these fuels in the coming years. The production technologies of these biofuels are, however, either still in the R&D phase or are only just starting commercial scale production, and current production capacity for advanced biofuels is very limited. As new production technologies are necessary to unlock the potential of ligno-cellulosic waste, residues and other types of low-ILUC biomass for sustainable transport fuel production, technology developments are crucial to the future growth of sustainable biofuels.

Therefore, despite the current uncertainties, recent outlooks in the literature of EU biofuel demand give a relatively consistent picture of developments to 2030: first generation biofuel production is expected to consolidate at best, while it will take time before significant increases of advanced biofuels can be expected. Cost forecasts in the literature vary, but biofuels are reported to be more costly than fossil fuels (in €/GJ), and expected to remain more costly at least until 2025/2030. Outlooks that analysed the potential implications of the FQD blend limits for FAME and ethanol all recognised these limits as a barrier to meeting the 2020 targets, and to further increases of biofuel sales.

Based on these findings, four hypothetical scenarios are developed that have a number of assumptions in common, but result in very different growth paths for biofuels until 2030:

- The **Base case scenario** assumes that the energy content of biodiesel (FAME/HVO) and ethanol in 2013 (i.e., 5.2% and 3.4%, respectively), will not change through 2030.
- **Scenario A** assumes full use of the blend limits in the EU from 2020 onwards, for both FAME (B7) and ethanol (E10). It furthermore assumes that there is no need for Member States to resort to higher blends: the blending limits remain at **B7** and **E10**.
- **Scenario B** assumes further growth of FAME and ethanol demand in the EU beyond 2020, and accommodates that with an introduction of **B10** and **E20** from 2020 onwards. B7 and E10 will remain available throughout the EU as protection grades, at least until 2030. The new standards will be introduced in the FQD before 2020, and vehicle manufacturers will be required to ensure that all diesel and petrol new vehicles that are sold from 2020 onwards are fully compatible with B10 and E20 respectively.
- **Scenario C** assumes an even stronger growth of FAME and ethanol demand in the longer term (2025-2030) than scenario B. Limitations due to biofuel availability also apply in this scenario, but these are assumed to be resolved after 2025. It assumes that **B10** and **E25** are introduced from 2020 onwards, B7 and E10 will remain available throughout the EU as protection grades, at least until 2030. In addition, a standard for **B30** will be introduced, to be used in captive fleets only.

These scenarios form the basis for the analysis conducted into the potential impacts of higher biofuels on air quality, carbon emissions and the refinery sector, which are described in Chapter 3, 4 and 5.

1.2 Introduction

This assessment presents a picture of current and future trends in biofuel blends used for road transport through 2020 and 2030, based on fuel production and biomass availability, fuel distribution and infrastructure, and vehicle compatibility. Additionally, it assesses the current and possible future availability of related biofuel sources, given the origins of bio-content (type of biofuel, geographic origin, and type of feedstock), if there were to be an increase of demand.

[20] ILUC = Indirect Land Use Change. The Directive can be found at http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1445417906699&uri=CELEX:32015L1513

All data and information for this analysis has been obtained from literature reviews, nine open-structured interviews with stakeholders, and a number of written responses to a questionnaire. A list of the organisations and people interviewed can be found in Annex 1.

Chapter 1 is structured as follows:

- Section 1.3 provides an overview of the current EU and Member State policies aimed at increasing the share of biofuels in the transport mix. The current progress towards the 2020 renewable energy target for transport is discussed, and the status of Member State policies for higher biofuel blend is described.
- Section 1.4 provides an overview of current biofuel consumption throughout the EU and fuel distribution. Estimates are provided on the potential for further biofuel growth within the current blending limits and potential technical and non-technical fuel distribution issues that may occur when higher blends are introduced are identified.
- Section 1.5 assesses the issue of market penetration of vehicles compatible with higher blends, illustrating the barriers that vehicle compatibility can form to biofuel growth.
- Section 1.6 describes the current biofuel production in the EU, imports and exports, and assesses potential future developments. Estimates are provided for the future biomass availability and biofuel cost.
- Section 1.7 integrates the main findings of the previous Sections and Chapter 2, and assesses potential biofuel consumption developments until 2030, given the current status, policies and policy outlooks. Based on the key findings, three different scenarios are developed for 2030, each based on different assumptions and choices regarding biofuel policies and ambitions, biofuel blending limits and technology development for advanced biofuels.

Conclusions and recommendations are provided at the end of each Section, with the exception of Section 1.7: this chapter concludes with the scenarios.

1.3 Policy incentives

1.3.1 Introduction

The EU has implemented a number of directives that are key to both the current and future developments of biofuel demand and supply in the EU. These drive biofuel consumption, as well as the type of biofuels used and their environmental impacts: the share of biofuels in the transport mix is unlikely to increase, and advanced biofuels and other biofuels with higher environmental benefits will not be developed further without effective policies and incentives. This is mainly due to the higher cost of biofuels compared to their fossil counterparts, and the higher cost of advanced biofuels compared to conventional biofuels (which will both be quantified in Section 1.6.5). This makes the biofuel sector, the consumption of biofuels and biofuel R&D almost completely policy-driven.

This Section first discusses the current and future European policy framework (in Section 1.3.2), where the main drivers for biofuels used in the EU are given, together with a number of enabling policies.

This is followed by an overview of the implementation at the national level in Section 1.3.3, including an analysis of the main similarities and differences between Member States. Section 1.3.4 then focuses in on the current status and experiences with higher blends in various Member States. The chapter ends with a number of conclusions and recommendations.

In this report, this EU regulatory framework was taken as the key driver for biofuel demand and supply, which also sets sustainability criteria that act as boundary condition for the developments. The framework is dynamic over time and therefore uncertain, but is not assessed in itself here.

1.3.2 European policies linked to the consumption of biofuels

The binding targets of both the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD) for 2020 are currently the main driver for biofuels in the EU, as they will mainly be met by an increase in biofuel consumption. Both Directives are described below. The currently ongoing policy developments on the sustainability requirements and the recent decision on an Indirect Land Use Change (ILUC) Directive are described in Section 1.3.2.3, followed by an overview of related policies.

1.3.2.1 Renewable Energy Directive (RED)

The RED (EC, 2009a) covers all types of energy in the EU, as it sets an overall binding target of renewable energy use for the EU (20% in 2020) and individual targets for the various Member States. It also regulates quite a number of issues concerning renewable energy in the various sectors (electricity, heating and cooling, and transport). Articles 3(4) and 17–21 are relevant for the transport sector. According to Article 3(4), each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of the final consumption of energy in transport in that Member State.

Only biofuels that meet the sustainability criteria for biofuels and bioliquids as laid down in Article 17 of the RED are allowed to count towards the 10% target. The sustainability criteria set minimum standards, like a minimum reduction target for GHG emissions and the exclusion of environmentally vulnerable areas for biofuel production. These criteria address direct effects caused by biomass cultivation and biofuel production. Indirect effects are not covered in these criteria – see 1.3.2.2 below. The same sustainability criteria are laid down in the Fuel Quality Directive.

Article 21(2) of the RED defines that 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.

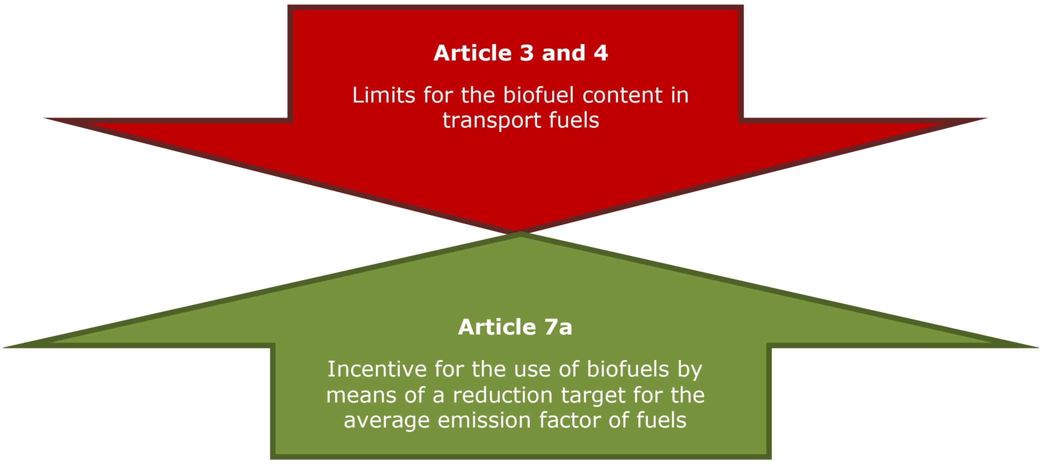
Furthermore, the electricity from renewable energy sources consumed by electric road vehicles shall be considered to be 2.5 times the energy content of the input of electricity from renewable energy sources (RED Article 3(4)), to account for the higher energy efficiency of electric vehicles compared to vehicles with an internal combustion engine.

1.3.2.2 The Fuel Quality Directive (FQD)

The FQD (EC, 2009a) has a double role in relation to the consumption of biofuels in the transport sector. On the one hand, the FQD provides an incentive for the use of biofuels in the transport sector by setting a target for the reduction of the average emission factor of fuels, however, on the other hand, the Directive limits the use of biofuels by setting limits for the biofuel content of fuels in the fuel quality specifications as prescribed by Articles 3 and 4.

In a way this may seem contradictory, but standardised fuel specifications also help to reach harmonisation across and among EU Member States. Both the limits in the fuel specifications as well as the reduction target of Article 7a are described in more detail in the next paragraphs.

Figure 1.1 Double-role of the FQD



Article 7a: the 6% reduction target for the average emissions factor of fuels

The FQD (EC, 2009b) requires fuels suppliers to gradually reduce the average life cycle GHG emissions of the transport fuels that they sell in the EU (Article 7a (2)). The targets were set in the Directive, but the methodology to calculate the contribution of various fuels and GHG mitigation measures towards the target has so far only been defined for biofuels, where the same methodology is used as defined in the RED.

Member States shall require suppliers to reduce life cycle greenhouse gas emissions per unit of energy from fuel and energy supplied by up to 10% by December 31st, 2020, compared with the fuel baseline. 6% of this reduction is mandatory and the remaining 4% can be met by, for example, the use of carbon capture and storage and credits purchased through the Clean Development Mechanism of the Kyoto Protocol, for reductions in the fuel supply sector. 'Suppliers' are, in general, the entities responsible for passing fuel or energy through an excise duty point.

The scope of the Directive is the fuels used by road vehicles, non-road mobile machinery (including inland waterway vessels when not at sea), agricultural and forestry tractors, and recreational craft when not at sea. The calculation methodology to determine the life cycle GHG emissions of biofuels is the same as the one used in the RED (and thus does not include ILUC emissions, see below).

Article 3 and 4: Fuel specifications

In addition to the relatively recent CO_2-target of the FQD, the Fuel Quality Directive has also laid down fuel specifications. These fuel specifications, for a range of fuels, aim to harmonise the technical specifications of the fuels brought on the European market. This harmonisation benefits the fuel industry and car manufacturers, because the fuel industry know what type of fuels to produce and can supply these to consumers throughout the EU, and car manufacturers and OEMs can use these specifications to optimise the performance of engines and cars and meet the emission standards.

With respect to fuels containing bio-components, the Fuel Quality Directive includes fuel specifications for petrol and diesel in Annex 1 and Annex 2, including a maximum content of ethanol in petrol (10 % v/v) and FAME in diesel (7% v/v).[21] What this means in terms of energy %, the unit in which the 10% target for renewable energy in transport is defined in the RED, is shown in the table below.

[21] See Annex 3 for background on the biofuels

Table 1.1 Maximum content of ethanol and FAME, as defined in the FQD, in term of volume and energy %

	volume %	energy %
Ethanol	10	6.8
FAME	7	6.4

Article 3 further indicates that Member States shall require suppliers to ensure the placing on the market of petrol with a maximum oxygen content of 2.7 % and a maximum ethanol content of 5 vol% until 2013, and they may require the placing on the market of such petrol for a longer period if they consider it necessary. Furthermore, they shall ensure the provision of appropriate information to consumers concerning the biofuel content of petrol and, in particular, on the appropriate use of different blends of petrol.

Article 4, however, does allow Member States to permit the placing on the market of diesel with a fatty acid methyl ester (FAME) content greater than 7 %, notwithstanding the requirements of FQD Annex II (without specifying a maximum level). There is no similar derogation for ethanol.

The FQD does not explicitly set maximum blending limits for drop-in biofuels such as pure diesel-like hydrocarbons made from biomass using the Fischer-Tropsch process (BTL, Biomass to Liquid) or hydro-treated vegetable oil (HVO). However, as the scope of the FQD is defined as petrol, diesel and gas oil containing at least 70% by weight of petroleum oils and of oils obtained from bituminous minerals, their share must remain below 30% by weight.

In addition, the FQD also requires the provision of appropriate information to consumers concerning the biofuel content of fuels and the appropriate use of biofuel blends.

1.3.2.3 Addressing ILUC

Before the adoption of the RED and FQD, researchers and NGOs had expressed their concerns regarding indirect emissions as a result of indirect land use change (ILUC) in various publications. Under the RED, the Commission had committed to investigate the subject and, if appropriate, to develop a proposal on how to deal with these indirect effects that may negate some or all of the GHG savings of individual biofuels (EC, 2012). In October 2012, the Commission published a proposal to amend the RED (EC, 2012) and the FQD. This proposal was then considered by the European Parliament and Council. The Directive has now been adopted by the Council at second reading and is likely to enter into force in late 2015.

Member States will then have two years to implement this new Directive in their national policies. The most relevant parts of the text adopted by Parliament are presented in Table 1.2.

Table 1.2 Key points of the text adopted by the Council and Parliament in the 2nd reading on ILUC[22]

Cap on land based biofuels in the Renewable Energy Directive	A cap has been introduced on the contribution that certain biofuels can make to targets in the Renewable Energy Directive. Biofuels and bioliquids produced from cereal and other starch-rich crops, sugars and oil crops and from some other crops grown as main crops primarily for energy purposes on agricultural land can contribute no more than 7% to targets in the RED. Member States may decide on setting a lower limit in their national implementation of the RED. They may also choose to apply this cap to the Fuel Quality Directive target.
Support for advanced biofuels and definition of advanced biofuels	Advanced biofuels are fuels produced from a defined list of feedstocks and feedstock categories, including cellulosic energy crops, algae, and cellulosic wastes and residues. A sub-target for advanced biofuels with a reference value of 0.5% has been introduced. Advanced biofuels and other waste biofuels (e.g. those made from used cooking oil) are double counted towards the 10% target for renewable energy in transport in 2020 (a feature which already applied in the RED). Member States are to report on their progress towards their national sub-target in 2020, to assess the effectiveness of the measures introduced by the Directive.
ILUC emissions	Fuel suppliers and the European Commission are to report on emissions deriving from ILUC, but they are not included in the sustainability criteria for the biofuels or the GHG calculation methodology of the RED and FQD. If appropriate, the Commission shall submit legislative proposals by 31 December 2017 for introducing adjusted estimated indirect land-use change emissions factors into the appropriate sustainability criteria of Directive 2009/28/EC
The use and value of ILUC factors	Provisional estimated ILUC emission factors are provided, distinguishing between three categories of feedstock: cereals and other starch-rich crops, sugars, and oil crops. These can be revised in later years to take account of technical and scientific progress.
Low ILUC conventional biofuels	The Commission shall report, by 31 December 2017, on the possibility of setting out criteria for the identification and certification of low indirect land-use change-risk biofuels and bioliquids. This could be, for example, biofuels from schemes that achieve productivity increases beyond business-as-usual.
Post-2020 support for sustainable biofuels	If appropriate, the Commission shall submit legislative proposals by 31 December 2017 for promoting sustainable biofuels after 2020 in a technology-neutral manner, in the context of the Horizon 2030 framework for climate and energy policies
Changes in the methodology to calculate the contribution from other	The electricity from renewable energy sources consumed by electrified rail transport shall be considered to be 2.5 times the energy content of the input of electricity from renewable energy sources when accounting towards targets in the RED. The electricity from renewable energy sources consumed by electric road vehicles shall be considered to be five times the energy content of the input

[22] Source: http://www.europarl.europa.eu/oeil/popups/summary.do?id=1387307&t=e&l=en and http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P8-TA-2015-0100#BKMD-6; both consulted on 10 July 2015.

renewable energy sources	of electricity from renewable energy sources when accounting towards targets in the RED. In the RED, these multiplication factors were 1 and 2.5, respectively.

In particular, the cap on land-based biofuels and the indicative sub-target for advanced biofuels could significantly influence feedstock use for biofuel production. However, as these only apply to the RED and not to the FQD nor to Member State support schemes, the actual impact is as yet unclear. The increase of the multiplication factors for renewable electricity in the RED effectively increases the contribution of this energy source towards the RED target, and thus reduces the need for biofuels to meet this target.

The impacts of these potential ILUC-measures are further discussed in Section 1.5 on biofuel production and biomass availability in relation to the sustainability of biofuels.

1.3.2.4 Relevant CEN-standards

Article 8 (1) of the Fuel Quality Directive obliges Member States to monitor compliance with the requirements of Articles 3 and 4, in respect of petrol and diesel fuels, on the basis of the analytical methods referred to in European standards EN 228 and EN 590 respectively. Both standards have been set by CEN's Technical Committee 'Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin' (TC19) (Working Group 24)(EC, 2009).

CEN TC19 develops European standards which standardize the methods of sampling, analysis and testing, terminology and specifications and classifications for petroleum related products, including petrol, diesel and biofuels (see standards.cen.eu). As such, it aims to ensure consistent quality of automotive fuels and biofuel blends, compatibility with car engines and fuel pump labelling (Constenoble, 2014).

B10 and B20/B30

Several activities have taken place within the CEN to further develop standards for higher levels of biocomponents in transport fuels. In relation to diesel, the 2015 Work Programme of CEN states that the organisation anticipates the adoption of new European standards including requirements and test methods in relation to B10 (EN16374:2014) and B20/B30 (EN16709:2014). Note that the current draft of B20/B30 standard explicitly states that it is intended for blends of more than 15 vol% up to 30 vol% of FAME in diesel fuel to be used in captive fleet application for designated vehicles, and both drafts state that these fuels are not suitable for all vehicles. Both standards are in their last phase of development.

Nowadays B20 and B30 are both blends that are already available, albeit limited to a number of Member States (such as Denmark, Spain, Italy, France, Poland and Czech Republic). Because these blends do not meet all the standards of regular diesel and they require close monitoring of fuel quality and engine oil dilution by FAME, they have been limited to application in 'captive fleets', like bus fleets (sources: interviews with automakers and the draft standard EN16709:2014). During the development of the draft standard EN16709:2014 this definition of 'captive fleets' has been a major point of discussion. Until this standard, captive fleets have been defined at the local level, resulting in numerous definitions, which have hindered harmonisation. At the end of 2014, the European Commission and the CEN working group reached an agreement on the definition of captive fleets, which facilitates the testing of new alternative fuel blends. At the same time, this requires improvements in labelling of these blends at the pump. The vote on the final text of this standard is foreseen for May 2015 (source: interview with NEN[23]).

Deciding on a final standard for B10 is a more complex process than deciding on a B20 or B30 standard, since B10 is not intended to be limited to captive fleets, but will be sold at

[23] NEN is the Netherlands Standardization Institute, which supports the standardization process in The Netherlands. Information from https://www.nen.nl/NEN-Shop/Vakgebieden/Energie-Distributie/Nieuwsberichten-Energie-Distributie/EC-en-CEN-bereiken-voorlopig-akkoord-over-wagenparken-en-biobrandstofmarkering.htm and personal communication with Ortwin Costenoble, NEN

public filling stations for the general fleet. This results in a number of additional requirements for the B10 standards: for example, because close monitoring of B10 impacts is not possible for non-captive fleets, there is a greater need to solve potential cold flow problems related to the application of FAME in winter circumstances (the requirements for 'cold properties' can be stipulated nationally, and may differ in winter and summer, and between countries, see AGQM, 2013). CEN concludes that further research on these technical problems and how these could be avoided is of great importance; a final vote on B10 can only be expected when there is sufficient trust in the solutions for these technical issues (source: interview with NEN) .

Ethanol

For ethanol a standard has been set, which prescribes the requirements for ethanol as a blend component for petrol in blends up to 85% ethanol (EN15376:2014). Several studies have been performed on the feasibility of the large-scale introduction of either E20 or E25. Further developments have, however, been limited to studies investigating the next steps required by different stakeholders to eventually introduce these blends on the market.

1.3.2.5 Energy and Climate package (2030)

The RED and FQD are both policies aimed at realising the overall targets of the Energy and Climate package for 2020, often referred to as 20-20-20 framework, because it requires a 20% reduction in EU GHG emissions compared to 1990 levels, a share of 20% renewable energy in EU energy consumption and a 20% improvement in EU energy efficiency.

In January 2014 the European Commission published as proposal for the new policy framework for energy and climate in 2030 (EC, 2014a), and on 23 October 2014 the EU leaders agreed on the so-called Energy and Climate package (European Council, 2014), which proposes:

- At least a 40% reduction of domestic GHG emission reduction compared to 1990 by 2030. To achieve this, the sectors covered by the EU emissions trading system (EU ETS) would have to reduce their emissions by 43% compared to 2005; emissions from sectors outside the EU ETS (including transport) would need to be cut by 30% below the 2005 level.
- At least 27% for renewable energy by 2030.
- Increasing energy efficiency by at least 27% by 2030.
- Reform of the EU emissions trading system.

At time of writing, it is still unsure if there will be a specific (or indicative) renewable energy source in transport target for 2030. Based on the Council decision, there will be no national binding renewable energy targets, only EU-wide targets.

In the recent Energy Union Package (COM(2015)80 final) a number of relevant actions were announced, namely that the Commission will propose a new Renewable Energy Package in 2016-2017, which will include a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU target is met cost-effectively. (EC, 2015)

1.3.2.6 Clean Power for Transport Directive

The Clean Power for Transport Directive of 22 October 2014 identifies biofuels, together with hydrogen, natural gas and LPG as one of the principle alternative fuels having a potential for the long-term substitution of oil. Biofuels are seen as an alternative for all modes of transport. However, according to the EC, the lack of a harmonised alternative fuels infrastructure could harm the uptake of alternative fuels in EU mobility. An important focus point of this Directive is the information provided to the vehicle users at refuelling stations, including information on the availability of fuels and compatibility of vehicles. Therefore Article 7 obliges Member States to ensure that all relevant information is available in motor vehicle manuals, at refuelling and recharging points, on motor vehicles itself and in motor vehicle dealer shops. This requirement applies to all motor vehicles (and manuals) brought on the market after 18 November 2016. (EC, 2014)

1.3.2.7 Guidelines on state aid

On June 28 2014 the European Commission has published the Communication 'Guidelines on State aid for environmental protection and energy 2014-2020'. These guidelines are applicable from 1 July 2014 until 2020 and contain several provisions related to state aid for biofuels, such as:

- The European Commission recognizes the current overcapacity in the food-based biofuel market and therefore does no longer see investment aid from government institutions in new and existing capacity to be justified. Investment aid should therefore only be allowed in case of conversion into advanced biofuel plants.
- Operation aid to food-based biofuels can no longer be granted after 2020. Operation aid until 2020 should only be granted to plants in operation before 31 December 2013.
- Biofuels that fall under a blending obligation and receive state aid as well will not result in an increased level of environmental protection and therefore should not receive any state aid. Member States are only allowed to grant state aid in case they can demonstrate the aid is meant for sustainable biofuels that are too expensive to come on the market without financial support.
- New and existing aid schemes for food-based biofuel should be limited to 2020.

Despite these limitations for financial support for biofuels, Member States will still be allowed to provide non-financial incentivises for food-based biofuel consumption after 2020. For examples, by the continuation of the current blending obligations. (EC, 2014)

1.3.3 National implementation

The RED sets a binding target for the share of renewable energy in transport in 2020, the FQD sets a reduction target for the GHG intensity of transport fuels in 2020, and both define sustainability criteria for the biofuels that count towards these targets. Neither of them, however, prescribe the policy measures that Member States should implement to comply with these Directives. Member States have therefore implemented both Directives in different ways, resulting in a range of different policy measures that all aim to increase the shares of biofuels on their market, in order to assure the realisation (or, in some cases, overachievement) of these targets by 2020.

The next paragraphs describe the various instruments and the differences between Member States, where we distinguish between quota and obligations (Section 1.3.3.1) and financial instruments (Section 1.3.3.2).

1.3.3.1 Quotas and obligations

Most of the EU28 Member States have decided to oblige fuel suppliers to put a share of total fuel sales as biofuels on the market. These quotas will help to ensure the increase of the consumption of biofuel volumes required to meet the 10% target in 2020 of the RED, as well as the 6% reduction target for the GHG intensity of transport fuels of the FQD.

In Table 1.3 an overview of the mandates per Member States is provided. Almost all Member States (25 to be specific), with the exception of Latvia, Cyprus and Estonia, had binding targets in place for the consumption of biofuels in 2014. All targets are presented in energy content in this table to facilitate comparison, although 11 countries have actually set volumetric targets. 12 countries also had subtargets in place for diesel and petrol. On average, lower subtargets are in place for petrol compared to diesel. The targets mentioned do include double-counting of biofuels from waste and residues (in line with Art. 21(2) of the RED), so the actual share in the fuel volume can be lower.

Table 1.3 Overview blending quota per Member State in 2014, in energy content

Member State	Overall Target	Target for petrol	Target for diesel		Overall target	Target for petrol	Target for diesel
France	7.57%	7.00%	7.70%	Bulgaria (v)	4.94%	3.34%	5.53%
Poland	7.10%			Hungary	4.90%	4.90%	4.90%
Slovenia	7.00%			Romania (v)	4.79%	3.00%	5.53%
Sweden (v)	6.41%	3.20%	8.78%	Luxembourg	4.75%		
Germany	6.25%	2.80%	4.40%	Czech Republic (v)	4.57%	2.73%	5.53%
Finland	6.00%			Slovakia (v)	4.50%	2.73%	6.27%
Lithuania (v)	5.80%	3.34%	6.45%	Italy	4.50%		
Austria	5.75%	3.40%	6.30%	Malta	4.50%		
Denmark	5.57%			Spain	4.10%	3.90%	4.10%
Portugal	5.50%			United Kingdom (v)	3.90%		
Netherlands	5.50%	3.50%	3.50%	Greece (v)	2.64%		
Belgium (v)	5.09%	2.66%	5.53%	Croatia (v)	2.06%		
Ireland (v)	4.94%			Mean target	5.15%	3.58%	5.81%

Source: Biofuel Barometer, 2014

(v) = obligations originally set in % v/v

France, Poland, Slovenia and Sweden have the highest targets, which could present problems in meeting within the current blending limits set by the FQD (see Section 1.3.2.2).

However, a number of options are available to address this issue:

- the share of double counting biofuels can be increased to meet the blending obligations without increasing the actual volumes of biofuels (in line with Article 21(2) of the RED, see Section 1.3.2.1);
- drop-in diesel fuels such as HVO can be used to further increase biofuel shares in diesel beyond the 7 % v/v limit for FAME;
- higher blends can be used in captive fleets (for example B20, B30) or on public filling stations if indicated clearly (for example E85, to be used in flex fuel vehicles)[24];
- Member States may permit the placing on the market of diesel with a fatty acid methyl ester (FAME) content greater than 7 % v/v, in line with Article 4 of the FQD (Section 1.3.2.2).

These options are all used to some extent by various Member States, as will be illustrated when looking at specific efforts to introduce high blends in a number of MS, in Section 1.3.4.

[24] Higher blends might also be used in non-road modes such as diesel rail transport. However, as these fuels are outside the scope of the FQD, these are not included in this assessment

The mandates typically increase over time, but so far most countries have only defined the targets until 2014 or 2015. To what extent the blending limits will pose an issue for more Member States to meet their 2020 targets will become clear in the next years.

The effectiveness of the mandates depend on the penalties that are imposed on fuel suppliers that do not meet the targets. These may vary between Member States. In Germany the fine is €19/GJ, which is estimated to be roughly two times the fulfilment cost (this factor varies depending on fluctuations in the market prices for biofuels and fossil fuels). Until now the quota has been fulfilled and the amount of penalties were minimal. (Interview: German BMU)

The following presents examples of how some Member States have addressed their obligations:

Germany: from tax reductions via blending obligations to a GHG reduction quota

In Germany, the first biofuel policies in place were tax incentives for biofuels. However, as biofuel volumes increased, the decreasing tax proceeds (2 billion euro a year at the highest point) were becoming a major concern. This was one of the reasons for the government to shift to quota and gradually reduce tax reductions or exemptions. At the time of writing, there are still a few tax exemptions for biomethane and BTL and cellulosic bioethanol, but all will expire by the end of 2015. From that date only the GHG quota will be in place.

Since 1.1.2015, another policy shift has occurred: the German government decided to shift from a blending quota system to a GHG reduction quota from 2015 onwards. Fuel suppliers are now not obliged to achieve a certain minimum level of biofuels but rather a minimum level of GHG savings, compared to conventional fossil petrol and diesel. The GHG savings to be achieved are 3.5% GHG in 2015 and 2016, 4% from 2017 onwards and 7% GHG from 2020[25].

To allow for optimization in terms of costs the German parliament decided to have only one target in place rather than separate targets for the share of renewable energy (aimed at the RED target) and for the GHG intensity target of the FQD (see Sections 1.3.2.1 and 1.3.2.2). The introduction has been widely discussed in public in the last year, but the political and legislative decision to shift from an energy quota to a GHG quota in 2015 was already taken in 2009.

With the GHG reduction quota in place, a direct incentive for the use of biofuels with a high GHG reduction potential is provided. However, the result is that the biofuel volumes are more difficult to predict: the higher the GHG savings of the biofuels sold, the lower the actual volume of biofuels sold will be. To avoid overlapping measures, the double counting of biofuels from waste and residues was discontinued. It is too early to assess the impacts of this shift, and estimates on the impacts on the biofuel volumes that will be sold in the coming years vary. Mineral oil companies expect an increase, whereas the biodiesel sector was concerned that it would specifically and negatively impact biodiesel volumes (source of this statement and the following: interview with German authorities). Small fuel suppliers were also found to fear higher prices. Even though there were different opinions on the level of the quota, stakeholders agreed on the principle of a shift from energy to GHG reduction quota. Based on initial feedback from the market a small increase in the amounts is expected this year, but so far little or no change in market share of the feedstocks is observed. A feedstock-based evaluation of the data for the quota year 2015 is expected not before mid-2016.

Spain: Lowering the targets because of energy prices concerns

On 22 February 2013 Spain decided to reduce the blending obligation from 6.5% to 4.1% in order to lower the energy prices in the country to improve Spanish market conditions. The subtarget for diesel was reduced from 7% to 4.1% and the subtarget for petrol from 4.1% to

[25] http://www.bmub.bund.de/themen/luft-laerm-verkehr/luftreinhaltung/luft-luftreinhaltung-download/artikel/zwoelftes-gesetz-zur-aenderung-des-bundes-immissionsschutzgesetzes/?tx_ttnews%5BbackPid%5D=704

3.9%. This resulted in an immediate drop of 57% in biodiesel consumption and 10.5% in biopetrol consumption (EurObserv'ER, 2014).

Italy: Subtarget for advanced biofuels

In anticipation of a decision to be taken on ILUC, Italy adopted a subtarget for advanced biofuels of 0.6% of all petrol and diesel as of 2018 in October 2014. This will increase up to 1% in 2022. Italy is the first Member State to introduce a subtarget for advanced biofuels. In 2013, the first Italian plant for advanced biofuel production was commissioned and three more plants will start operations in 2015. (European Parliament, 2015; Ministro Dello Sviluppo Economico, 2014)

At time of writing, the authors were not aware of other Member States that have or planned to introduce any subtargets for advanced biofuels, but it is likely that more will follow, in line with the ILUC Directive. It is therefore recommended to monitor the developments.

1.3.3.2 Financial instruments (tax exemptions and subsidies)

In addition to the blending obligations, specific type of biofuels can be granted a tax exemption or reduction. National customs authorities are in most cases responsible for implementing tax legislation related to biofuels. The following taxes can be differentiated in such a way that these provide an incentive for biofuel consumption:

- vehicle registration tax;
- circulation taxes;
- fuel taxes;
- CO_2 tax;
- Road charging.

The European Commission regularly publishes an overview of taxes (EC, 2015b). On an annual basis UPEI publishes an overview of actual financial incentives, based on information provided by their members. The most recent publication (UPEI 2014) provides this overview for the year 2014, although not all Member States are included in this report. Information from other sources (e.g. EC, 2015b) has been added to the (UPEI 2014) data to complete the list (Table 1.4).

Table 1.4 Overview of financial incentives for biofuels

	Biodiesel	Biopetrol
Austria	NI	A reduction of 33 EUR/ 1000l litres in excise duties is applicable for petrol with a minimum biofuel content of 46 l and sulphur content <=10 mg/kg (EC, 2015b)
Belgium	No more tax incentives since 1.6.2014. New government proposal to the EU: from 1.1.2015, to introduce a tax incentive of €17.2/m3 of end product if 7% tendered FAME, UCO or TME is blended. 45% of the market is liberalised (therefore only 55% of the needed volume for detaxation will be tendered). There is still no approval from the EU.	No more tax incentives since 1.6.2014. New government proposal to the EU: from 1.1.2015, to introduce a tax incentive of €15.3/m3 of end product if 5% or €30.6 if 10% tendered bio ethanol is blended. 35% of the market is liberalised (therefore only 65% of the needed volume for detaxation will be tendered). There is still no approval from the EU.
Bulgaria	NI	NI
Cyprus	NI	NI

	Biodiesel	Biopetrol
Czech Republic	No tax incentives for mandatory blended products, for blend >31% FAME has an advantage of 31% of basic excise duty. 100% FAME has 100% tax incentive (excise duty = 0) Diesel blend comprising of not less than 30 % of rapeseed oil methyl ester of volume: reduced rate as of 7665 CZK/1000 litres until 30 June 2015 (EC, 2015b).	No tax incentive for obligatory blending, E85: no tax on ethanol share, full tax on petrol share. On the low percentage blends of biofuels no excise duty exemption is granted. In the case of bioethanol comprising of not less than 70 % and not more than 85 % of the denatured ethyl alcohol, reimbursement of excise duty is granted at the level of the ethyl alcohol proportion in the mineral oil. High percentage blends with ethyl alcohol produced from biomass and 2nd generation biofuels are exempted from excise duty within pilot projects for technological development if intended for use as propellant (EC, 2015b).
Germany	From 2013: 2.14 ct/l/ no tax advantage on blend	E85: 100% for ethanol part No tax advantage on blend
Denmark	NI	NI
Estonia	None	None
Greece	Biodiesel is taxed like motor gas oil : 330 € per 1000 lt	NI
Spain	No tax incentive since 1 January 2013. New advantages could be considered for labelled blends.	
Finland	Biofuels have lower excise duty rates (EC, 2015b)	Biofuels have lower excise duty rates (EC, 2015b)
France	2013: 8 €/hl 2014: 4.5 €/hl 2015: 3 €/hl	2013: 14€/hl 2014: 8.25€/hl 2015: 7 €/hl
Croatia	No tax incentives. Pure biodiesel, B100 has 100% tax incentive (excise duty = 0)	NI.
Hungary	No tax advantage on bio part	No tax advantage on bio part. E85 is freely available in Hungary, there is tax advantage, but the tax of E85 has been increased year by year.
Ireland	No tax incentives	No tax incentives Substitute fuels, including biofuel, used as auto-fuel in substitute for petrol are taxed at the petrol rate. (EC, 2015b)
Italy	No tax incentives	No tax incentives
Lithuania	NI	-when the percentage of biological origin substances is not less than 30 percentage, the excise duty rate is reduced by the percentage in proportion to the percentage of additives of biological origin in the product; - when the percentage of biological origin substances is less than 30 percentage, the excise duty rate is reduced by the percentage in proportion to the percentage of additives of biological origin in the product and only for the part that exceeds

	Biodiesel	Biopetrol
		the compulsory blending of additives of biological origin (EC, 2015b).
Luxembourg	NI	NI
Latvia	No tax incentive up to 30% RME content. RME content 30-99%: tax incentive approximately 30% from original excise. 100% bio – 100% tax incentive	No tax incentive up to 70% bioethanol content. Bioethanol content 70-85% - tax incentive approximately 70% from original excise.
Malta	NI	NI
Netherlands	No tax incentives	No tax incentives
Poland	No tax incentives	No tax incentives
Portugal	NI	NI
Romania	The energy products used as motor fuel are exempted from the payment of excise duties when they are produced in totality from biomass (EC, 2015b)	The energy products used as motor fuel are exempted from the payment of excise duties when they are produced in totality from biomass (EC, 2015b)
Sweden	Energy tax reduction of 84% for FAME low blending, full exemption for high blending and HVO. Full exemption of CO2 tax treatment (EC, 2014e) Fame for low-level blending and HVO receive the energy tax reduction and the CO2 tax exemption only up to 5% (FAME) of 15% (HVO) of total declared fuel amounts. If the share is higher than these thresholds, the share of above the threshold is taxed fully	Energy tax reduction of 89% for biotethanol low blending, full exemption for high blending. Full exemption of CO2 tax treatment (EC, 2014e). Bioethanol for low-level blending receives the energy tax reduction and the CO2 tax exemption only up to 5% of total declared fuel amounts. If the bioethanol share is higher than this threshold, the share of bioethanol above the 5% threshold is taxed fully
Slovenia	Transport fuels in their pure form are exempt from excise duty. Blends of biofuels with fossil fuels may qualify for a refund of excuse duty paid or for an exemption from excise duty commensurate with the proportion of biofuel added, up to a maximum of 5%.	Transport fuel in their pure form are exempt from excise duty. Blends of biofuels with fossil fuels may qualify for a refund of excise study paid or for an exemption from excise duty commensurate with the proportion of biofuel added, up to a maximum of 5%.
Slovak Republic	Up to 5 vol-% for Biodiesel blending is without tax, more than that you have to pay the tax. The excise duty reduction for biofuels is granted only to companies that operate as tax warehouses.	Reduction in excise duty of 36 euro/ 1000 litres for petrol with a minimum biofuel content of 4.5% or more (EC, 2015b).
United Kingdom	20p/litre duty derogation on UCOME expired 31.3.2012	NI

NI: No information on tax incentives for biofuels found.

From Table 1.4 above the following conclusions can be drawn:

- There is a large variation in tax incentive for biofuels throughout the EU. Of the countries where data on tax incentives for biofuels were found, 50% has no tax incentives for biofuels. The remaining countries have many different incentives in place (described in the following bullets).
- As noted in Section 1.3.3.1, 25 of the EU's 28 Member States rely on blending or GHG reduction obligations to increase supply and demand of biofuels, and meet their RED transport target for 2020. This reduces the need to also provide financial incentives to meet the target, and only six EU Member States were found to provide financial incentives for biofuels that are sold in low blends (i.e. up to the FQD blending limits)
  - Slovenia and the Slovak Republic give excise duty reductions for low blends only up to a certain lever of biofuel content. Above this level normal rates apply.
  - Sweden provides an energy tax reduction and CO_2 tax exemption for low-level biofuel blending up to a certain level.
  - Finland also has tax incentives for biofuels as they can profit from lower CO_2 taxation
  - France has biofuel tax incentives which reduce over time
  - Lithuania only provides tax incentives for bioethanol volumes that exceed the blending obligations.
- Member States were found to have specific tax incentives in place for higher blends, namely
  - Germany and Hungary have incentives for E85 (in Hungary, these reduce over time)
  - Croatia provides an excise duty exemption for B100 only
  - Latvia has financial incentives for higher blends (30-100 vol% FAME, 70-85 vol% ethanol).
  - Lithuania provides an excise duty reduction for ethanol blends higher than 30%
  - Romania and Slovenia have excise duty exemptions for all pure biofuels
  - Sweden provides exemptions for high blending and HVO
  - the Czech Republic has no tax incentives for mandatory blended products, but there are incentives for FAME blends higher than 31vol% (with 100% FAME exempt from excise duties), for ethanol blends between 70 and 85 vol% and for 2nd generation biofuels from pilot projects.

1.3.3.3 Realisation of the targets in 2020

In Table 1.5 the development of the shares of renewable energy in transport (RES-T) are presented per Member State.

These data include all forms of renewable energy in transport (besides biofuels mainly renewable electricity in rail transport), in line with the calculation provisions of Article 3(4) of the RED (Source: Eurostat). Actual biofuel shares are therefore lower than these, and will be given in Section 1.4.2.2.

Most Member States have shown a steep increase in the share of renewable energy in transport in the period 2004 to 2010. The average share of RES-T then dropped in 2011, by 1.4% on average but much more in some counties such as the Czech Republic, Spain, Finland, France and Portugal. This can be mainly explained by the time required for the implementation of the biofuel sustainability schemes required by the RED (from 2011 onwards, Eurostat only included biofuels of countries that fully complied with the RED's sustainability criteria in Article 17 and 18 (source: Eurostat)), and partly also by developments of biofuel cost over the years (EEA, 2015)(EurObserv'ER Biofuels Barometers of recent years). Since 2011, however, implementation of the relevant RED provisions has progressed, and the shares have remained stable or increased in all countries.

The table clearly shows the variation in renewable energy shares throughout the EU. Sweden has by far the largest share in 2013, with 16.7%, clearly aiming for a much more ambitious level of biofuels in 2020 than needed for the RED and FQD targets. Austria, Germany, Finland and Poland have also reached RES-T shares of 6% or higher in 2013, and are well on their way to the 10% target in 2020. On the other side of the spectrum, a number of countries, namely Estonia, Spain and Portugal, reported shares of less than 1%. These different shares per Member State are typically the effect of the large variations in policies and blending obligations described in the previous two paragraphs, driven by very different ambitions and policy strategies in the various countries.

Note that when comparing the blending obligations that were shown in Table 1.3 with the results in Table 1.5, these data are not always consistent. This is due to a number of factors, most notably the fact that Member State policies change over time (Table 1.3 shows the obligations in 2014), the effect of financial incentives (Table 1.4) and other types of renewable energy in transport such as renewable electricity use in rail and road transport: these contribute to the share of RES-T in the table below, but are not included in biofuel quota.[26]

Table 1.5 Share of energy from renewable sources in transport (RES-T)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
EU-28	1.0%	1.4%	2.1%	2.8%	3.5%	4.3%	4.8%	3.4%	5.1%	5.4%
Austria	2.5%	2.8%	5.5%	6.3%	7.5%	9.1%	8.7%	7.7%	7.8%	7.5%
Belgium	0.2%	0.2%	0.2%	1.3%	1.3%	3.4%	4.2%	4.0%	4.4%	4.3%
Bulgaria	0.4%	0.3%	0.6%	0.4%	0.5%	0.5%	1.0%	0.4%	0.3%	5.6%
Cyprus	0.0%	0.0%	0.0%	0.0%	1.9%	2.0%	2.0%	0.0%	0.0%	1.1%
Czech Republic	1.1%	0.5%	0.8%	1.0%	2.3%	3.7%	4.6%	0.7%	5.6%	5.7%
Germany	1.9%	3.7%	6.4%	7.4%	6.0%	5.5%	6.0%	5.9%	6.9%	6.3%
Denmark	0.2%	0.2%	0.3%	0.3%	0.3%	0.4%	0.9%	3.3%	5.5%	5.7%
Estonia	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.3%	0.2%
Greece	0.0%	0.0%	0.7%	1.2%	1.0%	1.1%	1.9%	0.7%	1.0%	1.1%
Spain	0.8%	1.0%	0.7%	1.2%	1.9%	3.5%	4.7%	0.4%	0.4%	0.4%
Finland	0.5%	0.4%	0.4%	0.4%	2.4%	4.0%	3.8%	0.4%	0.4%	9.9%
France	1.1%	1.7%	2.0%	3.6%	5.8%	6.2%	6.1%	0.5%	7.1%	7.2%
Croatia	0.4%	0.4%	0.4%	0.5%	0.6%	0.7%	0.5%	0.4%	0.4%	2.1%
Hungary	0.4%	0.4%	0.6%	1.0%	4.0%	4.2%	4.7%	5.0%	4.6%	5.3%
Ireland	0.0%	0.0%	0.1%	0.5%	1.3%	1.9%	2.4%	3.9%	4.1%	5.0%
Italy	1.0%	0.8%	0.9%	0.8%	2.3%	3.7%	4.6%	4.7%	5.8%	5.0%
Lithuania	0.3%	0.5%	1.7%	3.7%	4.2%	4.3%	3.6%	3.7%	4.8%	4.6%
Luxembourg	0.1%	0.1%	0.1%	2.1%	2.1%	2.1%	2.0%	2.1%	2.2%	3.9%*
Latvia	1.1%	1.3%	1.2%	0.9%	0.9%	1.1%	3.3%	3.2%	3.1%	3.1%
Malta	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.8%	3.1%	3.3%
Netherlands	0.2%	0.2%	0.5%	2.9%	2.7%	4.3%	3.1%	4.6%	5.0%	5.0%
Poland	0.7%	1.0%	1.2%	1.2%	3.6%	5.1%	6.3%	6.5%	6.1%	6.0%

[26] Higher blends might also be used in non-road modes such as diesel rail transport. However, as these fuels are outside the scope of the FQD, these are not included in this assessment

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Portugal	0.2%	0.2%	1.3%	2.2%	2.3%	3.6%	5.3%	0.4%	0.4%	0.7%
Romania	0.9%	1.0%	0.8%	1.8%	2.7%	3.5%	3.2%	2.1%	4.0%	4.6%
Sweden	3.8%	3.9%	4.7%	5.7%	6.3%	6.9%	7.2%	9.5%	12.9 %	16.7 %
Slovenia	0.4%	0.3%	0.6%	1.1%	1.5%	2.0%	2.8%	2.1%	2.9%	3.4%
Slovak Republic	0.6%	1.1%	2.9%	3.5%	3.9%	4.9%	4.8%	5.0%	4.8%	5.3%
United Kingdom	0.2%	0.3%	0.6%	1.0%	2.1%	2.7%	3.1%	2.7%	3.7%	4.4%

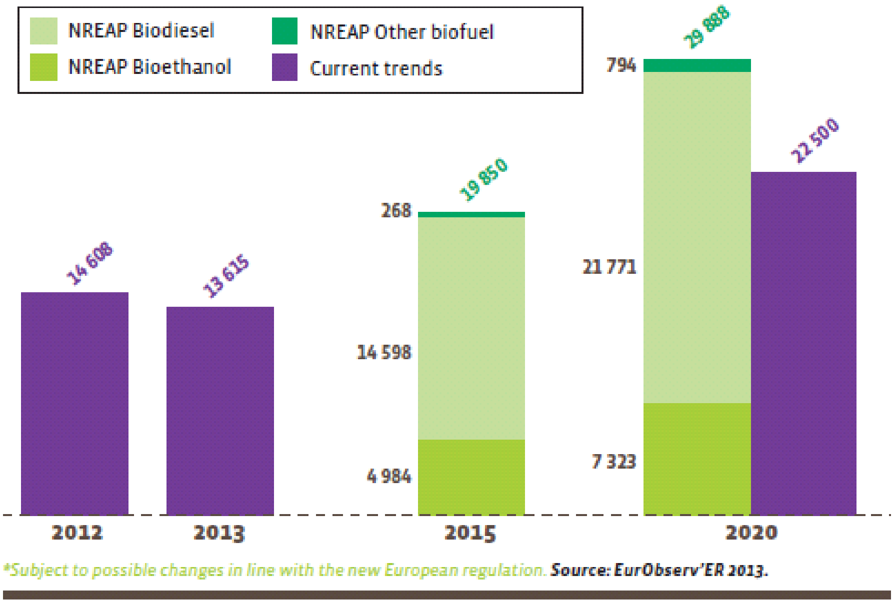
Source: Eurostat, 2015

Progress towards the 6% GHG reduction target of the FQD cannot be assessed in a similar way, as the GHG intensity data of the Member States or fuel suppliers are not yet monitored and reported on at EU level. Furthermore, the calculation methodology to determine the GHG intensity of fossil fuels, electricity, natural gas and various other types of fuels used in road transport has only recently been decided on (Council Directive 2015/652) and the GHG intensity reporting obligation that is included in Article 7a of the FQD was put on hold during the decision making process.

When looking at the question whether the renewable energy target for transport of the RED will be met in 2020, as a first step these trends can be compared with the indicative trajectories that the Member States provided to the Commission in their National Renewable Energy Action Plans (NREAPs)[27]. In the NREAPs the Member States have estimated the biofuel volumes they require for meeting the 10% target of the RED, for 2015 and 2020. From this comparison, EurObserv'ER (2014) concludes that on an EU level, the current biofuel consumption trend is insufficient to meet the 2020 biofuel volumes as predicted in the NREAPs, and to meet the RED target in 2020. Their graph of the currently realised biofuel volumes against the NREAPs quantities and EurObserv'ER's projection for 2020 is depicted in Figure 1.2. They expect that only 75% of the biofuel volumes planned for in the NREAPs will be realised in 2020.

[27] The NREAPs and links to related databases and forecasts can be found at ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans;

Figure 1.2 Comparison of the current biofuel consumption for transport trend against the NREAP



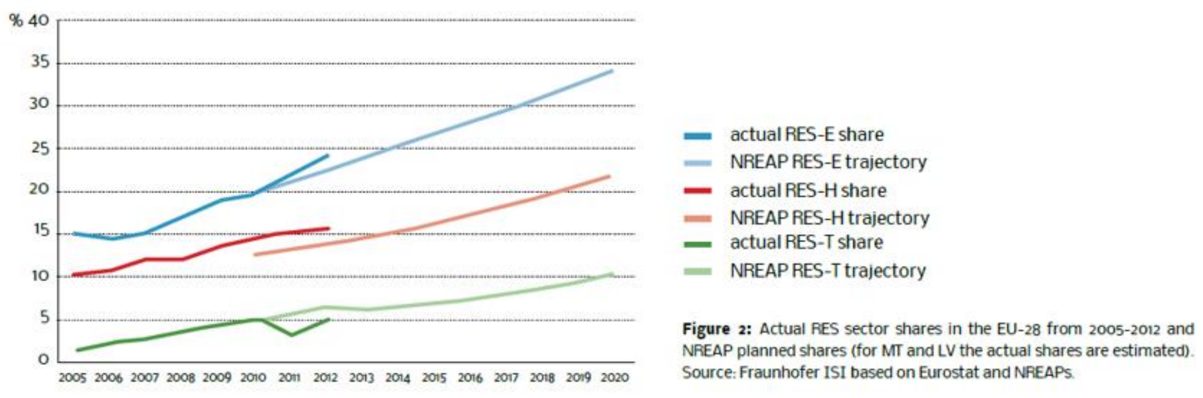
Source: National Renewable Energy Action Plan roadmaps (ktoe) (EurObserv'ER, 2014)

Note that this projection is relatively uncertain, as EurObserv'ER indicates that it is subject to the new European legislation on ILUC (as noted in the footnote of the graph), which may have a significant impact on the share of double counting biofuels in the total. The projection does take into account the draft ILUC directive that was subject to agreement with the Energy Council at the time of the analysis, and thus assumed the incorporation of a cap of 7% on conventional biofuels as well as 0.5 % of advanced biofuels (all in energy content).

The conclusion that progress is currently too low to meet the 2020 RED target is also confirmed by the EU Tracking Roadmap 2014 (Eufores, 2014): according to this roadmap, renewable energy in transport (RES-T) has seen less progress than the heating and cooling sector (RES-H/C) and electricity production (RES-E). In 2012, only 8 Member States have shown progress in line with their NREAP 2011 target, while the other 20 Member States lagged behind. Both the projected trajectory according to the NREAPs and the actual developments in RES-T shares are depicted in Figure 1.3.

Figure 1.3 Comparison of the current trends with trajectories presented in the NREAPs (National Renewable Energy Action Plan)

RES SECTOR SHARE IN FINAL SECTORAL ENERGY CONSUMPTION



Source: Eufores, 2014

Similar conclusions were drawn in a study that approached this issue more from a vehicle fleet and fuel demand perspective, and also taking into account the potential impact of the ILUC proposal: (JEC, 2014) assessed different fuel demand scenarios in the period until 2020, taking the ILUC proposal and amendments (status end 2013) into account. JEC finds that none of these will lead to achieving the RED and FQD targets. Their fuel demand scenarios were based on different regulatory sets of provision (including, for example, higher biofuel blend grades) and a range of other assumptions related to the vehicle fleet (more on this study in Section 1.7.2).

The Commission's recent Renewable Energy Progress Report, COM(2015)293, also finds that progress in the past five years (until 2013) towards the 10% transport target of the RED has been slow. Achieving 10% renewable energy target for transport by 2020 is therefore considered to be challenging, but still feasible, and progress achieved in some Member States testify to this.

Note that none of the above assessments take into account the increase of the multiplication factors for electricity from renewable sources in rail and road transport, as was included in the final ILUC decision. As this will increase the contribution of this energy source towards the RED target, it will reduce the need for biofuels to meet this target. This effect will depend on the Member States' implementation of the ILUC Directive, but the potential impacts can be illustrated by the following calculations, based on the expected consumption of renewable electricity in rail and road in 2020, as presented in the NREAPs:

- In the NREAPs, the 2020 EU-wide contribution of electricity from renewable sources towards the RED target is 0.7% for rail, and 0.5% for road transport. These percentages take the current RED multiplication factors into account, of 1 for electricity use in rail, and 2.5 for road.

- As the ILUC Directive increases these multiplication factors to 2.5 for rail and 5 for road, the EU-wide contribution of electricity from renewable sources towards the RED target increases to 1.6% and 1.0%, respectively.

- The contribution of other renewable energy sources, mainly biofuels, towards the 10% transport target of the RED could thus reduce by a total of 1.5 percentage point, compared to the situation without the ILUC Directive and the NREAPs.

- These effects differ between Member States, where some countries have higher shares of electric rail and road transport and thus higher impacts of this measure (notably Austria and Sweden), and others have much lower shares (including Estonia, Lithuania, Cyprus and Poland).

As mentioned above, the actual impacts of these multiplication factors on overall biofuel consumption in 2020 will depend on the Member States' implementation of the ILUC Directive.

Further discussion on expected developments and forecasts beyond 2020 is included in Section 6 of this chapter.

1.3.3.4 Introduction of higher levels of biocomponents in Member States

According to the NREAPs and RED progress reports most Member States have not reported any specific actions on marketing of biofuels nor expressed the need for mid or high blends in their strategies to realise the RED and FQD targets. Nevertheless, a number of countries have implemented policy measures aimed to facilitate marketing of the increasing biofuel volumes, notably by

- actively introducing E10,
- allowing B8 to be introduced,
- acknowledging the potential benefits of fungible (drop-in) biofuels such as HVO
- providing fiscal benefits to higher blends such as E85 or B30 (as described in Section 1.3.3.2) or subsidies for E85 compatible vehicles

In the following, the policy measures that have been implemented so far to promote these options are described in more detail.

1.3.4 Member State policies for high blends

This Section is based on literature, interviews with biofuel suppliers, petroleum companies and vehicle manufacturers, complemented by interviews with relevant national authorities for three Member States: Germany, Finland and France (see Annex 1). These three Member States were chosen as case studies as they have relatively ambitious biofuel policies, they have introduced E10 on their market and have relatively high shares of biofuels (6.3%, 9.9% and 7.2%, respectively, in 2013, see Table 1.5). Since not all Member States have been thoroughly assessed, this overview only provides a snapshot of specific policy actions. However, as higher blends are typically only actively pursued in countries with higher biofuel shares and ambitious targets, the policies and actions described can be seen as key and illustrative examples of the current EU developments in this area.

1.3.4.1 Member States with experience with E10

In Germany, Finland and France. E10 has been introduced in recent years. In all three countries bringing E10 onto the market is not obligatory, fuel suppliers may choose whether to offer E5 or E10 to their consumers. However, the blending obligations and related penalties are set at such a level that fuel suppliers find it necessary to increase the market share of E10, to enable them to sell the biofuel volumes required by the obligation.

Nevertheless, the strategy and policy measures taken varied between the countries, as well as the resulting effects: E10 was successfully introduced in France and Finland, but encountered significant resistance in Germany, resulting in limited market shares in that country. The actions taken can be divided into information provision and incentives and obligations.

Information provision and involvement of stakeholders

Since not all vehicles in the fleet can drive on E10, clear and accurate information provision to the vehicle owners is considered key to the successful introduction of E10. Additionally, apart from this technical issues, consumers also need to have confidence in the E10, both from a technical but also from an environmental point of view, otherwise they are likely to continue to buy the E5. The importance of these issues is clearly demonstrated when comparing the three countries analysed here.

In **France**, E10 was successfully introduced in April 2009. The government, together with car manufacturers, prepared for this introduction by compiling a list of E10 compatible vehicles, pumps were clearly labelled and the ethanol industry actively informed consumers using promotional literature (e.g., flyers). There was no specific opposition to E10 by stakeholders such as French NGOs.

Germany introduced E10 in December 2010, with a very different outcome. Before this introduction meetings with stakeholders, including car manufacturers, petroleum industry, etc. were held and concerted actions regarding user information and communication etc. were agreed upon. Despite these efforts, however, the introduction of E10 in Germany was hindered by low consumer acceptance. Reasons for this have been the strong opposition of NGOs due to concerns about the sustainability of the biofuels, and confusion caused by changing lists with compatible vehicles. The main lessons the national authorities have drawn from this are to improve the provision of information on the compatibility of vehicles, ensuring it is clear and correct, and to better explain the motivation behind the introduction of E10 to the general public and NGOs.

In **Finland** a special internet page on vehicle compatibility was set up to inform consumers as well: http://www.e10bensiini.fi/en. This website provides background information on the E10 fuel and contains a list of E10 compatible motors.

Tax incentives and blending obligations

As will be shown in Section 1.6.5, ethanol is more expensive than the petrol it replaces, and policies measures such as blending obligations and/or tax incentives are key to increase the biofuel volumes on the market. When these measures are effective and sufficiently ambitious, they automatically create a need for the fuel suppliers to move to higher blending levels such as E10: E10 allows them to add up to 6.8% of bioethanol to their petrol (on energy basis) instead of the 3.3% of E5.

In Germany, from the introduction of E10 in 2010 until the end of 2014, E10 was fully driven by the energy quota: fuel suppliers were required to put a minimum percentage of biofuels on the market, 6.25% by energy content in 2014. The associated fine for not meeting this quota, €19/GJ, was estimated to be roughly two times the fulfilment cost (although this factor varied depending on fluctuations in the market prices for biofuels and fossil fuels). The quota has been fulfilled in these years, and the amount of penalties were minimal. Since the beginning of 2015, the energy quota was replaced by a GHG reduction quota (see Section 1.3.3.1), with a penalty for not meeting the target of 0.47€/kg CO_2.

It is too early to assess the effect of this shift on the biofuel volumes and types, and therefore on the market share of ethanol and the need for E10 to meet these goals.

In **France**, the suppliers need the E10 sales to meet the blending obligation and prevent penalties, and make the E10 2 to 3 eurocents cheaper than E5, to encourage consumers with E10-compatible vehicles to buy the fuel. Tax exemptions, put in place to incentivise ethanol sales, are currently decreasing and will stop at the end of this year, but this is not expected to impact the growth of E10 sales, since the obligation de facto requires the fuel suppliers to sell E10.

In France, the fuel suppliers would like to see the tax exemption increased by a few €ct to make E10 more attractive. During the interview with the French ministry, it was explained that this is difficult to arrange due to the overlap between E5 and E10: E5 covers 0-5% ethanol and E10 covers 0-10%, thus creating overlap between the two blends. If there are tax differences between E5 and E10, it would de facto encourage E5 to be brought on the market as E10. This makes any tax advantage for E10 legally difficult to implement. During the interview, it was suggested that a modification of the Fuel Quality Directive, to ensure that E5 contains 0-5% ethanol and E10 5-10% (or even smaller ranges), would thus help from a government policy perspective: it would allow E10 to receive a higher tax incentive than E5.

E10 is broadly accepted (and sold) in **Finland**, because E10 is cheaper due to tax benefits (source: interview with government, E10 benefits from lower taxes on energy and CO_2). 70% of the vehicles are compatible to run on E10, and 60% actually run on E10, because car drivers prefer the cheaper option. According to the government official that was interviewed, there are even indications that consumers mix E85 with E10 to derive higher blends, because the fuels sales of E85 are about twice as much as would be expected from the market share of E85-compatible Flex Fuels Vehicles (E85 benefits from lower CO_2 taxes as well)[28].

The introduction of E10

Before the introduction of E10 in **Germany**, many refuelling stations offered three blends of petrol and two blends of diesel. With respect to petrol they offered E5 RON95, a RON91 fuel and a premium E5 RON98. In many cases the RON91 petrol has been replaced by the E10 RON95 (there is no E10 RON98 on the market), as this was seen to be the optimal solution considering refuelling station logistics and market share (economical) impacts. The result is that the national fuel sales statistics now show a very low share of RON91 (0.01%), and German refineries stopped providing it. The government official interviewed considered it

[28] This comment has not been substantiated further, it is recommended to further assess this issue to better understand the mechanisms that occur in the market.

possible that refuelling stations who still offer RON91 might in fact be selling E5 RON95 under the name of RON91, which is allowed legally due to higher quality of E5 RON95.

In **France**, before the introduction of E10, normally two grades of petrol were offered at service stations: a premium grade and E5 RON95. After the introduction of E10 most premium grades were replaced by E10.

1.3.4.2 Policy measures in other countries, in anticipation of the introduction of E10

There is no data on which Member States have started preparations for the introduction of E10, for example by adapting national legislation that allows oil companies to bring E10 on the market. In any case, this hasn't resulted in significant market shares of E10 in the Member States, besides Finland, France and Germany. For example, in the UK the national legislation allowed oil companies to supply petrol containing up to 10% ethanol since March 2013, in line with the EU standard for petrol (EN228), but until now no E10 has been brought on the market. The UK government decided in November 2013 to amend the Motor Fuel Regulations in order to guarantee the availability of E5 for another three years. Larger retailers selling more than three million litres or more must offer E10 unleaded and E5 super-unleaded until January 2017. Due to limited pump capacities smaller independent retailers have to choose what to offer (Department for Transport, 2013). This is in line with Article 3(3) of the FQD which obliges Member States to 'require suppliers to ensure the placing on the market of petrol with a maximum oxygen content of 2.7 % and a maximum ethanol content of 5 % until 2013 and may require the placing on the market of such petrol for a longer period if they consider it necessary. They shall ensure the provision of appropriate information to consumers concerning the biofuel content of petrol and, in particular, on the appropriate use of different blends of petrol.'

With respect to the latter, information provision to consumers, Poland has taken action on the labelling of E10 by drafting regulations for labelling requirements at the pump in February 2015. The marking methodology as laid down in these requirements should help consumers to distinguish the several blends. Information to be provided will include detailed information on the composition of E10. (ENDS Europe, 2015)

1.3.4.3 B8 in France

France faces problems with realising the blending obligation, because of its relatively ambitious targets: (7.7% energy content, of which 7% single counting and 0.7% double-counting). These levels exceed the maximum blending limits of both E10 (6.8% ethanol energy content) and B7 (6.4% FAME energy content), and other marketing options such as HVO or biofuel use in non-road transport are deemed to be insufficient to fill the gap. For this reason, France allows B8 on the national market since the start of 2015, making use of the provision in Article 4 of the FQD that allows Member States to permit the placing on the market of diesel with a FAME content greater than 7 % (see Section 1.3.2.2).

Until today almost no B8 have been brought on the market due to the discussion on the interpretation of this provision in the FQD, The European Commission, DG CLIMA communicated in a non-paper that Member States cannot go beyond B7 and anything above B7 requires a protection grade[29], but non-papers do not have a legal status. This has raised concerns about the practical implementation as well as a potential distortion of the market, as French service stations consist for 60% of supermarkets, which only have the infrastructure and facilities to sell 1 blend of diesel. They would have to choose which blend they will sell, and cannot offer both a protection grade and B8. The remaining (40%) service stations are linked to oil companies and could offer 2 grades premium/regular; they could introduce a higher diesel blend in a similar way as E10.

Because of the ongoing discussion the further introduction of B8 is currently on hold. Despite this interpretation issue, this case shows that certain Member States might encounter

[29] European Commission, Non-paper on the scope of the Fuel Quality Directive, Ref. ARES(2014)1760981 – 28/05/2014

problems with the current blending limits earlier than others due to the characteristics of their national fuel markets and the height of the blending obligations.

1.3.4.4 *Fungible biofuels*

Both France and Finland see fungible biofuels as part of the solution, but the higher prices of fungible fuels are seen as a barrier. Especially in Finland, where the individual target for renewable energy in transport was set twice as high as the 10% target of the RED, HVO has always been one of the key elements of its biofuel strategy, together with the introduction of E10 and E85. This is likely to be due to the large domestic production capacity of HVO (Neste Oil).

Currently, there is only one type of fungible biofuel on the market, HVO, produced by Neste Oil. Quantitative cost data for HVO are not available in public literature, and it is not traded publically as it is only produced by one company, but the fuel suppliers that were interviewed all confirmed that FAME is the cheaper biodiesel option, because the production process is inherently less complex than for HVO. When fuel suppliers decide on an optimal biofuel strategy in a certain country, they compare the different options, including HVO, to meet the blending obligations. Fungible fuels may be the optimal solution in some cases when comparing with the cost of introducing higher blends of FAME or ethanol. However, some fuel suppliers expressed their concerns that HVO is only provided by one producer, resulting in a lack of a competitive market for this product. Specific data on this cost comparison are confidential, and likely to depend on the specific situation and Member State policy. One fuel supplier indicated that they are actively pursuing the development of another type of fungible biofuel, but this is still in the R&D phase and a decision to invest in a larger scale plan will not be made before 2018.

1.3.4.5 *Other blends*

In **France** E85 has been stimulated with subsidies for E85 compatible vehicles; consequently, fuel tax on E85 is the lowest as allowed by the European legislation. Although 500 fuel stations are currently offering E85 in France, the market share of E85 vehicles is quite low. According to the interviews with government officials, this is mainly due to the car manufacturers not focussing on selling E85 vehicles, which may be interpreted as a sign of low consumer interest. It was further mentioned by government official that whereas in Sweden, retrofitting a petrol car with a flex fuel kit is legally allowed, this is not the case in France. This was also perceived to be a barrier to the uptake of E85 in France.

During a meeting with Renault, they stated that although the petrol options in **France** are labelled as E5 and E10, they are actually a mix of ethanol and ETBE (ethyl tertiary-butyl ether) derived from bio-ethanol so the oxygen content of the blend matches that of E5 and E10 respectively. For example, the E10 in France is 7% ethanol + 7% (approximately) ETBE so that the resulting blend has an oxygen content of 3.5% by weight. The use of ETBE in France is driven by the capacity of the largest local refiner TOTAL to manufacture ETBE. TOTAL also distributes its products in other countries in the EU. According to VW, in **Germany** there is some ETBE use but most E5 and E10 are ethanol blends.

In **Finland** E85 is completely produced from domestically produced waste, according to the government officials that were interviewed. Although the target for 2020 is estimated to be mainly realised by the use of E10 and fungible biofuels (HVO), E85 will play a role in the strategy to be completely carbon neutral in 2050. Therefore, from 2030 onwards, all new built vehicles should be able to drive carbon neutral. Finland is moving forward to achieve both this 2030 and the longer term target, for example by legally allowing retrofit of vehicle to achieve E85 compatibility

1.3.5 Conclusions

Biofuel consumption in Member States is being almost fully policy driven. At the EU level, the main drivers are the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) (EC, 2009a and EC, 2009b). The RED sets a binding 10% target (energy content) for renewable energy in transport in 2020, the FQD a reduction target for the GHG intensity of fuels of 6%, in 2020. Both directives also define sustainability criteria that the biofuels have to meet to count towards the targets, the RED furthermore regulates that biofuels from waste and residues are counted double towards the 10% target. Member States are free to decide on the policy measures to achieve these targets, within the boundaries provided by the EU regulations. The development of standards for high blend fuels is ongoing within CEN.

Recently, it has been decided to address the issue of indirect land use change effects by implementing a number of changes to both the RED and FQD, the main measures are that biofuels and bioliquids produced from cereal and other starch-rich crops, sugars and oil crops and from some energy crops can contribute no more than 7% to targets in the RED, and the introduction of a sub-target for advanced biofuels with a reference value of 0.5% in the RED. The effect of this new legislation is, however, as yet unclear.

The FQD also defines blending limits for FAME and ethanol, limiting the share of FAME in diesel to 7 vol% (6.4% energy content) and the share of ethanol in petrol to 10 vol% (6.8% energy content). Member States are, however, permitted to allow the placing on the market of diesel with a FAME content greater than 7%, under certain conditions.

The EU's energy and climate policy framework for 2030 does not provide binding targets for renewable energy in transport. The post-2020 renewable energy policy as well as the future policy on sustainable biomass and biofuels is yet to be shaped.

By 2014, almost all Member States, with the exception of Latvia, Cyprus and Estonia, had implemented biofuel obligations (quota) for fuel suppliers. However, the level of these obligations vary significantly between countries, from an average target less than 3% in Croatia and Greece, to 7% or higher in France, Poland and Slovenia. Member States have clearly not foreseen the same growth paths towards 2020. In addition, tax incentives for biofuels are provided in approximately half of the EU Member States, including one of the countries without obligation, Latvia (there is no information on tax incentives for Cyprus, and no incentive in Estonia). Nine Member States have specific tax incentives in place for higher blends: Germany, Hungary, Croatia, Latvia, Lithuania, Romania, Slovenia, Sweden and the Czech Republic. These incentives do differ, however, as they target different blends or provide different levels of incentives.

When assessing the progress of the various Member States towards the 10% target of the RED for 2020, current trends are found to be insufficient to meet the target on an EU level. However, achieving the target by 2020 remains feasible, as concluded in the Commission's recent Renewable Energy Progress Report (COM(2015)293). There is a significant variation in renewable energy shares throughout the EU (2013 data). Sweden has by far the largest share in 2013, with 16.7%, clearly aiming for a much more ambitious level of renewable energy in 2020 than needed for the RED target. Other Member States, notably Austria, Germany, Finland and Poland, are well on track to meet the target. On the other side of the spectrum, a number of countries, namely Estonia, Spain and Portugal, reported shares less than 1%. These different rates of progress are typically the result of large variations in blending obligations and financial incentives. Progress towards the 6% GHG reduction target of the FQD cannot be assessed in a similar way, as the GHG intensity data of the Member States or fuel suppliers are not yet monitored and reported on at EU level.

Blending limits have not been an issue in many Member States yet, as most biofuel obligations are still below these limits. Various options to go beyond the B7 and E10 limits have been implemented, mostly, but not limited to the Member States with high blending obligations and biofuel shares: Until now, E10 has been introduced in three Member States: Finland, France and Germany, where the rest of the EU has E5 or only pure petrol on the market (see the overview in the next chapter). Experiences with the introduction of E10 vary between these three countries, these are described in Section 1.3.4.1. B8 has been allowed in France (although it is not yet being sold yet), fungible (drop-in) biofuels such as HVO are being blended in the EU (but market shares are limited due to higher cost) and incentives for E85 are in place in some Member States (at least in France and Finland).

1.3.5.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations for improvement of the biofuel policy framework can be derived:

- Closely monitor and assess Member State policies and progress in the coming years, to ensure that the 2020 targets are met. A number of Member States with currently very low biofuel shares (Estonia, Spain and Portugal in particular, but see Table 1.5 for more information about the other countries) need to follow very ambitious growth paths in the coming years.
- The impacts of the ILUC decision on Member State policies and progress towards the targets should be assessed, to ensure that policies are adequately modified and the 2020 target is met with these new conditions. To facilitate this, it is recommended to revise the policy plans and indicative trajectories that the Member States submitted in their National Renewable Energy Action Plans, to align them with this new regulation. Potential issues that may arise due to the ILUC decision, for example related to potential insufficient supply of advanced biofuels or biofuels from waste and residues, will be further analysed in Section 1.6.
- Progress towards the FQD target for the GHG intensity of transport fuels should be monitored at the EU level, similar to the monitoring and reporting for the RED. The methodological basis for this monitoring was recently decided on, and laid down in Council Directive (2015) 652 (which is to be transposed by Member States by April 2017)
- Member States should be encouraged to assess what fuel blends they expect to need to meet the 2020 targets. As a start, it is recommended that all Member States prepare for the introduction of E10, as this allows an increase of the level of biofuels in petrol with relatively little effort (see Section 1.4.3 for a further assessment). This is likely to be necessary to supply the biofuel volumes to the market that are required to meet the 10% targets.
- Member States should furthermore develop plans for post-2020 policies for biofuels, and for the expected contribution of biofuels in their country towards the 2030 EU-wide target of 27% renewable energy. This will allow stakeholders to anticipate and prepare for future developments and demand.
- The FQD sets maximum contents of biofuels and, for instance allows E5 as a petrol with 0-5 vol% ethanol and E10 to contain 0-10 vol% ethanol. Avoiding such overlap in specifications by setting minimum level too could facilitate implementation of (financial) incentives for biofuel.

1.4 Biofuel consumption and distribution

1.4.1 Introduction

This Section discusses the impact of new biofuel blends on fuel distribution practices. Stakeholders involved in the fuel distribution chain mainly include refineries, oil companies, fuel suppliers and filling stations owners. The structure of this Section is as follows:

- Current market shares and fuel sales of petrol and diesel are given in Section 1.4.2.
- The potential biofuel levels that could be achieved with the B7 and E10 blending limits are assessed in Section 1.4.4.
- The structure of the fuel distribution market is discussed in Section 1.4.4.
- Technical opportunities and barriers are identified in Section 1.4.5.
- Non-technical opportunities and barriers are described in Section 1.4.6
- Conclusions and recommendations that can be drawn from these Sections can be found in Section 1.4.7

1.4.2 Current fuel sales

1.4.2.1 Market shares of petrol and diesel in transport

The current diesel and petrol fuel sales are presented in Table 1.6 (EU-level average) and Figure 1.6 (data per Member State). The diesel-to-petrol ratio varies significantly between Member States, as can be seen in Figure 1.6.

Refineries only have limited flexibility in the ratio of petrol and diesel they can produce, and the current EU fuel output does not meet EU fuel demand: 10% of diesel demand needs to imported, 40% of EU petrol production is exported[30]. From an economic point of view, oil companies would like to limit the level of diesel imports and the level of petrol exports. This deficit of diesel and surplus of petrol is the result of the fact that heavy duty vehicles must run on diesel to achieve the desired (technical) performance, in combination with Member State fuel taxation regimes that favour diesel over petrol (this is the case in all EU Member States, with the exception of the UK which has equal excise duties for diesel and petrol, status 2013[31]).

The demand for biofuels will impact these figures:

- increasing the share of biodiesel will may reduce the need for the import of diesel,
- replacing petrol by biopetrol could potentially increase export levels.

The net effect will depend on the balance between these two types of biofuel.

Oil companies and fuel suppliers will take this effect into account when deciding on the fuels they will supply as it effects the economics of these decisions. The potential impact of increased biofuel demand on refineries will be evaluated in Part 3 and 5 of this study.

Table 1.6 Share of diesel and petrol versus the share of biodiesel and biopetrol in the EU in 2014

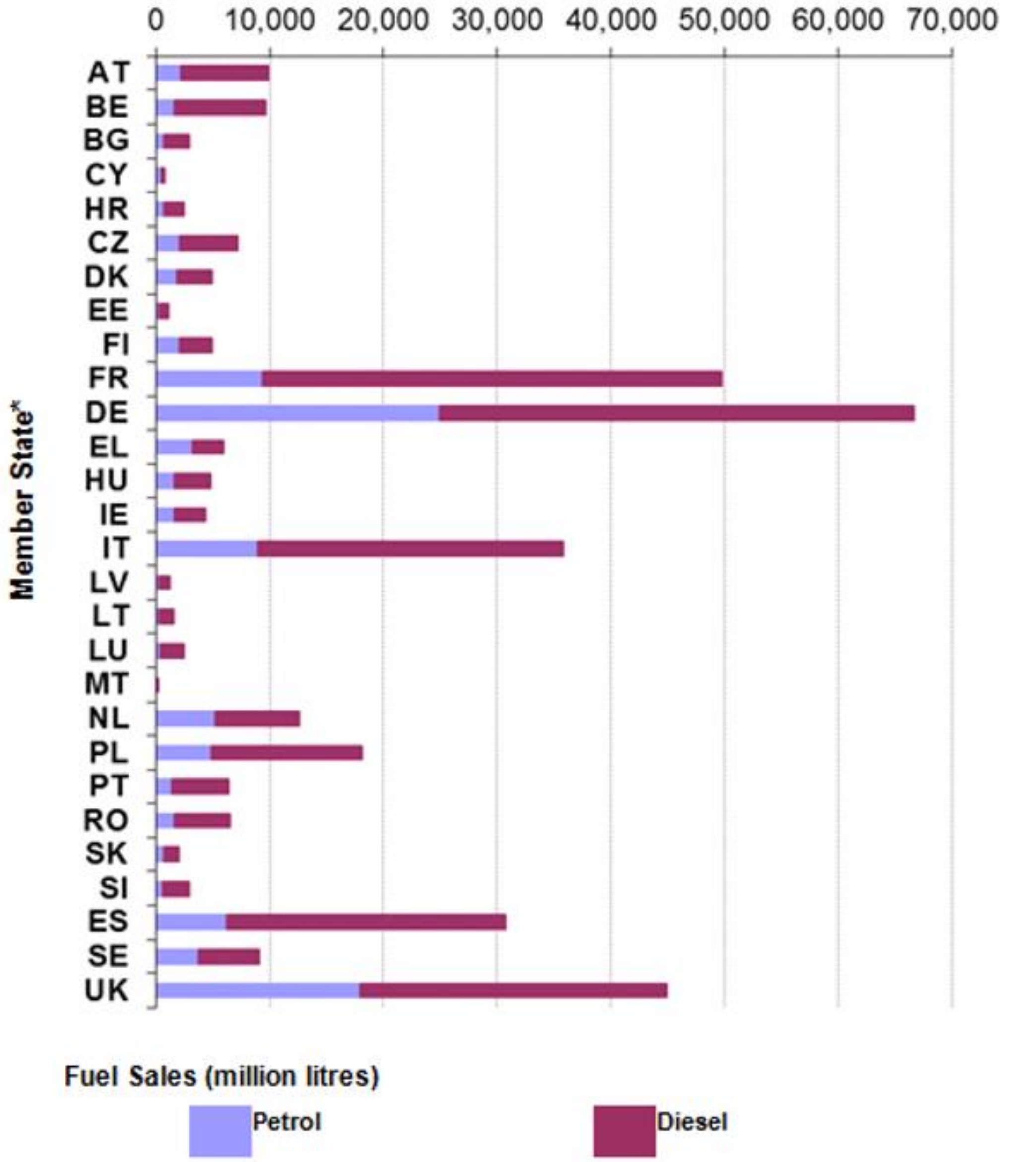
Diesel	70%	Biodiesel	80%
Petrol	30%	Biopetrol	20%

Source: Eurostat, 2015

[30] http://www.epure.org/media-centre/opinion-editorial/ethanol-best-choice-achieve-higher-ghg-savings#_ftn3 based on FuelsEurope/Eurostat/Biofuels Barometer

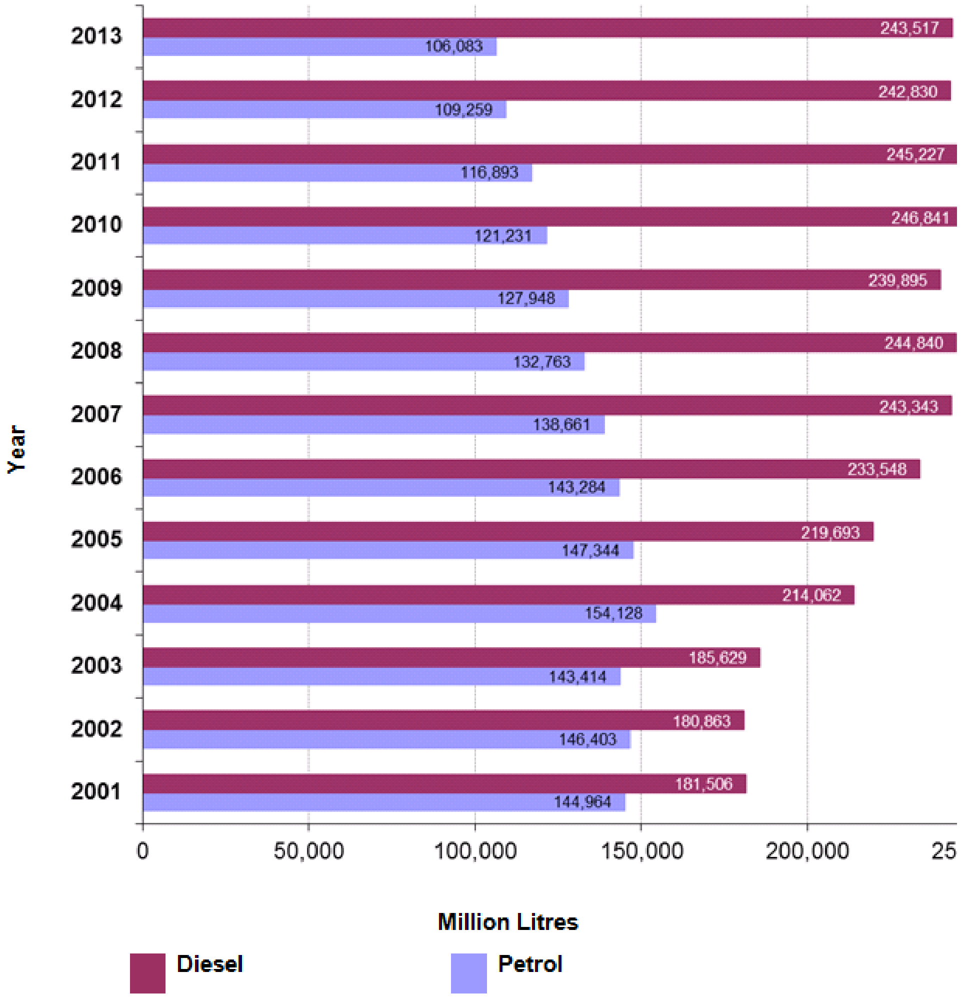
[31] See http://www.eea.europa.eu/data-and-maps/daviz/road-fuel-excise-duties#tab-chart_1

Figure 1.4 National fuel sales by fuel type across the EU (million litres)



The shift to diesel is still ongoing in the EU, as can be seen in the data of Figure 1.5. This trend is expected to continue in the coming years: in 2020 diesel volumes on the European market are predicted to be four times as high as petrol sales (Ricardo-AEA, to be published).

Figure 1.5 Temporal trends in EU fuel sales (Ricardo AEA, to be published)

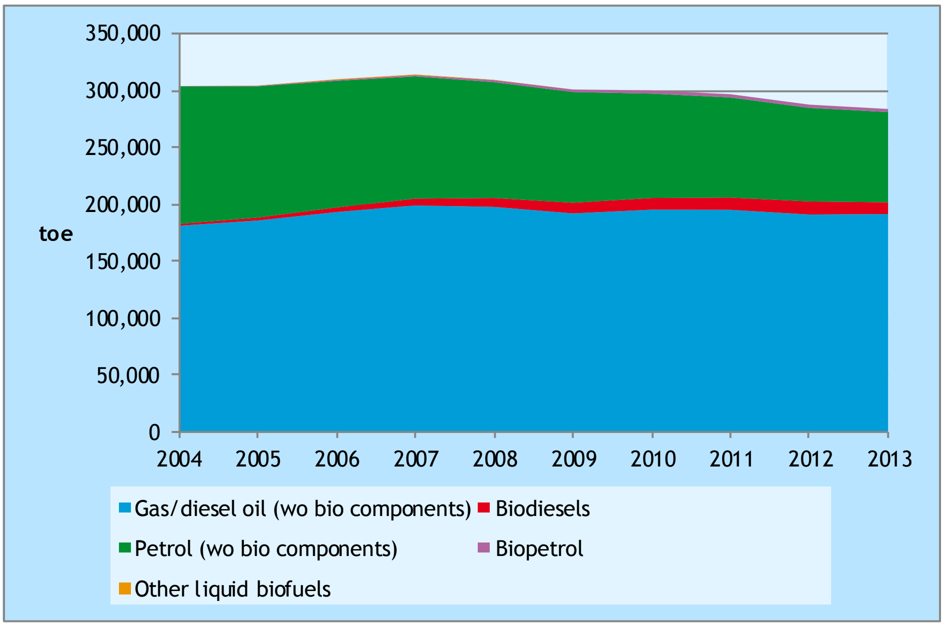


* Excludes France in 2003 - 2005, as no submissions were provided. Excludes Luxembourg in 2007 to 2009 and Malta in 2006 and 2009 as no reports were provided. In addition, the EU expanded in 2004, 2007 from 15 to 27 Member States and in 2013 to 28 Member States.

1.4.2.2 Biofuel consumption and developments over the years

In 2013, 4.6% of the EU's transport fuels was biofuels (in terms of energy content, rather than volume), which amounts to 13.6 Mtoe (source: Eurostat data). 79% of this was biodiesel, mostly FAME, 20% was biopetrol, the remainder mostly biogas fuel (Eurobserver, 2014). Putting these data into perspective, the total development of transport energy consumption in the EU is shown in Figure 1.6. The share of biofuels has clearly increased since 2004, but the large majority of transport fuels are still diesel and petrol.

Figure 1.6 Final Energy Consumption – Transport

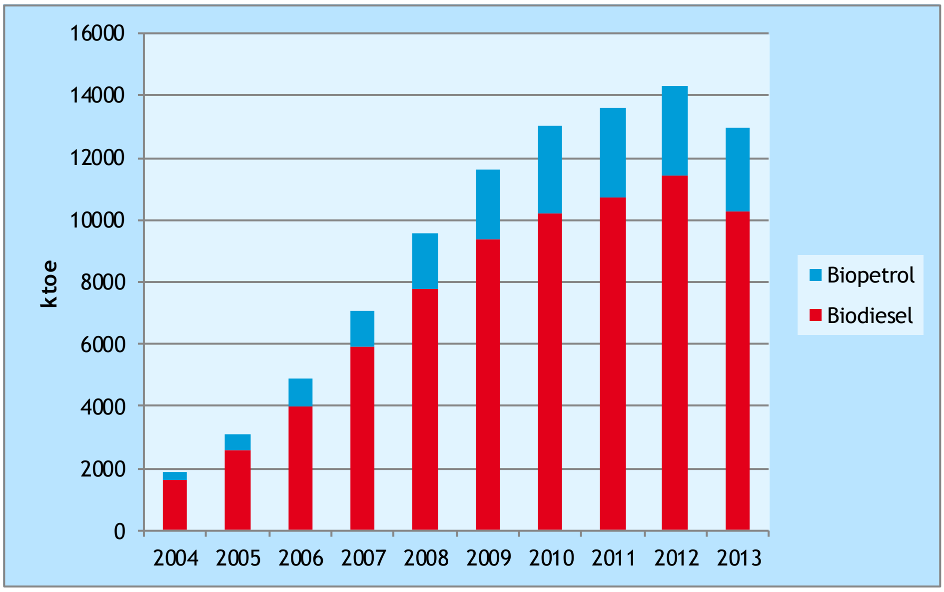


Source: Eurostat, 2015

Looking into the trends of biofuel consumption in more detail (Figure 1.7) it can be seen that after a steep growth of biofuel demand in the EU between 2004 and 2009, the growth curve has levelled off, and demand even dropped between 2012 and 2013. This is mainly explained by the introduction of the sustainability criteria (these Eurostat data only take into account biofuels that comply with the criteria), policy changes (e.g. lowering of the target in Spain, see Section 1.3.3.1) and an increasing use of double counting biofuels (from waste and residues, see Section 1.6.2.1) to meet the biofuel obligations.

The relatively large share of biodiesel in the biofuel mix is mainly due to economic reasons (source: interviews with fuel suppliers). As mentioned in Section 1.3.3.1, some Member States have set minimum levels of biopetrol in their overall biofuel obligations to specifically ensure that the market also demands petrol-replacements, and a diverse mix of biofuels is developed. The biodiesel consumed in the EU is mainly FAME, with HVO having a market share of about 7 to 8 percent (source: Neste Oil).

Figure 1.7 Development of biofuel consumption in EU-28 between 2004-2013



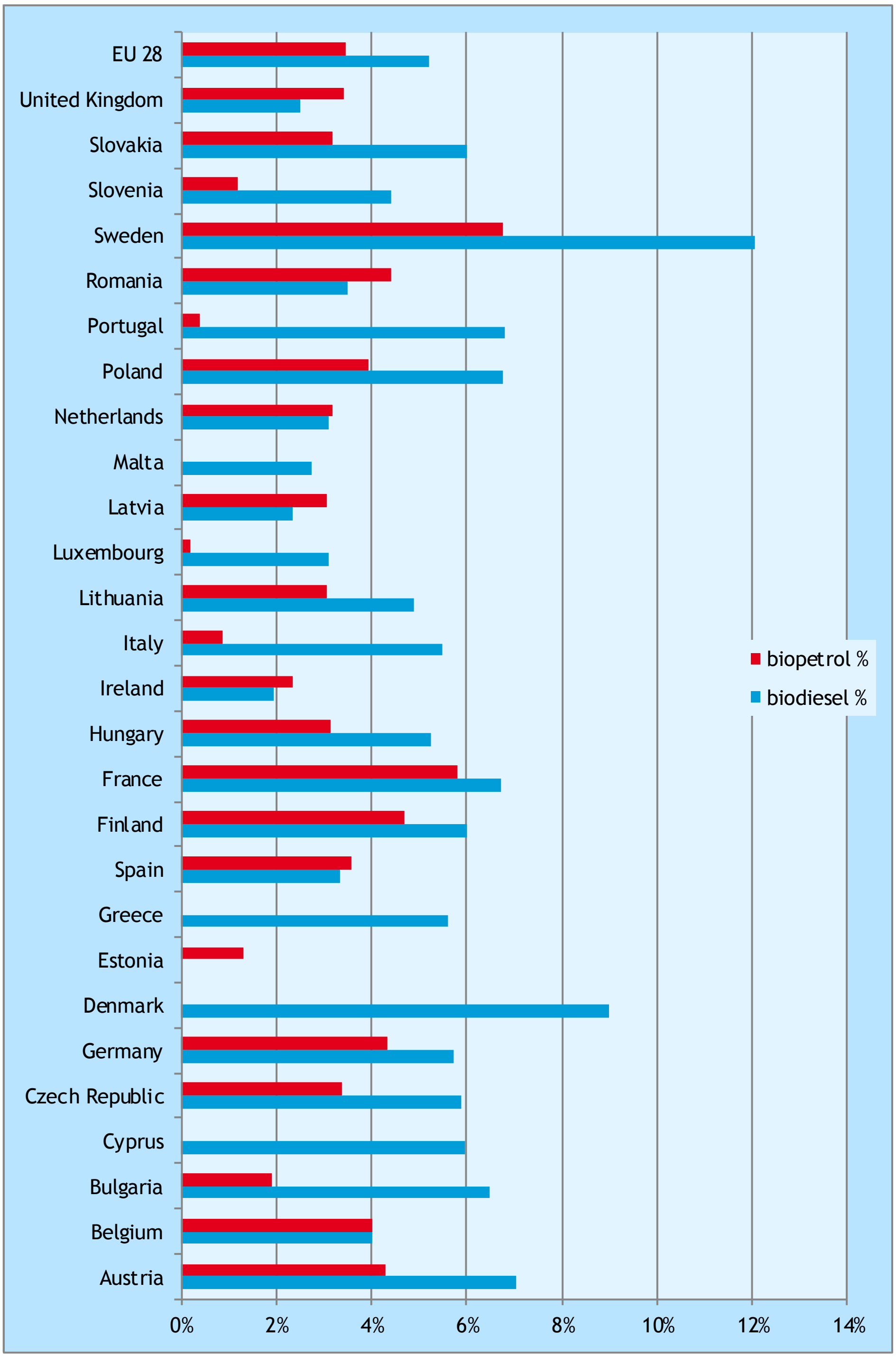
Source: Eurostat, 2015 (double counting not taken into account)

With a 4.6% average share of biofuels in total EU transport fuel sales (based on energy content), the variations between Member States are quite significant, as can be seen in Figure 1.8. Sweden clearly has the highest share, more than 16% in 2013, and another fifteen Member States have achieved market shares above 4%, in 2013. Nevertheless, there were still quite a few countries with shares below 1%: Bulgaria, Estonia, Greece, Spain, Cyprus, Malta, Portugal and Finland.

In the EU as a whole, and in most Member States, biodiesel has a higher share in diesel than biopetrol has in petrol, as shown in Figure 1.8 – the only exceptions are the UK, Romania, the Netherlands, Latvia, Ireland, Spain and Estonia. Belgium has equal (4.0%) biofuel shares in both petrol and diesel.[32]

[32] Details about the share of FAME and HVO in the biodiesel consumption data are not reported by Eurostat. National consumption data of HVO are confidential, but NesteOil, the main producer, reports that HVO was sold to 17 of the 28 Member States (source: NesteOil).

Figure 1.8 Shares of biodiesel and biopetrol in total diesel and petrol sales, respectively, in 2013



Source: Eurostat, 2015

Comparing these data with the current blending limits of B7 and E10:

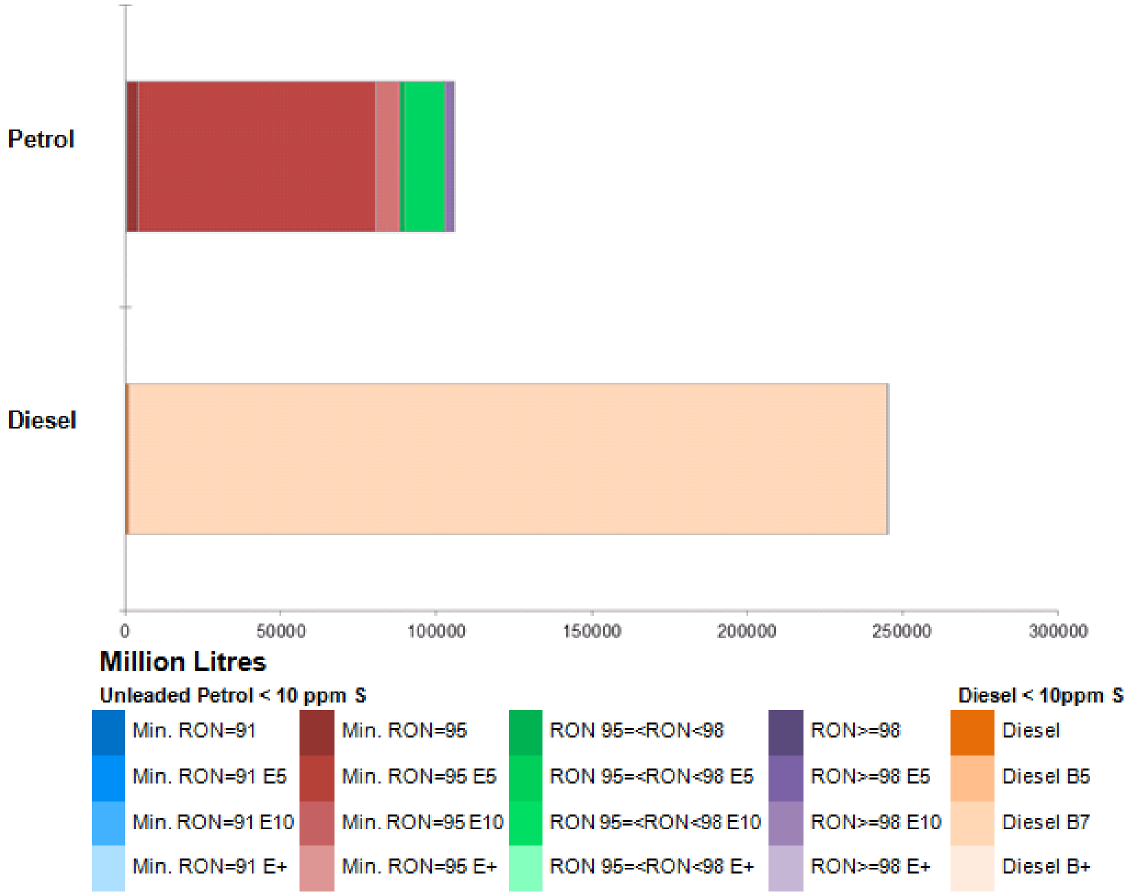
- six Member States achieved a higher share of biodiesel sales than 7 vol%, i.e. 6.4 % energy content: Austria, Bulgaria, Denmark, France, Poland, Portugal and Sweden. This can be achieved with sales of FAME in higher blends in captive fleets (B20, B30 or B100), or by adding HVO.
- no Member State exceeded the E10 level, i.e. 6.8% energy content, although Sweden just reached this level.

Only Sweden had an overall biofuel share above the 7% energy content that was set as limit for biofuels from food-based crops to count towards the RED target in the recent ILUC decision. Note that this does not mean that they overshoot the 7% cap, as part of Sweden's biofuels are produced from waste and residues (exact data are on this share are, however, not available as Eurostat currently does not differentiate between food-based and other types of biofuels) and Sweden already exceeds the 10% target – the cap only applies to the biofuels that count towards the target.

1.4.2.3 Petrol and diesel blends in the Member States

Looking at the type of blends used to achieve these shares, the annual Fuel Quality Monitoring reports of Member States can be of help. Based on the reports submitted over 2013, the shares of the different blends on the European market are depicted in Figure 1.9 (EC, 2015c).

Figure 1.9 EU Fuel Sales volumes by fuel type



Source: EC, 2015c

Note: E+ are petrol types with ethanol levels higher than E10, B+ includes all diesel with FAME levels higher than B7

The petrol fuels sold on the European market mainly have been sold as RON95 fuels and, to a lesser extent, as RON 98. The majority of the fuels was labelled as E5. The overall shares of E10 and E85 (indicated as E+ in the figure) are negligible in the overall sales, although may be significant in some Member States (see below).

Diesel has been almost entirely (99%) been sold as B7.

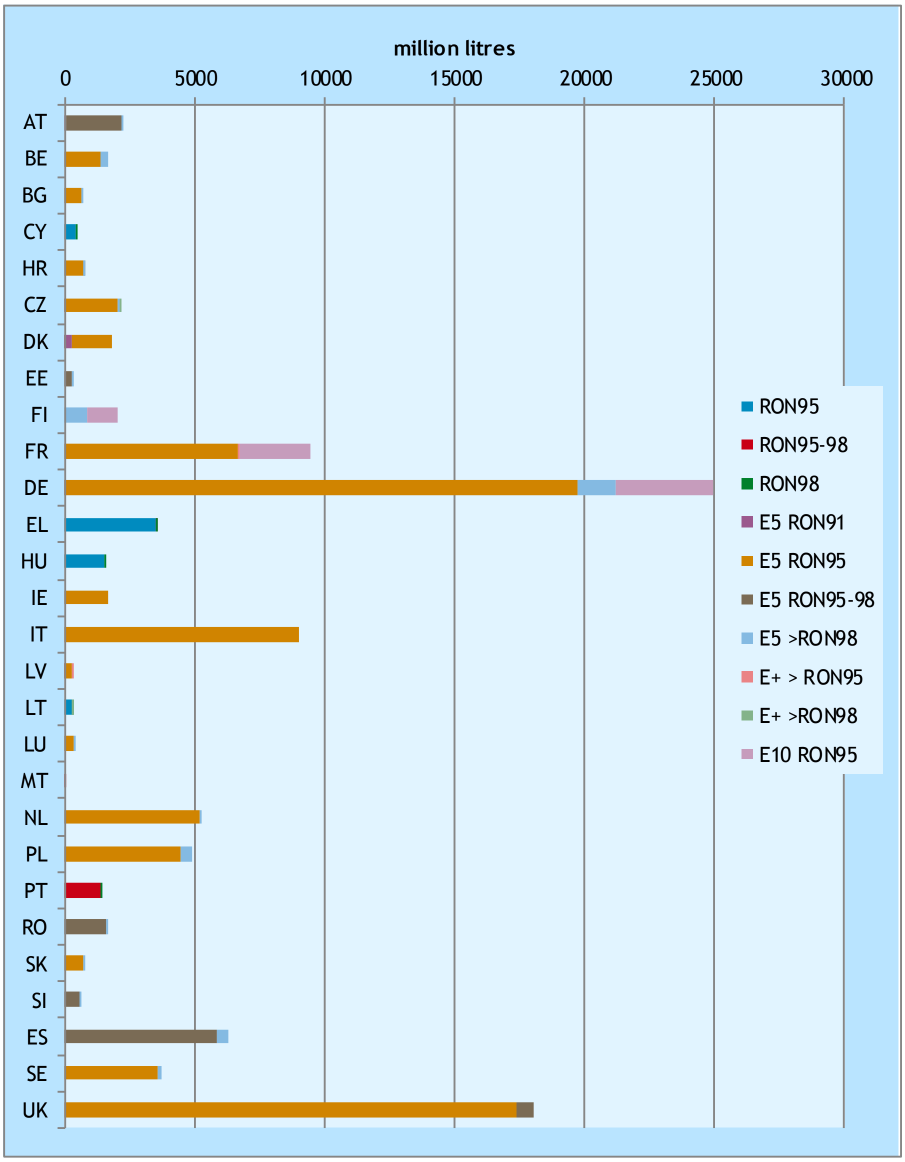
The variation in petrol grades between Member States is quite significant, as illustrated in the figures below[33]: absolute sales of different grades of petrol are shown in Figure 1.10, the same data are expressed as shares of total fuel sales (i.e. volume %) in Figure 1.11.

[33] These figures are based on (Ricardo-AEA, 2015), a report for the European Commission which is confidential but contains more detailed data than (EC, 2015c). Permission was granted to use these data in this report.

A somewhat different cross Section of the data is shown in Figure 1.12 and Figure 1.13, where the different RON-grades are combined, and the figures only distinguish between E0, E5, E10 and E+.

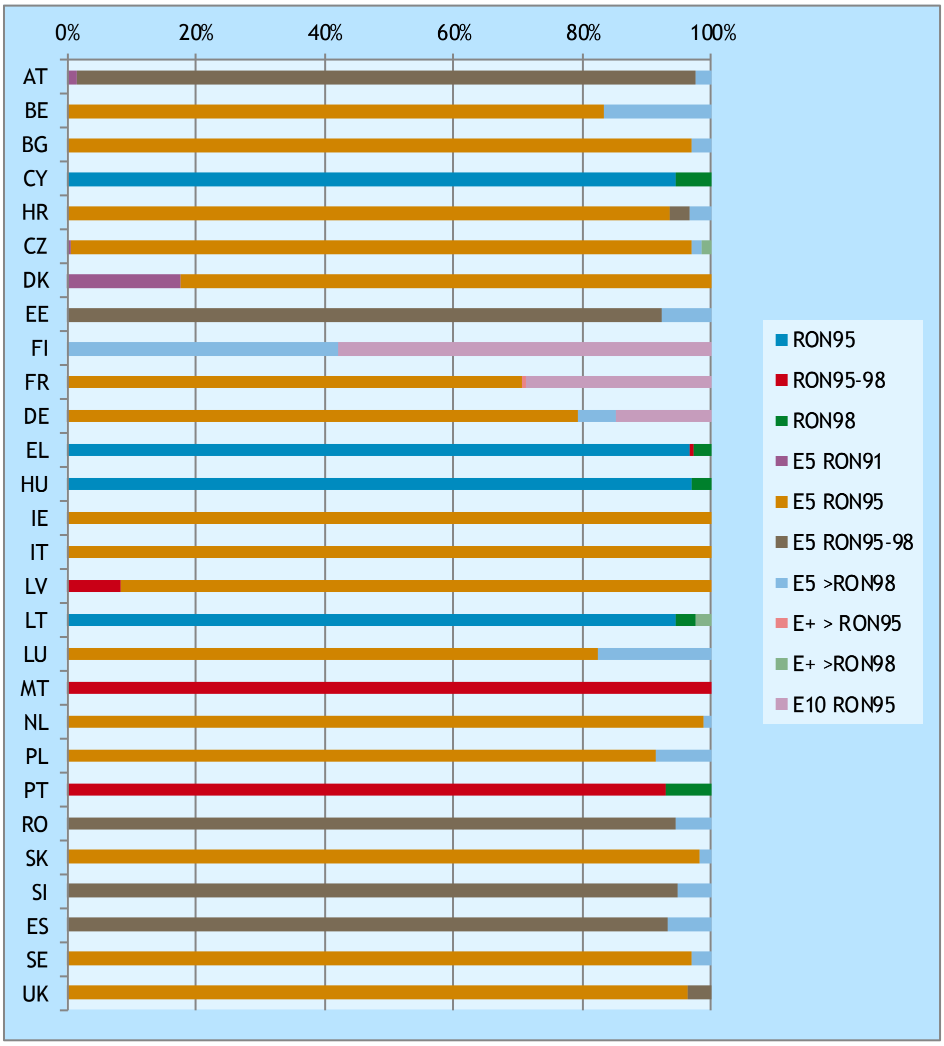
The figures show that E5, and in particular E5 RON 95, is the main petrol grade sold in most Member States. However, some countries, namely Cyprus, Greece, Hungary, Lithuania, Malta and Portugal have almost no E5 in their fuel mix, only pure petrol, according to Ricardo-AEA, 2015. As discussed in the previous chapter, E10 is only available in Germany, France and Finland. The market share of E10 is highest in Finland, almost 60% of the total petrol market, whereas France has about 30% market share of E10, and Germany about 15%. E+, i.e. ethanol blends higher that 10 vol%, has been sold in France, Czech Republic, Lithuania and Latvia. However, these data are somewhat uncertain, as (Ricardo-AEA, 2015) states that Member States reporting of fuels with high bioethanol/ FAME blends (e.g. E85) is inconsistent, as this type of fuel is not covered by the Fuel Quality Monitoring Directive.

Figure 1.10 Fuel sales of ethanol blends per Member State in 2013, in million litres



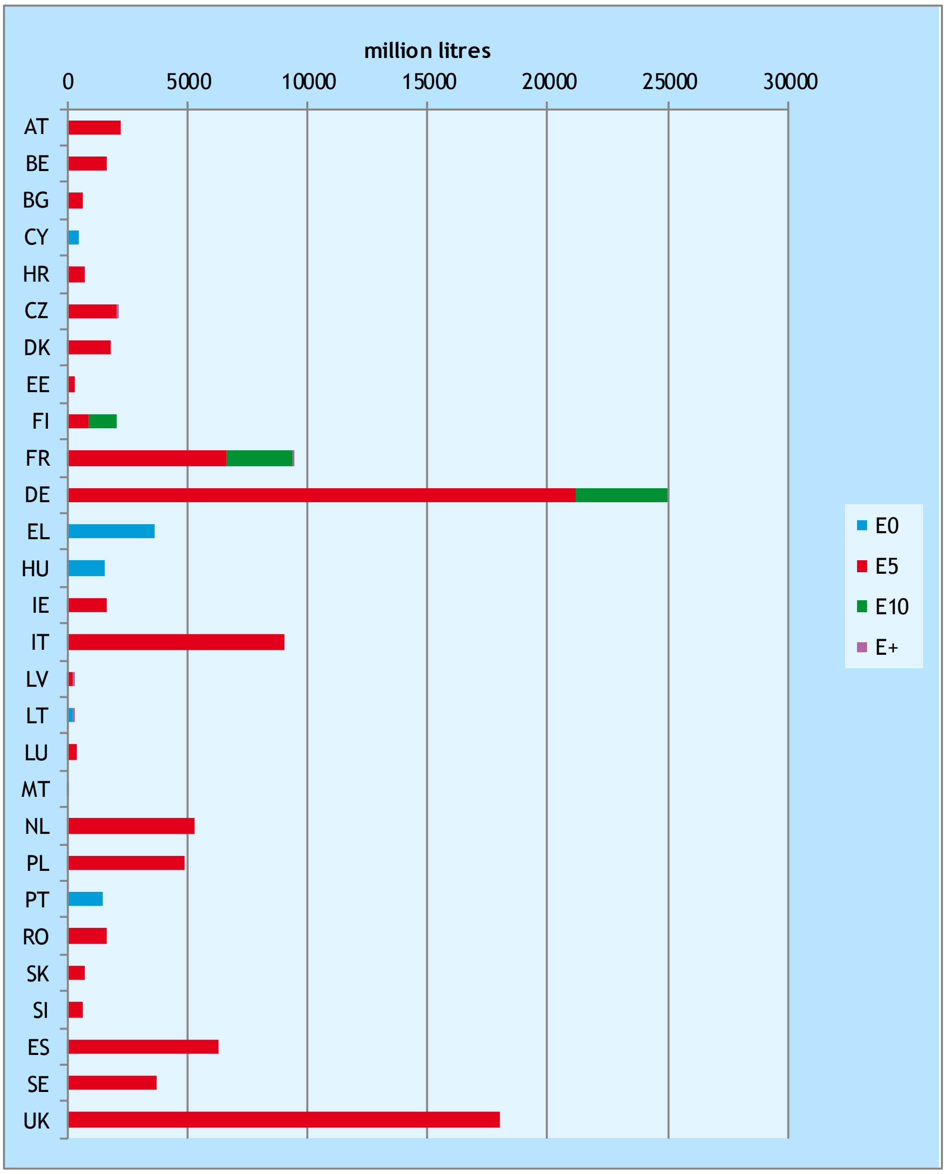
Source: Ricardo-AEA, 2015

Figure 1.11 Fuel sales of ethanol blends per Member State in 2013, in volume %



Source: Ricardo-AEA, 2015

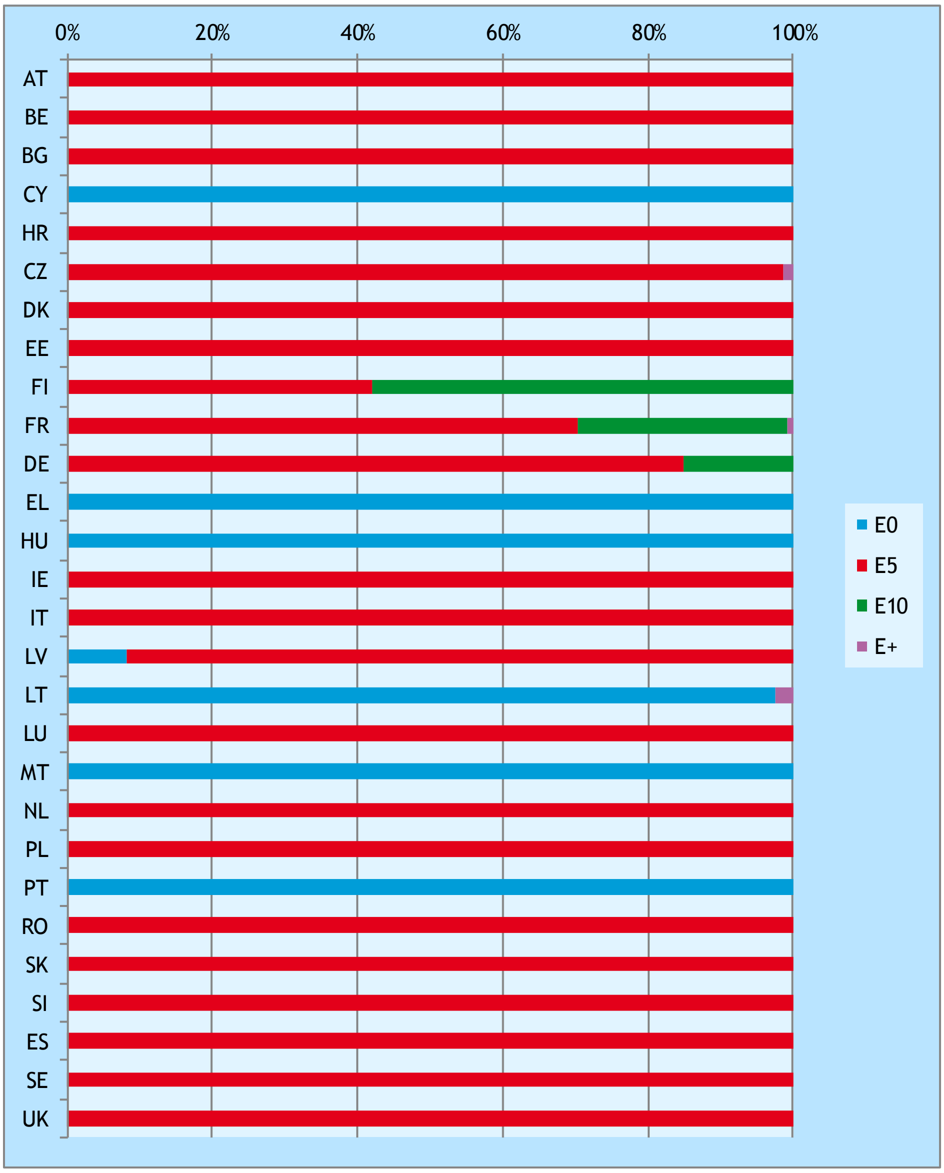
Figure 1.12 Fuel sales of ethanol blends per Member State (aggregated) in 2013, in million litres



Source: Ricardo-AEA, 2015

Note: E+ are petrol types with ethanol levels higher than E10

Figure 1.13 Fuel sales of ethanol blends per Member State (aggregated) in 2013, in volume %

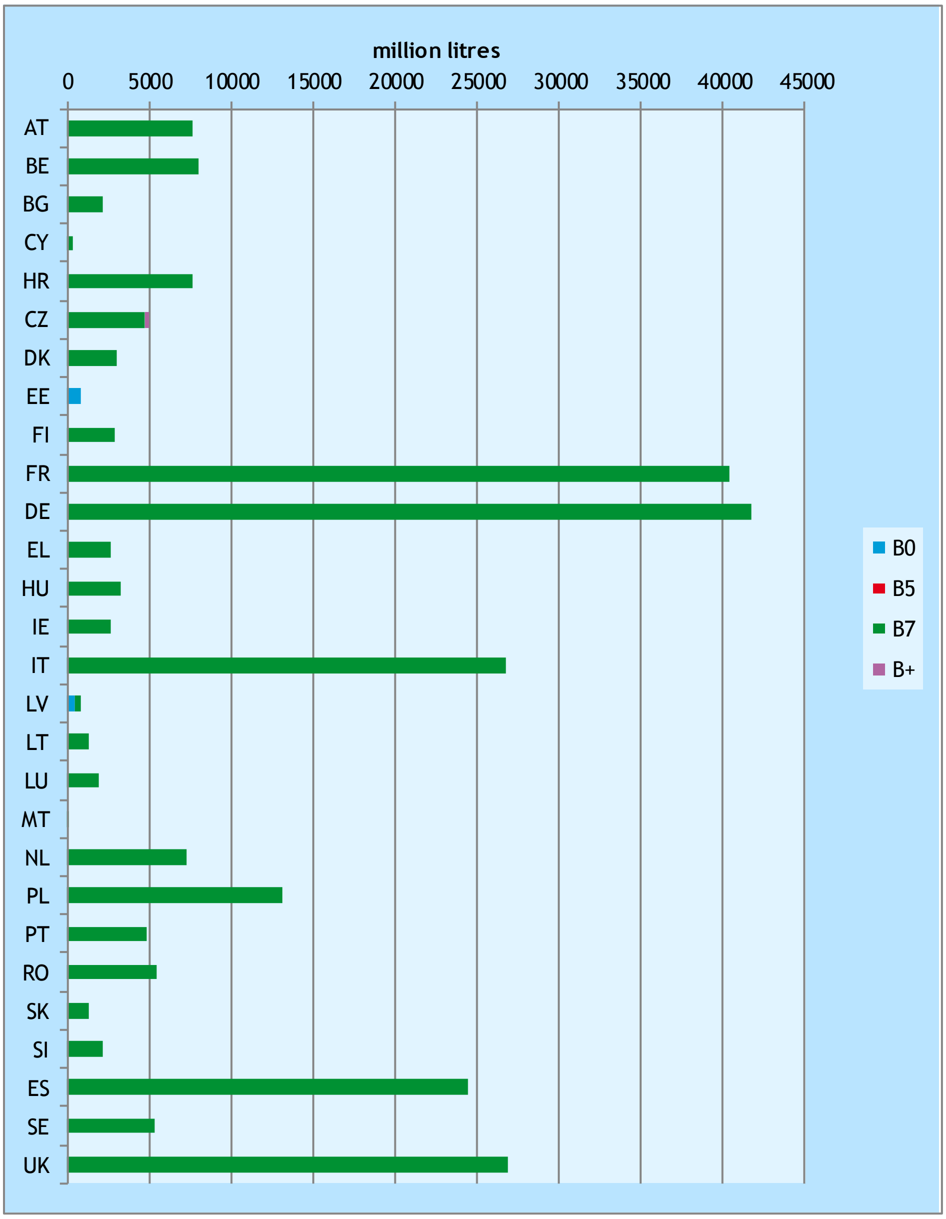


Source: Ricardo-AEA, 2015

Note: E+ are petrol types with ethanol levels higher than E10

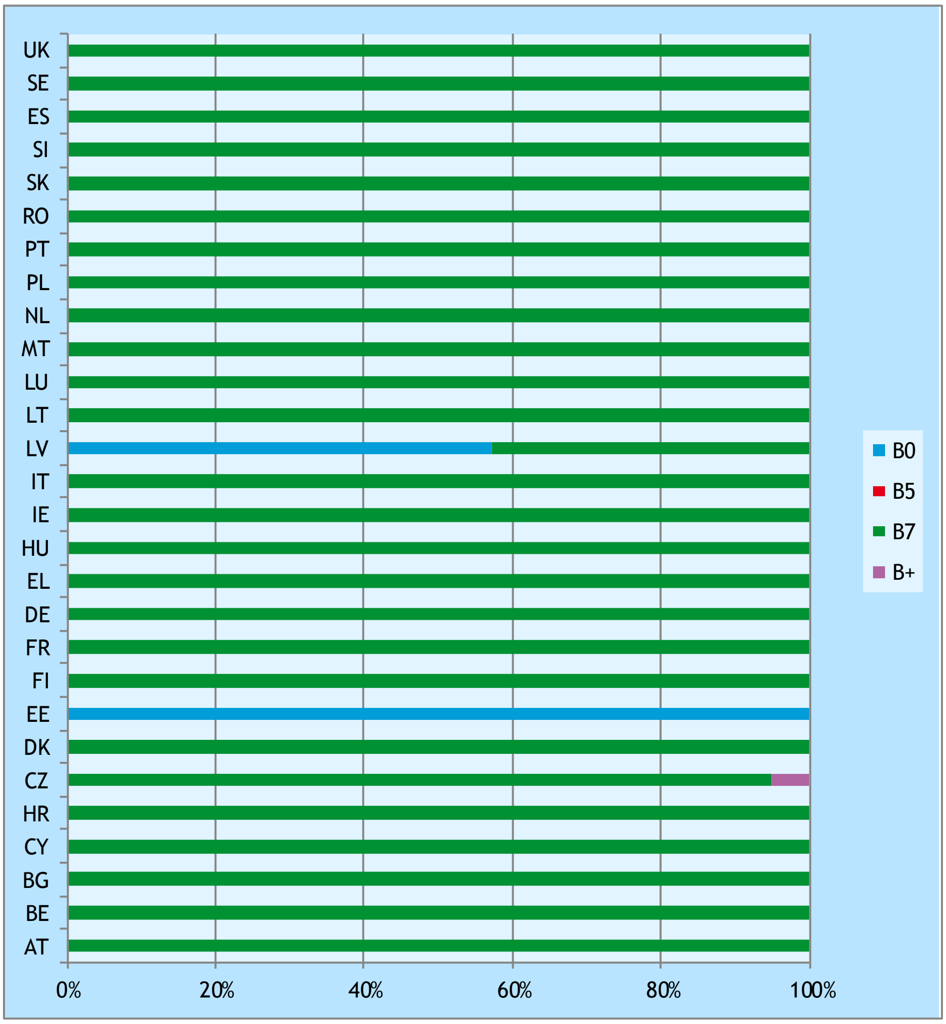
Looking at the diesel blends in the EU, shown in Figure 1.14 (absolute sales) and Figure 1.15 (in vol%), it can be concluded that the majority of Member States only have B7 on their market. The only exceptions are Estonia and Latvia: in the first, only pure diesel is available, in the second, pure diesel still has a market share of almost 60%. Diesels with FAME levels higher than B7 (B+) are only reported in the Czech Republic. These are used in dedicated vehicles or captive fleets, typically as B20, B30 or B100. However, as mentioned above, Member State reporting of these high blend fuels may not be consistent as this type of fuel is not covered by the Fuel Quality Monitoring Directive (Ricardo-AEA, 2015).

Figure 1.14 Fuel sales of diesel blends per Member State in 2013, in million litres



Source: Ricardo-AEA, 2015. B+ are diesel types with FAME levels higher than B7

Figure 1.15 Fuel sales of diesel blends per Member State in 2013, in volume % of total diesel sales



Source: Ricardo-AEA, 2015

Note that these data are sales of different petrol and diesel grades, which do not as such indicate whether Member States have allowed the blends specified in the FQD on their national markets. So the fact that E10 has only a substantial market share in a few Member States does not imply E10 has not been allowed in national legislation.

Also, they do not say anything about the actual biofuel volumes sold: as explained before, the names of the biofuel blends only indicate the maximum volume% that is allowed in that type of petrol and diesel, as specified in the FQD. For example, B7 may contain a FAME vol% between 0 and 7.

There are only limited and relatively uncertain data available on trends regarding biofuel blends in the EU, as Member States are only required to report on biofuel content from 2011 onwards, and the report on 2011 still had a number of inconsistencies (e.g. the Netherlands reported only E0 and B0 on its market, whereas Eurostat data show that biopetrol had a share of 3 energy% in overall petrol consumption, and biodiesel has a 2.5 energy% share of overall diesel consumption). Since then, however, reporting has improved, as (Ricardo-AEA, 2015) concludes.

1.4.3 Potential of B7/ E5 and E10

As the majority of Member States do not yet make use of the full potential of the current blending limits B7 and E10, several stakeholders mentioned that a more widespread use of B7 and E10 would be a logical next step in increasing biofuel volumes. The maximum marketing potential of these blending limits have not been reached yet, and this would be a relatively simple route to increase biofuel sales without vehicle adaptations and with limited impact on fuel distribution. The only implications would be introducing E10 on all national markets, for example by putting the necessary incentives in place and implement information campaigns for consumers, as was discussed and illustrated by the experiences in Finland, France and Germany in Section 1.3.4.1. As was shown in Section 1.3.2.2, in terms of energy content, B7 would allow up to 6.4% FAME, E10 up to 6.8% of ethanol.

As will be demonstrated in the following, there is still a lot of potential to further increase ethanol sales, if more, and eventually all, Member States would introduce E10, either by providing specific incentives for E10 or by gradually increasing the obligations and thus encouraging the fuel suppliers to introduce and actively market E10. Similarly, FAME sales can be further increased within the current blending limits if all Member States would move to B7, and at the same time increase their biofuel obligations so that fuel suppliers indeed blend FAME in their diesel to the maximum level allowed.

1.4.3.1 The current situation

This is demonstrated in the following tables, where the 2013 fuel sales data are analysed for all EU Member States. Table 1.7 compares the current biodiesel consumption to the maximum level within the limits, B7 (which equates to 6.4% FAME, in energy content). As was shown in the previous Section, several countries, namely Austria, Bulgaria, Denmark, France, Poland and Portugal, already consume more biodiesel than the B7 level would allow, where Sweden sells almost twice as much as the blending limit allows. These are also the countries with relatively high blending obligations, in some cases supported by tax incentives for biofuels – see the Member State policy overview in Section 1.3.3. These higher shares can be achieved with higher FAME blends in captive fleets, non-road modes and/or by blending HVO.

In the other Member States the share of FAME can still increase quite significantly within the current blending limits: a total of 12 Member States can still add two or more percent of FAME to their diesel within the limits.

Note that Estonia is the only country that did not sell any biodiesel in 2013, which is confirmed by Fuel Quality Monitoring data shown in the previous Section (100% pure diesel in Estonia). The other country that still had a significant market share of pure diesel (almost 60%), Latvia, achieved a 3% share of biodiesel in 2013.

Table 1.7 Maximum current blending potential (ktoe) in diesel for the individual Member States

	Total diesel consumption	biodiesel consumption (2013)	2013 biodiesel share (energy %)	Additional blending potential (to B7)
AT	6,003	423	7.0%	-0.7%
BE	7,007	281	4.0%	2.4%
BG	1,483	96	6.5%	-0.1%
CY	252	15	5.9%	0.4%
CZ	3,808	224	5.9%	0.5%
DE	33,075	1,893	5.7%	0.7%
DK	2,517	227	9.0%	-2.6%
EE	484	0	0.0%	6.4%
EL	2,164	121	5.6%	0.8%

	Total diesel consumption	biodiesel consumption (2013)	2013 biodiesel share (energy %)	Additional blending potential (to B7)
ES	21,335	716	3.4%	3.0%
FI	2,576	155	6.0%	0.4%
FR	34,285	2,299	6.7%	-0.3%
HU	2,009	106	5.3%	1.1%
IE	2,282	45	2.0%	4.4%
IT	21,435	1,176	5.5%	0.9%
LT	1,052	51	4.9%	1.5%
LU	1,772	55	3.1%	3.3%
LV	642	15	2.4%	4.0%
MT	109	3	2.8%	3.6%
NL	6,304	194	3.1%	3.3%
PL	8,930	603	6.8%	-0.4%
PT	3,751	255	6.8%	-0.4%
RO	3,468	122	3.5%	2.9%
SE	3,746	451	12.0%	-5.6%
SI	1,266	56	4.4%	2.0%
SK	1,353	81	6.0%	0.4%
UK	23,772	599	2.5%	3.9%
EU total	**196,884**	**10.261**	**5.2%**	**1.2%**

Source: Eurostat fuels consumption in transport data, 2013

The 2013 data for petrol are shown in Table 1.8. Here, the 2013 petrol consumption data are compared with the biopetrol consumption, illustrating that biopetrol shares are still relatively limited in almost all Member States. As most Member States only have E5 petrol grades on their market (equal to 3.3% energy), it is not surprising that many countries have biopetrol shares lower than 3.3%.

However, there are still quite a number of countries with biopetrol shares between 3.3 and 5 energy%, namely Austria, Belgium, Czech Republic, Germany, Spain, Finland, Poland, Romania and the UK. In Germany and Finland, this can be explained by the market shares of E10, in the other countries we can assume that E85 also has a market share (either in captive fleets or on public filling stations, for flex fuel vehicles). Note that many of these countries had tax incentives for higher blends of biopetrol, as shown in Section 1.3.3.2.

Only France and Sweden had shares higher than 5 % (energy content, which equals about 7.6 vol%). For France, this can be explained by the relatively high market share of E10 (almost 60%, see Section 1.4.2.3). As Sweden only reported E5 petrol grades, it can be assumed that the remaining bioetprol is due to sales of E85. However, as explained in Section 1.4.2.3 the current Fuel Quality Monitoring requirements do not require reporting of high biofuel blends, and reliable data on consumption of these blends are currently not available.

Table 1.8 Maximum current blending potential (ktoe) in petrol for the individual Member States

	Petrol consumption	biopetrol consumption (2013)	2013 biopetrol share (energy %)	Additional blending potential (to E10)
AT	1,561	67	4.3%	2.3%
BE	1,193	48	4.0%	2.6%
BG	442	8	1.9%	4.7%
CY	369	0	0.0%	6.6%
CZ	1,574	54	3.4%	3.2%
DE	17,591	765	4.3%	2.3%
DK	1,336	0	0.0%	6.6%
EE	241	3	1.3%	5.3%
EL	2,834	0	0.0%	6.6%
ES	4,666	167	3.6%	3.0%
FI	1,401	66	4.7%	1.9%
FR	6,739	392	5.8%	0.8%
HU	1,193	38	3.1%	3.5%
IE	1,186	28	2.3%	4.3%
IT	8,399	74	0.9%	5.7%
LT	210	6	3.1%	3.6%
LU	327	1	0.2%	6.4%
LV	210	6	3.0%	3.6%
MT	75	0	0.0%	6.6%
NL	3,956	125	3.2%	3.4%
PL	3,660	144	3.9%	2.7%
PT	1,148	5	0.4%	6.2%
RO	1,268	56	4.4%	2.2%
SE	2,662	180	6.8%	-0.1%
SI	485	6	1.2%	5.4%
SK	563	18	3.2%	3.4%
UK	13,450	459	3.4%	3.2%
EU total	**78,736**	**2,715**	**3.4%**	**2.9%**

Source: Eurostat fuels consumption in transport data, 2013

1.4.3.2 Expectations for 2020

In (CE Delft, 2013), the potential of the current blending limits were compared to the biofuel volumes that the Member States expected to use in 2020, according to their NREAPs. This allowed to assess to what extent the 2020 renewable energy in transport target could be met with the current blending limits, and to determine whether higher blends or other measures would be needed (without taking into account the recent ILUC decision).

The EU-wide result is shown in Table 1.9, together with the blending potential of non-road modes (not part of this assessment) and a volume of HVO that was considered to be the maximum achievable potential for 2020 (limited by production capacities). This table shows that overall EU sales of both biodiesel and biopetrol can still increase significantly within the current blending limits: biodiesel sales, currently at 10.7 Mtoe (2013), can increase to 17 Mtoe, of which 15 Mtoe FAME, and biopetrol can increase from the current 2.7 Mtoe to 7 Mtoe.

However, the table also shows that B7 is insufficient to accommodate the Member State's plans regarding biodiesel volumes in 2020. 5 Mtoe of FAME will have to be brought on the market through higher blends, higher shares of HVO or much larger volumes of double counting biodiesel than anticipated in the NREAPs – in the NREAPs, Member States expected that 7% of their biodiesel would be double counting in 2020.

The gap is smaller for biopetrol: if all Member States make full use of E10 in 2020, 1 Mtoe of biopetrol would have to be sold through higher blends, more use of double counting ethanol or other biopetrol options. In the NREAPs, MS expect 9% of the biopetrol in 2020 to be double counting.

As mentioned before, the biofuel plans outlined by the Member States in the NREAPs do not yet take the ILUC decision into account. This decision may be expected, for example, to result in an increase of the share of double counting biofuels, which will reduce the actual biofuel volumes that need to be consumed to meet the 10% target in 2020. This is likely to reduce the gap, i.e. reduce the biofuel volumes that remain after the blending limits have been used to the maximum. The increase in multiplication factors in the RED for renewable electricity used in road and rail may further enhance this effect, and also results in a reduction of biofuel consumption that is required for the 10% RED target. As new plans have not yet been submitted, this analysis is still based on the most recently submitted NREAPs.

Table 1.9 Maximum blending potential (Mtoe) in diesel and petrol, and gap with the NREAPs in 2020

Type of biofuel	Application	Biofuel blending potential (Mtoe)	Actual sales in 2013 (Mtoe, Eurostat)	Mtoe expected in 2020, according to NREAPs	Gap with NREAPs
Biodiesel	FAME B7 in road	13	**10.7**	**22**	**5**
	FAME B7 in non-road	2			
	HVO	2			
	Total	**17**			
Biopetrol	E10 in road	7	**2.7**	**7**	**1**
	E10 in non-road	0			
	Total	**7**			
Total		**22**		**29**	**8**

Source: CE Delft, 2013 and Eurostat, 2013

Note: Non-road includes mobile machinery.

There are large differences between Member States, however, due to different diesel-to-petrol ratios and different biofuel strategies. This can be seen in the tables below, where the detailed data for the various Member States are shown (from CE Delft, 2013)[34]. It should be noted that these data are relatively uncertain, as the blending potential was estimated using PRIMES fuel demand forecasts for 2020 (reference scenario 2012) which are relatively uncertain on a Member State level (CE Delft, 2013).

The results for diesel, shown in Table 1.10, show that almost all Member States, with the exception of Cyprus, Hungary, Latvia, Malta and Slovakia, are likely to need higher blends, a large share of double counting biofuels or some other solutions (HVO, FAME in non-road modes) it they are to achieve the biodiesel shares given in their NREAPs, in 2020. Assuming these forecasts are correct, there are eleven Member States that can only blend less than 60% of their expected biodiesel volumes in 2020 as FAME in road transport, with the current blending limits: Belgium, Bulgaria, the Czech Republic, Germany, Estonia, Finland, Ireland, Lithuania, Poland, Slovenia and the UK. They all need to resort to other solutions to bring more than 40% of their expected biodiesel volumes onto the market.

Table 1.10 Maximum blending potential (ktoe) in diesel in 2020, compared the NREAPs expectations, for the individual Member States

	B7: FAME blending potential in 2020 (ktoe)		Biodiesel demand in NREAPs (ktoe)	Gap with NREAPs (ktoe)	Gap (in % of biodiesel demand in NREAPs)
AT	313		411	98	24%
BE	385		697	313	45%
BG	117		220	103	47%

[34] Note that non-road modes and HVO are not included in this table.

	B7: FAME blending potential in 2020 (ktoe)		Biodiesel demand in NREAPs (ktoe)	Gap with NREAPs (ktoe)	Gap (in % of biodiesel demand in NREAPs)
CY	24		24	-2	-8%
CZ	291		494	203	41%
DE	1,997		4,443	2,446	55%
DK	141		167	26	16%
EE	29		50	21	42%
EL	150		203	53	26%
ES	1,894		3,100	1,206	39%
FI	136		430	294	68%
FR	1,911		2,849	939	33%
HU	208		203	-7	-3%
IE	172		342	170	50%
IT	1,381		1,880	499	27%
LT	62		131	69	53%
LU	131		193	62	32%
LV	50		29	-21	-72%
MT	10		7	-2	-29%
NL	418		552	134	24%
PL	721		1,452	728	50%
PT	299		449	153	34%
RO	244		325	84	26%
SE	246		251	7	3%
SI	100		174	74	43%
SK	112		110	-2	-2%
UK	1,297		2,463	1,166	47%

Source: CE Delft, 2013

NB. Positive numbers: blending potential lower than expected demand; negative numbers: blending potential higher than expected demand

The results for petrol, i.e. the E10 blending potential, shown in Table 1.11, is quite different. Comparing the petrol demand forecast with the NREAP biofuel volumes, many Member States do not expect to use the blending potential that E10 offers, in 2020. Portugal and Slovenia only use a quarter and one third of the E10 blending potential, respectively. These countries can significantly increase overall biofuel demand within the current blending limits by increasing the share of ethanol demand up to the E10 level.

Table 1.11 Maximum blending potential (ktoe) in petrol in 2020, compared the NREAPs expectations, for the individual Member States

	E10: Bioethanol blending potential in 2020		Biopetrol demand in NREAPs	Gap with NREAPs	Gap (in % of biopetrol demand in NREAPs)
AT	127		79	-45	-57%
BE	103		91	-12	-13%
BG	43		60	17	28%
CY	21		14	-7	-50%
CZ	162		129	-33	-26%
DE	1163		857	-308	-36%
DK	105		93	-12	-13%
EE	17		38	21	55%
EL	253		413	160	39%
ES	490		399	-88	-22%
FI	105		129	24	19%
FR	640		650	10	2%
HU	122		303	184	61%
IE	119		139	19	14%
IT	970		600	-368	-61%
LT	31		36	5	14%
LU	26		24	-2	-8%
LV	24		19	-7	-37%
MT	2		5	2	40%
NL	201		282	81	29%
PL	356		451	96	21%
PT	107		26	-81	-312%
RO	129		162	33	20%
SE	232		466	234	50%
SI	50		19	-31	-163%
SK	48		74	26	35%
UK	1039		1744	702	40%

Source: CE Delft, 2013 and Eurostat, 2013

NB. Positive numbers: blending potential lower than expected demand; negative numbers: blending potential higher than expected demand

1.4.4 Fuel distribution impacts of introducing a new blend

When new blends or fuel grades such as E20 or B10 are to be introduced on the fuel market, they cannot just replace the current E5/E10 or B7, as a large share of the current vehicle fleet is not compatible with these new fuels. The current blends need to remain available throughout the EU as protection grades for many years, until the non-compatible vehicles are phased out of the market. The following Section will zoom in on the implication of additional blends to fuel distribution, from refineries to the retail stations and end consumers. The issue of compatibility vehicles and their market penetration is discussed further in the next chapter.

If a new blend is introduced, all stakeholders in the fuel market, i.e. fuel suppliers, distributors and owners of retail stations will be faced with the choice of whether they will offer the new blend to their customers. They have three basic options:

a. introduce the new blend by replacing an existing fuel grade that they offer;

b. invest in expanding the existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics and add the new blend to their existing portfolio;

c. not introduce the new blend, i.e. maintain their current fuel grade portfolio, and wait until market demand for the new blend is sufficient to warrant replacing one of their existing fuel grades.

The latter option assumes that they are not obliged to offer the new blend.

The cost and benefits of these three options, and therefore the optimal choice for a specific stakeholder, depends on the specific situation: on the local fuel market, the characteristics of the distribution and retail stations (for example the number of grades they are equipped to sell) and the cost and practical feasibility of expanding the infrastructure. The ownership of the infrastructure and retail stations is also a relevant factor: larger companies typically have more resources and opportunities for investments than smaller companies or retailers that sell with low margins.

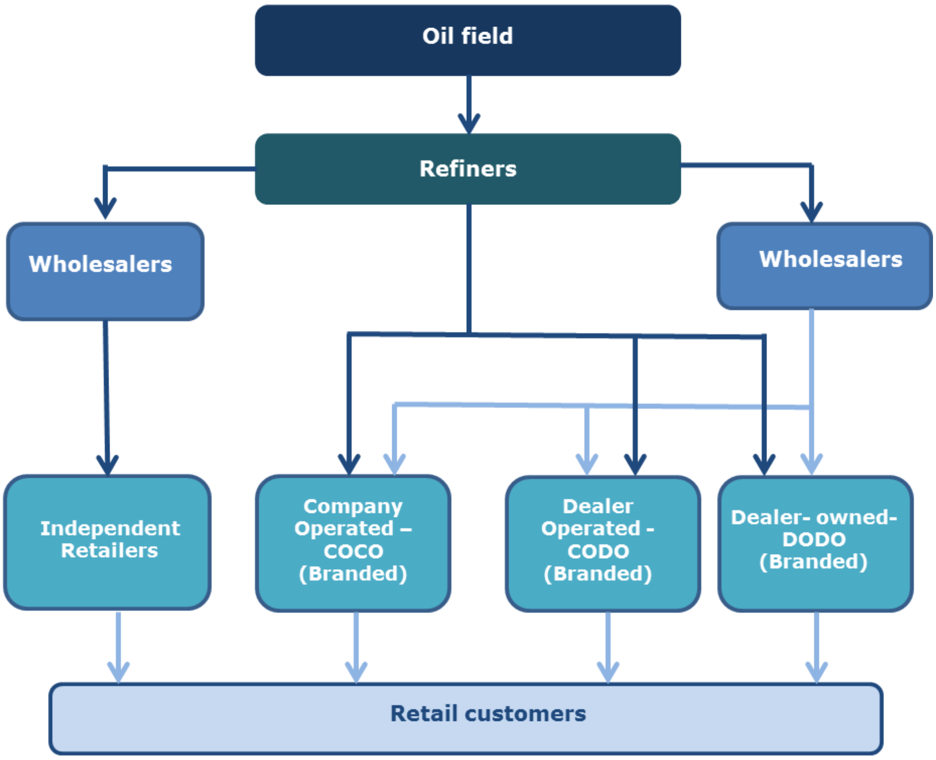
As cost and benefits will vary between suppliers and even per fuel retail station, introducing a new blend may cause market distortion effects: if one retailer has the opportunity to add the new blend to its portfolio with limited cost, and a competitor does not and has to choose which blend to offer (for example, a small service station with just one fuel grade and insufficient means to invest), the latter is likely to lose market share to the first. As will be demonstrated in the next Section, there are a number of countries where this issue is particularly relevant.

To create insight in the effects that introducing a higher blend may have on the fuel distribution sector, the following paragraphs provide an overview and qualitative assessment of the impacts that may occur. First, the structure of the fuel market is addressed, followed by an overview of the technical opportunities and barriers of introducing a new blend on the market. This analysis is qualitative only, however, as data on cost and economic impacts of the various options are unavailable in public literature. As far as we are aware, the potential financial impacts of higher blends on fuel distribution and the relevant stakeholders have not been quantified or analysed in detail yet in the public literature. The introduction of E10 in France, Finland and Germany (described in Section 1.3.4.1) provides some information on the mechanisms that occur in the market when an additional petrol grade is introduced, but a (quantitative) assessment of the impacts has not yet been carried out.

1.4.4.1 Structure of the fuel market

Fuel markets in different Member States can have various ownership structures, depending on national circumstances and regulations. This is illustrated in Figure 1.16 where the potential routes from the oil fields to retail customers are depicted for fossil fuels. (OECD, 2013) In some countries, supermarkets are also an important point of retail for fuels (see below).

Figure 1.16 Road fuel supply chain



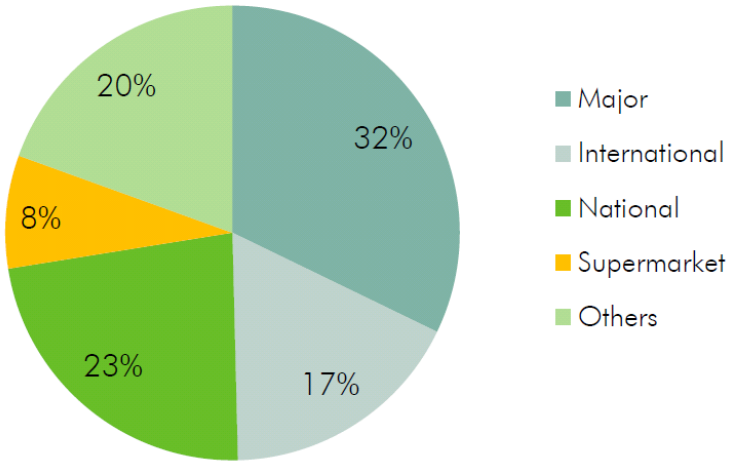
Source: OECD, 2013 (adapted from Deck and Wilson (2004)

Biofuels can be added to these fossil fuels at various stages in the supply chain: they can be added at the refinery site itself, before the fuel is transported to distribution sites, or at the point of fuelling the tanker, when it is filled up to supply the filling stations.

As shown in the figure above, there are four different type of retailers:

- **Vertically integrated oil companies operating at all levels of the fuel chain (company owned – company operated (COCO)):** Prices at the pump are determined by refiners.
- **Dealers operating under an oil company (company owned – dealer operated = CODO):** Dealers operating under an oil company carry the commercial risk and are responsible for their own prices. However, these businesses can be strongly influenced by contractual arrangements between the oil companies and the dealer.
- **Independent fuel suppliers – dealer owned –dealer operated (DODO):** Independent fuel suppliers own and operate their service stations. Although they are often supplied by oil companies, these fuel suppliers are less affected by contractual agreements and they can determine their own prices.
- **Supermarkets:** supermarkets are not depicted in the figure above, but are a category on its own, and have a significant market share in some countries. The retail of road fuel is typically not part of the core business of supermarkets, but these service stations are mostly located near shopping centres and can be considered to be a means to attract customers. These service stations typically buy very high volumes of fuel at lower wholesale price and also sell it at a very low gross margin.

Figure 1.17 Market share per fuel retailers type[35]



Source: Verdict Retail 2012

Table 1.12 shows how the ownership structure varies for a number of Member States in the EU (source: (OECD, 2013), unless stated otherwise). Note that not all MS are included in this table as not all have been assessed in these studies, so this table rather provides an illustration of the variation throughout the EU, rather than a comprehensive EU-wide overview.

In Germany, Greece, Italy and, to a lesser extent, Austria, Bulgaria, Portugal, Romania, Spain and Sweden, the fuels market is largely dominated by a limited number of major companies – in these countries, they hold market shares of more than 60%. The fuel markets in Latvia, Lithuania, Poland and the UK are much more fragmented. In these countries, independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales.

Table 1.12 Description of fuel market for 13 Member States

Austria	Of the 1545 petrol stations (end 2011), 60 %, were so called major-branded. The majors' market shares are – also relating to sales – comparatively high but decreasing over the last years (in 2003 they had a common market share of 85 % of annual fuel sales, in 2008 it declined to 77 %, the five biggest firms having 76 %).
Bulgaria	The sole distributor for the fuel quantities produced in the one refinery in Bulgaria is “Lukoil Bulgaria”, accounting for approx. 60 % of the petrol and 70 % of the diesel supply in Bulgaria. “Lukoil Bulgaria” was a pricing leader on both wholesale and retail markets (2009-2011). Significant market share at the retail level of vertically integrated wholesalers. Except for the branded petrol stations the retail market was composed of a large number of insignificant market players (around 3200 independent petrol stations in Bulgaria).
Germany	Five leading companies (vertically integrated along the value chain), together hold a dominant position on the retail market.
Greece	There are approximately 6.500 petrol filling station that cover the demand for oil products. The majority of them are company owned-dealer operated (CODOs) or dealer owned dealer operated (DODOs).. Nearly 400 are unbranded / independent.
Italy	The Italian fuel retail market (studied in 2010-2012) is still dominated by the seven vertically integrated oil companies, controlling 22000 fuel stations. There are around 2000 independent retailers and 82 retailing stations owned by supermarkets. The number of independent retailers, however, has significantly

[35] From http://www.cbre.eu/portal/pls/portal/res_rep.show_report?report_id=3217

	increased in the last few years (in 2005 they were estimated to be around 1100).
Latvia	Latvia's fuel retail market (2011) is predominantly operated by small independent retailers, which own 32.5% of service stations. The top three players, account for 62% of total fuel volume sales in Latvia (Data monitor group 2013)
Lithuania	There are approximately 880 service station in Lithuania (January 1, 2012). The Top Five players by fuel volume share accounted for only 35.0% of the Lithuanian service station network, indicating a fragmented (Data monitor group 2013).
Poland	Orlen (former state monopoly in the wholesale and retailing of petroleum products) is by far the largest retailer of road fuels, controlling about 25% of all petrol stations in Poland (around 1750 stations) through ownership, franchising or similar contracts. Orlen-controlled. Its largest 4 competitors (Vertically integrated oil companies) have a share of 5-7% in the national retail market. Only 2-3% of stations are operated by supermarket chains. Of the remaining 3000 stations, which constitute about 45% of the national market, the vast majority are owned and operated independently or within small regional chains
Portugal	The top four fuel retailers in Portugal account for 70.6% of the national service station network, with Galp, the largest player, accounting for 29.7% of all sites (Data monitor group 2013). The aggregate market share of super/hypermarkets in the retail market for diesel and petrol-95 has reached around 25%.(OECD, 2013)
Romania	In 2011, the top five fuel retailers in Romania accounted for 63.9% of all service stations (1,944 sites).
Spain	In Spain there are about 9,000 petrol stations, most of which (83%) are owned by wholesale operators through exclusive distribution agreements. Three operators with refining capacity in Spain jointly own 70-73% retail market share. Petrol stations hypermarkets and supermarkets only have 3% of market share,
Sweden	The Top Five retailers in Sweden accounted for 71.3% of all service stations (2,786) in 2011 (Data monitor group 2013).
United Kingdom	Supermarkets have share of road fuel sold in the UK of 39 per cent in 2012. This share is increasing (OECD 2013). The station are owned for 55% by oil companies, 19% by main retailers, 16% by supermarkets and 10% by unbranded and other retailers (Energy institute 2014)..

Source: OECD, 2013

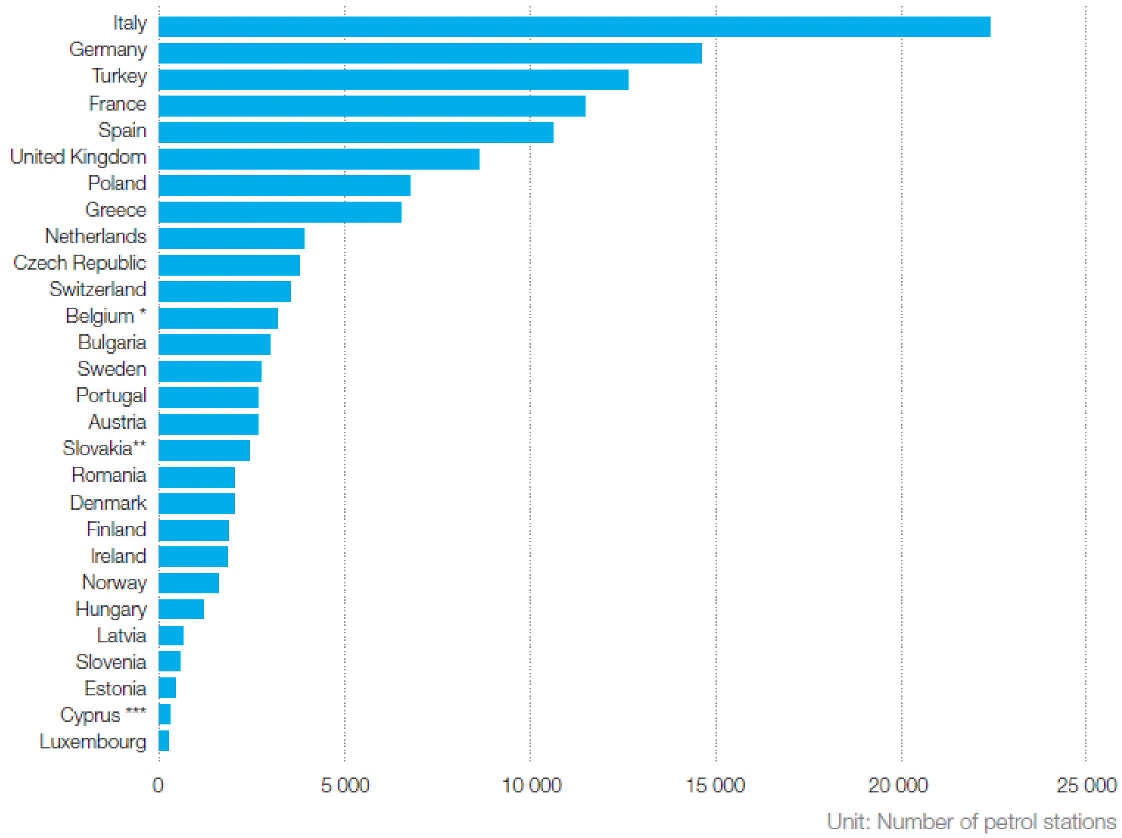
In the countries with a limited number of dominant companies in the market (e.g. Germany, Greece and Italy in Table 1.12), it is to be expected that these companies will be in a key position to decide on whether or not a new fuel grade is rolled out on a large scale. If they do so, the smaller retailers either need to follow and also offer the new grade, or rather keep the current portfolio of fuel grades, thus risking to lose market share to those competitors that do offer the new grade. This may have two implications: first, a limited number of stakeholders control the fuel market and are therefore key to the successful introduction of a new fuel grade, and second, introducing a new blend can lead to negative economic impacts on the smaller retailers.

In the countries with a more fragmented and diverse fuel market (such as Latvia, Lithuania, Poland and the UK), a successful roll-out of a new blend requires the active involvement of many different stakeholders (i.e. retailers). As these stakeholders are likely to have more limited resources than the major oil companies, they may still be faced with potential negative economic impacts: in all countries listed in this table, major oil companies have at least some market share, and thus can decide to introduce the new grade. This may then lead to the same type of market distortion described above, although the impacts are likely to be smaller than in the countries with a limited number of dominant market players.

In view of the potential impacts of new blends on the market structure and the current lack of (quantitative) insight into these effects, it is recommended to further assess these impacts before considering policy options. This assessment could start with an analysis of impacts of the introduction of E10 in Finland, France and Germany on the market structure and the various stakeholders, in order to identify whether any market distortion effects occurred and to assess whether the market structure poses barriers to the successful introduction of a new blend.

To illustrate how many petrol stations would be involved in the roll-out of a new blend in each Member State, Figure 1.18 provides data from the National Oil Industry Association on the number of petrol stations throughout Europe: there are about 130,000 petrol stations within the EU, almost half of these are located in Italy, Germany, France and Spain. There are no data on the number of fuel pumps or fuel grades that these petrol stations can offer.

Figure 1.18 Number of petrol stations in Europe in 2013



* Source: FAPETRO (department of the Federal Public Services Belgium)
** Source: Statistical Office of the Slovak Republic
*** Source: Petrol Owner's Association
Note: Data for Bulgaria and Slovakia refer to 2012

Source: Fuel Europe, based on data from the National Oil Industry Associations

1.4.5 Technical issues and barriers to introducing higher biofuel blends

Despite fuel standards and quality control, biofuels have somewhat different technical characteristics than fossil fuels. Higher blends can thus cause a number of technical issues in fuel distribution, which will be described in the following Sections.

1.4.5.1 Refinery/distribution level

BOB (blendstock for oxygenate blending)

Nowadays oil companies usually use two base blendstocks (BOB = blendstock for oxygenate blending): one for E5 and E10 RON95 and one for RON98 (Davison Consultants ltd, 2013). The introduction of new blend levels is expected to directly impact the number and type of base blendstocks, so called BOB, because higher ethanol blends require other BOBs (with lower vapour pressure, modified distillation characteristics and reduced octane) to still meet the fuel specifications, as laid down in EN228. Addition of ethanol to petrol also offers a significant octane boost, more than hydrocarbon streams, Davison (2013) concludes that the octane gain from an additional 10% ethanol is about 3 points RON. This can be beneficial to the fuel economy of vehicles if the engine is optimised for this higher octane level, as discussed in Chapter 2.

Therefore, from a logistics perspective an increase in BOBs in the EU would increase cost and require investments, for example in additional storage tanks[36]. A solution would be to define a new specification other than EN228 to be able to have only one BOB in place for all fuel blends, (Davison Consultants ltd, 2013) concludes. They suggest to develop a table for vapour pressure waiver for different levels of ethanol (e.g. 15-20 vol% or 20-25 vol%), similar to the waiver that is currently included in EN228, for ethanol levels from 0 to 10%. Different petrol specifications could have implications for the engines (drivability) and vehicle emissions, as these are sensitive to the fuel characteristics. (Davison Consultants ltd, 2013) recommends that further study of these issues is required.

1.4.5.2 Service station level

Practical issues when introducing a new fuel grade

As shown in Section 1.4.4.1, there are currently about 130,000 petrol stations within the EU, but detailed data on the fuel grades that they provide or the number of fuel tanks or pumps they have available are not available. From the interviews with fuel suppliers it can, however, be concluded that some of these may offer up to 3 to 4 grades of petrol and up to two grades of diesel, which typically include:

- 95 RON E5
- 95 RON E10
- 98 RON E5 premium
- 100 + RON super premium
- Standard and premium diesel grade

For many smaller refuelling stations, however, this number will be limited to 1 or 2 grades of petrol, and 1 grade of diesel.

If a new grade is introduced, for example E10 or, in the future, E20, part of the vehicle fleet will switch to that new blend, but part may continue to buy the older grades, for example E5 – typically either because their vehicle is not compatible with the new grade, or because of a cost differential. As explained earlier, the smaller service stations may then have to choose which blend they will sell, as they are limited in the number of fuel grades they can sell. They may then loose customers that want to buy any of the other blends.

Alternatively, they may consider to make the investments required to offer more fuel grades. This typically involves investments in new (subsurface) fuel tanks and the necessary infrastructure to fill these tanks and sell the fuels (pumps, fuel piping, etc.), and requires a suitable location as well as permits from the relevant authorities. Although (S. Searle, 2014) report that the cost to retrofit an existing dispenser to use a higher ethanol blend, such as E25 is between US$1000-US$4000, there is still insufficient data on the potential costs to introduce a new blend at a filling station, of which new storage is the largest cost element.

[36] These costs have not yet been quantified.

These data are typically confidential, and will differ between service stations, so the cost of the various options cannot be quantified at the moment.

Because the options to add a new fuels grade are limited and may require significant investments, it is likely that refuelling stations will first try introduce new blends by replacing other already existing blends. This could be observed in the Member States where E10 has become available, as was described in Section 1.3.4.1:

- in Germany, before E10 was introduced many petrol stations offered E5 RON95, a RON91 fuel and a premium E5 RON98. In many cases, the E10 RON95 has replaced the RON91 petrol (source: interview with German authorities).
- in France, the premium petrol grade (typically RON98) was typically replaced by E10 RON95 (source: interview with French authorities), which is now sold next to E5 RON95 (see the fuels sales data in Section 1.4.2.3, Figure 1.11).

When moving towards new biofuel blends that cannot be used by the whole vehicle fleet, it is thus important to think about what will be the protection grade, and what will be the best options for fuel suppliers and service stations to offer. For example, two potential longer term options to move beyond the current E10 limit for petrol would be to:

- replace E5 with E10 as the base (protection) fuel (i.e. discontinue the sales of E5), and offer E20 or E25 as a new fuel
- replace E10 with a E20/25 100+Ron fuel, and retain a E5 or hydrocarbon 98+ premium fuel as protection grade.

These options both have the advantage that the whole fleet can be supplied with two different grades of petrol, but have different implications regarding potential biofuel sales, pricing, perhaps regarding number of BOB required (depending on specifications), etc.

The need for protection grades in currently existing infrastructure raises the question how long protection grades should be offered. This depends of course on the renewal rate of the vehicle fleet (to be discussed in Section 1.5 below), but also on the more subjective choice regarding at what share of incompatible vehicles it is justified to stop offering the protection grade. The time period may be reduced if it is possible to retrofit older cars to make them compatible or at least tolerant to the new fuel, or if an additive can be added to the fuel to achieve the same result. However, as the average lifetime of passenger cars is more than 15 years, and a significant share of the new cars currently sold is expected to have lifetime (much) longer than this, it is clear that complete renewal of a fleet takes more than two decades.

Impacts on equipment / material compatibility

Besides logistical modifications and physical space required for additional storage tanks and equipment, higher levels of biocomponents may also require modifications to equipment due to material compatibility issues. This is especially an issue for higher ethanol blends: the higher the blend, the more measures need to be taken to prevent corrosion.

According to (Davison Consultants ltd, 2013), oil companies state that technical issues arise beyond E15. For some oil companies, blend levels above E15 cause issues in their tank systems through the supply chain from depot to petrol station, which increases cost. Costs may further increase due to additional infrastructure needs. Beyond E18 there may be a need to change metalwork in terminals due to corrosion, although this depends on the nature of the tank coating as well as water content of the fuel. Beyond E23 (or E25) potential for galvanic corrosion is introduced. The oil companies thus conclude that if ethanol blends are to increase, it appears to be that E20 strikes the right balance against increased infrastructure costs (Davison Consultants, 2013).

Quality control and aging

The quality of diesel fuel containing FAME in the storage tanks at service stations and indeed also in vehicles, for example during long term parking, decreases over time, as aging occurs during storage and use. This is mainly linked to the oxidation stability of FAME, which is much worse compared to conventional fuels, the higher boiling point of FAME and cold weather characteristics. When considering large scale introduction of higher blends of FAME, it is important to understand both these issues and the risks to the fuelling infrastructure and vehicles that this may cause, so that the necessary measures can be taken to resolve these issues and reduce the risks.

This was analysed in a joint industry study (Lacey et.al, 2010), in which the change in fuel quality was measured that occurred in B10 fuels, during warm climate storage conditions during a period of 27 weeks, in vehicles that were only occasionally operated. The study concluded that aging may result in formation of insoluble materials and acids, which may create materials compatibility issues, filter plugging, corrosion, durability problems and deposit formation. Lacey further found that the aging rate was strongly dependent on storage conditions, with large variations between vehicle types (particularly rapid changes in stability occurred in passenger vehicles compared to light-duty vans), and with rates of aging decreasing over time. However, the causes for these variations could not be identified, and the impacts of this aging on the vehicles was not measured. (Lacey et.al., 2010) therefore recommends that these issues be further studied.

Aging and resulting quality issues are compounded by a low uptake by the market, for example if a higher FAME blend is introduced at service stations with low throughput, fuel suppliers (members of Fuels Europe) observed during an interview. For conventional fuels, aging is not a big problem, because both the stability of the fuels and the consumption rate are high enough. However, higher biofuel blends might stay in tanks for longer period of times, if there aren’t sufficient compatible vehicles on the road or when consumers do not choose these specific blends, for example because of higher costs.

Fuel suppliers deliver fuels that comply with high quality standards as defined in the FQD and by CEN, but can no longer control the quality once the fuels are stored in the storage tanks at service stations or in the vehicles. Especially in relation to the ramp-up period of new biofuel blends in the market, when service stations start to offer the product but sales are still limited, this point is an issue of concern to the fuel suppliers. A possible option suggested by fuel suppliers would be to introduce a best before date for biofuel blends (source: interview with Fuels Europe).

It can thus be concluded that aging of higher FAME blends may lead to quality control issues throughout the fuel chain that need to be understood and possibly resolved before roll-out of these blends as they may result in technical problems both in the fuel chain and in the vehicles. Research on these issues so far has been limited, it is thus recommended to further study the potential issues and solutions.

1.4.6 Non-technological barriers to introduction of a new blend

From the available literature and the interviews with stakeholders, several non-technological barriers to the introduction of higher blends were identified. These mainly relate to consumers and marketing, to potential impacts on the competitiveness of fuel suppliers (ranging from oil companies to retail stations) and refineries and potential impacts on harmonisation of the fuel market in the EU.

1.4.6.1 Information provision and consumer acceptance

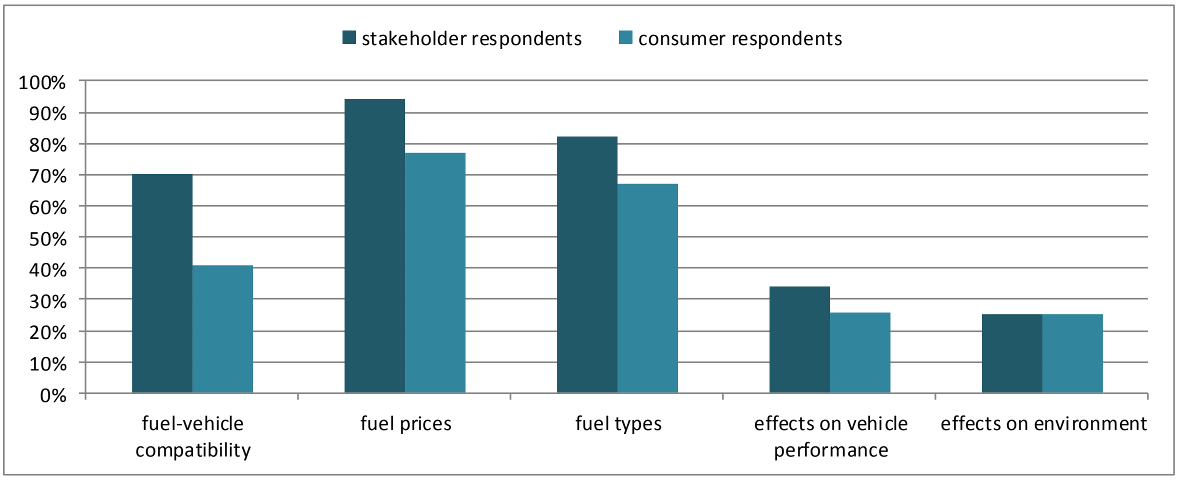
Consumer acceptance and willingness to buy is crucial to successfully introducing a new biofuel blend or fuel grade at filling stations. As long as the old fuels are still for sale – which has to be the case when higher biofuel blends are introduced since not all vehicles are compatible with these higher blends - consumers that can buy the new fuel have a choice with which fuel they will fill up their vehicle. They therefore need to be convinced to fill their cars with the new fuel. Prices are important (discussed below), but also other considerations are at play.

Both the oil industry (interviews with Fuels Europe and UPEI) as well as governments (Germany, Finland and France) stressed the importance of consumer acceptance: the oil industry depend for their market shares on consumer acceptance, governments depend on consumer acceptance to meet their targets. Wrong or incomplete information and lack of understanding of the reasons for the introduction of higher level of biocomponents can harm consumer trust. Civic Consulting (Civic Consulting, 2014) has performed an extensive study including both a consumer and stakeholder survey on several aspects, such as:

- understanding of information on fuel-vehicle compatibility
- ability to compare prices (energy content differences)
- attitude towards sustainability of biofuels

The survey outcomes showed a mismatch between the perception of stakeholders (competition authorities, other public authorities, consumer organisation and auto clubs and industry organisations) and the perception of consumers on how easy information can be found. Especially, the easiness to find information on fuel-vehicle compatibility have been assessed differently by the two groups: 70% of the stakeholders find information on compatibility easy to find against 41% of the consumers. Somewhat smaller gaps are found for information on fuel prices, fuel types and effects on vehicle performance. Except from the equal opinion on the accessibility of information on the effects of fuels on the environment, stakeholders overestimate the easiness to find information compared to that experienced by consumers.

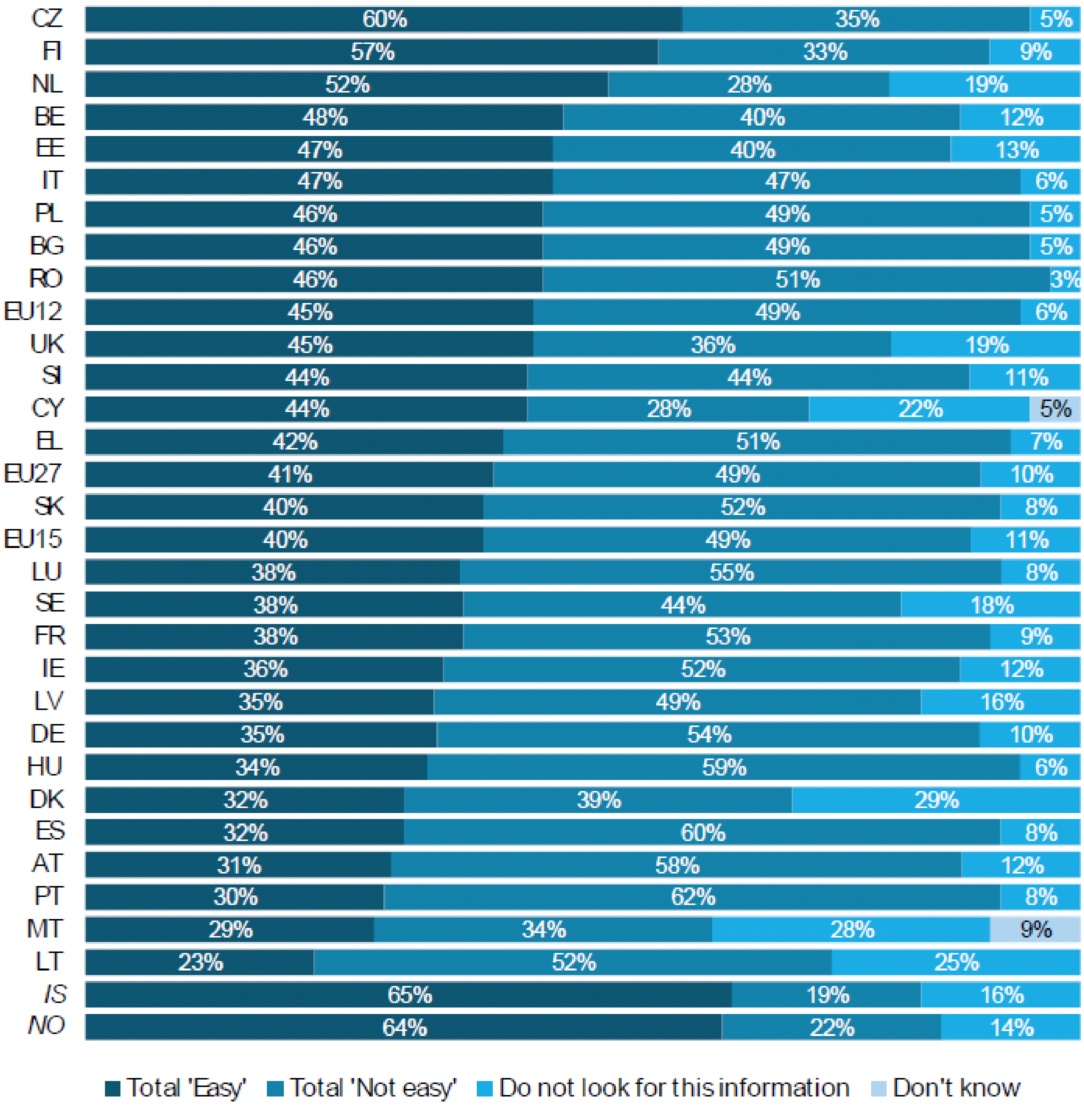
Figure 1.19 Disparities between consumers and stakeholder opinion on easiness to find information on fuel related aspects



Source: Civil Consulting, 2014

In Figure 1.20 the perception of consumers on the ease of finding information on fuel-vehicle compatibility per Member State is depicted and shows that only in a few countries more than 50% of the consumers find it easy to find this information. In all other countries, the majority of the consumers faces problems in their search for information or have simply not yet looked for the information.

Figure 1.20 Ease of finding clear information about fuel-vehicle compatibility analysis by country (based on consumer survey, N=25797 for EU27)



Source: Civil Consulting, 2014

According to some of the fuel suppliers that were interviewed, the timing of introduction of new blends and specifications is crucial to a successful market strategy, and all aspects of the fuel chain should be taken into account. For example, biofuel blends should only be introduced on the market when a significant share of vehicles is compatible, consumers have been informed and additional information is easily accessible.

What the minimum market share of compatible vehicles needs to be before a new fuel can be rolled out on EU or Member State level is currently unknown. This is likely to depend on the local and national market structure and will even vary between service stations and fuel suppliers, as the cost and benefits of introducing a blend varies between retail stations (as explained in Section 1.4.4). There is no relevant past experience that can be used here as empirical evidence, apart from the recent introduction of E10 in Finland, France and Germany. This took place at a time where most of the vehicles could drive on E10, about 70 % of the petrol cars (source of this estimate: interview with Finish government official). None of the stakeholders interviewed (government officials, fuel suppliers or vehicle manufacturers) suggested that vehicle compatibility was too low at that time. Whether this is also the minimum (or optimal) level is, however, unknown.

The different experiences with introducing E10 in Finland, France and Germany, as described in Section 1.3.4.1, do illustrate that the importance of consumer acceptance: in

Germany, low consumer acceptance proved to be a significant barrier to the introduction of E10, resulting in much lower market shares of E10 in the total fuel sales than in Finland and France (see Section 1.4.2.3), where this was not issue.

1.4.6.2 Opportunity for differentiation of products

Fuel suppliers can improve their market position by a differentiation of their products. That is why many fuel suppliers offer premium fuels such as 98RON at their refuelling stations.

As explained in Section 1.4.4, when a new biofuel blend is introduced, fuel suppliers have the option to substitute premium fuels by the new blend. This has been observed in France, where refuelling stations were seen to replace their premium grade with E10 (source: interview with French authorities, see also Section 1.3.4.1).

However, this reduces the opportunities for branding and market differentiation and thus negatively influences the competitiveness of fuel suppliers (source: interviews with fuel suppliers). The extent of this impact is, however, not known (i.e. it has not been analysed in the public literature, this data is confidential to the fuel suppliers and services stations).

1.4.6.3 Price barriers

As consumers are not obliged to buy a higher biofuel blend, they will need some form of an incentive to buy to higher blend. Higher ethanol blends may provide fuel efficiency benefits (see Chapter 2) but otherwise, consumers will base their choice mainly on price (perhaps in combination with some other incentive such as a saving scheme).

However, the costs of biofuels are higher than of their fossil counterparts, as will be shown in Section 1.6.5. Therefore, higher biofuel blends are more expensive than fuels with lower shares of biofuels.

Nevertheless, in the countries where E10 has been available on the market (Finland, France and Germany), E10 is typically 2 or 3 Eurocents cheaper to consumers[37] (source: interviews with the government authorities and car manufacturers). In Finland, this is due to a lower CO_2 tax on the fuel (biopetrol is exempt from this tax), but in France and Germany, there are no tax benefits for E10 compared to E5. In these countries, the lower price of E10 is driven by the biofuel obligations: fuel suppliers have to meet the obligations, and therefore need to encourage consumers to buy the higher blend[38]. The price differentials between fuels is then not only driven by actual cost of the fuels, but also by the biofuel obligation.[39]

Tax reductions or strategic price setting can therefore be a very efficient means to encourage customers to buy a specific blend. However, if there are no tax reductions, the evidence suggests that fuel suppliers will only change their fuel prices in favour of the high blends if they must sell them: a biofuels or GHG obligation that cannot be met by low blends only is likely to be a prerequisite for fuel suppliers to promote the more costly higher blends. This is due to the competitive market in which they operate: any cost increase or price reduction may affect their margins. However, as long as a biofuels (or GHG reduction) obligation is equal for all fuel suppliers, the impact on their profit margins can be limited by passing on any additional cost of biofuels to the customers. All competitors are then faced with the same requirements, and therefore with (roughly) the same compliance cost.

In reality, some market distortion may still occur, especially for those fuel suppliers and retail stations that compete with suppliers that do not have to meet the obligations. This may occur close to national borders, when the policies in neighbouring countries are less ambitious. Fuel suppliers on that side of the border then add lower shares of biofuels, resulting in lower

[37] Note that part of this price differential will be offset by the higher fuel consumption (in terms of litre per kilometre), because ethanol has lower energy content than petrol.

[38] This is further driven by the legal provisions in the obligations of France and Germany that fuel suppliers receive a fine from the government if they do not meet their blending obligations.

[39] The real cost of E10 without any subsidy or tax benefit is unknown. The 2-3 cent lower cost of E10 is based on anecdotal evidence from interviews, and could not be further substantiated.

overall fuel cost and a competitive advantage to fuel suppliers in the country with more ambitious policies.

This border effect has been observed in the past, as demonstrated in a recent study in the Netherlands on the effect of increasing the excise duty in 1.1.2014 (Ministry of Finance, 2014). The Dutch excise duty on petrol was increased by 0.013 €/litre (about 1.7%), and by 0.038 €/litre (8.6%) for diesel[40]. This measure result in a stronger reduction of fuel sales in the region within 10 kilometre from the Dutch border: petrol sales decreased by about 11% in the first quarter of 2014 compared to Q1 of 2013, whereas average petrol sales in the Netherlands decrease by 4%. Beyond 10 kilometres, the effect was found to be negligible (Ministry of Finance, 2014). A similar effect, although somewhat smaller, could be observed for diesel.

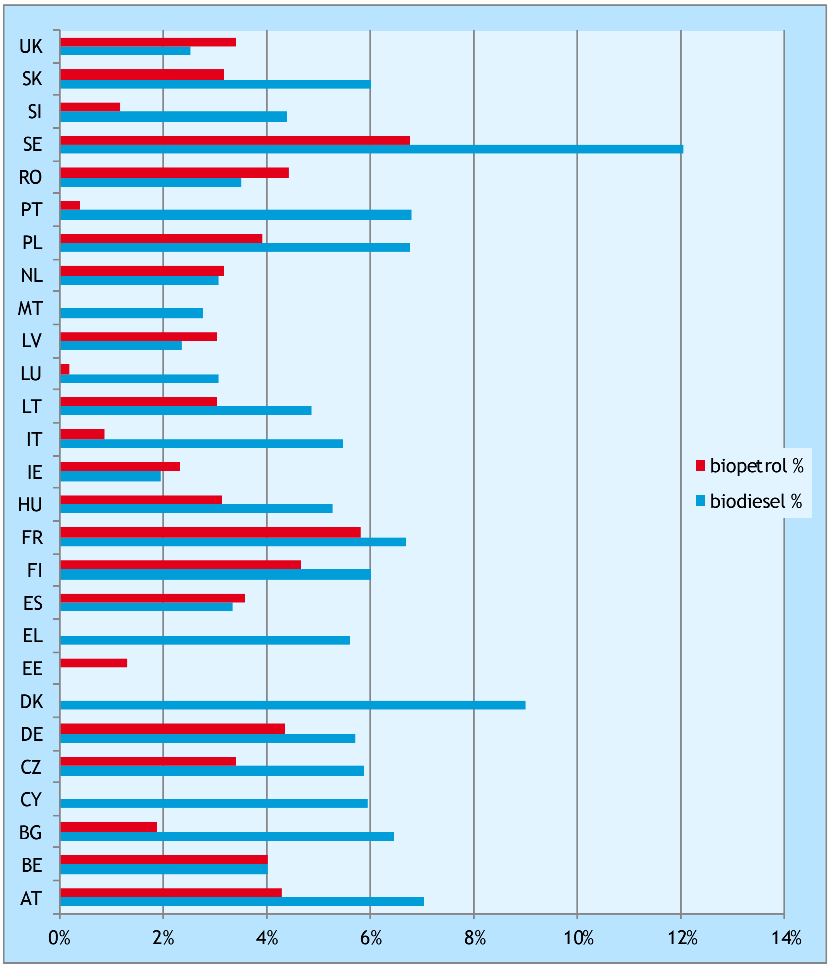
In conclusion, there is a cost differential between higher blends and the standard fuels, due to the higher cost of biofuels. However, this does not need to be a barrier to the successful introduction of a higher blend, if an effective biofuel policy is in place, such as a blending obligation: offering these higher blends at lower prices than the standard grade can be a very effective means for fuel suppliers to increase the sales of higher blends and thus meet the obligation. Lower tax levels for higher blends can have the same result, as well as a biofuel (or GHG) obligation that is set high enough for fuel suppliers to sell the higher blends. The competitive impacts can be expected to be limited, if all fuel suppliers need to meet the same obligation, but suppliers close to national borders may be impacted if the neighbouring countries have a less ambitious policy in place.

1.4.6.4 Different blends in different Member States

Several oil refineries mentioned during the interviews that the currently limited level of harmonisation of national policy in the RED and FQD results in a market barrier that increases cost. The RED and FQD both set out binding requirements regarding the share of renewable energy in transport and the CO2-intensity of fuels in 2020 (see Section 1.3.2), but Member States are free to choose the policy measures with which they want to achieve these targets. This has resulted in a broad range of biofuel policies, as shown in Section 1.3.3, and an equally broad range of biofuel shares throughout the EU, as was demonstrated in the Section 1.3.3.3 and further detailed in Figure 1.21. In 2013, biodiesel shares varied between 0% in Estonia and 12% in Sweden, biopetrol shares varied between 0% in Cyprus, Denmark, Greece and Malta to 6.8% in Sweden.

[40] The excise duty in 2014 in the Netherlands was higher than in both Germany and Belgium: for petrol the differential was 0.104 and 0.145 €/litre respectively, for diesel this was 0.008 and 0.05 €/litre respectively.

Figure 1.21 Shares of biodiesel and biopetrol in the EU Member States



Source: Eurostat, 2013

The data on fuel grades available in the various Member States, in Section 1.4.2.3, further illustrates the diversity of the fuel market in the EU, especially for petrol (there are 10 petrol grades and only 3 diesel grades on the EU market).

Due to these differences between Member States, oil refineries and fuel suppliers that supply various national markets typically have to offer multiple blends (up to 7 in some cases, as mentioned by fuel suppliers during the interviews). Introducing more blends on the market will further increase the number of fuel grades and blends that they need supply, thus further increasing operational costs for refineries and suppliers. Note that there is no technical limitation to the number of fuel grades that can be supplied, although refineries and fuel suppliers may have to invest in additional infrastructure, depending on the existing situation, and the specific characteristics of the new grade. The extent of the cost and efforts to the refineries to add more blends to their portfolio will be assessed in Task 3 and 5 of this study.

1.4.7 Conclusions

Diesel currently has a market share of 70% in overall road transport fuel sales in the EU, and this share is increasing over time, a share of around 80% is expected for 2020. As refineries cannot produce this petrol to diesel ratio, 10% of the EU's diesel is currently imported, and 40% of petrol production is exported. Increasing the share of biodiesel reduces the imbalance, while replacing petrol by biopetrol has the opposite effect. The impact of this effect on biofuel demand and supply is unknown, but oil companies and fuel suppliers will take this effect into account in their operational decisions.

In 2013, 13.6 Mtoe biofuels was consumed in the EU, which represented a share of 4.6% of the EU's petrol and diesel consumption (in energy content, most recent Eurostat data). 79% of this was biodiesel, mostly FAME, 20% was biopetrol. 2013 was the first year since 2004 that biofuel consumption reduced. The biofuel shares varied significantly between Member States: where Estonia had a share of only 0.4% in petrol and diesel sales (in energy content), Sweden achieved 9%.

In most Member States, E5 and B7 are the main fuel grades on offer. E10 has been introduced on the market in only a few countries (Finland, France and Germany). The market share of E10 is highest in Finland, almost 60% of the total petrol market, whereas France has about 30% market share of E10, and Germany about 15%. Some countries, namely Cyprus, Greece, Hungary, Lithuania, Malta and Portugal have almost no E5 in their fuel mix, only pure petrol (data from 2013)

There is still a lot of potential to further increase biopetrol sales within the current blending limits, if all Member States would introduce E10, either by providing specific incentives for E10 or by gradually increasing the obligations and thus encouraging the fuel suppliers to introduce and actively market E10. As most Member States only have E5 petrol grades on their market (equal to 3.3% energy), it is not surprising that many countries have biopetrol shares lower than 3.3%. However, there are also quite a number of countries with biopetrol shares between 3.3 and 5 energy%, namely Austria, Belgium, Czech Republic, Germany, Spain, Finland, Poland, Romania and the UK. Only France and Sweden had shares higher than 5 % (energy content, which equals about 7.6 vol%).

Biodiesel sales can also be further increased within the current blending limits. Firstly, the two Member States that have not yet switched completely to B7, Estonia and Latvia (2013 data), should do so. Secondly, biofuel obligations can be increased further so that fuel suppliers are encouraged to indeed blend FAME in their diesel to the maximum level allowed. Having B7 on the market does not mean that a share of 7 vol% FAME (6.4% energy content) is indeed achieved: a total of 12 Member States can still add two or more percent of FAME to their diesel within the limits. Some Member States seem to have reached the maximum level already: Austria, Bulgaria, Denmark, France, Poland and Portugal, consume more biodiesel than the B7 level, where Sweden sells almost twice as much as the blending limit (2013 data)[41]. In addition, even though actual HVO consumption data are unavailable, it can be derived from production capacity data that the maximum level of HVO in diesel can also be increased further within the current fuel specifications (the FQD limits the share of biocomponents in diesel to 30%)

The introduction of higher blends such as E20 or B10 requires so-called 'protection grades', as only part of the vehicle fleet will be compatible with the new blend. How long this protection grade should be kept on the market mainly depends on the renewal rate of the vehicle fleet, but may well be up to 20 years. All stakeholders in the fuel market, i.e. fuel suppliers, distributors and owners of retail stations will then have the following options:

a. introduce the new blend by replacing an existing fuel grade that they offer;
b. invest in expanding the existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics, and add the new blend to their existing portfolio;
c. not introduce the new blend, i.e. maintain their current fuel grade portfolio, and wait until market demand for the new blend is sufficient to warrant replacing one of their existing fuel grades

The cost and benefits of these three options, and therefore the optimal choice for a specific stakeholder, may depend on the specific situation of the filling station: the number of grades they sell and their market shares, whether or not they have the (physical and financial) possibilities to expand their infrastructure, etc.

[41] Biodiesel levels above the B7 limit may be achieved with consumption of fungible biodiesel (HVO), higher FAME blends in captive fleets or use of FAME in non-road modes.

Fuel markets in different Member States can have various ownership structures. For example, in Germany, Greece, Italy and, to a lesser extent, Austria, Bulgaria, Portugal, Romania, Spain and Sweden, the fuels market is largely dominated by a limited number of major companies, whereas fuel markets in Latvia, Lithuania, Poland and the UK are much more fragmented. In these countries, independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales. This has implications for the introduction of a new blend (in a more fragmented fuel market, a successful roll-out of a new blend requires the active involvement of many different stakeholders). In both cases, introducing a new blend may lead to negative economic impacts on the smaller retailers, as they will have fewer resources to invest. These effects have, however, not yet been quantified or assessed.

Introducing a higher biofuel blend may cause a number of technical issues that need to be resolved to ensure fuel quality and prevent technical issues in the fuel supply chain. For higher FAME blends, these are mainly related to quality control and aging. For higher ethanol blends, technical issues may occur due to corrosion. Costs to resolve these issues increase with increasing shares of ethanol.

A number of non-technical issues and barriers were also identified. One of these is consumer acceptance and willingness to buy: this is crucial to successfully introducing a new biofuel blend since the lower, protection grade fuels, remains available. The higher price of biofuels results in a higher price of fuels that contain higher shares of biofuels, but this does not have to be a barrier to the sales of high blends. Effective biofuel policies such as a biofuel obligation or tax incentives can provide sufficient incentives for fuels suppliers to sell these fuels despite the higher cost.

1.4.7.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations can be derived if one would consider to increase the maximum content of biofuels in petrol and/or diesel and thereby introduce a new fuel grade:

- Member States should be encouraged to assess how the biofuels needed to meet the 2020 targets can be supplied to the market, taking into account the recent legislation including the ILUC decision. This assessment should include making full use of blending options within current limits, i.e. whether to prepare for the introduction of E10 and to make full use of the B7 blending potential are attractive options in the national context, as these are options that can be relatively easy to implement.
- Further analyse the implications of introducing a new blend on the fuel distribution and market structure, assess potential market distortion effects in the varying markets that exist in the EU. The introduction of E10 in Finland, France and Germany can serve as good case studies for this.
- Assess the potential options for phasing out the protection grades E5 and B7 or even E10 in the future in exchange for a higher blend, if such a higher blend is to be introduced. This assessment should explore questions such as: How many years should a protection grade remain available on the market? What social and economic impacts of phasing out a protection grade can be expected (as some vehicles in the fleet may still need the protection grade fuel at the time of phasing out)? What are the potential options to reduce the negative effects?
- Further assess the technical issues and barriers to introducing higher blends of FAME or ethanol. Specific areas of concerns are quality control and aging of higher FAME blends.
- When designing a new standard for higher ethanol blends, attention should be given to the blendstock for oxygenate blending (BOB). Higher bioethanol blends require different BOBs (with lower vapour pressure, modified distillation characteristics and reduced octane) to still meet the fuel specifications, increasing cost to refineries and distribution. It is therefore recommended to assess options to resolve this.

1.5 Market penetration of vehicles fully compatible with higher blends

1.5.1 Introduction

The future growth of higher biofuel blends such as B10, E20 or E25 is closely linked to the compatibility of the vehicle fleet to run on these blends. As will be seen in Section 1.6 on biofuels and biomass availability, vehicle compatibility is certainly not the only barrier to future biofuel growth, but it can play an important limitation which must be anticipated well in advance. This Section focusses on the potential market penetration of vehicles that are compatible to higher blends.

It should be noted that in this context, vehicle compatibility can mean different things:

- Vehicles can be **tolerant** to the higher blend, where they can drive on these blends without technical or safety issues. For example, most petrol vehicles manufactured after 2003 are E10 tolerant (see Chapter 2), and from 2011 onwards, a majority of cars made in the EU are E20 tolerant. However, the E10 and E20 tolerant cars will not have been optimised for the higher blends (and so will not receive any fuel efficiency benefit), but rather for the blending limits and FQD requirements at the time of sales of these vehicles. Also, vehicle warranties may not include use of the higher blends, as these may refer to the fuel standard at time of the sales.
- Vehicles can be **fully compatible** with the blend: there are not technical or safety issues, and the blend is included in the warranty of the vehicle. If necessary, the maintenance schemes are adapted to the blends (e.g. more frequent oil changes). Additionally, in the case of ethanol blends, hardware and/or software changes have been incorporated into the vehicle to achieve the fuel efficiency benefit of the biofuel blend. For example, in the case of E20 rated at 100+RON, this could result in fuel efficiency gains between 3% and 6.4% (Chapter 2, Section 2.3.3.3). There is no fuel efficiency gain expected from using higher levels of FAME in diesel.

The discussion in the following mainly refers to the latter category, fully compatible vehicles, where it is assumed that only vehicles explicitly sold as fully compatible with higher blends will consume these blends. Use of these blends in tolerant vehicles may be technically possible but might have legal (warranty) and other implications, and is not considered here in more detail. If this would be considered a potential viable option to further increase biofuel use beyond blending limits, it is recommended to further assess potential barriers and opportunities to this route, in close cooperation with the vehicle manufacturers.

Note that this chapter is only relevant for FAME and ethanol. Fungible biofuels such as HVO or BTL are already compatible with the current fleet; thus, the market penetration of compatible vehicles is not an issue for these fuels.

1.5.2 Market penetration of vehicles

As described in (CE Delft, 2013), the market introduction of vehicles fully compatible with higher biofuel blends typically requires the following steps:

- Deciding on fuel specifications for the new blend (within CEN)
- Car manufactures and OEMs to develop vehicles that are compatible with these fuels, i.e. meet the emissions regulations as well as lifetime requirements, and optimise the engine performance (i.e. fuel efficiency) for the new blend (as described in Chapter 2).
- Type approval of these vehicles
- Bringing these new cars to the market. Two different approaches are possible:
  - All new vehicles are fully compatible with the new blend, from a certain date onwards.
  - Part of the new vehicles are fully compatible with the higher blend, vehicle manufacturers continue to also offer vehicles fully compatible with other blends.

  An example of the first approach is E10: all new vehicles are currently fully compatible with E10. This is the preferred way forward if a higher blend will be rolled out to public

filling stations and it is foreseen that this will become the new protection grade fuel in the future.
Examples of the second approach is E85 (some new vehicles are flex fuel and compatible with E85, but not all) and B30, which is intended for use in captive fleets only.

- Consumers then need to buy these fully compatible vehicles. This does not require any action in the first approach, but specific marketing efforts may be required in case of the second approach.

The market penetration rate of the fully compatible vehicles then determines the potential growth of sales of these higher blends. It also determines how long the protection grade has to be available.

As is discussed in Chapter 2, Section 2.3.2, as of 2011, the majority of the petrol cars made in the EU are already E20 tolerant. This means that even if vehicles have been type approved and fully compatible for lower blends, no safety or technical issues will occur if the higher blend is used. However, tolerant vehicles will gain no efficiency advantage in using the higher blend and car warranties may in fact limit the actual use to current fuel specifications and blending limits, i.e. to E10.

To obtain the efficiency benefit of E20, vehicles that are fully compatible with this fuel will need to be developed. These vehicles will then also be tolerant to lower ethanol blends. This tolerance has the advantage that it prevents any technical issues even when the vehicle owners do not use the blend their vehicle was designed for. It also allows fuel suppliers to use the full range of ethanol blends that E10 and E20 fuel specifications allow, i.e. between zero and 10 or 20 vol% ethanol. The potential downside is the potential lower vehicle efficiency when different blends are used in practice (Chapter 2).

1.5.2.1 *Timeline*

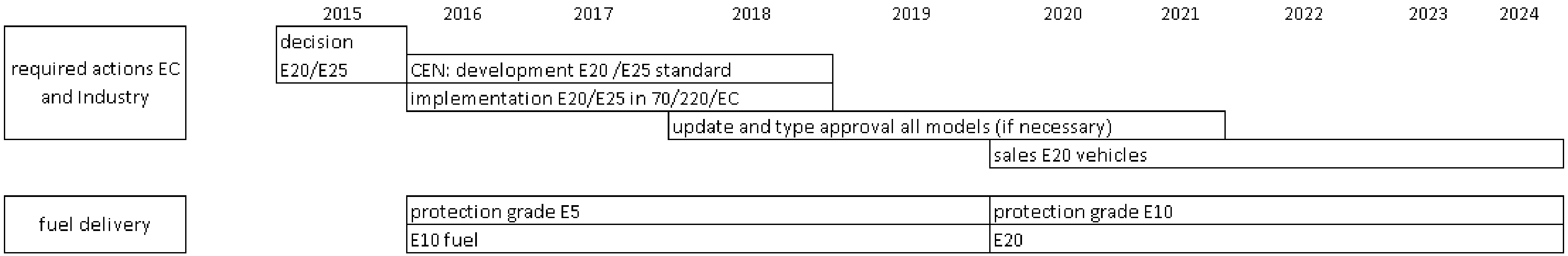
In (CE Delft, 2013), illustrative timelines were constructed for the implementation of vehicles specifically designed for a higher blend, following the steps described above. Figure 1.22 shows the result for the case of E20/E25, if vehicles and blends are to be introduced throughout the EU, based on a hypothetical decision to start the process in 2015.

- First, the CEN will develop a new standardisation, in close cooperation with stakeholders.
- This will have to be implementation in the relevant legislation (FQD and type approval). In the figure below, it is assumed that by the end of 2018, the new legislation is in place.
- Vehicle manufactures will start to adapt their vehicles and optimise them for the new standards once it becomes clear what the new standards will be (at the end of 2017, in the figure).
- Once models are type approved, they can be sold. This can be expected to start with some models, in the timeline below it is assumed that by 2020 all new vehicles will be required to be E20/E25 compatible.
- From that time onwards, E20/E25 can be rolled out to fuel stations, together with the necessary information provision and incentives to consumers. E10 will then become the new protection grade fuel, and E5 will be removed from the market.
- Depending on the incentives provided, the market share of E20 fuels can increase gradually over time, as the share of E20/E25-compatible vehicles in the total fleet increases.

A later decision on the standards, or any other delay in the decision making will, of course, result in a delay of these steps.

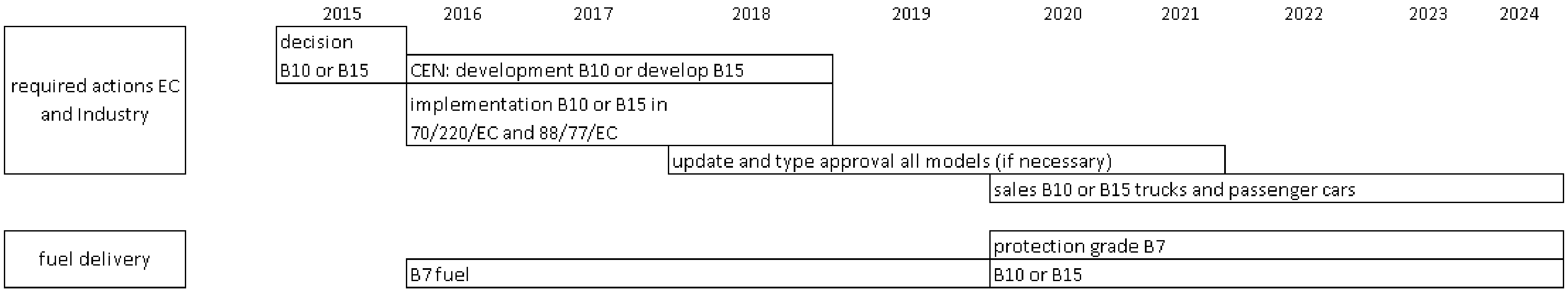
The process to arrive at a higher FAME standard can follow a similar, hypothetical timeline, see Figure 1.23.

Figure 1.22 Illustrative timeline for implementation of E20 or E25 for petrol based on a hypothetical decision in 2015



Source: CE Delft, 2013. Bringing biofuels on the market, Options to increase EU biofuels volumes beyond the current blending limit (years adjusted)

Figure 1.23 Illustrative timeline for implementation of B10 or B15 for diesel based on a hypothetical decision in 2015



Source: CE Delft, 2013. Bringing biofuels on the market, Options to increase EU biofuels volumes beyond the current blending limit (years adjusted)

1.5.2.2 Market penetration of fully compatible vehicles

Once the high-blend fully compatible vehicles become available on the market, their share in the total vehicle fleet will increase over time. This can be illustrated in the following – again hypothetical - example. The actual timing of the different steps in this timeline may, of course, be quite different, depending on the actual timing of the decision making process.

- Assuming that by the end of 2015, an EU-level decision is made that B10 and E20 will become the new high blends, and the process described in Figure 1.22 will be started.
- B10 and E20 compatible vehicles will be brought on the market by 2016, as some vehicle manufacturers have already developed these vehicles. They will not be type approved for B10 and E20 yet, but these vehicles will be compatible with the higher blends and their warranty will explicitly include driving on B10 diesel and E20 petrol, respectively.
- The share of B10 and E20-approved vehicles in the new vehicles sales will then increase between 2016 and 2020.
- From 2020 onwards, all new diesel vehicles (light and heavy duty) will be compatible with B10, all new petrol vehicles will be compatible with E20. This is in line with the finding in Chapter 2 that the lead time for manufacturers to design engines optimised for E20 would be 4 to 5 years.

Using the PRIMES reference scenario (2012) (also used in Section 1.4.3.2) as a basis to determine the EU vehicle fleet renewal data, the results indicate that in this hypothetical example,

- a market share of almost 25% of B10 and E20-optimised cars can be expected in the EU-wide vehicle fleet in 2020, and 19% B10 compatible trucks;
- these shares increase to more than 85% B10 and E20-optimised cars in 2030, and 78% B10-compatible trucks.

The remaining part of the fleet in 2030 will still need to drive on B7 or E10 (unless some form of retrofit is applied).

These results, of course, depend on fleet renewable rates, which is a function of vehicle sales and vehicle lifetimes: if vehicle renewable is slower and vehicle lifetimes are longer than assumed in this PRIMES reference scenario, the market share of compatible vehicles will be lower than calculated here[42]. It also depends on the ramp-up of the sales of B10- and E20-optimised vehicles: if it takes longer to develop these vehicles, market shares will also be lower in 2020 and 2030.

1.5.2.3 The potential role of captive fleets

High blends can be rolled out to public fuelling stations, but it can also be decided to only introduce them in captive fleets, which are vehicle fleets that refuel at dedicated filling stations[43]. More specifically, vehicle manufacturers and fuel suppliers recommend that some biofuel blends, notably FAME blends above B10 (e.g. B20, B30 or B100), should be used in captive fleets only, as they require closer quality monitoring of both fuels and vehicles (Chapter 2, Section 2.4.2).

These captive fleets are owned and operated by companies with their own fuel depot, for example large hauliers, bus or taxi companies or couriers with a fleet of delivery vans. Switching these to high blends has the advantage that they can be monitored closely, providing an opportunity to introduce higher blends without requiring large scale availability of high blends at public service stations.

[42] Note that the assumptions in PRIMES reference scenario (2012) are not shown here as this concerns quite a lot of detailed data. These calculations should be seen as an illustrative example.

[43] Higher blends may also be applied in non-road modes with dedicated fuelling stations such as diesel trains, however, these are outside the scope of this assessment.

Unfortunately, as concluded in CE Delft, 2013, there are only very limited data on the fuel consumption of centrally-fuelled captive fleets in the EU and its Member States, and estimates in literature appear to be quite limited and show significant ranges. Based on these data (CE Delft, 2013), estimates that about 25% of diesel fuels sales would be through captive fleets, a figure that will also be used in the scenario development in this study (see Section 1.7.3).

1.5.3 Vehicle compatibility and biofuel demand

The compatibility of vehicles in the EU fleet will set a maximum boundary to the FAME and ethanol volumes that the fleet can absorb, i.e. to the maximum market potential of these biofuels from a vehicle point of view. As noted above, this may not be an issue if biofuel supply proves to be the main barrier (to be discussed in the next chapter) or Member States prefer to meet their climate and energy goals with measures other than biofuels. However, as it takes time to achieve market penetration of high blend fully compatible vehicles, it is important to start this process well in advance before the high blends need to be sold.

In the example above it takes about 15 years from the time of the decision to move forward with B10 and E20 until an 85% market share is achieved in the passenger car vehicle fleet, and even longer in the heavy duty fleet. By that time, the remaining share of the fleet are vehicles older than 10 years and fully compatible for use with B7 or E10 only. The maximum FAME and ethanol shares that the total vehicle fleet can then handle is

- 8.7% FAME (energy content) in diesel, which is about 23,476 ktoe FAME in the EU in 2030 (according to the PRIMES reference scenario (2012) used here)
- 13% ethanol (energy content) in petrol, this equals about 6,400 ktoe ethanol in the EU in 2030 (again based on the PRIMES reference scenario (2012)).

Whether or not this maximum share of biofuel consumption is achieved then depends on the availability of the biofuels and on the policy incentives provided – without policy incentives it is unlikely that fuel suppliers will bring the high blends on the market, and consumers would buy these blends rather than the protection grade fuel. This could be tax incentives for high blends (see Section 1.3.3.2 for examples), or biofuel obligations for fuels suppliers that are set at levels high enough to encourage fuels suppliers to sell these higher blends (as the recent experiences with E10 have illustrated (see Section 1.3.4.1).

1.5.4 Conclusions

In the EU, most petrol vehicles manufactured after 2003 are E10 tolerant, and from 2011 onwards, a majority of cars made in the EU are E20 tolerant; all diesel vehicles can run on B7. The term tolerant implies here that they will not have safety or relevant performance issues with these fuels. These vehicles are not fully compatible with blends higher than the current blending limits B7 and E10, and warranties may not include higher blends.

Irrespective of the hypothetical scenarios explored in this study, it is considered that the introduction of new, higher biofuel blends requires fully compatible vehicles, which will be developed and sold once the technical specifications of these blends are decided on. The introduction of vehicles fully compatible for higher blends first requires agreement on fuel specifications (in the CEN), which are then included in the FQD and type approval regulation. Vehicle manufacturers can then develop and optimise vehicles for this new fuel standard, and introduce these on the market. The market penetration rate of these fully compatible vehicles determines the potential (maximal) growth of sales of these higher blends, and therefore provides a boundary condition to the consumption of these biofuels. Once the first fully compatible vehicles enter the market, it will take more than 20 years before the entire vehicle fleet will be compatible with the new blends.

The rate of fleet renewal also determines how long the protection grade has to be available: the share of vehicles incompatible with the higher blend (or fully compatible for lower blends) will reduce gradually over time. In the example used in this chapter (Chapter 1, Section 1.5.2.2), 15 to 22% of the vehicle fleet will still be incompatible with the higher blend 15 years after a standard for B10 or E20 has been decided on.

Vehicle manufacturers and fuel suppliers recommend that some biofuel blends, notably FAME blends above B10 (e.g. B20, B30 or B100), can best be used in captive fleets only, as they require closer quality monitoring of both fuels and vehicles. There is, however, very little data on current EU-wide fuel sales in captive fleets, a rough estimate (to be used in the scenario development in Section 1.7.3) would be 25%.

Vehicle compatibility is only one part of future biofuel developments. Whether or not the maximum share of biofuel consumption is actually achieved then depends on the availability of the biofuels and on the policy incentives provided – without policy incentives it is unlikely that fuel suppliers will bring the high blends on the market, and consumers would buy these blends rather than the protection grade fuel.

1.5.4.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations can be derived:

- It is recommended to take the timelines for the market introduction of high blend compatible vehicles into account when drafting future (2020 and 2030) forecasts and plans for biofuel developments, to ensure that vehicle compatibility is properly taken into account.
- Fleet renewal rates are likely to vary between Member States, and may also vary over time, as both vehicle sales and the lifetime of vehicles may vary over time. It is therefore recommended to assess market penetration of compatible vehicles in more detail, and for individual Member States.
- Assess the extent of captive fleets in the EU, to determine what share of diesel is sold through private rather than public filling stations. This will enable a more reliable estimate of the volume of higher FAME blends that could be sold through these channels.

1.6 Biofuel and biomass availability

1.6.1 Introduction

This chapter assesses the future availability of biofuels from the perspective of the availability of both feedstock and production capacity. These can both be barriers to further growth of biofuel supply and demand, and therefore potentially important areas for policy makers to address, and to take into account when developing forecasts and scenarios for 2020, 2030 and beyond.

As explained in Section 1.3, the biofuel demand, the biofuel blends, the type of biofuels that will be brought on the market and the feedstocks used to produce these biofuels in the coming decades strongly depend on the EU and national policies in place. These determine both demand and supply, define the sustainability criteria that the biomass feedstock has to meet and the specifications of the fuels themselves.

Until 2020, these developments are mainly determined by the RED and FQD, where the RED sets a 10% binding target for the share of renewable energy in transport fuels in 2020 (with biofuels from waste and residues counted twice towards the target) and the FQD sets a 6% mandatory target for the reduction of the GHG intensity of transport fuels. In addition, both directives define the sustainability criteria that biofuels have to meet to be counted towards these targets. The Member States implemented these directives in recent years, and, as required by the RED, submitted National Renewable Energy Action Plans to the Commission providing, inter alia, indicative trajectories for the development of renewable energy in transport shares between 2010 and 2020, and outlining their plans and policies to meet the transport target in 2020.

However, as the ILUC Directive is likely to enter into force in the second half of 2015 (see Section 1.3.2.3), there will be implications for the future Member State biofuel policies and biofuel demand. As long as the revised Member State policies are unknown, it is difficult to predict the extent of these implications, but impacts can be expected due to

- a 7% cap on the contribution towards the RED target of biofuels and bioliquids produced from cereal and other starch-rich crops, sugars and oil crops and from some other crops grown as main crops primarily for energy purposes on agricultural land.
- the introduction of a sub-target for advanced biofuels in the RED, with a reference value of 0.5%.
- an increased contribution of electricity consumption from renewable source in rail and road transport, due to higher multiplication factors in the calculation methodology of the RED.

These provisions will require the biofuel sector to move from biofuels from food crops to biofuels from waste, residues, ligno-cellulosic biomass, algae, etc., which generally achieve higher GHG savings and also have fewer negative impacts on other environmental indicators such as on biodiversity (EC, 2012b). This shift towards double-counting biofuels, as well as the increased contribution of electricity from renewable sources towards the target, can furthermore result in lower biofuel consumption than expected in the NREAPs.

The extent of these two effects is currently, however, difficult to predict as the Directive leaves room for Member States to continue to support food-based biofuels (it only restricts their counting towards the RED target), and the cap does not apply to the FQD. Furthermore, Member States are allowed to set a national target for advanced biofuels lower than the 0.5%, provided this decision is well-founded (potential grounds are specified in the Directive).

Developments beyond 2020 are even more uncertain at this time as the design and decision making process for the post-2020 renewable energy policies is still ongoing. The EU's 2030 energy and climate package (EC, 2014a and European Council, 2014) does not yet provide details about renewable energy in transport policies beyond 2030, although the Commission's proposal (EC, 2014a) does state that first generation biofuels have a limited role in decarbonising the transport sector. In the recent Energy Union Package, it was announced that the Commission will propose a new Renewable Energy Package in 2016-2017, which will includes a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU target is met cost-effectively (EC, 2015).

From the EU Energy Roadmap 2050 (COM(2011) 885/2) and the EU White Paper 'Roadmap to a Single European Transport Area' (COM(2011) 144), it can be concluded that a further increase of biofuels use is to be expected, as it is necessary to meet the longer term EU and Member State climate goals. Nevertheless, a number of scenarios are possible to meet the longer term climate goals, both in terms of timeline (i.e. growth over time) and in the future biofuels and feedstock mix.

In view of these uncertainties, it is as yet unclear how demand for biofuels will develop throughout the EU until 2030, at what rate the level of advanced biofuels is likely to increase during that time period, and whether the level of biofuels from food commodities and energy crops will be reduced over time or not.

Even with the ILUC Directive in place, the EU-wide supply and demand for biofuels from food and energy crops can still grow by several percent in the EU without exceeding the RED cap: it restricts the contribution that biofuels from food and some energy crops can make towards targets in the RED to 7%, whereas the EU average biofuel share was 4.6% in 2013 (see the data provided in Section 1.4.2.2). The EU average share of biofuels from food crops was even lower, and likely less than 4% (based on the 2012 share of 15% biofuels from waste and residues, see Section 1.6.2.4, this share is not known for more recent years).

In the case that the EU's post-2020 renewable energy policy would continue to impose a cap on food-based biofuels to count towards renewable energy targets (or Member States would implement such a cap in national policies on their own accord), future growth of biofuel supply and demand can be expected to be dominated by biofuels produced from waste and residues and other types of feedstock (including some types of energy crops) that do not compete with crops grown on agricultural land. This would be in line with the Commission's statements on the limited role of first generation biofuels in decarbonizing the transport sector, in the 2030 energy and climate package (EC, 2014a).

As will be shown in the following, this would require a significant change to the biofuel production sector, currently to a large extent geared towards first generation biofuels. Second generation biofuel production capacity and feedstock availability are likely to remain important boundary conditions to the future supply of advanced biofuels, and removal of these barriers depends to a large extent on the success of research, development and investment efforts in this area. However, as post-2020 policies are not yet decided on, it is as yet unclear whether these developments will indeed take place.

The chapter will start with an overview of the key data on the biofuel sector in the EU: current biofuel production and biofuel production capacity in the EU, as well as export and import of biofuel data and feedstocks used are discussed in Section 1.6.2. The different biofuel production routes are presented in Section 1.6.3, where it will be shown that most second generation production routes are still in R&D phase, thus posing a barrier to fast growth of second generation biofuel supply. Availability of feedstock for these conversion routes is assessed in Section 1.6.4, followed by an overview of expected cost developments of biofuels, in Section 1.6.5.

1.6.2 Biofuel production, exports and imports

1.6.2.1 Biofuel production in the EU

In Figure 1.24 the EU28 primary production of the various types of biofuels is presented for the period 2004-2013. In line with the consumption of biofuels in the EU, the production of biofuels has increased sharply since the introduction of biofuel indicative targets under the Biofuel Directive of 2003. Production dropped in 2011, mainly due to increased biodiesel imports in that year, but increased again in recent years after anti-dumping legislation was implemented (see Section 1.6.2.3). EU biofuel production is almost completely first generation biofuels, to a large extent based on feedstock such as rapeseed oil, sugar beet, grains, etc., supplemented by biodiesel production from residual oils and fats from both food industry and consumers (see section 1.6.2.4 for a more detailed feedstock overview).

Similar to the EU's biofuel consumption pattern, biodiesel[44] has the largest share in production, about 80% of total biofuel production in 2013. Biodiesel production data include both FAME and HVO, but there are not separate statistics on these two types of fuel[45]. It is nevertheless reasonable to assume that FAME has (by far) the largest market share as the EU's production capacity of FAME is significantly higher than that of HVO (see next Section, 1.6.2.2), and cost of FAME are typically lower (as was discussed in Section 1.3.4.4). This was also confirmed in the interviews with both fuel suppliers and car manufacturers

Biopetrol[46] production is mainly bioethanol. This can then be blended directly with petrol, but it can also be first converted to bioETBE. There are, however, no data on which share of the bioopetrol volumes depicted here are bioETBE.

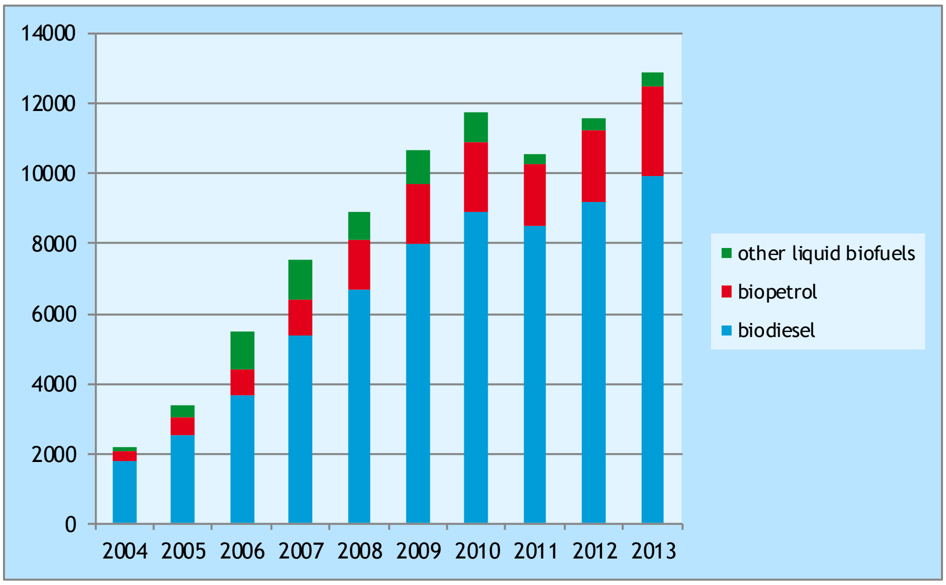
Note that 'other liquid biofuels' are not specified by Eurostat.

[44] Biodiesel data include FAME, HVO, and cold-pressed bio-oil

[45] Note that the production capacity data of HVO are not reported by Eurostat, but based on data provided by NesteOil, the main producer of HVO – see the next Section.

[46] Biogasoline data include bioethanol, bioETBE, biomethanol and bioMTBE

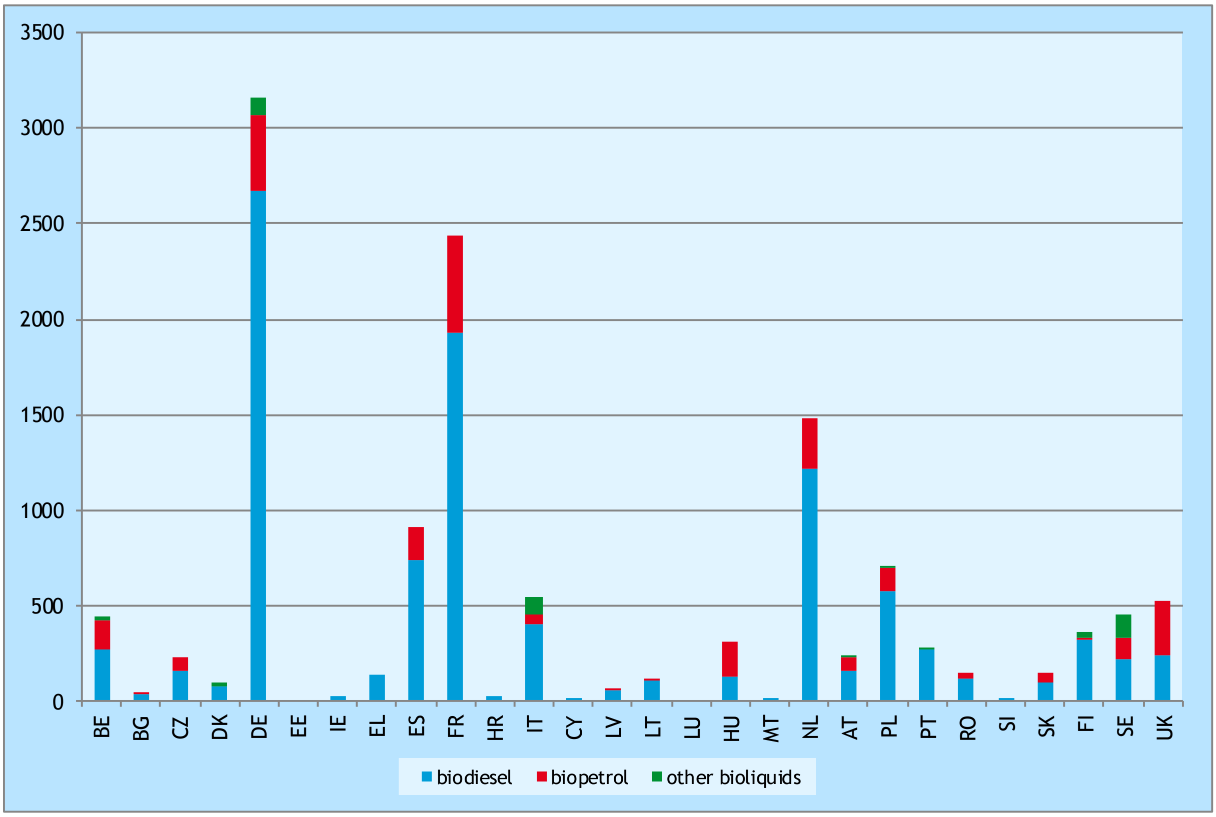
Figure 1.24 Primary production 2004-2013 in ktoe, EU28



Source: Eurostat, 2013

Figure 1.25 shows that Germany, France and the Netherlands have been mainly responsible for the EU's biofuel production in 2013 with Germany being the largest biofuel producing country.

Figure 1.25 Production of biofuels per Member State in 2013 in ktoe



Source: Eurostat, 2013

1.6.2.2 Capacity installed

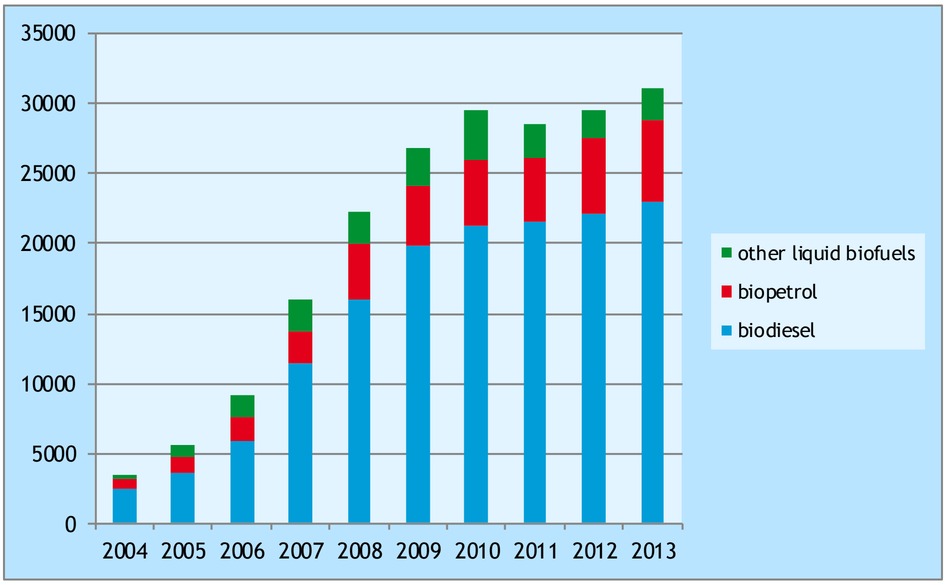
The production capacity installed in the EU is significantly higher than production itself, as shown for the various biofuels in Figure 1.26. In 2013, only 43% of the EU's biodiesel production capacity was actually used, 44% of biopetrol capacity and only 17% of capacity for other liquid biofuels[47]. In absolute terms, biodiesel had the most idle capacity available. In line with current EU biofuel production, this production capacity is almost completely for first generation biofuels (see section 1.6.2.4).

This situation of overcapacity has been in place since 2009/2010, resulting in relatively limited investments and roll-out of in new capacity since 2010. Investments in new capacity are still very limited due to the existing overcapacity, in combination with the uncertainties in future demand and sustainability criteria (and state aid guidelines that effectively limit state investment aid to conversion into advanced biofuel plans from 2014 until 2020, see Section 1.3.2.7). Stakeholders indicate that a clear outlook for biofuel demand until and beyond 2020 is required before investments will pick up again.

Production capacity per Member State is shown in Figure 1.27 (in ktoe total capacity) and Figure 1.28 (share per Member State). More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, 44% of the production capacity of biopetrol is located in France, Germany and the UK. The category 'other liquid biofuels' is left out of the latter graph (for clarity), but Germany accounts for 86% of capacity in this category. In 2013, only two Member States did not report any biofuel production capacity: Estonia and Luxemburg. Another 11 Member States, namely Bulgaria, Denmark, Ireland, Hungary, Cyprus, Latvia, Lithuania, Malta, Romania, Slovenia and Slovakia, each also accounted for less than 1% of production capacity.

The biodiesel production capacity is mainly FAME, but Neste Oil also has a number of HVO production plants in operation in the EU, in Finland (380 kton/annum) and Rotterdam (800 kton/annum)[48]. Together, this accounts for about 5% of the EU's biodiesel production capacity.

Figure 1.26 Biofuel production capacity 2004-2013 in ktoe, EU28

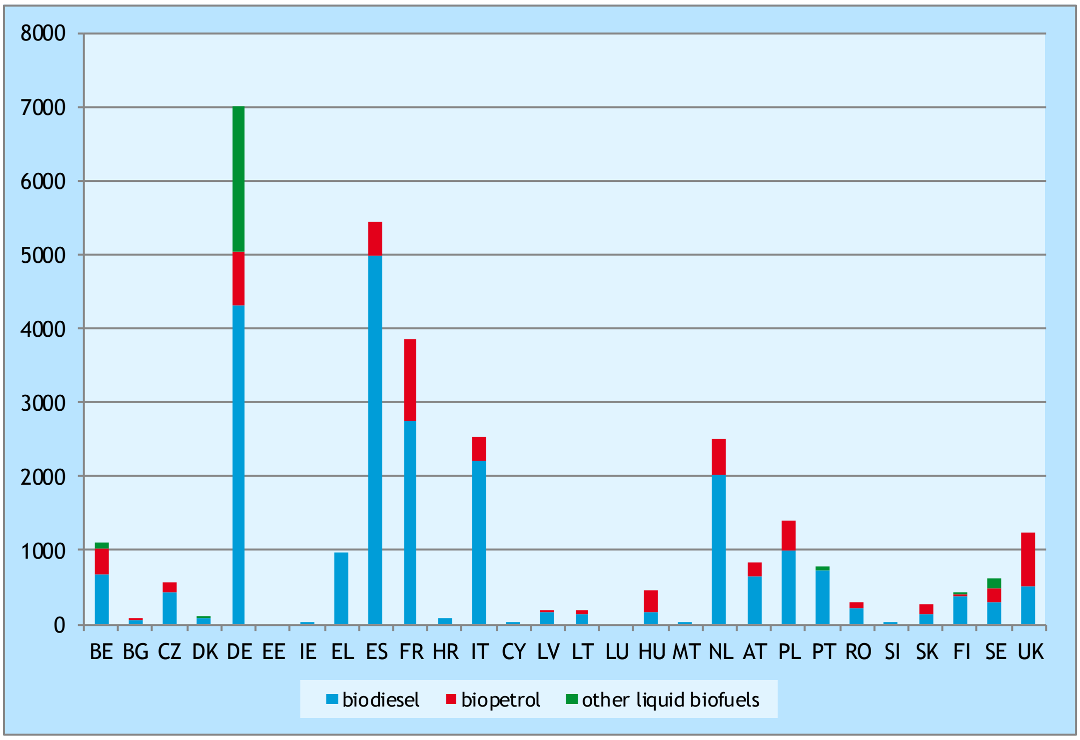


Source: Eurostat, 2013

[47] 'Other liquid biofuels' are not specified by Eurostat.

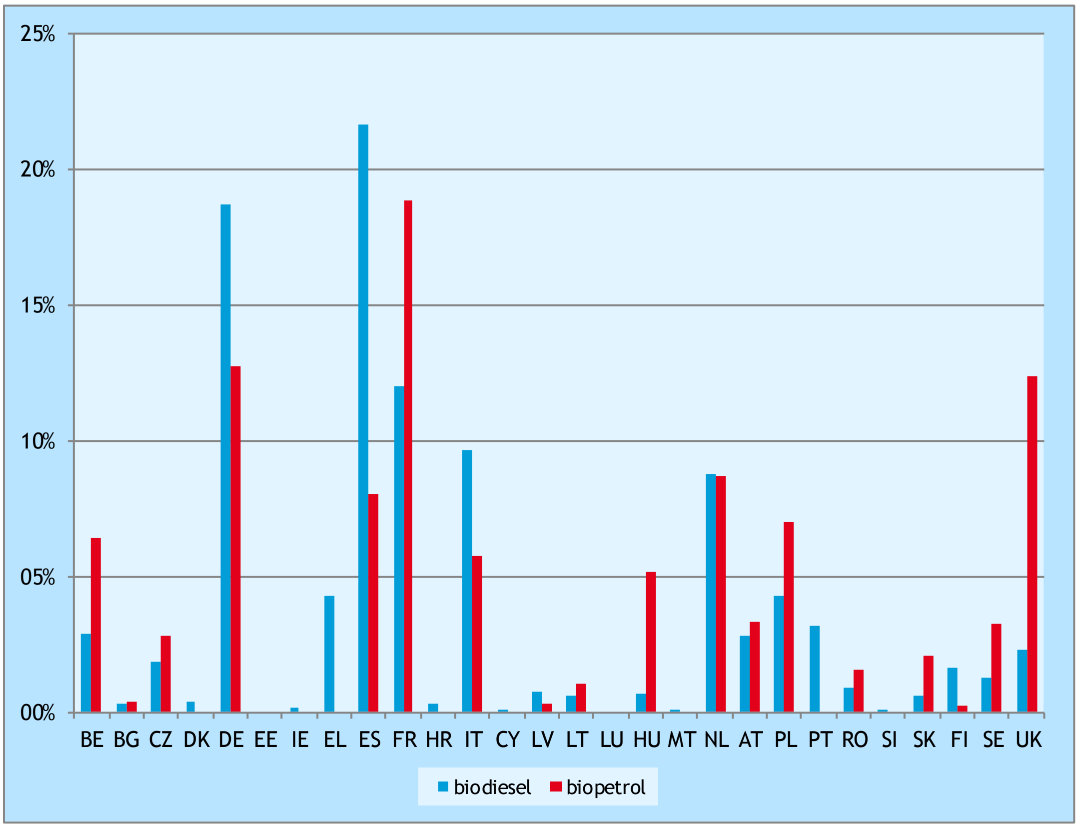
[48] Source: www.nesteoil.com

Figure 1.27 Biofuel production capacity per Member State in 2013 in ktoe



Source: Eurostat, 2013

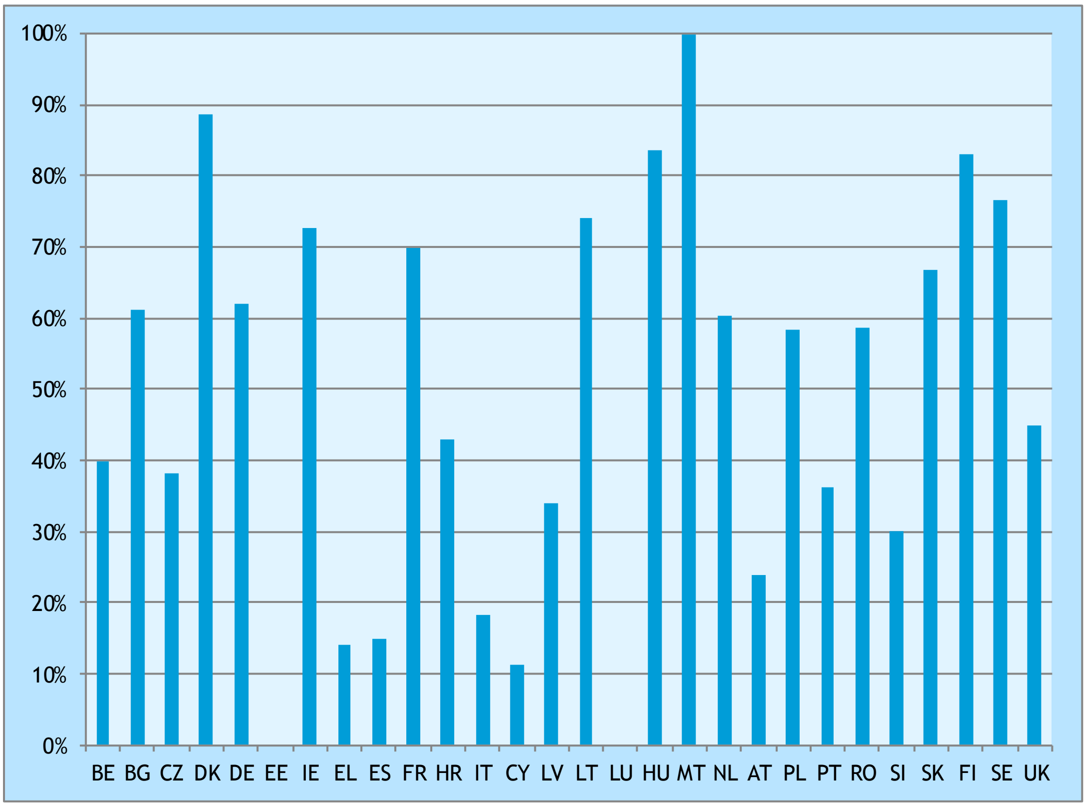
Figure 1.28 Share of biodiesel and biopetrol production capacity per Member State in 2013



Source: Eurostat, 2013

Zooming in on the use of biodiesel capacity in the EU, Figure 1.29 illustrates that in the ratio between production and capacity varies quite strongly between Member States. Biodiesel production capacity is used by more than 80% in Denmark, Hungary, Malta and Finland. However, in Europe's main biodiesel producing countries Spain, Germany and France, this ratio is only 15%, 62% and 70% respectively.

Figure 1.29 Ratio of actual production versus installed capacity for biodiesel in 2013



Source: Eurostat, 2013

There are several reasons for the underutilisation of production capacities, as Ecofys concluded in (Ecofys, 2012), based on their analysis of the data until 2010:

- The market seemed very attractive when decisions for construction were taken and construction started at many places concurrently. Once the plants came into production there was an overcapacity;
- Changing legislation especially in Germany, meant an immediate decrease in demand, especially for biodiesel;
- Increasing imports to the European Union, led to lower use of domestically produced European biofuels. Amongst others, low-cost imports of FAME from the USA and Argentina were driven by favourable blending subsidies (USA) and export policies (Argentina) in those countries;
- Increasing oil and feedstock prices increased the biofuel production cost but did not raise the competing pump prices for diesel and petrol at the same pace. The gap between biofuel production cost and value at the pump became too big to be bridged by the incentive schemes in place;
- The consumption increase has been lower than expected, partly related to sustainability concerns, and poor introduction of higher blends (E10 in Germany).

Is the current production capacity sufficient to meet 2020 biofuel demand?

When these capacity data are compared to the biofuel demand in 2020 according to the Member States' plans outlined in the National Renewable Energy Action Plans (NREAPs), it can be concluded that

- the 2013 biodiesel production capacity (22,983 ktoe) is already sufficient to meet the 2020 expected demand (21,646 ktoe) (ECN, 2011). MS expected to import 7,825 ktoe of this demand, i.e. 36%, which would not be necessary from a production capacity point of view.
- the European 2013 biopetrol capacity (5,779 ktoe) is not yet sufficient to supply the bioethanol/bioETBE that the Member States expect for 2020: 7,306 ktoe.(ECN, 2011). However, as MS are expected to import 3,216 ktoe of this volume from outside the EU, the current capacity can be considered sufficient to meet the (remaining) demand from EU-produced bioethanol/bioETBE: 4,091 ktoe.

The NREAPs do not provide separate trajectories of forecast for FAME and HVO, nor for bioethanol and bio-ETBE.

However, the plans outlined in the NREAPs did not yet take the ILUC Directive into account, and the upcoming changes in Member States plans and strategies that will be the result of its national implementation in the coming years. The increased multiplication factors for use of electricity from renewable sources in rail and road transport may reduce the projected biofuel consumption in the coming years. Furthermore, the sub-target for advanced biofuels that is introduced in the RED could be an effective driver to increase R&D and expand production capacity for advanced biofuels in the EU, provided that Member States decide to introduce these in national legislation. The Eurostat data do not distinguish between the different types of biofuels that are defined and addressed in the RED and FQD (e.g. biofuels from various food crops, biofuels from used cooking oil or animal fat, biofuels from feedstocks as defined in Annex IX Part A), but from the available data it can be concluded that advanced biofuel production capacity still has a very limited market share in total EU biofuel production capacity (see, for example, the EurObserv'ER Biofuels Barometers of recent years, Pelkmans, 2014, and section 1.6.3). As sub-target of 0.5% throughout the EU would require almost 1,300 ktoe advanced biofuel consumption, based on the 2020 petrol and diesel consumption forecast of the PRIMES reference scenario.

The possible implications of the policy developments, and in particular of a future shift from first to second generation biofuels, in the light of Europe's current biofuel production capacity, will be discussed further in Section 1.6.3 and Chapter 1.7.

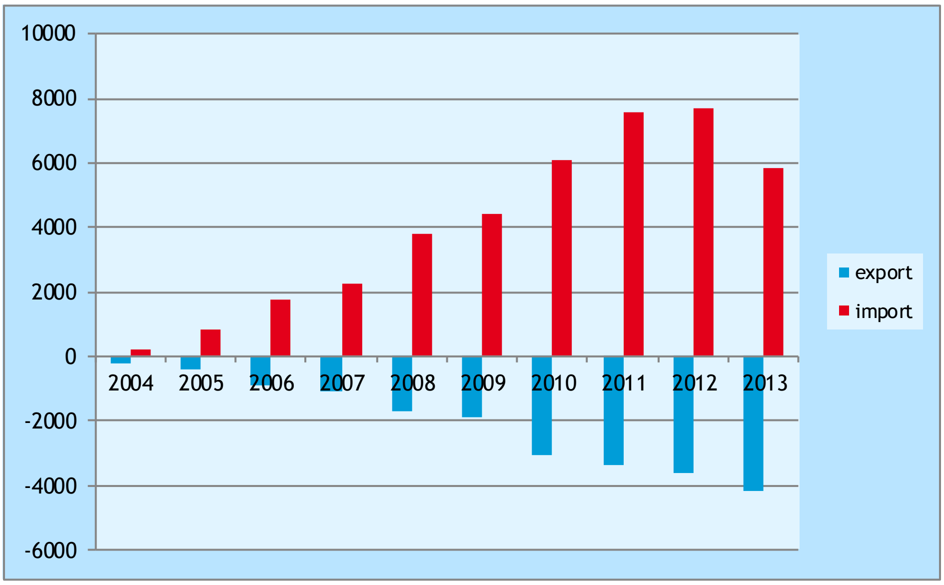
1.6.2.3 Export and import of biofuels from outside EU28

Despite the current overcapacity, the EU28 as a whole is a net importer of biofuels, as can be seen in Figure 1.30. Import increased steeply between 2006 and 2011, mainly due to increased demand in the EU and relatively low cost of biofuels outside the EU, but reduced by 20% again between 2012 and 2013, which can be at least partly attributed to anti-dumping barriers to imports from the USA, Argentina and Indonesia[49]. (Eurobserver, 2014) reports that since 2010, more than 90% of Europe's biodiesel import was sourced from the latter two countries.

Export continues to increase in recent years.

[49] Anti-dumping taxes were imposed on American bioethanol imports from February 2013 onwards (62.9 Euro per tonne, for a 5 year period), barriers for imports from Argentine (additional custom duties of 215-250 Euro per tonne) and Indonesian biodiesel (120-180 Euro per tonne) came into force on 28 November 2013 (Eurobserver, 2014)(for more background information, see also (Eurobserver, 2013))

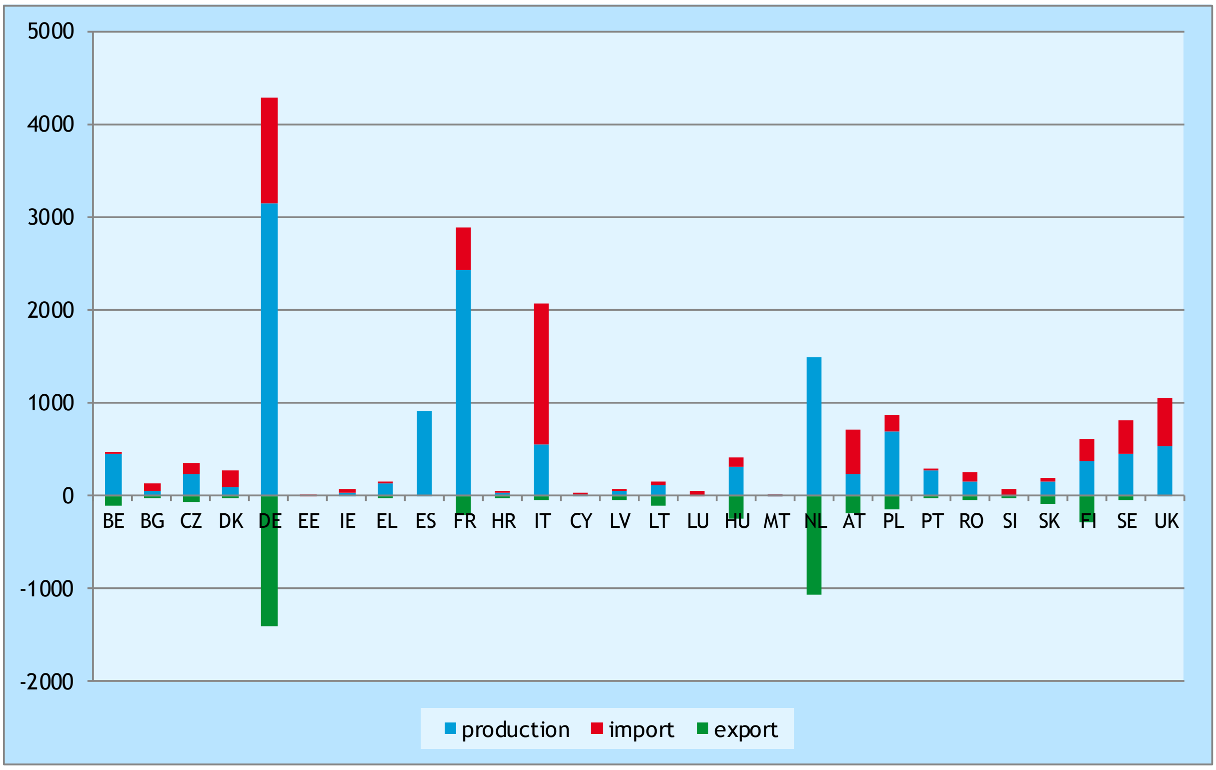
Figure 1.30 Export and import of biofuels in the EU28 in 2013 in ktoe



Source: Eurostat, 2013

Looking at the Member State data (Figure 1.31), it can be seen that Germany and the Netherlands are both large importers and exporters of biofuels, with France and Italy also importing significant volumes. These are countries with good (port) access for tankers.

Figure 1.31 Production, import and export of biofuels per Member States in 2013 in ktoe



Source: Eurostat, 2013

1.6.2.4 Feedstocks used for biofuel production

Biofuel production in the EU has up to recently been based predominantly on FAME and bio-ethanol production routes, almost exclusively using primary agrocommodities as feedstock:

- rapeseed oil (approximately 70%) and to a lesser extent soybean oil and residual oil for biodiesel.
- sugar beet, grains (mainly wheat and corn, some barley and rye) and surplus wine for ethanol.

An exception to this development is utilization of residual fats from both food industry and consumers for biodiesel production (see, for example, Pelkmans, 2014).

For a few years there have also been HVO production and glycerine (and natural gas) based methanol production facilities in The Netherlands and Scandinavia. HVO production has been based on a mixture of primary and secondary feedstocks. Globally, Neste Oil, the operator of the HVO facilities in Finland and The Netherlands, refined about 1.1 MMT of palm oil and other vegetable oils, and 1.3 MMT of waste and residues. The waste and residues consist of mainly palm fatty acid distillate (PFAD), and animal fats, UCO, and in smaller volumes, tall oil pitch, technical corn oil, and spent bleaching oil (source: interview with Neste Oil).

These are all mature biofuel production technologies. These biofuels are double counted towards the 10% RED target, but the biofuels produced from animal fats (categories 1 and 2 with Regulation (EC) No 1069/2009) and UCO do not count towards the sub-target for advanced biofuels of the RED as defined in the ILUC Directive.

EU-production of advanced biofuels produced from ligno-cellulosic biomass (included in Annex IX Part A of the ILUC Directive) has only started recently. In Crescentino, Italy, a first commercial 40 ktonnes/year ethanol plant processing wheat and rice straw and giant reed (grown locally) has been commissioned in 2013 (Eurobserver, 2014). Several other advanced ethanol plants are currently in the planning stage: in Italy, the US and China at commercial scale (up to about 80 ktonnes/year) and in Sweden and Spain at industrial pilot plant scale (see Eurobserver, 2014 for a more detailed overview).

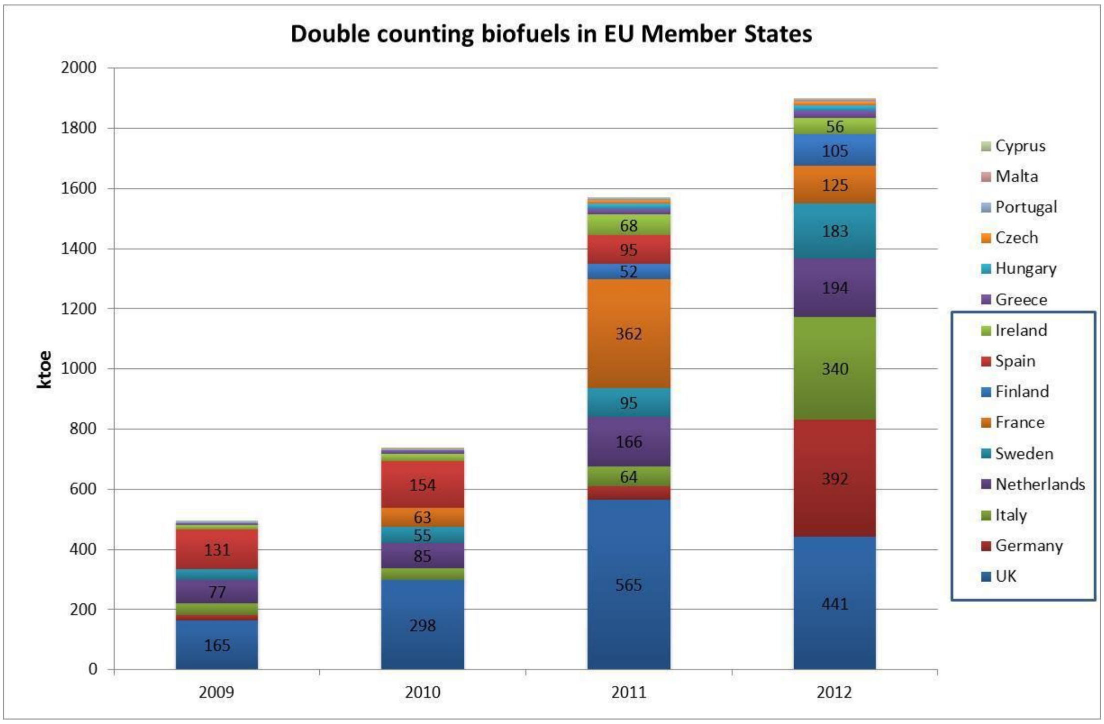
Based on the Member State's RED progress reports, Pelkmans (2014) made an overview of the consumption of double counting biofuels (i.e. biofuels from waste and residues) in the various Member States, as shown in Figure 1.32. In 2012, only four Member States, namely the Netherlands, Italy, Germany and the UK, were responsible for 70% of the biofuels from waste and residues consumed in the EU. More than 90% of these were produced from used cooking oils and animal fats (Pelkmans, 2014). Comparing these data with the overall biofuel consumption data in the EU (above), the share of biofuels from waste and residues is found to have increased from 1.4% in 2010 to almost 15% in 2012.

These are consumption data, production data are not available at this level of detail. Part of these biofuels are imported from outside the EU, as can be seen in the detailed UK and Netherlands biofuel reports (Department for Transport, 2014 and NEa, 2014), but these data are not yet available for the whole of the EU (and Eurostat production statistics currently does not distinguish between types of feedstock, or double and single counting biofuels). The national progress reports that the Member States submit biannually do provide data for the consumption of biofuels that comply with Article 21(2), i.e. production from waste and residues, as well as data of the share of imported biofuels. (Pelkman, 2014) used the most recent data for the analysis, which was consumption data for 2012.

Eurobserver, 2014 finds the implementation of the double counting incentive, Article 21(2) of the RED, in an increasing number of Member States to be the main reason for this strong growth, and expects this trend to continue in the coming years as investments in conversion capacity for biodiesel from used oils and waste fats and in ethanol from cellulosic biomass are ongoing. As these biofuels will not fall under the 7% cap in the RED for biofuels from food crops, as agreed in the ILUC Directive, this directive will further promote their demand in the longer term[50].

[50] The ILUC Directive will replace Article 21(2) by Article 3(4f), which will further specify the types of feedstock to be double counted and removes the obligation for Member States to implement double counting in national biofuel policy. The double counting towards the RED transport target remains.

Figure 1.32 Overview of double counting biofuels in the EU Member States



Source: Pelkmans, 2014

In addition to double counting and the ILUC-related cap in the RED, biofuel feedstock will also be influenced by the biofuel sustainability criteria of the RED and FQD. These require minimum GHG emission savings from biofuels, as defined in the ILUC Directive: currently 35% GHG emissions savings, increasing to 50% from 2018 for biofuels in operation before the ILUC Directive comes into force, and 60% for installations starting operation after the Directive comes into force (all values refer to direct emissions only, ILUC effects not included).

Based on life cycle assessments of GHG savings of various types of biofuels, both the 50% and 60% minimum GHG saving required in the future might create a preference for ethanol above biodiesel. For biodiesel, rapeseed oil is a mandatory main component (especially in winter, to meet the specific cold flow requirements, see, for example AGQM, 2013), but typical GHG savings for rapeseed oil based biodiesel amounts to only 45% (Annex V of the RED). However, studies indicate that in most Member States the 50% reduction target can be met (Hamelinck, 2013), as processes are adapted over time to meet the more stringent criteria.

If, however, ILUC related emissions were to be taken into account in the GHG balance in future sustainability criteria and/or in the FQD GHG intensity calculations, the result might be a strong reduction or even end of primary vegetable based biodiesel and HVO production and consumption in the EU, as these feedstock typically have relatively high indirect GHG emissions (see the provisional estimated ILUC emission in Annex V of the ILUC Directive: oil crops are allocated a mean value of 55 gCO_{2eq}/MJ, whereas cereals and sugars have a mean value of 12 and 13 gCO_{2eq}/MJ, respectively).

Future feedstock use is therefore dependant on a range of policy developments, most notably on the post-2020 development of the sustainability and ILUC policies, such as the minimum level of GHG savings in the biofuel sustainability criteria, the cap on biofuels from food and energy crops, and sub-targets for advanced biofuels.

1.6.3 Current and future biofuel conversion routes

Besides the current biofuel conversion routes, mainly resulting in FAME, bioethanol/bio-ETBE and HVO, a number of new biofuel production technologies are under development and might gain market shares in the future. In view of the sustainability and ILUC concerns and the EU's ambition to move away from first generation biofuels (as described in EC, 2014a), most R&D efforts are spent on further developing the routes that can use non-food and/or low-ILUC biomass as feedstock.

Efforts are also specifically put into research to develop new conversion routes that can produce fungible and versatile biofuels (such as drop-in biofuels that can also be converted into jet fuel), from non-food and/or low-ILUC feedstocks. These would resolve any issues with FQD blending limits, and would have the significant advantage over FAME and bioethanol that they can be used in the existing vehicle fleet and fuel distribution system, to any level that may be required in the future.

Annex 2 of this report contains an overview of both current and potential future conversion routes for biofuels, distinguishing between both diesel and petrol replacers.

The key characteristics of these routes are outlined in Table 1.13, which presents an overview of the currently applied and potentially upcoming biofuel production routes (sources: see Annex 2). In this overview a distinction is made between:

- The type of production process;
- The comparability with conventional automotive fuels (fungible/non-fungible)
- The applied types of feedstocks per production route and the expected level of indirect land use change (ILUC) per type of feedstock.
- The status of the production process: mature (conventional) and in R&D phase (advanced).

Production routes not included concern for example bio-butanol and DME. Bio-butanol production is still in development and low yields per unit of time and unit or reactor volume make it questionable whether this route will ever become economically sufficiently viable. Development of the DME route in Sweden has ceased. Nevertheless, it should be realised that as research efforts into different routes continue, new conversion technologies and fuels may appear in the future.

The main conclusion that can be drawn from this overview is that there are several conversion technologies available that can convert food crops into biofuels, but these are all associated with high or moderate risks of ILUC – the only exception is FAME and HVO production from used cooking oil, and HVO production from tall oil.

Production technologies to convert other feedstocks with low or no risk of ILUC (typically ligno-cellulosic,agricultural and forestry residues, such as wheat straw/corn stover/bagasse, wood based biomass, non-food crops such as grasses, miscanthus, algae, or industrial waste and residue streams), are being developed, but are not yet mature and commercially available in significant volumes. Of these, bioethanol production from ligno-cellulosic biomass is currently the most advanced: as mentioned earlier, the first European commercial 40 ktonnes/year ethanol plant processing wheat and rice straw and giant reed was commissioned in 2013, in Italy. Fuel suppliers and biofuel producers generally mentioned the lack of certainty in the EU policy making as the main obstacle for investments and commercialization of advanced biofuels in the EU.

Whether or not the more advanced routes will reach large-scale, commercial application in the future, and by when they can be expected, is currently difficult to predict. The R&D route from smaller scale to large scale application can take many years and even decades: Fischer Tropsch (BTL) biodiesel production, for example, has been under development of several decades but has not yet reached commercial scale production. It is also possible that some of these technologies will never reach maturity, if technical problems persist, if funding is insufficient or cost cannot be reduced to levels that are commercially attractive.

In the EU, the developments of advanced biofuel processes are supported by EU-level R&D funding. For example, the Commission supports innovative bioenergy projects through the both the Horizon 2020 and the NER 300 programme, and the European Biofuels Technology Platform (EBTP). These programmes include a number of advanced biodiesel and bioethanol projects – see http://www.biofuelstp.eu/funding.html for an overview of European R&D projects related to advanced biofuels production. In this context, it can also be noted that R&D into advanced biofuels is not limited to the EU, it is also actively pursued in, for example, the USA, Brazil and China (see, for example, Eurobserver, 2014). Once these R&D efforts are successful, they may also be applied in the EU.

Stakeholders from both the oil and the biofuel industry (including the EBTP) furthermore stress the potential importance of regulatory support such as a cap on biofuels from food crops and a target for advanced biofuels. They stress that concrete policies for 2030 can help to provide a positive market outlook for these biofuels, which is a prerequisite for the market to invest in R&D, demonstration and commercial-scale production units. The current incentive for biofuels from waste and residues, the double counting provision of the RED (Article 21(2)), has not yet resulted in innovation, as was concluded in the recent mid-term review of the RED (CE Delft, 2015), its positive effect is limited to incentivising the use of mature conversion processes only, i.e. FAME and HVO production from used oils and fats.

Table 1.13 Overview of applied and upcoming biofuel production routes

		Type of feedstock converted	Conversion technology	Type of feedstocks used	Fungibility	low ILUC / no ILUC/	conventional / advanced
Diesel (and kero) replacement	FAME						
	■ oil seeds, arable land	oils and fats, vegetable or animal	esterification of vegetable oils	rape seed, sun flower, soy, …	non-fungible	high	conventional
	■ oil seeds, plantation crops			oil palm, coconut	non-fungible	high	conventional
	■ UCO			UCO (used cooking oil)	non-fungible	no	conventional
	HVO						
	■ oil seeds, arable land		hydro-deoxygenation of vegetable oils	rape seed, sun flower, soy, …	(fungible)	high	conventional
	■ oil seeds, plantation crops			oil palm, coconut	(fungible)	high	conventional
	■ UCO			UCO (used cooking oil)	(fungible)	no	conventional
	■ tall oil			tall oil	(fungible)	no	conventional
	FT-diesel, wood	Ligno cellulosic	Gasification + catalytic CxHy formation from syngas	wood (thinnings)	fungible	no	advanced
Petrol replacement	Bio-ethanol						
	■ cereals	Sugars (and starches)	Starch hydrolysis, sugar fermentation, ethanol isolation	wheat, maize, …..	non-fungible	moderate	conventional
	■ starch crops			cassave	non-fungible	moderate	conventional
	■ sugar crops		sugar fermentation, ethanol isolation	sugar cane, sugar beet, sweet sorghum	non-fungible	moderate	conventional
	■ straw, giant reed, biochemical route	Ligno cellulosic		straw, giant reed	non-fungible	no - moderate	advanced
	■ wood, thermochemical route		Gasification + catalytic C2H5OH formation from syngas	wood (thinnings)	non-fungible	no	advanced
	Methanol	Ligno cellulosic	Gasification + catalytic CxHy formation from syngas	Glycerol	non-fungible	high	advanced

		Type of feedstock converted	Conversion technology	Type of feedstocks used	Fungibility	low ILUC / no ILUC/	conventional / advanced
Petrol /Kero / Diesel	Fischer Tropsch (BTL), Virent bioforming process, Hydropyrolysis	Ligno cellulosic	Catalyzed thermochemical routes	Wood, straw, lignocellulosic crops. For bioforming process: sugar and starch containing crops	fungible	no - moderate	advanced

1.6.3.2 How much first generation and advanced biofuel production capacity would be needed in 2030?

Due to the current uncertainties regarding EU and Member State policies after 2020, it is nearly impossible to predict the demand for biofuels in 2030 at this point in time.[51] Nevertheless, some illustrative calculations can be made, for a number of hypothetical assumptions. These can help to create insight in, for example, the advanced biofuels production capacities that would need to be developed in the coming decade for certain biofuel blend limits and caps on first generation biofuels. A more extensive exploration of future biofuel developments can be found in the next chapter, where three concrete (but also hypothetical) scenarios are developed for 2030.

To assess how much biofuel and therefore biomass demand there might be in 2030, first, road transport energy demand in 2030 has to be estimated. In the EU PRIMES reference scenario (2012), used for the analysis in the Transport White Paper of 2011, it is estimated that in 2030, EU road transport (blended) diesel demand is 185 Mtoe, and (blended) petrol demand amounts to 105 Mtoe. Using these data as a basis for the calculations, the following can be concluded.

- If the current FAME and ethanol blend levels (B7 and E10) still apply in 2030, they would allow blending of 11.8 kton FAME and 7.0 ktoe ethanol – see Table 1.14. More biofuels can be added if they are fungible (drop-in), for example HVO diesel or Fischer Tropsch (BTL) fuel.
- If the biofuel blend levels were raised to B10 and E20 throughout the EU, this would allow blending of almost 17 Mtoe FAME and 14 Mtoe bioethanol. Again, more biofuels can be added if they are fungible (drop-in). The overall blend limit for bio-components in standard diesel and petrol is currently 30 vol% (as defined in the FQD), although higher blends can be used in captive fleets.
- A 7% cap on first generation biofuels would amount to a maximum of 20.3 Mtoe of biofuels from food crops in 2030. The maximum potential of the current blending limits (B7/E10) could then be achieved by these biofuels only, without exceeding the cap.

Table 1.14 Maximum biofuel demand in 2030 in Mtoe, assuming the whole vehicle fleet runs on B7/E10 or B10/ E20, compared to current (2013) EU production levels

	total fuel demand	max. FAME and ethanol with B7 and E10 (current limits)	max. FAME and ethanol with B10 and E20	current production FAME and ethanol	current EU production capacity FAME and ethanol	max. volume from food feedstocks (in case of a 7% cap)
diesel	185	11.8	16.9	10.0	23.0	
petrol	105	7.0	13.9	2.5	5.8	
total	290	18.8	30.8	12.5	28.8	20.3

Source: CE Delft analysis, based on PRIMES reference scenario (2012) for fuel demand, and Eurostat data on production capacity

The table furthermore illustrates that

[51] Including because the ILUC Directive cap is applicable to the target in the RED - Member States may choose to provide incentives for biofuels as national policy without accounting this against the RED target.

- the current FAME production capacity in the EU would be sufficient to supply even B10 throughout the EU. This capacity can be used to produce FAME from plant oils as well as from a number of UCO and animal fats.
- Ethanol production capacity would have to be more than doubled to supply the volume needed for E20 throughout the EU, or imports would have to increase very significantly. For comparison: 2013 ethanol imports were about 1 Mtoe. As discussed before, current bioethanol production capacity is first generation only, production and consumption of advanced ethanol is still very limited, although Europe's first larger scale production plants for ethanol from ligno-cellulosic feedstocks (e.g., straw) are becoming operational.

Reasons for the underutilisation of production capacity in the past years were given in section 1.6.2.2, these do not indicate any particular barriers to increasing the utilisation of the EU's existing production capacity as EU biofuel demand increases. However, as the biofuel market is a global one, these opportunities, and in particular the share of imports of biofuels, will depend on the development of cost and demand, both within the EU and globally. Regarding advanced biofuels, the global market is still very much in its infancy, and further analysis on future investments in production capacity and advanced biofuel cost would be required to provide more insight in risks and opportunities for the European biofuel sector.

It is important to realise that the figures given above also depend on the development of energy efficiency and alternative renewable energy options in transport: an increase of electric vehicles and other types of renewable energy use (e.g. hydrogen, biomethane) may reduce the need for biofuels to meet any Member State targets or ambitions regarding GHG emissions and renewable energy use in transport. This effect is enhanced by the multiplication factors for electricity from renewable sources in the RED, but it is currently unknown whether these will be continued in post-2020 policy.

1.6.4 Biomass availability

Increasing the demand for biofuels in the EU requires an equal increase of suitable biomass supply, where suitable can be defined as

- it can be converted to a (high-quality automotive) biofuel;
- both the biomass and the resulting biofuel meet the sustainability criteria that apply in the future;
- the cost of the biofuel is reasonable, compared to other renewable energy in transport and GHG reduction options;
- security of supply is secured.

Assuming that the ILUC Directive and the EU's post-2020 energy and climate framework are successful in creating a shift in production and demand from first to second generation biofuel, in line with the ambitions expressed in (EC, 2014a), future growth of biofuel demand will have to come from low-ILUC feedstock such as cellulosic energy crops, algae, cellulosic wastes and residues.

The answer to the question what the potential supply of these sustainable feedstocks could be, at acceptable cost, is thus key to assess any future potential for biofuel growth.

As discussed in the previous Section, many of these feedstocks, in particular the cellulosic ones, require different conversion technologies than the ones used today. As these are either still in R&D phase or still at the beginning of large scale roll-out, it has to be seen which of these routes will reach full commercialisation and, therefore, which of these low-ILUC feedstocks can indeed be used for biofuel production in the future.

At the same time, the same feedstocks can also be used for other sectors and applications, such as for production of electricity, heat, chemicals or materials. Thus, it is not only about the potential volumes of suitable and sustainable feedstock, but also about future demand from other sectors.

Detailed estimates of potential availability and cost of biofuels from the non-food feedstock that does not fall under the cap are not yet available, and have not been assessed in the Impact Assessment of the proposal (SWD(2012) 343 final).

A quick scan of the available literature was performed to derive an estimate of the main feedstocks that are included in Annex IX of the ILUC Directive as well as of low-ILUC biomass, and their potential availability in the EU. This analysis can be found in A2.1, the main results are presented below. These findings provide an indication of the options available and their potential. However, it is recommended to assess these issues in more detail now that the ILUC Directive has been decided on. A full analysis should furthermore also look at options for imports, and at potential demand for these feedstocks from other sectors, as they can also be used, for example, for production of renewable electricity and heat and as feedstock for the chemical industry[52].

To illustrate the potential increase of biomass and waste from other sectors: the PRIMES reference scenario 2013 (EC, 2013) projects the following:

- the contribution of biomass to the EU's electricity generation will double in the coming decades, from 4% in 2010 to 6% in 2020/2030 and 8% in 2050.
- the share of biomass in steam supply will increase from 26% in 2010 to 35% in 2050, district heating is predicted to relying on biomass for 57% in 2050 (in comparison to 26% in 2010)

These shares, and therefore biomass demand, are even higher in the decarbonisation scenarios developed for the EU Energy Roadmap 2050 (EC, 2011b). In the various scenarios that were developed, total use of biomass in 2050 varied between about 186 Mtoe (reference scenario) and 320 Mtoe (High RES scenario), compared to the 86 Mtoe of biomass used in the EU in 2005. This includes biomass demand for all energy purposes, including transport, electricity and heat - the share of biofuels in these figures varies between 20% and 30%.. Note that these scenarios do not further specify the different types of biomass.

An overview of what the findings of A2.1 mean in terms of maximum potential of advanced biodiesel and biopetrol is provided in Table 1.15.

This table shows that there is a very significant potential of biomass from low-ILUC biomass or feedstocks that are included in Annex IX. Most of this is either cellulosic or woody biomass, which requires advanced conversion technologies to be converted into a high quality liquid biofuel, or cultivated, low-ILUC biomass (see A2.1 for further details). As discussed in the previous Section, the technology to use these cellulosic and woody feedstocks to produce bioethanol is currently the most advanced, but efforts are ongoing to develop a number of alternative conversion processes that could produce both petrol and diesel replacements from these feedstocks. Note that the potential availability of these types of feedstocks is one of the key drivers for these R&D efforts: if the share of sustainable biofuels in transport fuels is to be increased significantly in the future, both the fuels suppliers and the biofuel industry needs to be able to rely on routes with sufficient and reliable sustainable biomass supply (source: interviews with these stakeholders, and literature).

The results in Table 1.15 also show that there is still potential to increase production and consumption of biodiesel from UCO, animal fats and tall oil: current consumption is about 1.7 to 1.9 Mtoe (see Section 1.6.2.1), potential supply is estimated at 4.0 to 7.1 Mtoe - representing 2.2% to 3.8% of EU-wide diesel demand in 2020, as calculated in the PRIMES reference scenario (see previous paragraph)

There are two important issues to consider when interpreting these data:

- As noted in the remarks Section of the table and mentioned above, many of these feedstocks can also be used for other applications. The waste and residues can typically also be used for electricity and heat production, and as renewable feedstock for the

[52] Such an assessment is currently being carried out in a study commissioned by the European Commission, DG Energy, to be published.

chemical industry. The cultivated low-ILUC biofuels can also be used for food and feed. To derive a realistic estimate of potential availability for the biofuel sector thus requires a much more extensive and complex assessment of future availability and demand from all sectors involved.

- As mentioned before, the uncertainties regarding future success of the R&D efforts in the various advanced biofuel routes are still significant. Especially the advanced biodiesel processes still seem to be relatively far away from commercial application.

Table 1.15 Key results on potential availability of biofuels from non-food biomass within the EU (in Mtoe/yr)

		Mtoe/year			Economical and technical feasibility	Sustainability	Remarks
Diesel replacement	UCO	1	-	3.1	+	+	
	Animal fats/fats from slaughtered animals (C3 - C1)	2.5	-	3.1	+	-/0	competes with other uses
	Tall oil	0.5	-	0.9	+	-/0	competes with other uses, subsidy driven
	Total	**4**	**-**	7.1			
Petrol replacement	Additional sugar beet cultivation	45	-	32	?	+	
	Ethanol from cover crops	30	-	38.4	?	+	
	Straw	23	-	17.9	+	+	Sustainable potential, Actively developed by biofuel producers
	Prunings and other agri residues	5	-	3.84	?	depends on soil impacts	competes with power/heat generation
	Additional thinnings	18	-	12.8			
	Branch and top wood	10	-	7.05			
	Additional wood from landscape care	6	-	3.84			
	intensified mobilization of forest wood and residues	5	-	3.84			
	Wet residual grass	3	-	2.56	?	+	First small scale initiatives by research institutes
	Biodegradable consumer waste	2	-	1.92	+	+	Actively developed by biofuel producers
	Total	**147**	**-**	124			

1.6.5 Cost of biofuels

In the previous Sections of this Chapter, it was mentioned on several occasions (notably in Sections 1.3 & 1.4) that costs of biofuels are higher than the costs of the fossil fuels they replace. In the following, these costs will be quantified, and estimates for the future development of biofuel costs provided.

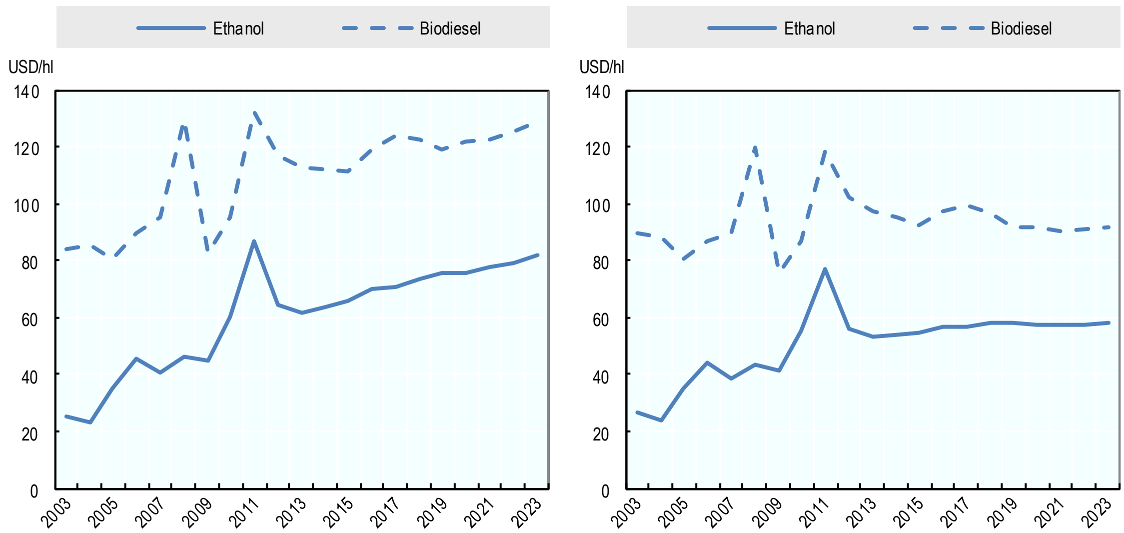
The 'cost of biofuels' that consumers have to pay, the retail prices, typically consist of cost of the biofuels itself (incl. production and distribution), taxes and excise duties. As was shown in Section 1.3.3.2, financial incentives such as excise duty reductions are applied throughout the EU to compensate for the higher cost of biofuels: of the countries where data on tax incentives for biofuels were found, 50% has tax incentives for biofuels in place, ranging from lower excise duty for low or (specific types of) high blends to exemption from CO_2 taxes for biofuels. Import tariffs can also impact the cost of biofuels. For example, there is a general import duty in place on ethanol. As was mentioned in Section 1.6.2.3, anti-dumping taxes are put in place on American bioethanol, as well on biodiesel from Argentine and Indonesia (Eurobserver, 2014). On the other hand, many of the exporting countries benefit from duty-free or reduced duty access to the EU market as a result of the General Scheme of Preferences[53] (GSP) or Tariff Reduced Quota (TRQ)[54], as part of trade agreements with the EU.

Actual data on biofuel cost are not as transparent as the cost of fossil fuels, as biofuels are typically sold to consumers in the EU as blends and not as pure biofuels. Their cost are thus hidden in overall fuel cost and not transparent to the general public, but some data sources exist. Cost of advanced biofuels are even more difficult to estimate, as these are usually confidential and there is no experience with large scale production plant yet (IEA, 2011).

An overview of recent (2013) cost of FAME biodiesel and bioethanol in the EU is provided in (EP, 2015), where is its estimated that the cost of rapeseed FAME is approximately 65% higher than that of conventional diesel, in terms of € per GJ. Similar ratios were found for the cost of ethanol from EU wheat or sugar beet, compared to petrol. However, in practice, both prices of various biofuels and fossil fuels vary significantly over time.

Recent global cost developments for biodiesel (FAME) and bioethanol, and expectations until 2023, as presented in OECD/FAO, 2014, are shown in Figure 1.33. These data are for the pure biofuels (i.e. for the biofuel part of a blend), and do not take into account any taxes such as import duties or excise duties. This figure shows that biofuel prices fluctuated significantly between 2007 and 2012, but have stabilised since then. OECD/FAO expects prices to remain almost constant in real terms until 2023 (right graph).

Figure 1.33 Biofuel prices expressed in nominal terms (left) and in real terms (right)



Source: OECD/FAO, 2014

The cost of biofuels is determined by the sum of the following cost items:

- feedstock cost, including cost of transport to the biofuel production plant and any pre-conditioning that is required (such as oil seed crushing)

[53] http://ec.europa.eu/trade/policy/countries-and-regions/development/generalised-scheme-of-preferences/index_en.htm

[54] http://ec.europa.eu/taxation_customs/common/databases/quota/index_en.htm

- cost of biofuel production
- cost of transport and storage of the biofuels to the point of retail
- profit of any co-products of the biofuel production, such as DDGS, glycerine, bagasse, lignin or waste heat
- Import tariffs.

In the current situation in the EU, biofuels are not economically competitive with conventional fuels (i.e. petrol and diesel). Brazilian sugarcane ethanol could be competitive without the import tariff, but not with the tariff in place. This is confirmed by the empirical evidence that biofuel uptake in the EU only occurs when obligations or effective financial incentives are in place, and by detailed IEA biofuel cost analyses (IEA, 2011)(IEA, 2013).

These IEA assessments undertook bottom-up cost calculations for a range of biofuels, and estimated the impact of technological development and future oil price. (IEA, 2011) and (IEA, 2013). The results for the cost of fuel production in the 'Current Technology Scenario' (IEA, 2013) are shown in Figure 1.34. Not all fuel pathways that were analysed are included in this graph: FAME, for example, is not included, but costs were found to be about 20% higher than the cost of corn ethanol. Costs of HVO were not assessed. A somewhat different approach was taken in IEA, 2011, where expected future biofuel cost developments were assessed using two different scenarios:

- a low-cost scenario in which a minimal impact of rising oil prices on biofuel production cost is assumed; and
- a high-cost scenario which assumes a greater impact of oil price on feedstock and production cost.

The results are given in Figure 1.35. In both scenarios, the oil price is assumed to be 120 USD/bbl in 2050, the analysis is furthermore based on estimates of the lowest costs that may be achieved in the future.

Both IEA reports note that cost predictions are relatively uncertain and actual cost of biofuels depend on the local conditions, but following key conclusions can be drawn from these studies (IEA, 2011)(IEA, 2013):

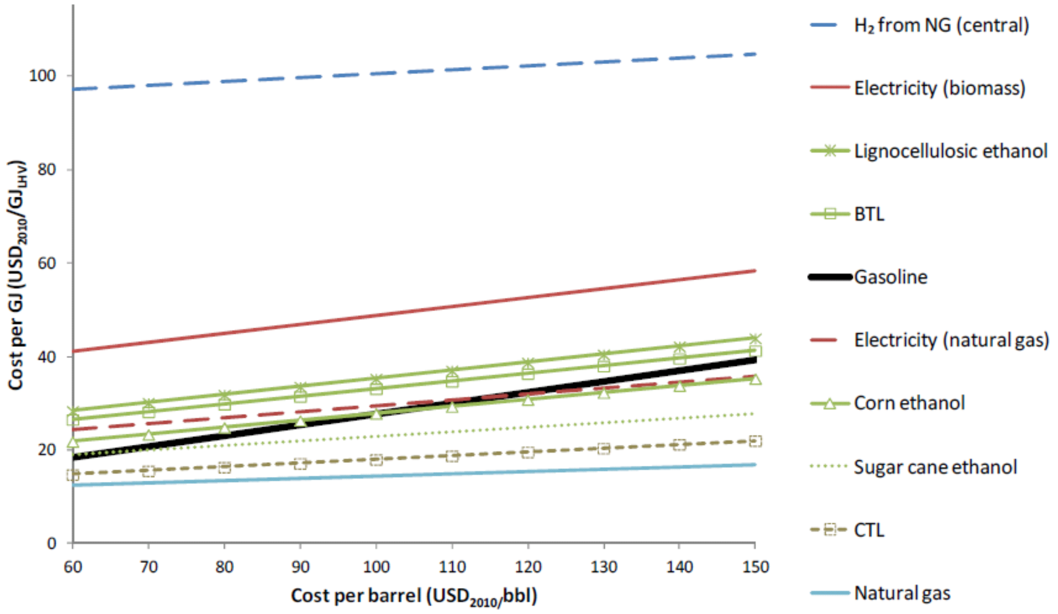
- In the Current Technology Scenario, sugar cane ethanol is competitive with conventional fuel at an oil price greater than 60 USD/bbl. However, corn ethanol can become competitive at oil prices above 110 USD/bbl, where FAME follows at about 130 USD/bbl according to (IEA, 2013).   IEA, 2011 finds much higher prices for FAME (see Figure 1.35) than IEA, 2013, due to different assumptions used.[55] At the time of writing this report, crude oil spot prices (in 2010 USD), are approximately 50 USD/bbl, and World Bank projections indicate it could be 65 USD/bbl in 2020, and 83 USD/bbl in 2025.[56] This will have major implications for the competitiveness of biofuels with conventional fuels during the timeframe of this study.
- Advanced biofuels such as lignocellulosic ethanol and biomass-to-liquid (BTL) are more expensive than petrol and conventional biofuels, and this situation is not expected to change when technologies mature. It is expected that ligno-cellulosic bioethanol and BTL biodiesel would be competitive with fossil fuels at oil prices over USD 130/bbl.
- Oil price is a relevant parameter, not only for petroleum fuels but also for biofuels, as energy is used throughout the biofuel chain, from crop cultivation to final transport to the retail station. This is also the case for the advanced biofuels such as lignocellulosic ethanol and BTL. Increasing oil prices thus also cause biofuel prices to increase.

[55] Import tariffs not taken into account and comparing prices of pure ethanol with pure petrol

[56] World Bank commodity price forecasts (April, 2015); http://www.worldbank.org/content/dam/Worldbank/GEP/GEPcommodities/PriceForecast_20150422.pdf

- Feedstock prices play a major role in biofuel cost: for conventional biofuels today, the main cost factor is feedstock, which accounts for 45% to 70% of total production cost[57]. The situation is different for advanced biofuels: for advanced ethanol and BTL, the main cost factor is capital cost (35% to 50%), followed by feedstock (25% to 40%). This has the advantage of reduced feedstock cost volatility, the relatively high upfront investment cost can, however, create a barrier to investors.
- The benefits of co-products from the biofuel production process can be quite significant: DDGS, glycerine, bagasse, lignin or waste heat can reduce biofuel production costs by up to 20% depending on the fuel type and use of co-product.
- Biofuel cost significantly depend on the scale of the production plant and the technology complexity, and will eventually also depend on future learning rates and cumulative production.

Figure 1.34 Cost of fuel production versus oil price for select fuels in Current Technology Scenario



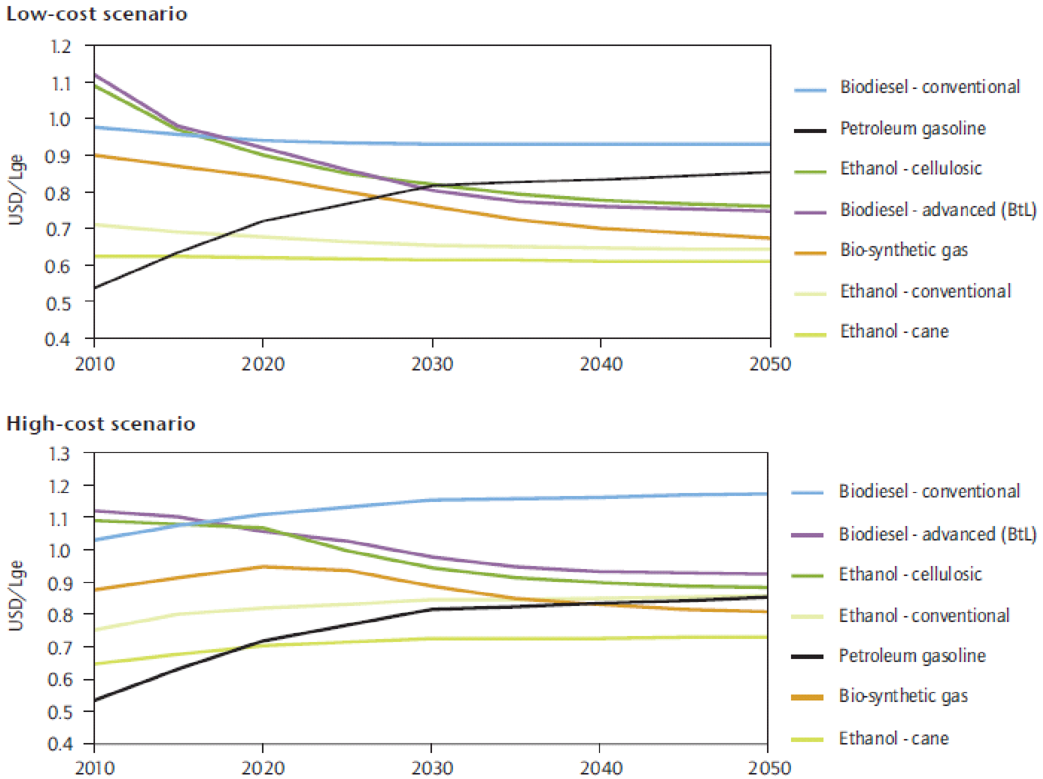
Note: BTL = biomass-to-liquids; CTL = coal-to-liquids; NG = natural gas; USD_{2010}/bbl = 2010 nominal USD per barrel of oil; USD_{2010}/GJ_{LHV} = 2010 nominal USD per gigajoule using lower heating value. Fuel production costs in this figure are extrapolated from their USD 60/bbl value using an arithmetical average of the two methods (Petroleum Intensity and Historic Trend) are discussed below (see Chapter "Results").

Source: unless otherwise stated, all material in figures and tables derive from IEA data and analysis.

Source: IEA, 2013

57 (IEA-ETSPA/IRENA, 2013) even states that feedstock cost may be 80% to 90% of the final cost of palm biodiesel, corn ethanol and rapeseed diesel (differences are likely due to different assumptions, feedstock cost) .

Figure 1.35 Cost of different biofuels compared to petrol



Note: costs reflect global average retail price without taxation. Regional differences can occur depending on feedstock prices and other cost factors.

NB. Cost are given in USD per litre petrol equivalent (USD/lge), to account for differences in energy content.

Source: IEA 2011

The development of the cost differential between biofuels and fossil transport fuels is therefore relatively uncertain, and depending on technological development of the biofuel routes, feedstock price and, to a lesser extent, the oil price. In the low-cost scenario of (IEA, 2011) and the high oil price range of (IEA, 2013), conventional biofuels are found to become competitive over time, but this was not the case in the other scenarios. Furthermore, all scenarios find that advanced biofuels remain more costly than both fossil petrol and conventional, first generation biofuels (although cost predictions of FAME were found to vary significantly).

It can therefore be concluded that policy incentives for biofuels in general, and for advanced biofuels in particular, remain necessary in the time period until 2030, and that it is likely that the biofuel market will remain dependent on incentives also in the longer term. This also means that transport energy is likely to become more costly when the share of biofuels is increased, and even more so when increasing the share of advanced biofuels. (IEA, 2011) estimates for their biofuel roadmap that use of biofuels would increase global cost of transport energy by between 0.2% and 1.1 in 2030, where advanced biofuels account for the major share of these costs. This assumes an increasing share of biofuels in total global transport fuel demand, resulting in about 9% in 2030 (and, eventually, a 27% share in 2050).

1.6.6 Conclusions

In line with the consumption of biofuels in the EU, the production of biofuels has increased sharply since 2004. Production dropped in 2011, mainly due to increased biodiesel imports in that year, but increased again in recent years after anti-dumping legislation was implemented. Biodiesel has the largest share in production, about 80% of total biofuel production in 2013. Germany, France and the Netherlands have been mainly responsible for the EU's biofuel production in 2013 with Germany being the largest biofuel producing country.

The production capacity installed in the EU is significantly higher than production itself. In 2013, only 43% of the EU's biodiesel production capacity was actually used, 44% of biopetrol capacity (ethanol, mainly) and only 17% of capacity for other liquid biofuels. More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, 44% of the production capacity of biopetrol is located in France, Germany and the UK. In 2013, only two Member States did not report any biofuel production capacity: Estonia and Luxemburg. Another 11 Member States, namely Bulgaria, Denmark, Ireland, Hungary, Cyprus, Latvia, Lithuania, Malta, Romania, Slovenia and Slovakia, each also accounted for less than 1% of production capacity. HVO production capacity is about 5% of the EU's total biodiesel production capacity.

The 2013 biodiesel production capacity (22,983 ktoe) is already sufficient to meet the 2020 demand (21,646 ktoe) as predicted in the NREAPs. The European biopetrol capacity (5,779 ktoe) is not yet sufficient to supply the bioethanol/bioETBE that the Member States expect for 2020: **7,306 ktoe.** However, as Member States expected to import 3,216 ktoe of this volume from outside the EU, the current capacity can be considered sufficient to meet the (remaining) demand. The NREAPs do not provide separate trajectories of forecasts for FAME and HVO, nor for bioethanol and bio-ETBE.

Current FAME production capacity in the EU would be sufficient to supply B10 throughout the EU. Ethanol production capacity would have to be more than doubled to supply the volume needed for E20, or imports would have to increase significantly. Current bioethanol production capacity is first generation, production and consumption of advanced ethanol is still very limited, although Europe's first larger scale production plants for ethanol from ligno-cellulosic feedstocks (e.g straw) are becoming operational. FAME production capacity can be used to produce FAME from plant oils and from waste and residues.

Despite the overcapacity, about 4 Mton of biofuel is exported and 6 Mton is imported (data for 2013). Especially imports can be seen to vary over time, depending on the availability of low-cost biofuels, on import taxes and anti-dumping measures. Export is increasing steadily over the years.

In 2012, about 15% of the EU's biofuel consumption was produced from waste and residues (most recent data), the rest was mainly produced form rapeseed and other oils, and sugar beets and grains. Future development of feedstock used is strongly dependant on policy developments: the minimum level of GHG savings in the biofuel sustainability criteria, the cap on biofuels from food crops and on incentives such as sub-targets in obligations for advanced biofuels. The ILUC Directive is a step towards a shift from food-crops to waste and residues, although the 7% cap in the RED still allows the consumption of biofuels from food crops to grow in the coming years.

Several technologies are available that can convert food crops into biofuels, but these are all associated with high or moderate risks of ILUC – the only exception is FAME and HVO production from used cooking oil, and HVO production from tall oil**.**

Production technologies to convert other feedstocks with low or no risk of ILUC (typically ligno-cellulosic, agricultural and forestry residues) are being developed, but are not yet mature and commercially available in significant volumes. Of these, bioethanol production from ligno-cellulosic biomass is currently the most advanced. Whether or not the more advanced routes will reach large-scale, commercial application in the future, and by when they can be expected, is difficult to predict. The R&D route from smaller scale to large scale application can take many years and even decades.

Biomass availability uncertainties are significant, but results show that there is very high potential in the EU for straw, thinnings and branch and top wood, as well as of low-ILUC feedstock production such as sugar beet cultivated on degraded land. The latter, however, only qualifies to count above the 7% cap in the RED under certain conditions, whereas the first requires advanced production technologies.

Biofuels are more costly than fossil fuels (in terms of €/GJ), and will remain more costly at least until 2025/2030 and perhaps also in the longer term, depending on technology development, cost of feedstock and oil price. Advanced biofuels are more expensive than conventional biofuels, and this is expected to remain the case in the future. Policy incentives for biofuels in general, and for advanced biofuels in particular, remain necessary in the time period until 2030, and that it is likely that the biofuel market will remain dependent on incentives also in the longer term.

1.6.6.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations can be derived:

- Improve EU-wide monitoring of feedstock used for biofuels consumed in the EU. Distinguish between biofuels from food crops, biofuels from feedstock specified in Part B of Annex IX of the ILUC Directive, and biofuels from feedstock listed in Part A in statistical data gathering and reporting[58].
- Assess the implications of the ILUC Directive, and any future changes in sustainability criteria, on biofuels and biomass demand and cost. This can create insight into the development of the market, cost, and potential barriers to future growth of biofuels. In this context, further analysis of potential global market developments are also recommended, to provide more insight into the underutilisation of production capacity and other associated risks and opportunities for the European biofuel sector.
- Assess the potential of biofuels from the various types of non-food feedstocks in more detail. This analysis should look at availability in the EU but also look at options for imports. Also, assess potential demand for these feedstocks from other sectors, as they can also be used, for example, for production of renewable electricity and heat and as feedstock for the chemical industry, taking into account principles such as cascading of biomass. The status of conversion technologies should also be taken into account[59].
- Assess the options to provide more room for low-ILUC, cultivated (energy) crops in future biofuel policy. This may increase the potential future biofuel supply significantly.
- Continue to support R&D for advanced production technologies, and implement effective incentives for advanced biofuels in national policies.

1.7 Development of biofuel demand to 2030

1.7.1 Introduction

This chapter aims to provide an outlook of future biofuel demand in the EU, until 2030, based on the findings in the previous sections and in Chapter 2. This outlook can provide insight in the potential developments, and provide a basis for future policy development related to high blends, as it helps to identify the possible implications of current policies, the uncertainties that exist and the gaps in current knowledge.

Combining the findings of the previous chapters, a number of key conclusions can be drawn regarding the current status of biofuel demand and the outlook until 2030.

- In recent years, biofuel demand in the EU increased to an average share of 4.6% of road transport fuels in 2013 (energy content). The political debate regarding the ILUC proposal, which could potentially have significant impact on biofuel policies and demand,

[58] Note that Member State RED progress reports include data on the share of double-counting biofuels, but these do not distinguish between Part A and Part B feedstocks. Furthermore, these reports are only bi-annual, instead of annual as the Eurostat fuel statistics.

[59] Such an assessment is currently being carried out in a study commissioned by the European Commission, DG Energy, to be published.

created uncertainty in the market. This has resulted in limited investments in new production capacity in recent years.

- Now that this been decided, the outlook for the sector until 2020 will become clearer. Member States will implement the ILUC regulation in the coming years, which shall ensure that the contribution biofuels from food crops towards the RED target does not increase beyond 7%, and provide additional incentives for biofuels from waste and residues. However, Member States have some flexibility when implementing the RED-related policies of the ILUC Directive (e.g. they may choose to set a lower cap for biofuels from food crops and deviate from the reference value for the sub-target for advanced biofuels), and the cap does not apply to the FQD nor to national support policies. It may therefore not be before 2017, when the ILUC proposal has to be implemented in all Member States, that details regarding biofuel demand in 2020 will be known.
- From 2020 onwards, the EU will not set binding targets for renewable energy in transport use in Member States, only an EU-level overall RES target of 27% in 2030. This suggests that each Member States can decide on the role of transport energy in their overall RES policies. Details of the post-2020 renewable energy regulatory framework are still unknown (to be proposed by the Commission in 2016-2017), but in view of recent policy debates, the authors of this study would expect that this will include sustainability criteria for biofuels that will be a continuation or further strengthening of the current criteria including ILUC.
- In view of these uncertainties, both in the coming years and even more so between 2020 and 2030, the development of biofuel demand is difficult to predict.
- This is further complicated by the currently limited production capacity for advanced biofuels. The current policies, especially the double counting provision of the RED (Article 21(2)), have proven to be an effective incentive for biofuels from waste and residues that can be produced with well-developed, mature production processes. This has resulted in a strong increase of consumption of biodiesels (FAME and HVO) from used cooking oil and animal fats. Advanced biofuels, i.e. biofuels that can be produced from the feedstock listed in Part A of Annex IX of the ILUC Directive, are, however, still in R&D phase or are only just starting commercial scale production. As new production technologies are necessary to unlock the potential of ligno-cellulosic waste, residues and other types of low-ILUC biomass for sustainable transport fuel production, technology development is crucial to the future growth of sustainable biofuels. Commercial scale production of advanced bioethanol production has started only recently, advanced biodiesel production from ligno-cellulosic biomass has not (yet) progressed this far.
- The ILUC decision can be a certain driver for these types of biofuels in the longer term, depending on the level of the cap (for food-based biofuels) and sub-target (for advanced biofuels) after 2020 and 2030 Member State policies and ambitions.
- The data on biofuel policies and actual biofuel consumption show a significant variation in ambition throughout the EU: average biofuel shares in 2013 varied between 0.4% in Estonia and 9.8% in Sweden. As all Member States will have to meet the 10% target in 2020, this range will become smaller in the coming years, but without binding renewable energy in transport targets after 2020, differences between Member State's ambitions and energy policy strategies are likely to remain also after 2020.
- Apart from biomass and biofuel availability, the FAME and ethanol blend limits can become a significant barrier to further growth of consumption of these fuels: the current limits only allow blending of up to 6.4% energy content of FAME (B7) and up to 6.8% energy content of ethanol.
- Most Member States still have biofuel shares well below these FAME and ethanol blending limits. In France, B8 was allowed on the national market in order to meet the biofuel obligation of 7.7% energy content, in line with a specific provision of the FQD.

- 25 of the 28 Member States have not yet introduced E10 on their market, E10 has so far only gained market shares in Finland, France and Germany. In the rest of the EU, E5, which includes up to 3.3% (energy content) bioethanol, is still sufficient to meet the targets and obligations. Once blending obligations increase in the coming years, as the 10% target of 2020 becomes closer, it can be expected that the number of Member States with E10 will increase, as this is a relatively straightforward and well regulated way to increase ethanol sales from 3.3% to 6.8%, based on energy content.
- A number of other Member States make use of higher blends, by promoting E85 (for example in France, Finland, Sweden) or B20 or B30 in captive fleets (for example in Spain, Italy, France and Poland). Fungible biofuels such as HVO, not affected by these limits, currently have a market share less than 5% of the EU's biodiesel consumption.

Despite the uncertainties, the following aims to provide some insight in to potential developments through 2030. First, based on a literature analysis, an overview of findings from a number of recent analyses and assessments is presented. This assesses the implication of a cap on biofuels from land-based feedstock, and also takes into account blending limits and vehicle compatibility issues. Then, in Section 1.7.3, three scenarios are derived for the period until 2030. These are based on the findings in Chapters 1 and 2 of this report, and will be used as input for the remaining tasks of this project.

1.7.2 Expectations until 2030: literature analysis

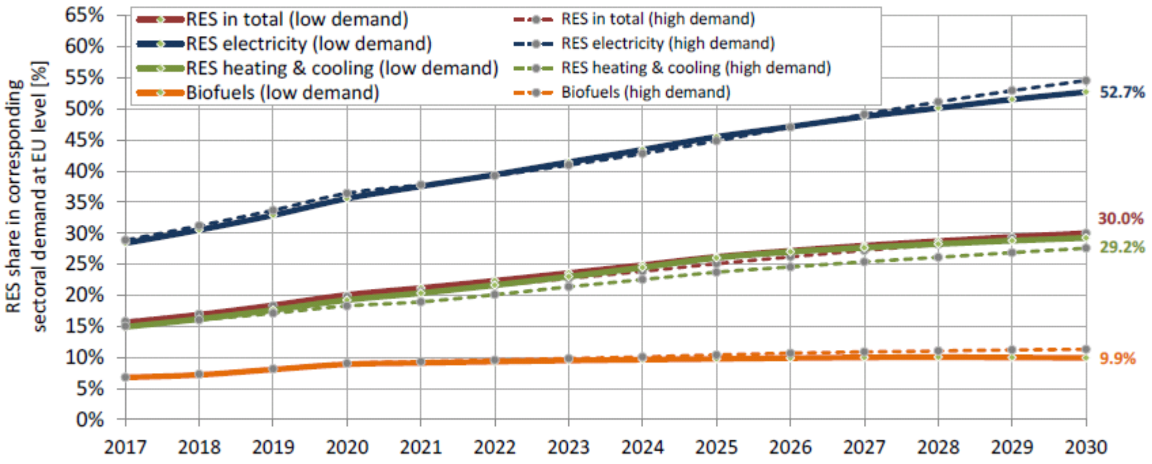
As discussed earlier, a cap on biofuels from food crops will have quite significant impacts on the feedstock that can be used for future (growth of) biofuel production. A number of forecast and outlooks have been published in recent years to assess this impact.

These studies either specifically looked at the European situation and the potential effects of current or expected policies (Resch et al, 2014)(JEC, 2014)(E4Tech,2013), or assessed the global developments, focussing on impacts on agriculture and forestry (OECD/FAO, 2014)(IEA, 2015). Not all of these studies provide outlooks until 2030 and all had different assumptions on policy developments, but most studies incorporate a shift from first generation biofuels (from food crops) to advanced biofuels (from waste and residues, ligno-cellulosic biomass etc). Without going into the details of each of these studies, for these we refer to the original literature, the key assumptions and main results are provided below.

Note that as part of this literature analysis, the European Commission's Impact Assessments of the ILUC proposal (EC, 2012b) and of the proposal for a 2030 climate and energy policy package (EC, 2014a) have also been analysed. However, these are only high level assessments, and potential impacts on, for example, biofuel and feedstock demand, vehicle compatibility or costs are not assessed, so they have not been included in the following.

Resch et al., 2014 carried out a brief assessment of the potential impact of 2030 RES targets for Europe on renewable energy use in the different sectors. Various targets were assessed, with the 30% target the closest to the agreed target of 27%. They do not specify the sustainability criteria that they assumed for biofuels, but it can be derived from their conclusion that a cap on food-based biofuels is assumed. They conclude from their modelling results that this 30% RES target would result in stagnation of biofuel consumption between 2020 and 2030, and result in a shift from first to second generation biofuels. They find that biofuel demand is somewhat dependent on developments in other sectors: in case the implementation of energy efficiency measures in the heating and cooling sector turns out to be unsuccessful (high energy demand scenario) a slightly higher renewable energy in transport contribution is foreseen to compensate for these failing measures (Resch et al., 2014). Their forecast for biofuel demand is depicted in Figure 1.36, they expect a share of about 10% in transport energy demand in 2030.

Figure 1.36 Future renewable energy sources (RES) pathways up to 2030 at EU level, pursuing a 30% target, in total and per energy sector depending on the future gross final energy demand



Source: Resch et al, 2014

JEC, 2014 only looked at developments until 2020, and focussed on the transport sector. This study included a much more detailed assessment of some of the barriers to future biofuel development that were also identified in the previous chapters: blend limits, vehicle compatibility and advanced biofuel production capacity. The study took into account the 2013 ILUC proposal by the Commission, as well as the outcome of EP and Council discussions, status end of 2013. It does include, therefore, a 7% cap on first generation biofuels in 2020, and voluntary Member State sub-targets for advanced biofuels. JEC, 2014 assessed different fuel demand scenarios in the period until 2020, based on different regulatory sets of provision (including the introduction of two higher biofuel blend grades: E20, and B10 in captive HD fleets) and a range of other assumptions related to the vehicle fleet. Costs and investments were not assessed. The main conclusions from that study are the following:

- None of the scenarios, tested against the legislative concepts discussed at the time, would achieve the RED and FQD targets
- The introduction of an accounting cap on conventional biofuels towards achieving the RED target will diminish the potential impact of higher biofuel blends. It will also affect the use of drop-in fuels from such sources to blend beyond the current (diesel) grade.
- Switching to low-ILUC risk feedstocks has the potential to have a major impact on achieving the FQD and RED targets but is expected to be limited by feedstock availability.

In line with the findings of this study, the study stresses that both the supply of advanced biofuels and vehicle compatibility are barriers to increasing biofuel demand under the new ILUC regulation.

In the **Autofuel roadmap** developed by E4Tech (E4tech, 2013), the energy share of biofuels in road transport is foreseen to be between 5.8 and 6.3% in 2020 and 10.6-11.8% by 2030, as shown in Table 1.16. Their forecast for the growth of the share of biofuels is also quite conservative, in line with the reports above and for the same reasons: it takes into account the time needed for the shift to advance biofuels as well as limitations due to blending limits and vehicle compatibility. Regarding high blends, it assumes that the FAME limit of B7 is not increased (because of the engineering challenge associated with making engines that use biodiesel blends higher than B7 compatible with Euro-VI air quality requirements, and due to the expected tightness in the sustainable vegetable oils market). The ethanol limit in petrol is increased, however, by introducing E20 in 2025, and E10 is assumed to be rolled-out across the EU by 2020. These findings are based on policies in place in 2013, i.e. the GHG thresholds outlined in the RED, the ILUC proposal and decision were not taken into account Costs were not assessed. (E4Tech, 2013)

Table 1.16 Energy share of biofuels in transport in 2020 and 2030

	2020	2030
Road transport	5.8-6.3%	10.6%-11.8%
All transport (incl. non-road transport)	6.7%-7%	12-15%
Biofuels from waste and residues		diesel: 9-21% petrol: 16-21%

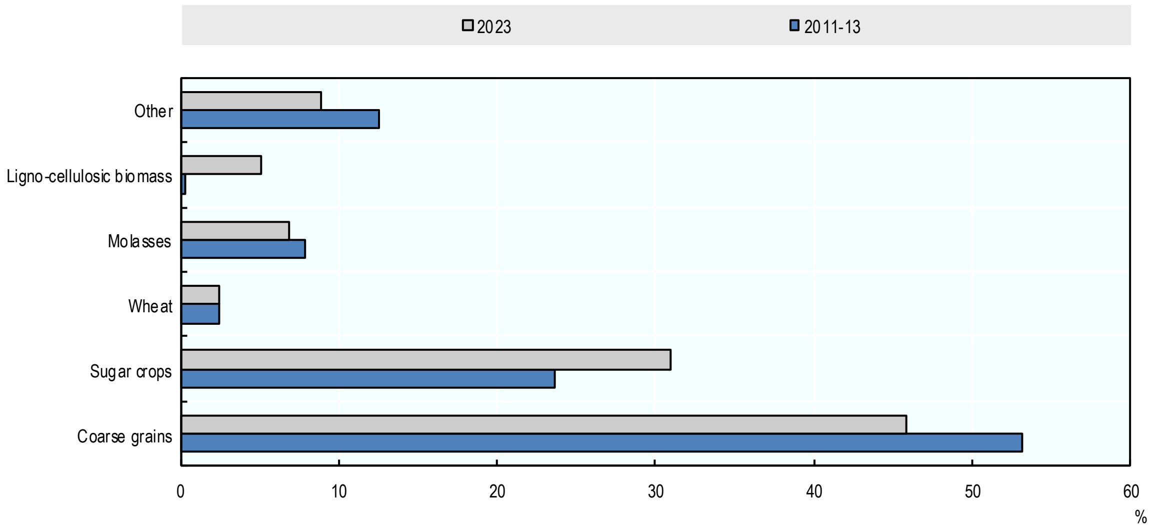
Source: E4Tech, 2013

The OECD/FAO and EC regularly publish reports and detailed outlooks for agricultural markets and forestry, which also address production and consumption of biofuels in the EU. These outlooks are limited to the period until 2023 or 2024, and give a diverse picture:

The **2014 – 2023 OECD FAO Agricultural Outlook** (OECD/FAO, 2014) predicts a steady and significant increase of 50% in domestic production, imports and consumption up to 2020, after which all three remain at the 2020 levels. This Outlook takes into account global policy developments regarding biofuel supply, demand and global trade. It does not take into account the ILUC proposal and decision but rather assumes that the current biofuel policies in the Member States are continued.

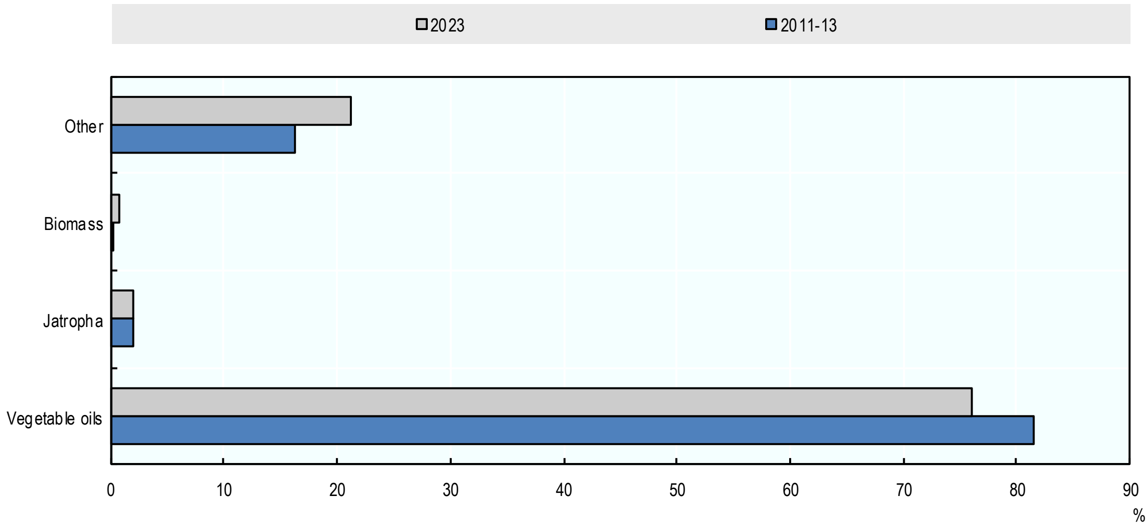
- Biodiesel demand will increase until 2020, and remain at a constant level in beyond 2020. Production of second generation bioethanol will remain very limited. Imports will be necessary to meet the RED target.
- Second generation biodiesel production is not assumed to take off during the outlook period 2014-2023. Ligno-cellulosic biomass based ethanol is expected to grow towards the end of the projection period, it is projected to account for 5% of the world ethanol production. The OECD/FAO expect global feedstock use for biofuel production to develop as shown in the figures below. The Outlook does not provide specific data for feedstocks for EU biofuel production.

Figure 1.37 Share of feedstocks used for bioethanol production



Source: OECD/FAO, 2014

Figure 1.38 Share of feedstocks used for biodiesel production



Source: OECD/FAO, 2014

The **Prospects for EU agricultural markets and income 2014-2024** (EC, 2014f) also forecasts developments in the biofuel market. It assumes that progress towards the 10% RED target is progressing, but that by 2020, biofuels only have a share of 7% of liquid transport fuels – due to the slow increases of biofuel demand in recent years and absence of strong policy incentives. The main conclusions for the developments until 2024 are the following

- Production of biodiesel will grow slightly, but growth is only related to increased utilization of waste oils. Utilization of primary vegetable oils will remain at current level;
- 1st generation bio-ethanol production in the EU will increase slightly with 10% - 20% and will be based increasingly on cereals while utilization of sugar beets (and molasses) will decline.
- There will hardly be any 2nd generation biodiesel (i.e. biodiesel from ligno-cellullosic and woody feedstock) and only limited volumes of 2nd generation bio-ethanol on the market in 2024.
- Imports of bio-ethanol are expected to double from 0.5 to 1.0 Mtoe, while imports of biodiesel are expected to decline from 1.0 Mtoe to 0.5 Mtoe.
- Total share in transportation fuels will amount to approximately 7% (energy content) in 2018 and will next remain constant up to 2024. By 2020, food-based biofuels will have a share of 5%. Contribution of biodiesel from waste oils will amount to 2.9 Mtoe and a share of 1.1% (counting as 2.2%).

Despite their differences, the outlooks give a relatively consistent picture of a future with consolidation of the first generation biofuel production at best, while any incentives for advanced biofuel demand take time to result in significant increases of these biofuels on the market. Overall biofuel shares are likely to remain limited to 10-12% (energy content) in 2030. Outlooks that analysed the potential implications of the FQD blend limits for FAME and ethanol all recognised these as a barrier to meeting the 2020 target, and to further increases of biofuel sales. Whether these developments are sufficient to meet the longer term 2050 target of 60% GHG reduction in transport (EC, 2011) is unknown, and requires further analysis.

In any case, 2030 biofuel demand will strongly depend on the 2030 climate and energy policies, the sustainability criteria and ILUC policies, but it will also be affected by global biofuel policies, agricultural demand, technology developments and oil price. So far, no comprehensive study has been carried out to predict biofuel demand and supply in the EU until 2030 in any detail. It is recommended to assess these issues further now that the ILUC proposal has been decided on. This can provide valuable input to 2030 policies development, both on EU and on Member State level.

1.7.3 Three scenarios for the time period until 2030

To do the uncertainties justice, four scenarios for the period until 2030 are developed. These aim to 'cover the playing field': they are not meant to predict the future, but explore what might be possible, given the current technical constraints, opportunities and ambitions, and policy developments. All four are considered to be feasible, albeit three of the four require significant policy efforts and investments, starting in the coming years.

These scenarios will be used as a basis for the analysis of Tasks 2, 4 and 5 of this project.

The Base case scenario assumes that the energy content of biodiesel (FAME/HVO) and biopetrol in 2013 (i.e., 5.2% and 3.4%, respectively), will not change through 2030.

The remaining scenarios have a number of assumptions and methodological issues in common, all based on the findings in this report:

- They all take the current blending limits and current situation regarding vehicle fleet and biofuel market as a starting point, as well as the RED and FQD targets for 2020 and the recent ILUC decision. As the 2030 energy and climate package does not specify the share of biofuels in 2030, this is varied in the scenarios.
- They all assume that the cap on biofuels from food crops in the EU's renewable energy policy will either remain at the 7% level after 2020, or will be lowered over time. It is furthermore assumed that Member States will also adopt this cap for biofuels policy measures that go beyond any EU targets, i.e. the share of food-based biofuels in the EU will not exceed 7% of road transport fuels. Growth beyond this cap will then have to come from biofuels from waste and residues or energy crops, as included in Annex IX of the ILUC Directive. A further increase of biofuel demand will thus be limited by the availability of the feedstocks listed in Part B of this Annex, and by production capacity for the advanced biofuels that are produced from feedstocks listed in Part A (see the analysis in Section 1.6).
- To meet the RED target in 2020, all Member States have switched to B7 and E10 as the main road transport fuels, and fuel suppliers make full use of these limits.
- By 2020, it is assumed that the whole vehicle fleet throughout the EU can drive on B7 and E10, and lower blends can be removed from the market. There will still be a small share of older petrol vehicles that have to drive on E5 (See Chapter 2), but this is assumed to be resolved by either government incentives (scrappage schemes), retrofit or by a limited number of filling stations, typically located in regions where there are relatively high shares of these vehicles. Compared to overall fuel consumption, these volumes will be negligible.
- In all three scenarios, B7 and E10 will be protection grade fuels between 2020 and 2030. These remain available in all Member States as part of the vehicle fleet are not compatible with higher blends.
- The potential share of fungible (drop-in) biofuels will be limited by production capacities and cost.
- The scenarios assume that EU-wide transport energy demand develops in line with the forecast of PRIMES reference scenario (2012). This forecast estimates that in 2030, EU road transport (blended) diesel demand is 185 Mtoe, and (blended) petrol demand amounts to 105 Mtoe.

The key parameters that are varied in these scenarios are:

- The blending limits for diesel and petrol
- Assumptions regarding vehicle compatibility for higher blends
- Introduction of higher blends in the Member States

- The actual share of biofuels in diesel and petrol (distinguishing between FAME, ethanol and fungible (drop-in) fuels)

In the next paragraphs, the key assumptions and rationale of the three scenarios will be described (Section 1.7.3.1), followed by an assessment of the biofuel consumption that is to be expected in each of these scenarios, in 2020 and 2030 (Section 1.7.3.2): how much biofuels will be consumed in each scenario, and are these volumes feasible in the light of the findings of Section 1.6, i.e. given the biofuel production capacities and the expected shift from food-based to advanced biofuels? Section 1.7.4 then addresses what would be necessary to achieve the scenarios.

1.7.3.1 The key assumptions of the scenarios

An overview of what assumptions were used for these parameters in each of the three scenarios is provided in Table 1.17.

The rationale behind these assumptions, and the key characteristics of these scenarios are described in the following. Note that these scenarios are designed based on the key findings and conclusions of the assessments of Chapter 1 and 2. They are not the result of a quantitative modelling exercise of biofuel developments of a detailed assessment of cost.

The **Base Case Scenario** assumes that current (2013) energy content of biodiesel (FAME/HVO) and ethanol is 5.2% and 3.4%, respectively. The Base case scenario reflects the assumption that due to policy uncertainty there is no change in the biofuel levels (i.e., % energy content) from current 2013 levels. Consequently, 2020 and 2030 will also have biodiesel (FAME/HVO) and ethanol consumption at 5.2% and 3.4%, energy content, respectively.

Scenario A: the FQD blending limits remain at **B7** and **E10** and MS will ensure an actual supply up to these limits. This implies introduction of E10 in all Member States, and increasing actual blend levels up to the maximum allowed by these limits. The scenario would include the result of the ILUC decision and a certain further shift from first generation to advanced biofuels after 2020, while the ILUC directive de facto limits the range of feedstocks and production processes that will be used for biofuels that are consumed in the EU.

This scenario is generally in line with the outlooks for post-2020 biofuel developments provided in Section 1.7.2. It is also in line with the outlook for the availability of advanced biofuels that followed from Section 1.4 - limited production capacity, the need for further R&D and uncertainties regarding biomass availability are all barriers to the growth of advanced biofuel production and consumption in the EU, with the current slow uptake of E10 throughout the EU (indicating little need for higher blends at the moment) and the relatively limited biofuel share in many EU Member States (see Section 1.3.3 for details).

As this scenario assumes that the levels of FAME and ethanol will be the maximum allowed by the blending limits, in all Member States, between 2020 and 2030, their shares will then remain constant in this time period, at 6.4% and 6.8% respectively, based on energy content. These could be all from food crops if the 7% cap is held constant, but it seems reasonable to assume that the Member States policies will promote production from waste and residues (e.g. by continuing the double counting after 2020 and/or by setting sub-targets for advanced biofuels) which will result in an increasing share of biofuels from waste and residues in these volumes.

In this scenario, the share of fungible fuels (HVO and possibly new options that are currently under development) is expected to increase gradually over time: as the blending limits are not raised, fungible fuels will be an attractive option for Member States that wish to have ambitious biofuel targets to meet their post-2020 targets. The rate of increase will be limited, for the same reasons that were mentioned above. In is assumed that fungible biofuels will only be diesel replacers (as is HVO), and their share in total diesel sales will increase from 5% in 2020 to 10% in 2030.

This scenario would imply that a decision about blending limits is postponed to a time when the key barriers to biofuel growth are removed and there is more certainty about the future biofuel demand and supply.

Scenario B assumes further growth of FAME and ethanol demand in the EU beyond 2020, and accommodates that with an introduction of **B10** and **E20** from 2020 onwards. B7 and E10 will remain available throughout the EU as protection grades, at least until 2030.[60] The new standards will be introduced in the FQD before 2020, and vehicle manufacturers will be required to ensure that all diesel and petrol new vehicles that are sold from 2020 onwards are fully compatible to B10 and E20 respectively. They should also be tolerant to B7 and E10. Member States and fuel suppliers will be free to bring these higher blends on the market. As Member States ambitions are likely to vary after 2020 (as they do now, see Section 1.3.3) it is likely that the introduction of higher blends will also vary between Member States.

The need to retain a protection grade E5 fuel beyond 2020 has been stressed by some fuel system suppliers. The presence of E5 fuel however, will limit the transition to E10 and partially defeat the intent of this scenario. One option is for EU governments to offer a free upgrade of the fuel system to make the vehicles E10 tolerant, or pay for accelerated scrappage of the affected vehicles if the cost of the upgrade of an old vehicle exceeds its value. For example if the vehicle population of the seriously affected vehicles is about 100,000 vehicles (corresponding to the remaining 2000 to 2005 model year vehicles that Bosch suggests has serious issues) in 2020, than payments can be made to those select vehicles to have their owners scrap them.

This scenario acknowledges that blending limits can be a barrier to the further growth of biofuels, and aims to remove this barrier in such a way that takes into account preferences expressed by fuel suppliers (see Section 1.4.4) and conclusions drawn from Chapter 2. As discussed earlier in Section 1.4, on the one hand, introducing the higher blends will incur additional fuel distribution and infrastructure cost, and may result in market distortions; quality issues and aging of B10 require further analysis (and possibly measures to resolve), and, depending on the fuel standard, E20 may require adaptation to refineries and fuel distribution. On the other hand, E20 allows for fuel efficiency gains of vehicles (see Chapter 2, Section 2.3.3.3), and any technical issues related to the fuel supply chain can be resolved at relatively limited cost. B10 and E20 are deemed technically feasible, both by the fuel suppliers and the vehicle manufacturers. Furthermore, introducing higher blends in EU and Member State regulation enables Member States to increase their biofuel obligations and targets, whilst leaving it up to the fuel suppliers whether they want to achieve these targets with FAME, ethanol or fungible biofuels.

The assumed continuation of the 7% cap on biofuels from food crops and limited availability of advanced biofuels also limits biofuel growth in this scenario, but to a lesser extent: this scenario assumes a faster development of advanced biofuel production capacity than in scenario A.

This scenario assumes that the actual levels of FAME in B10 will gradually increase from 7 vol% in 2020 to 10 vol% in 2030, which equals 6.4% to 9.1% energy content. This is likely to be a mix of FAME from food crops and from used cooking oil and animal fat mainly. The actual levels of ethanol in E20 will increase from 10 vol% to 20 vol% between 2020 and 2030, i.e. from 6.8% to 13.2% based on energy content. This will be a mix of ethanol from food crops and from ligno-cellolusic feedstock, where it is assumed that the share of the latter will increase over time as R&D is progressing and production capacities for advanced bioethanol increase. The protection grade fuels are assumed to contain the maximum levels of FAME and ethanol that are allowed, in the timeframe 2020 and 2030.

In this scenario, the share of fungible fuels (HVO and possibly new options that are currently under development) is expected to increase gradually over time, albeit at a somewhat slower

[60] As discussed in Section 2.3.3.3, it is assumed that a protection grade E5 fuel beyond 2020 will not be provided as it will limit the transition to E10 and partially defeat the intent of this scenario. However, by not offering an E5 protection grade, it is assumed that there will be either government incentives (scrappage schemes), or retrofit.

rate than in scenario A as there is less need for these type of biofuels in road transport fuels. The share of fungible diesel is assumed to increase from 5% in 2020 to 8% in 2030. No fungible biopetrol is expected in this scenario, as the development of advanced ethanol is already progressing, and the blending limit of E20 is assumed to be sufficient to accommodate demand growth between 2020 and 2030.

Scenario C assumes an even stronger growth of FAME and ethanol demand in the longer term (2025-2030) than scenario B. Limitations due to biofuel availability also apply in this scenario, but these are assumed to be resolved after 2025. It assumes that **B10** and **E25** are introduced from 2020 onwards, B7 and E10 will remain available throughout the EU as protection grades, at least until 2030.[61] In addition, a standard for **B30** will be introduced, to be used in captive fleets only. Based on the discussion above in Section 1.5.2.3, it is assumed that captive fleets are responsible for about 25% of the EU's diesel sales.

As in scenario B, the new standards would be introduced in the FQD before 2020, and vehicle manufacturers would be required to ensure that all diesel and petrol new vehicles that are sold from 2020 onwards are compatible with B10 and E25 respectively. They should also be tolerant to B7 and E10. Member States and fuel suppliers will be free to bring these higher blends on the market. As Member States ambitions are likely to vary after 2020, it is to be expected that the introduction of higher blends will also vary between Member States.

Compared to scenario B, this scenario allows for a more rapid growth of FAME and ethanol shares in Member States. However, cost for fuel suppliers will be higher than in scenario B, as more severe investments are required to resolve technical issues (see Section 1.4.5). Furthermore, the production capacity of advanced biofuels is expected to be a limiting factor to biofuel growth,

Regarding actual biofuel consumption, this scenario assumes that the actual levels of FAME in B10 diesel sold at public filling stations (i.e. to non-captive fleets) will gradually increase from 7 vol% in 2020 to 10 vol% in 2030, which equals 6.4% to 9.1% energy content. The share of FAME in B30 diesel sold to captive fleets will increase even more rapidly, from 7 vol% in 2020 to 30 vol% in 2030 (27.4 % energy content). With a 25% market share of B30 and the remaining diesel B10, this results in an average share of FAME of 11.0%.

The actual levels of ethanol in E25 will increase from 10 vol% to 25 vol% between 2020 and 2030, i.e. from 6.8% to 16.5% based on energy content. This will be a mix of ethanol from food crops and from ligno-cellolusic feedstock, where it is assumed that the share of the latter will increase over time as R&D is progressing and production capacities for advanced bioethanol are increasing.

As in scenario A and B, the protection grade fuels B7 and E10 are assumed to contain the maximum levels of FAME and ethanol that are allowed, in the timeframe 2020 and 2030.

In this scenario, the share of fungible fuels (HVO and possibly new options that are currently under development) is expected to increase gradually over time, at a rate comparable to than in scenario B: the share of fungible fuels is assumed to increase from 5% in 2020 to 8% in 2030. As in scenarios A and B, no fungible biopetrol is expected in this scenario, as the development of advanced ethanol is already progressing, and the blending limit of E25 is assumed to be sufficient to accommodate demand growth between 2020 and 2030.

[61] Although there maybe vehicles that are not E10 compatible, it is assumed that these will be addressed by either government incentives (scrappage schemes), or retrofit, and not an E5 protection grade.

Table 1.17 Overview of the three scenarios developed for this project

	Scenario: Base Case	Scenario A: B7 and E10	Scenario B: increase limits to B10 and E20	Scenario C: increase limits to B10 and E25, B30 for captive fleets
Blending limit for diesel	B7	B7 remains in place until 2030	The limit will be raised to B10 from 2020 onwards. B7 has to remain on the market as protection grade.	The limit will be raised to B10 from 2020 onwards. B7 has to remain on the market as protection grade.
Blending limit for petrol	E10	E10 remains in place until 2030.	The limit will be raised to E20 from 2020 onwards. E10 has to remain on the market as protection grade.	The limit will be raised to E25 from 2020 onwards. E10 has to remain on the market as protection grade.
Blending limit for captive fleets	None	none	none	A B30 standard will be introduced from 2020 onwards, to be used in captive fleets only
Diesel vehicle compatibility	No change	whole fleet is B7 compatible from 2020 onwards	Whole fleet is B7 compatible from 2020 onwards. From 2016 onwards, B10 compatible vehicles will come on the market. The share of B10 compatible vehicles in the new vehicle sales will then increase gradually from 0% in 2015 to 100% in 2020	Whole fleet is B7 compatible from 2020 onwards. From 2016 onwards, B10 and B30 compatible vehicles will come on the market. The share of B10 compatible vehicles in the new vehicle sales for non-captive fleets will increase gradually from 0% in 2015 to 100% in 2020. The share of B30 compatible vehicles in the new vehicle sales for captive fleets will increase gradually from 0% in 2015 to 100% in 2020. From 2020 onwards, all new diesel vehicles will be either B10 or B30 compatible
Petrol vehicle compatibility	No change	whole fleet is E10 compatible from 2020 onwards	Whole fleet is E10 compatible from 2020 onwards. From 2016 onwards, E20 compatible vehicles will come on the market. The share of E20 compatible vehicles in the new vehicle sales will then increase gradually from 0% in 2015 to 100% in 2020	Whole fleet is E10 compatible from 2020 onwards. From 2016 onwards, E25 compatible vehicles will come on the market. The share of E25 compatible vehicles in the new vehicle sales will then increase gradually from 0% in 2015 to 100% in 2020

	Scenario: Base Case	Scenario A: B7 and E10	Scenario B: increase limits to B10 and E20	Scenario C: increase limits to B10 and E25, B30 for captive fleets
Introduction of the higher blends in the Member States	none	E10 will become the standard petrol grade in all Member States	Member States will start introducing B10 and E20 from 2020 onwards. The number of countries with B10 and E20 will gradually increase of time, until all Member States have these blends on their market in 2030.	Member States will start introducing B10 and E25 from 2020 onwards, the same holds for B30 in captive fleets. The number of countries with B10, B30 and E25 will gradually increase of time, until all Member States have these blends on their market in 2030.
Share of FAME in diesel	4.9% (energy content) from 2013 onwards	7 vol% from 2020 onwards (6.4 % energy content)	B10: 7 vol% in 2020 (6.4 % energy content), gradually increasing to 10 vol% in 2030 (9.1% energy) B7: protection grade, with 7 vol% throughout 2020-2030	All grades: 7 vol% in 2020 (6.4 % energy content). B10: In non-captive fleets, gradually increasing to 10 vol% in 2030 (9.1% energy). B30: In captive fleets, gradually increasing to 30 vol% in 2030 (27.4 % energy content)
Share of ethanol in petrol	3.4% (energy content) from 2013 onwards	10 vol% from 2020 onwards (6.8 % energy content)	E20: 10 vol% in 2020 (6.8 % energy content), gradually increasing to 20 vol% in 2030 (13.2% energy) E10: protection grade, with 10 vol% throughout 2020-2030	E25: 10 vol% in 2020 (6.8 % energy content), gradually increasing to 25 vol% in 2030 (16.5% energy) E10: protection grade, with 10 vol% throughout 2020-2030
Share of fungible biofuels	0.26% (energy content) from 2013 onwards	Increase gradually, from 5% of all diesel sales in 2020 to 10% in 2030 (energy content). Fungible biofuels in diesel only.	Increase gradually, from 5% of all diesel sales in 2020 to 8% in 2030 (energy content). Fungible biofuels in diesel only.	Increase gradually, from 5% of all diesel sales in 2020 to 8% in 2030 (energy content). Fungible biofuels in diesel only.

1.7.3.2 Biofuel consumption in the scenarios

The resulting EU-wide biofuel demand in these scenarios, for each type of biofuel, is given in Table 1.18. For scenarios A, B and C, the biofuel consumption at the starting point of 2020 is the same, as the market introduction of higher blends does not start until 2020. Scenarios A, B and C assume that B7 and E10 are fully used throughout the EU, and biofuel levels have increased to the maximum allowed by 2020, because of the RED and FQD targets in 2020.

Biofuel consumption in 2030 does, however, differ between scenarios A, B and C.

- **Scenario A** results in a small increase of FAME consumption between 2020 and 2030 and ethanol consumption reduced by about 25% (due to a predicted reduction of petrol demand in the EU). However, consumption of fungible fuels more than double between 2020 and 2030: in this scenario, demand for these biofuels increases due to the relatively low blending limits.

- **Scenario B** assumes that FAME and ethanol demand grows significantly between 2020 and 2030, which is enabled by the higher blending limits (B10 and E20) and the increasing share of compatible vehicles in the vehicle fleet. Fungible fuels still play an important role in the EU biofuel mix, but consumption increases at a somewhat lower rate than in scenario A as FAME and ethanol consumption can also grow.
- **Scenario C** is even more ambitious: biofuel demand increases even more than in scenario B. The higher blending limit for ethanol allows EU-wide ethanol consumption to increase to 16.4%, the introduction of B30 in captive fleets allows FAME consumption to increase to 11.0%, energy content.

For comparison, the 2013 actual consumption data that were shown in Section 1.4.2.2 are included in the table[62].

Clearly, consumption of all types of biofuels would be expected to increase significantly in scenarios B and C, compared to the current levels. These scenarios would also result in biofuel shares higher than the (assumed) 7% cap on food-based biofuels in 2030, they would therefore require significant volumes of biofuels from non-food feedstock as well. Comparing these data with the findings in Chapter 1.6, it can be concluded that these volumes would be feasible, if

- the 7% cap remains in place, and
- bioethanol and fungible biofuels are produced mainly from non-food feedstock in 2030.

As discussed in Section 1.6.3, the latter still requires significant R&D efforts, as well as (eventually) significant investments in production capacity for these advanced biofuels. As efforts are ongoing and technologies seem to be progressing well, expansion of the production capacities to the levels required in scenarios B and C can be considered technically feasible, but nevertheless uncertain. In any case, effective policies, both on EU and Member State level, would be a prerequisite to achieving the ambitious growth paths needed for these scenarios.

A potential barrier to meeting scenario B and, to an even larger extent, scenario C, is the limited potential for FAME production from non-food feedstock. The 7% cap allows about 18,500 ktoe of first-generation biofuels to be consumed. As the maximum EU potential of FAME from used cooking oil and animal fats was estimated to be only 3,500 to 6,200 ktoe, a large share of the FAME would have to be produced from food crops. FAME production would then use a relatively large share of the first-generation biofuels allowed under the cap.

Table 1.18 Biofuel volumes sold in the EU in each of the three scenarios, in 2020 and 2030 (in ktoe and in % energy content, of total diesel or petrol blend sales) (Source actual consumption: Eurostat)

		Actual consumption	Base case scenario		Scenario A, B and C	Scenario A	Scenario B	Scenario C
		2013	2020	2030	2020	2030	2030	2030
ktoe	FAME	10,293 (FAME and fungible biodiesel)	10,817	10,987	13,620	13,836	18,713	23,476
	Ethanol	2,717	2,202	1,667	4,390	3,325	6,402	8,027
	Fungible biodiesel		569	578	10,551	21,437	17,150	17,150
%	FAME	5.2% (FAME and fungible biodiesel)	5.2% (FAME and fungible biodiesel)	5.2% (FAME and fungible biodiesel)	6.5%	6.5%	8.7%	11.0%

[62] Where it should be noted that no separate statistics for HVO and biodiesel consumption are available

	Ethanol	3.4%	3.4%	3.4%	6.8%	6.8%	13.1%	16.4%
	Fungible biodiesel				5.0%	10.0%	8.0%	8.0%

1.7.4 What would be necessary to achieve these scenarios?

In **Scenario A** no additional EU-level policy measures are required to achieve this scenario at this point in time. Member States take the actions necessary to implement the ILUC decision and meet the RED and FQD targets in 2020. In particular, all Member States would have to move to B7 and E10 before 2020, and increase biofuel obligations and/or financial incentives in order to increase biofuel volumes fully exploiting these allowed blending levels. Member State policies for the post-2020 period would be a continuation of these policies. Increasing the level of fungible fuels such as HVO can then be the result of increasing the biofuel obligations and targets in Member States levels that can be accommodated by the blending limits.

As was concluded in Chapter 2, Section 2.5.2, expansion of B7 blend use to all EU Member States does not require changes to vehicle technology and can be implemented immediately. Chapter 2, Section 2.5.2 furthermore concludes that roll-out of E10 does not create any technical issues in the EU.

As noted above, this scenario assumes a relatively limited contribution of biofuels to the overall climate and renewable energy targets and ambitions for 2030, in the EU as a whole and in individual Member States. This means that other sectors will need to contribute more to these goals, or alternative renewable energy options in transport, notably, electricity or hydrogen need to be increased more than in scenarios B and C.

It is furthermore recommended to revisit the FQD blending limits on a regular basis to ensure that these limits do not create barriers to the further development of biofuels.

Scenario B and C, require a lot more effort including at EU level: the specifications for the higher blends need to be decided on, vehicle manufacturers need to develop fully compatible vehicles as described in Chapter 2, the technical and non-technical barriers described in Sections 1.4.5 and 1.4.6 need to be removed and the necessary R&D and investments into advanced biofuels must be realised. EU and Member State policies and actions are crucial to provide the right incentives to ensure that all stakeholders involved take the necessary actions.

Scenario C is more ambitious than scenario B as it assumes an even faster growth of (advanced) biofuel volumes on the market, and B30 and E25 are blends that require more effort to introduce than B10 and E20 (as discussed in Chapter 2 and Section 1.4.5 above). Nevertheless, both scenarios require the same type of actions.

The following list, derived from the various assessments and findings throughout this report, provides an overview of what would be necessary to achieve these higher blend scenarios in addition to and as prerequisite for a legislative change of the fuel specifications under FQD:.

- **Development of fuel standards for B10 and E20 (scenario B) or for B10, E25 and B30 (scenario C).** This requires
  - A detailed assessment of potential issues with quality control and aging of FAME, to ensure that technical issues with higher blends of FAME are prevented.
  - An assessment of options to reduce the need for a different BOB (relevant for higher ethanol blends, see Section 1.4.5.1).
  - A decision on a possible range of biofuel blends in the standards. A smaller range (for example, E20 has to contain between 15 and 20 vol% ethanol, rather than between 0 and 20%) will reduce or remove overlap between the higher blends and the protection grade fuels, which allows governments to provide specific incentives for these higher blend. A smaller range is also desirable from vehicle manufacturer point of view, as these stakeholders have stated (in interviews for this study). However, fuel suppliers prefer a broader range, as they can use the resulting flexibility to optimise operations.

- **Development of fully compatible and optimised vehicles**
  - Once the standards are defined, a timeline for the introduction of compatible vehicles can be decided on (for example stating that all new petrol vehicles must be E20/E25 compatible by 1.1.2020). The vehicle manufacturers can then develop these vehicles and optimise the engines, to meet air quality regulations with these new fuels and, in case of new ethanol standards, to make use of any fuel efficiency benefits that the higher ethanol blends may offer (Chapter 2, Section 2.3.3.2).
- **Availability of blends at refuelling stations**
  - As in scenario A, E10 will become the base grade in an increasing number of Member States, by 2020 all Member States will have switched from E5 to E10. Likewise, all Member States will need to move to B7 as base grade for diesel by 2020.
  - In countries where E20/E25 enters the market from 2020 onwards, E10 will replace E5 as a protection fuel. As discussed in Chapter 2, Section 2.3.3.4, there will still be a share of the vehicle fleet (possibly between 1.3 and 6.8%) of older petrol vehicles that have to drive on E5 by 2020. This needs to be resolved by retrofitting, government incentives (scrappage schemes) or by a limited number of E5 filling stations, typically located in regions where there are relatively high shares of these vehicles. Compared to overall fuel consumption, these volumes will be negligible, and reduce further over time, between 2020 and 2030.
  - As recommended in (Chapter 2, Section 2.3.2), auto manufacturers should identify the exact vehicle models that are incompatible with E10, and develop (retrofit) solutions to resolve the issues that may arise when E5 is discontinued.
  - Member States and fuel suppliers may introduce the higher blends once the FQD has been adapted. It is assumed in the scenarios that this introduction will take place gradually over time, by 2020 all Member States will have these higher blends on their market.
  - It is recommended to analyse and assess the potential market distortion that the introduction of a higher blend may have in the various Member States, in order to address and possibly alleviate any issues that this may cause (see Section 1.4.4).
- **Availability of the biofuels**
  - Production and consumption of biofuels from food-based feedstock can still grow in the coming years, until the 7% cap on these types of biofuels is reached (assuming that the cap is continued after 2020, at EU and/or MS level, see above). Production capacity for FAME seems to be sufficient, potential shortages for ethanol may be resolved via imports (Section 1.6.2).
  - The development of advanced biofuels is a crucial precondition to ensure future growth of biofuel consumption within the boundary conditions of the sustainability criteria for biofuels and the ambition expressed by the Commission to move away from first generation biofuels (EC, 2014a) (see Chapter 1.6 and Section 1.7.2). This requires further R&D into various types of biofuels, and then investments to develop and expand commercial-scale production plants. The latter can be supported by targeted Member State policies, for example by sub-targets for advanced biofuels.
  - R&D into advanced fungible biofuels (i.e. from feedstocks included in Part A of Annex IX of the ILUC Directive) should also be supported, as these may have significant longer term advantages over the non-fungible advanced biofuels: they do not require additional fuel grades or blends to be introduced.
  - Biomass availability for these advanced biofuels can also be a barrier to their future development and growth. It is recommended to further assess the potential availability, including the potential competition with other users and the cost of these sources.
  - Fuel suppliers need to be incentivised to increase the share of biofuels on the market. The biofuel obligations, implemented by 25 of the 28 Member States (status 2014, see Section 1.3.3.1) have proven to be an effective means to achieve this.
- **Harmonisation of the EU fuels market**

  - Introducing new blends may further diversify and possibly fragment the fuel market, as different countries make different choices regarding blends on their market, shares of advanced biofuels in their mix, etc. Even in the current situation, refineries and fuel suppliers may need to supply many different blends to their customers, depending on the national policies and regional circumstances (see Section 1.4.6.4). It is therefore recommended to assess the possible impacts of new blends on the EU market, and, if necessary, identify potential solutions to resolve negative impacts.

- **Cost of biofuels**
  - There is currently only limited evidence regarding cost of advanced biofuels, and therefore of the financial implications of increasing biofuel consumption with a cap on biofuels from food-based feedstock in place. It is recommended to further assess these costs, to ensure that future biofuel policies can be designed in a cost-effective way.
  - For the same reason, it is also recommended to assess cost of introducing the higher blends.

- **Acceptance of consumers**
  - Consumers that have bought a vehicles that is compatible with the high blends are crucial to the successful roll-out of the higher blends: they need to accept and trust these blends. This requires clear and adequate communication to the public, about the reasons for these high blends, and regarding vehicle compatibility.
  - Consumers also need to be incentivised to fill their vehicles with the high blend and not with the protection grade fuel. This can be either done by financial (government) incentives such as a CO_2-tax or differentiated excise duties (see Section 1.3.3.2 for examples) or by implementing a biofuel obligation that is set at a level that encourages fuel suppliers to implement price incentives themselves (see Section 1.3.4.1).

- **Monitoring and reporting**
  - It is also recommended to improve the statistical data gathering and monitoring in the EU, so that the statistics distinguish between biofuels from food-crops and biofuels from waste and residues (non-ILUC biofuels), as well as between the various types of biodiesels (e.g. FAME and HVO) and biopetrols. This enables closer monitoring of the developments, in particular of the shift from food-based biofuels to advanced (non-ILUC) biofuels.

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2 Implications for automotive technology

Abbreviations/acronyms

ACEA	European Vehicle Manufacturers Association
API	American Petroleum Institute
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
CO	Carbon Monoxide
CR	Compression ratio
DI	Direct injection
DISI	Direct injection spark ignition
DOC	Diesel Oxidation Catalysts
EGR	Exhaust gas recirculation
EPA	US Environmental Protection Agency
ESC	EU Steady State Cycle
ETBE	Ethyl tertiary-butyl ether
ETC	European Transient Cycle
FAME	Fatty Acid Methyl Esters
FE	Fuel Economy
FFV	Flex Fuel Vehicles
FQD	Fuel Quality Directive
FTP	US Federal Test Procedure
GHG	Greenhouse gas
GTL	Gas-to-Liquids
HCCI	Homogeneous charge compression ignition
HVO	Hydro-treated Vegetable Oils
MON	Motor Octane Number
NEDC	New European Driving Cycle
NMHC	Non-methane hydrocarbons
PM	Particulate Matter
PZEV	Partial Zero Emissions Vehicle
RON	Research Octane Number
RVP	Reid Vapour Pressure
SAE	Society of Automotive Engineers
SCR	Selective catalytic reduction
THC	Total hydrocarbon
UDC	Urban Driving Cycle
VVT	Variable valve timing
WLTC	World Light-duty Test Cycle

2.1 Summary

This chapter presents a review of the implications of different ethanol-petrol and bio-diesel blends for automotive technology, in terms of the tailpipe emissions, impact on energy efficiency, impact on engine and emissions after-treatment durability, and impact on future engine designs. The assessment has been based on literature review, and stakeholder consultation.

In the EU, petrol engines are used almost exclusively in personal use light duty vehicles and all commercial vehicles use diesel engines. Future improvements in petrol engine technology is expected to progress along two pathways. The approach favoured by European manufacturers relies upon increased turbocharger boost and engine downsizing to improve fuel economy. The second approach, favoured by Japanese manufacturers, will use very high compression ratios (13 to 15) in combination with Atkinson or Miller cycles. For diesel engines, future technology improvements are not expected to alter diesel fuel combustion requirements but engines will see further increases in turbocharger boost pressures and engines will be further downsized. Regardless of the approach to improve petrol and diesel engine technology in the future, the analysis indicates that there will be no change in the impact of biofuel blends relative to their impact on current engines.

2.1.1 Petrol engines

Based on the analysis, the following summarises the impacts of three possible options for the expansion of ethanol use in petrol vehicles:

Expansion of E10 option availability and use to all countries in the EU with E5 blend as the protection fuel maintained available. There are no technical issues related to this option, as most post-2003 vehicles are E10 tolerant. The use of E5 will produce some small positive benefits for emissions of regulated pollutants and air toxics (e.g., 5% lower carbon monoxide (CO) emissions; 5-10% lower particulate (PM) emissions) when compared to current engines using E0 fuel. No change in carbon dioxide (CO_2) emissions is expected; although nitrogen oxide emissions could be slightly higher.

Replacement of E5 as the protection fuel with E10 across the EU in 2020. There are technical issues related to this option, which could affect vehicles produced before 2003, which comprise between 1.3 to 6.8% of the 2020 EU light duty fleet. In these older vehicles, fuel leaks or fuel system corrosion could occur. This could be addressed by upgrading fuel system gaskets and elastomers for costs of <200 Euros, but there may be some vehicles requiring hardware changes. There is no public data on affected models and the EU must work with auto-manufacturers to identify affected vehicles, upgrade costs and affected populations in 2020. There are small positive benefits for emissions of regulated pollutants 10% lower CO, 10-20% lower PM) and air toxics (from lower benzene) associated with this approach; however, there could be small absolute increases aldehyde emissions.

Implementation of E20 for purpose designed cars starting in 2020. Manufacturers are favourably disposed towards E20, but only if the new E20 fuel is a splash blend fuel rated at 98 to 100 RON as a premium fuel that can be used by purpose designed cars starting in 2020. Although most post-2011 vehicles are E20 tolerant, the use of E20 fuel with the same octane rating as current E5 and E10 fuels (i.e., 95 RON) will produce a 6.5 to 7% increase in fuel consumption and, thus, offers no benefit to the consumer. In contrast, the high octane E20 strategy has the advantage of providing a 3% to 6.4% energy efficiency benefit potential for the auto-industry and provides value to the customer from the high octane rating of ethanol. (Volumetric fuel consumption would change by -2.5% to +1%).This high octane E20 fuel could slowly displace hydrocarbon based premium petrol (98+ RON) in the EU starting in 2020 as auto-manufacturers introduce more vehicle models capable of exploiting the octane advantage of E20 and eventually become the mainstream fuel by 2030.The fuel could result in positive benefits for regulated pollutants (20% lower CO, 20-30% lower PM, 1-7% lower CO_2) and toxic emissions (lower benzene). Unlike purpose built engines, which will likely see no change in aldehyde emissions compared to current engines using E0 fuel; the use of E20 in current “E20 tolerant” vehicles could result in higher aldehyde emissions. It is assumed that the costs of this approach will be near zero for naturally aspirated engines and under Euro 50 for turbocharged engines if the changes are incorporated in the design stage. This approach will affect future manufacturer product plans as engines will need to be modified to take advantage of the high octane of E20 splash blends. A lead time for 4 to 5 years will be required for manufacturers to design such engines.

2.1.2 Diesel engines

The analysis indicates the following possible implications from the expansion of biodiesel use in diesel vehicles:

Expansion of B7 blend use with FAME to 7% limit to all countries in the EU requires no changes to vehicle technology and can be implemented immediately. This approach could lead to decreases in PM, hydrocarbon (HC) and CO emissions from most vehicles, although the PM decreases from trap equipped vehicles may be undetectable due to measurement limitations. NOx emissions could increase by zero to 1%.

Replacement of B7 with B10 FAME blends across the EU will have similar but slightly higher regulated pollutant emissions impacts as B7. However, vehicles with duty cycles having short trip lengths and many cold starts daily could experience significant oil dilution issues. The technical solution to this problem is improved monitoring of engine oil and more frequent oil change intervals. This option will not impact manufacturer product plans or new technology but could result in the oil change interval being reduced from current levels of 25,000 to 30,000 km to less than 20,000 km. In addition, the use of B10 during winter months may need to be prohibited.

Expansion of B30 FAME bio-diesel to captive fleets. This approach would only be applicable if used in “captive” fleets across the EU, where owners of large fleets could implement an oil dilution monitoring program and ensure careful oversight of fuel quality. Due to significant concerns related to oil dilution and cold storage problems, B30 FAME blends may not be suitable for consumer use. It is unclear if any upgrades of the fuel system are needed for modern (post-2010) vehicles to use B30, but vehicle hardware changes, if any, are expected to be minor. With the use of B30, in modern vehicles certified to Euro 5 and 6 standards, HC and CO emission declines of 15% are likely, when compared to the use of B0 diesel fuel; however, NO_x and PM changes, if any, may be too small to be reliably detected. Fuel consumption penalties are small, in the range of 0 to 2% for B30 in light duty vehicles. For heavy-duty vehicles data suggests that for each 10% increase in the bio-diesel content, there will likely be a 1% reduction in fuel efficiency with about the same 1% degradation in available torque.

The use of HVO+FAME blends that could utilize 7% FAME-diesel with any level of HVO up to 26% is possible without any negative performance effects for all diesel vehicles. In general, HVO use with diesel or B7 FAME-diesel blends will result in emission declines for all regulated emissions, but volumetric fuel consumption could increase by about 0.5% for every 10% increase in HVO content in the blend. This option will likely have no effect on auto-manufacturers, but fleet test data to confirm this is not yet available (but could be available later in 2015).

There are concerns about the oxidation stability of FAME when used in plug-in vehicles where the tank fuel can be used over several months if the vehicle is operated primarily in electric mode. Not much is known about this issue as plug-in diesels have entered the market only in 2014, but is an area of manufacturer concern for the future.

2.2 Introduction

The following assesses the implications of different bio-diesel blends and different ethanol-petrol blends for automotive technology, in terms of the tailpipe emissions, impact on energy efficiency, impact on engine and emissions after-treatment durability, and impact on future engine designs. The range of blends examined was based on the current policy framework (FQD) and the recently announced climate and energy policy framework for 2030 (COM(2014)) 15 final, which recommends no new targets for renewable energy or the greenhouse gas intensity of fuels used in the transport sector.

All data and information for this assessment has been obtained from literature review, and stakeholder consultation. For the latter, discussions were held with Renault, Volkswagen (VW), Daimler and Bosch to obtain their inputs. Auto-manufacturer inputs on the range of acceptable blends were also a major factor in the selection process.

Section 2.3 below reviews biofuel blend options for petrol engines in the context of future engine technology developments, and selected auto manufacturer inputs. The impacts of higher blends on petrol engines is then assessed in more detail in Section 2.3.3. Section 2.4 presents blend options for diesel engines, followed by a review of their potential impacts (Section 2.4.3). Chapter 2 closes with a summary of the main conclusions for ethanol and biodiesel blends (Section 2.5).

2.3 Biofuel blend options for petrol engines

2.3.1 Future directions in petrol engine technology in the EU

In general, auto-manufacturers design cars based on their expectations of available fuels, but future fuels can be tailored to expected changes in engine technology to enhance the future performance of vehicles. This Section examines how petrol technology will change through 2030, and estimates the properties of future fuels that could enhance the performance of future engine technology. In the EU petrol engines are used almost exclusively in personal use light duty vehicles and all commercial vehicles use diesel engines. ICF's report to the American Petroleum Institute (ICF, 2013) is the basis for the following discussion.

A wide range of technological options are either under consideration or are being introduced for the next generation of spark ignition engines. Examination of data on product plans shows that manufacturers are proceeding on two divergent pathways. The first involves turbo-charging and downsizing the engine. A more novel variant includes lean burn with turbo-charging and downsizing the engine; this technology may have only limited market penetration to 2020 but could be dominant by 2030. The second path involves using high compression ratios and preventing knock by novel methods such as the use of a Miller or Atkinson cycle with late intake valve closing. Both paths also can involve using a common set of new technology such as variable valve timing (VVT), valve actuation and cooled exhaust gas recirculation (EGR). The advantages and disadvantages of the pathways are examined below.

2.3.1.1 Direct Injection Turbocharged Engines

Stoichiometric direct injection spark ignition (DISI) engines are now being used by most auto-manufacturers. The technology trend is moving toward higher injection pressures and more sophisticated injection strategies such as pulsed-injection. There are many applications of direct injection (DI) with naturally aspirated engines but many manufacturers have also introduced DISI in combination with turbo-charging and variable valve timing as a package.. Suppliers such as Bosch have claimed that with higher boost pressures, the Turbo-DI package will achieve up to 25% increase in fuel economy if the engine is resized for constant performance. In combination with additional technology packages and extreme downsizing, Mahle (2011) indicated that up to 35% improvement in fuel economy is achievable. Further synergies can be found with other technologies including electrification. One measure of the boost pressure is the mean operating cylinder pressure at wide open throttle, which is referred to as brake mean effective pressure or BMEP[63]. As a reference, a non-turbocharged engine has a typical BMEP of about 12 bar.

Many first generation Turbo DISI engines in the EU market are representative of 18 bar BMEP-level technology. VW/Audi was one of the first manufacturers to sell these engines (which they refer to as TSFI) in the mass market on a wide variety of vehicle platforms, but all European manufacturers offer this technology as of 2015. The trend continues towards higher boost pressures and most engines today with this technology have maximum brake mean effective pressure (BMEP) levels of 19.5 to 20 bar. As of 2015, most mass market vehicles have not yet moved to boost levels of 24 bar and higher, but it is expected that this trend towards higher boost and smaller engines will continue. European auto-makers like Audi, Porsche and BMW already offer high performance models with engines having a BMEP up to 24 bar and maintain the compression ratio (CR) at 10, but some require premium fuel (98+ RON). It is anticipated that by 2025, most mass market cars will employ boost levels of 22 to 24 bar with regular 95 RON petrol while automakers of high priced vehicles (Mercedes, BMW, Audi, Porsche) will increase boost to 28 to 30 bar with premium petrol (at 98 to 100 RON).

2.3.1.2 Lean-Burn DISI Engines

The 1st generation lean burn direct injection engines marketed in Europe in the 2000 time frame achieved fuel-air mixture stratification through a special combustion chamber design which is referred to as “wall-guided” mixture formation. The technology did not achieve wide success since combustion was difficult to control at different engine speeds. The newer technology variants use a centrally placed injector to achieve a “spray guided” mixture stratification. This process uses a small spacing between the injector and the spark plug electrode and the air-fuel mixture formation near the spark plug takes place almost independent of gas flow and piston movement. Use of lean burn systems can typically improve fuel economy by 12 to 15 percent over the New European Driving Cycle (NEDC).

The spray guided systems, however, use high pressure piezo-injectors to achieve the desired level of mixture control, with attendant high injection system cost. Automakers makers such as BMW and Mercedes have been introducing the spray guided DISI lean burn engines in Europe since 2014 with up to 20% fuel consumption improvement and there is renewed optimism that such technology can be widely used. Mercedes uses a sophisticated conical spray piezo-fuel injector and fuel injection is done in multiple pulses (Breitbach, et al., 2013). At light throttle (up to 4 bar BMEP), the engine runs very lean at an overall lambda[64] of over 3. There is a transition region from 4 bar BMEP to 7 bar at medium throttle levels where the combustion mode is termed “Homogeneous- Stratified” (HOS) where most of the mixture is homogeneous and the air-fuel mixture (lambda) is about 2 but the region near the spark plug is near stoichiometric. Beyond 7 bar BMEP or close to full throttle, the engine operates like a conventional engine with the air-fuel ratio at stoichiometric (lambda of one).

More recently, Mercedes has extended this concept to a 2L turbo-charged engine with a maximum BMEP of 23 bar. The turbocharged lean burn engine also showed similar benefits relative to a turbocharged stoichiometric engine. This suggests that combining the concepts of DI/ Turbo with stratified lean-burn can provide a total fuel consumption benefit of 25 percent from the engine alone, with 10% to 12% from turbo-charging and 12% to 15% from lean operation. However, the piezo fuel injector and the emission control system are currently expensive, and lean burn technology will likely be restricted to expensive cars to 2020. During the 2020 to 2030 time frame, there is considerable optimism that the technology can be transferred to mass market cars.

[63]BMEP is the engine maximum torque divided by the displacement and is a measure of the specific engine output

[64] Lambda is a measure of the air-to-fuel ratio and is equal to one when all of the available oxygen in the air results in complete combustion of the fuel. Lambda values higher than one indicate excess air, or lean combustion.

2.3.1.3 High Compression Ratio Engines

Theoretically, an engine's efficiency will increase with increased Compression Ratio (CR). Modern petrol engines generally operate in a CR range from 10:1 to 11:1 but the trend is to develop engines with higher CR, particularly with DI available to cool the charge mixture. Mazda has introduced the Skyactiv-G engine with CR of 14:1 and claims up to 15% increase in fuel efficiency and torque (Goto, et al., 2011). The technology was enabled by using a redesigned exhaust manifold that minimizes hot residual gases, multi-hole DI injectors, injection pressure of 2,900psi and a re-worked control system. Mazda has claimed that the brake specific fuel consumption (BSFC) is close to that of a current diesel engine, and in a vehicle application, Mazda has demonstrated fuel consumption reduction of 15% based on certification data. However it appears that only 5 to 6 percent of the improvement is attributed to the CR increase since the engine uses a Miller cycle at part load to reduce pumping loss, while reduced friction loss and idle speed reduction, as well as reduced accessory loss (in the oil pump and water pump), contribute to the 15% total.

In 2013, Honda introduced a 13 CR 2.0L 4 cylinder engine with port fuel injection (PFI) and cooled exhaust gas recirculation (EGR), as well as Atkinson cycle operation at part load by using a 2 stage variable valve lift and timing (VVLT) system. The cooled EGR suppresses knock and enables operation at near optimal spark timing without knock even with the very high compression ratio. Honda has published an SAE paper showing a BSFC of 214 g/kW-hr which is one of the lowest levels ever achieved on a spark ignition engine (Yonekawa, et al., 2013). In addition, the cooled EGR and VVLT system reduces pumping loss at part load so that the engine has very good fuel consumption over a wide range of torque and speed. Although the engine is currently used only in the Accord hybrid, the engine power rating is only a little lower than that of other 2L PFI engines, at 140 HP. In comparison, Mazda's 2L DI engine is rated at 154 HP. It is possible that the Accord hybrid engine strategy could be adapted to conventional drivetrains with some modifications in the near future, by 2020.

Other Japanese manufacturers are also working on similar concepts such as high CR engines with an Atkinson cycle instead of a Miller cycle. The Toyota Prius and other hybrid vehicle models use the Atkinson cycle with a CR of about 12, but the power loss has restricted the use of these engines to hybrid models exclusively. Nissan has introduced a 1.2L 3 cylinder engine with 13 CR, and the engine is unique in that it also employs supercharging. In order to enable use of high CR, many of the same technologies used by Mazda such as a high tumble intake port, shallow cavity piston, a multi-hole GDI injector, and the Miller cycle are also used in the Nissan engine (Kishi and Satou, 2012). The engine also employs many new friction reduction technologies. The net fuel economy improvement is substantial, with the Nissan Micra equipped with this engine is certified at 95 g/km CO_2 on the NEDC cycle, which is equal to that of the best diesel engine powered car of similar size and performance.

ICF contacts with Japanese automobile industry staff suggest that high CR technology is the preferred direction for the next generation of engines emerging from Japan. ICF expects high CR engines with Miller or Atkinson cycles to be offered by Honda, Toyota and Nissan later this decade. The next step with such engines is to use "homogeneous charge compression ignition" (HCCI) combustion which is a form of lean burn that allows ultra-lean combustion at light loads. The technology becomes more feasible with high CR and advanced valve control, and Mazda plans to introduce this technology by 2018/19. Other manufacturers are more cautious but optimistic about HCCI emerging in the 2020 time frame. HCCI has the potential to improve engine efficiency additionally by as much as 10%.

For all future technologies, the use of ethanol blends as opposed to hydrocarbon petrol and E5 is not expected to cause any unique problems as the combustion characteristics of ethanol are quite similar to those of hydrocarbon petrol. One aspect of ethanol that will be useful for future technologies is its higher Research Octane Number, while a second aspect that can be useful is its high latent heat of vaporization[65].

2.3.2 Manufacturer Inputs on Biofuel Blend Options for Petrol

As noted discussions were held with three manufacturers and one major fuel system supplier, and their opinions on the bio-fuel market are summarized. Our discussions suggest that they have lost interest in first generation bi-fuels. All of the manufacturers stated that NGO support and public opinion has turned against such fuels due to the food-for-fuel and land use issues, as well as costs of bio-fuels. More recently, with the financial crisis, subsidies for bio-fuels are being reduced in most EU countries. Renault stated that investments to prepare for fuels like E85 in France and Sweden have not paid off and public interest in even E10 is poor. None of the auto-makers expect commercial scale second generation ethanol plants to be operational before 2020, and are not optimistic such fuels can be cost competitive with conventional fuel in the next 10 to 15 years. Hence, there is a great deal of reluctance to invest in vehicle design changes for any new bio-fuels program. Our discussion focused on what can be done technically to increase bio-fuel use to meet the 10% energy requirement for 2020 to 2030.

The selected auto-manufacturers stated that they saw considerable potential for expansion of ethanol use in the EU even with no changes to the basic market structure of having E5 as the protection fuel and E10 as an option. This is because many southern European countries are not using any ethanol blends and hence, using E5 in these countries will boost EU wide ethanol volumes considerably. In addition, E10 availability is currently restricted to 3 countries in the EU, and more widespread availability in all EU countries will ensure greater ethanol use.

These manufacturers are also relatively open to the prospects of using E10 as the protection fuel starting in 2020. Most vehicles manufactured after 2003 are E10 tolerant, but there are a number of models (many of which are identified in consumer alerts issued in Finland[66] and Germany[67]) that are not, with one such example being some early direct injection systems introduced in the 1998 to 2001 time frame that use aluminium high pressure pumps that can be damaged by E10. By 2020, manufacturers expect that only a portion of the fleet (>2%) may experience problems with ethanol and hence provisions for the upgrading of these vehicle's fuel systems must be made if E10 becomes the protection fuel in the EU. However, inputs from all EU based vehicle manufacturers are required before this option can be implemented. E10 can be expanded to 100% of the market in the 2020+ time frame.

Manufacturers suggest that E15 will not be a possible choice in 2020 as the base (protection) fuel since a large fraction (>10%) of the fleet could have problems with this blend in 2020. Manufacturers noted that as of 2011, a majority of the cars made in the EU are E20 tolerant (in the sense that there will be no efficiency advantage in using E20 in these vehicles but they will not have safety or performance issues with this fuel). These issues are not related to a different type of E20 fuel with higher octane, which is discussed below.

A third option recommended by some of the manufacturers is to enhance the value of ethanol to customers by using its higher RON value and creating a new high octane fuel that can be used only in purpose designed cars for the future. Mercedes and Ford, in particular, have suggested that 15% to 20% of ethanol be "splash blended" or specially blended with current E5 95 RON fuel that is the base fuel available in much of the EU today. Other manufacturers are more cautious but supportive of the trend towards a higher octane fuel. (Splash blending is a term used to denote a simple mixing of ethanol with current base petrol blend stock with no adjustments to the properties of the blend stock but some prefer the use of the term "tailored blend"). Splash blending will result in an E20/25 fuel with a RON of about 100 to 102 when starting from a 92 RON blend-stock used for E5, or 102 to 104 if

[65] A high latent heat of vaporisation means that ethanol may contribute to lower combustion temperatures and, therefore, potentially reduce NOx emissions.

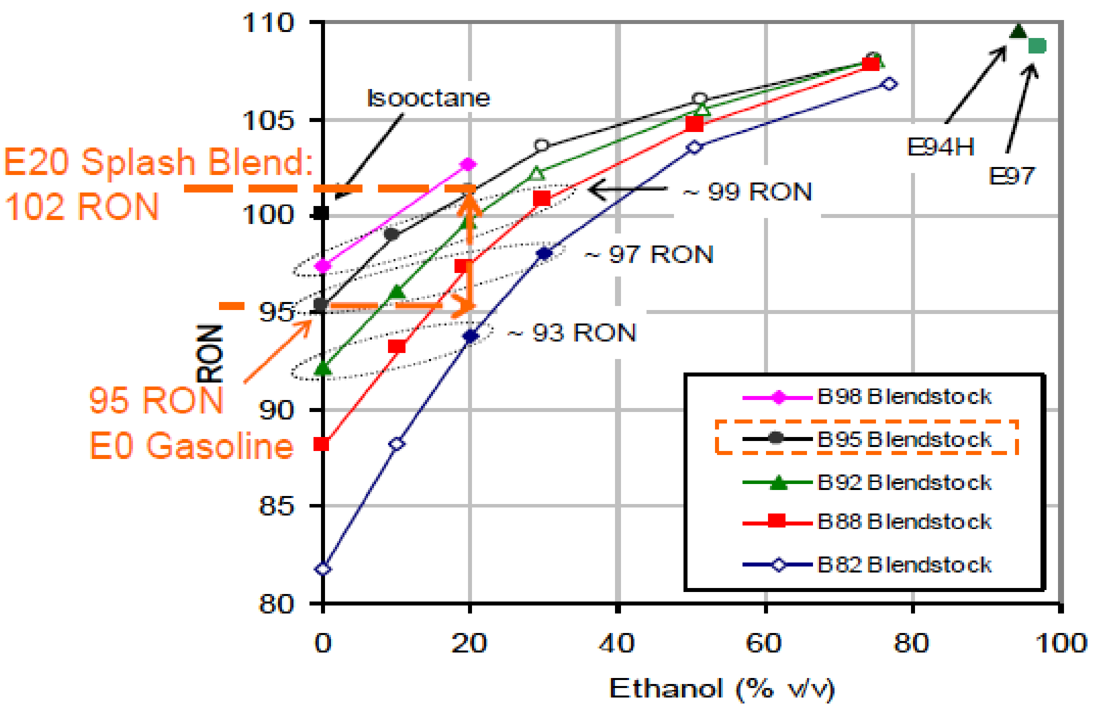
[66]http://www.e10bensiini.fi/e10_compatible_motors (Finland)

[67]http://www.dat.de/e10liste/e10vertraeglichkeit.pdf (Germany)

splash blended with E0 95 RON fuel (Sieler and Kramer, 2014) as shown in Figure 2.1. The vapour pressure of this E20/25 blend will be lower than that of E5 so that any waivers for blend volatility do not need to be increased but will need to be made applicable to E20/25.

The strategy of using E20 as a premium fuel is to allow market introduction of this fuel without a complete overhaul of the fleet and the refuelling infrastructure. The ultimate goal is to make E20 a mainstream fuel of choice for all consumers, but the slow turnover of the fleet implies that a transition will occur over the 2020 to 2030 period. Introducing this fuel as a premium high octane gasoline blend has been suggested by some auto-manufacturers.

Figure 2.1 Blend Octane Number as a Function of Base Petrol Blend-stock RON and Ethanol Content



Source: Sieler and Kramer, 2014

The increased RON of the E20 blend can be used to increase the CR of the engine or the boost level of the turbo (or some combination of the two) which in turn can enhance fuel efficiency. However, such engines must be purpose-designed for 100 RON fuel and cannot typically use 95 RON fuel except as a “limp home” emergency fuel. This option can potentially grow ethanol sales in the 2020 to 2030 time frame.

2.3.3 Impact of using higher ethanol blends

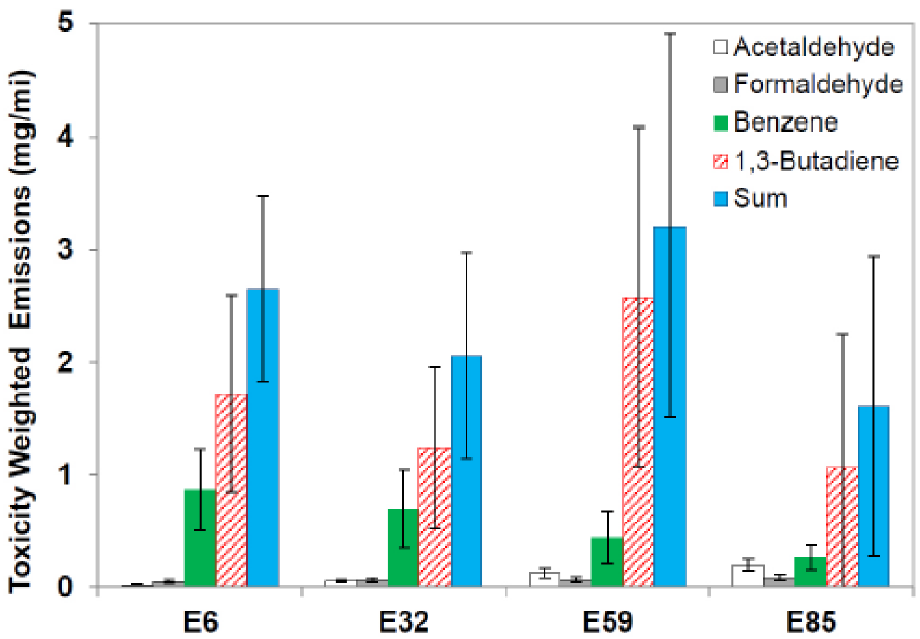
2.3.3.1 Exhaust Emissions

Ethanol petrol blends ranging from E5 to E85 have been used in the EU for decades and the emissions impact of higher ethanol blends (relative to the current E5) are well understood, as are the technical challenges to the fuel system and engine. Broadly speaking, there is a consensus that ethanol results in cleaner combustion than petrol because it is a simpler molecule that yields lower levels of complex combustion by-products such as 1,3- butadiene (a carcinogen). The blending of ethanol also results in the displacements of toxic compounds in petrol such as benzene.

In a summary study of the effects of ethanol blends, Ford researchers provide an overview of all emission effects (Stein, Anderson and Wallington, 2013). Increased blend levels of ethanol are typically accompanied by reduced engine-out levels of the regulated pollutants such as hydrocarbons and carbon monoxide as well as toxic emissions of compounds such as benzene and 1,3- butadiene. However, as detailed below, there are increases in aldehyde emissions, notably those of formaldehyde and acetaldehyde. When all of the toxic emissions are weighted by toxicity factors utilized by the California Air Resources Board, the sum of toxics is far lower for E85 relative to E0.

The Ford paper states that results from studies examining E5 to E32 blends have not been as consistent in reporting reduced toxics with increased ethanol content, which they attribute to absolute emissions levels being so low that the measurement errors can influence the results.

Figure 2.2 Results of CRC study on Toxic Emissions from Flex-Fuel Vehicles



Source: CRC, 2011

One such study was conducted by the Coordinating Research Council (CRC) and published in 2011, where Flex Fuel Vehicles (FFV) were tested on ethanol petrol blends ranging from E6 to E85, using the US Federal Test Procedure. Flex fuel vehicles automatically change spark timing and injection timing as a function of ethanol content and their emissions are likely to be similar to an optimized engine from an engineering perspective since the only difference is associated with the Compression ratio (CR). CR changes and turbo boost changes in optimized engines have modest emission effects on light load cycles like the NEDC and WLTC, so that future high CR engines are not likely to display different emission response to ethanol blends from those of current flex fuel vehicles.(Thomas, West and Huff, 2015) The results shows toxicity weighted emissions generally decreasing with increased ethanol content, except for the emissions of the E59 blend being higher than that for the E32 blend (Figure 2.2), but the size of the error bars show that this anomalous result can be explained by measurement uncertainty.

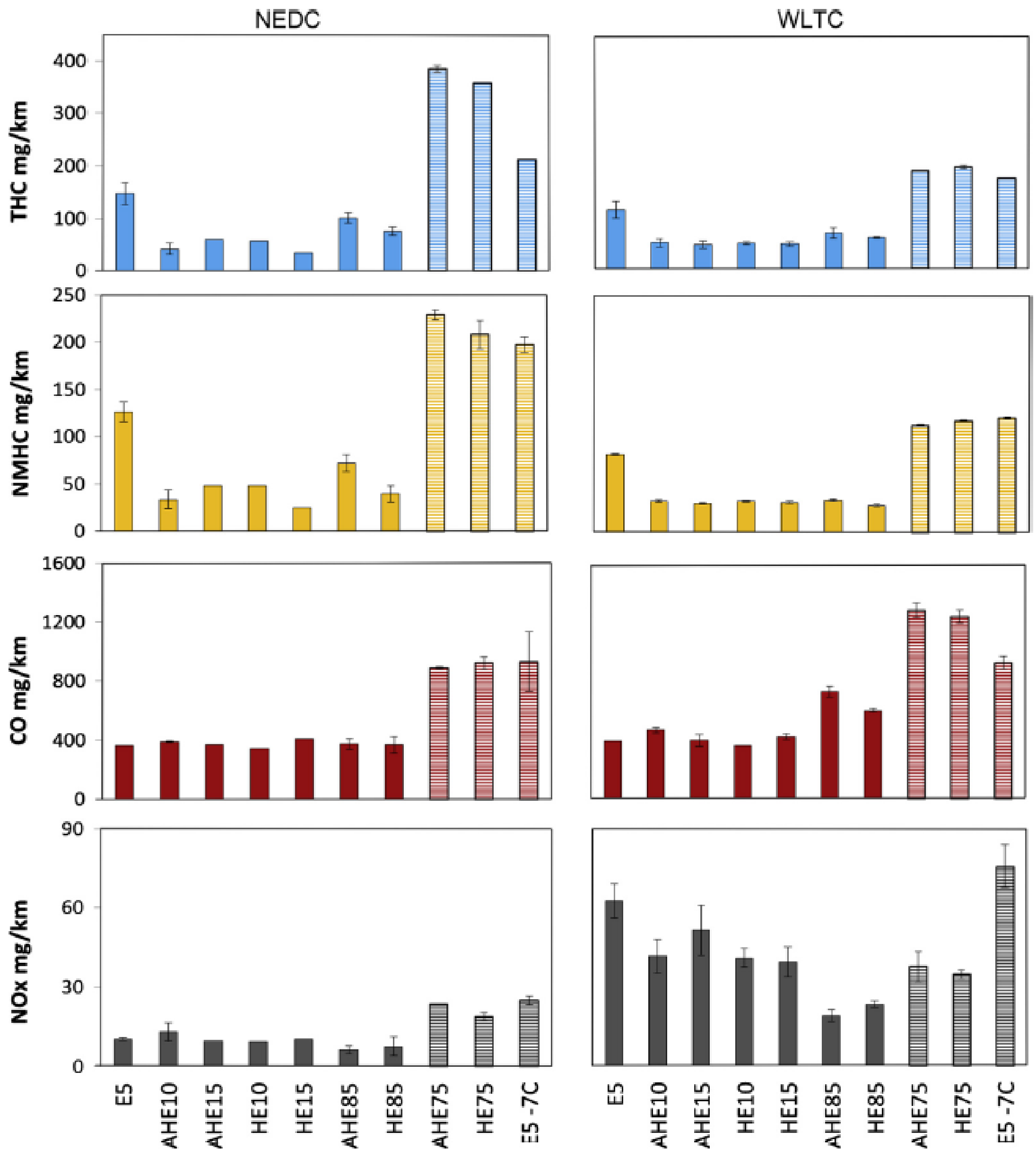
Emissions of the regulated pollutants of hydrocarbons, carbon monoxide and oxides of nitrogen do not show any significant trends with increased ethanol content because catalysts remove 99+% of the emissions from the engine and tailpipe levels are very low so that changes in engine-out emissions are not reflected at the tailpipe. The CRC study referenced above found no significant trends for any of these emissions with increased ethanol content but some studies have noted decreases in non-methane hydrocarbons (NMHC) with increased ethanol content.

Flex-fuel vehicles of recent vintages have also been tested at the European Commission’s Joint Research Center at Ispra (Dardiotis, et al., 2015). A Turbo-charged Direct Injection Euro 5 compliant vehicle and a Port Fuel Injected Euro 4 compliant vehicle were tested with E5 as the reference fuel and E85 as a summer fuel along with E75 as a winter fuel. Tests were conducted on the NEDC test cycle at 22° C and -7° C. The results for the two vehicles were not directionally similar, with the Euro 5 vehicle showing reductions in all regulated emissions with increased ethanol content blends but the Euro 4 vehicle showing increased HC emissions and NO_x emissions with increased ethanol content blends.

The JRC also conducted additional tests on the Euro 5 vehicle to measure toxic emissions and also to measure emissions on the harmonized World Light-duty Test Cycle (WLTC) (Suarez-Bertoa, et al., 2015, p.173-182). It should be noted that virtually all flex-fuel vehicles have been withdrawn from the EU market and the JRC stated that this Euro 5 vehicle was the only flex-fuel vehicle left in the EU market in 2014. Fuels included four blends of E10, E15, E75 and E85 with anhydrous ethanol and 4 with hydrous ethanol (the water content of the hydrous ethanol blends were in the range of 1% by weight for the E10 blend, which was almost ten times higher than the content with anhydrous ethanol). Figure 3-4 provides the results across all tests and fuels. Note that the hatched bars are results for tests conducted at -7 C and should be compared to the right most bar of the E5 reference fuel tested at -7 C. It can be seen that there are no strong tendencies for emissions increases in the E5 to E15 range at 20° C but there is some increase in non-methane hydrocarbons (NMHC) and total hydrocarbon (THC) for the E75 and E85 blends when tests are conducted at -7° C using the NEDC test.

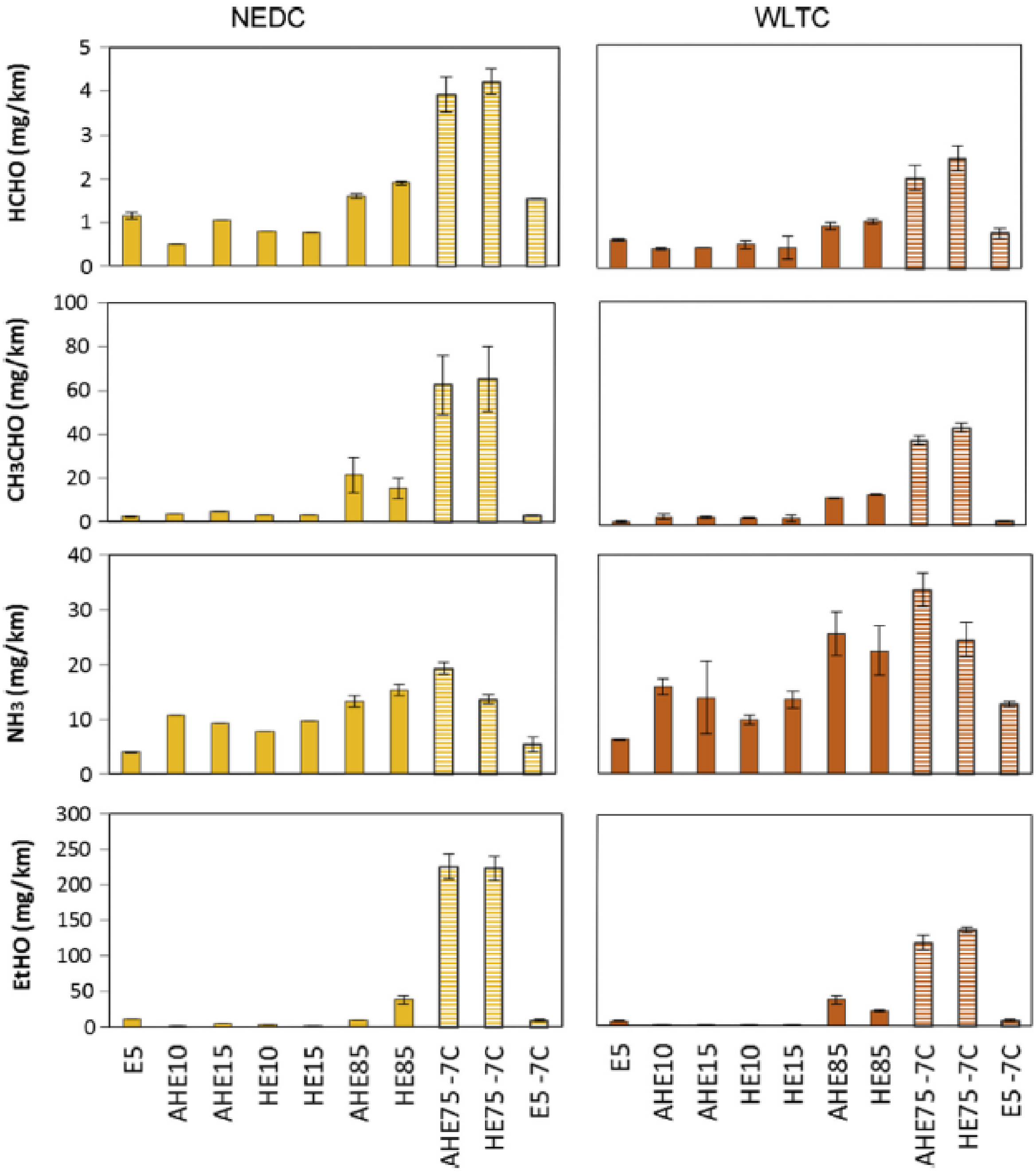
The study also reported a modest increase in aldehyde emissions with increased ethanol content for E75 and E85 blends but no statistically significant change in emissions was noted in the E5 to E15 range of blends. Formaldehyde emissions were between zero and 1mg/km for the E5 to E15 blends (near the detection limit) but about 1 mg/km for the E85 blend, while acetaldehyde emissions were 3mg/km for the E5 to E15 blends compared 11 to 12 mg/km for E85. The paper did not report on benzene and 1, 3- butadiene emissions, but provided information on ammonia emissions and ethanol emissions. This data is shown in Figure 2.3 which employs the same format as Figure 2.4.

Figure 2.3 JRC Study Results on Tests of Euro 5 Compliant Vehicle with Different Ethanol-Petrol Blends (Hatched Bars are Tests Conducted at -7° C)



Source: Suarez-Bertoa, et al., 2015, p.173-182

Figure 2.4 JRC Study Results for Emissions of Toxics on Tests of Euro 5 Compliant Vehicle with Different Ethanol-Petrol Blends (Hatched Bars are Tests Conducted at -7° C)

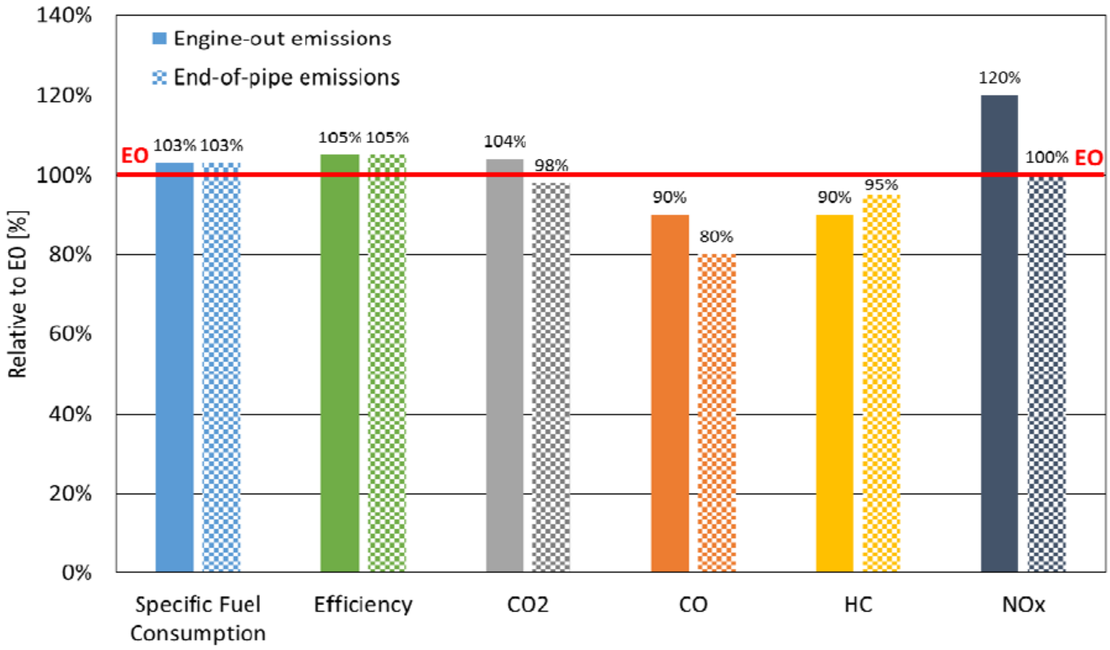


Source: Suarez-Bertoa, et al., 2015, p.173-182

Numerous studies have examined Particulate Matter (PM) emissions from direct injection engines and concluded that PM emissions decline with increasing ethanol content in petrol blends. In a 2010 study conducted by Oak Ridge National Laboratory (Storey, et al., 2012), a vehicle equipped with a 2L turbocharged, direct injection engine was tested on a variety of transient and steady state cycles including the US Federal Test Procedure (FTP), the high load USO6 cycle and full load accelerations. As the fuel ethanol content was increased from E0 to E20, PM emissions decreased by 30% on the FTP cycle and 42% on the USO6 cycle, suggesting that the benefits increase with ethanol content and average load factor. It should be noted that absolute levels of PM emissions were quite low at 2.3 mg/km with E0. Ford's own tests with a 3.5L V6 turbocharged DI engine showed PM mass reductions of about 20% for a E17 fuel relative to an E0 fuel. Since petrol engine PM was uncontrolled at that time, engine-to-engine variability in response is to be expected depending on the contribution of lubricating oil to total PM emissions, but the emission decreases are directionally consistent.

In 2014, CEN commissioned a study of E20 to E25 blends when used with non-optimized vehicles that are tolerant of these blends. The study consisted of a literature review of emissions data from the EU on the emissions effects of E20 and E25 blends, as well as testing of two Euro 5 compliant vehicles with E20 blends. The literature review was conducted by the Vienna University of Technology (Geringer, et al., 2014) and the study concluded that all tailpipe emissions were either reduced or stayed constant relative to pure hydrocarbon petrol (E0). The summary of the study is shown in Figure 2.5 below. This study examines the CEN study results to gauge its consistency with other reported results, as some have suggested the results are controversial.

Figure 2.5 EU meta-study results of engine-out and tailpipe emissions of E20/25 vs. E0

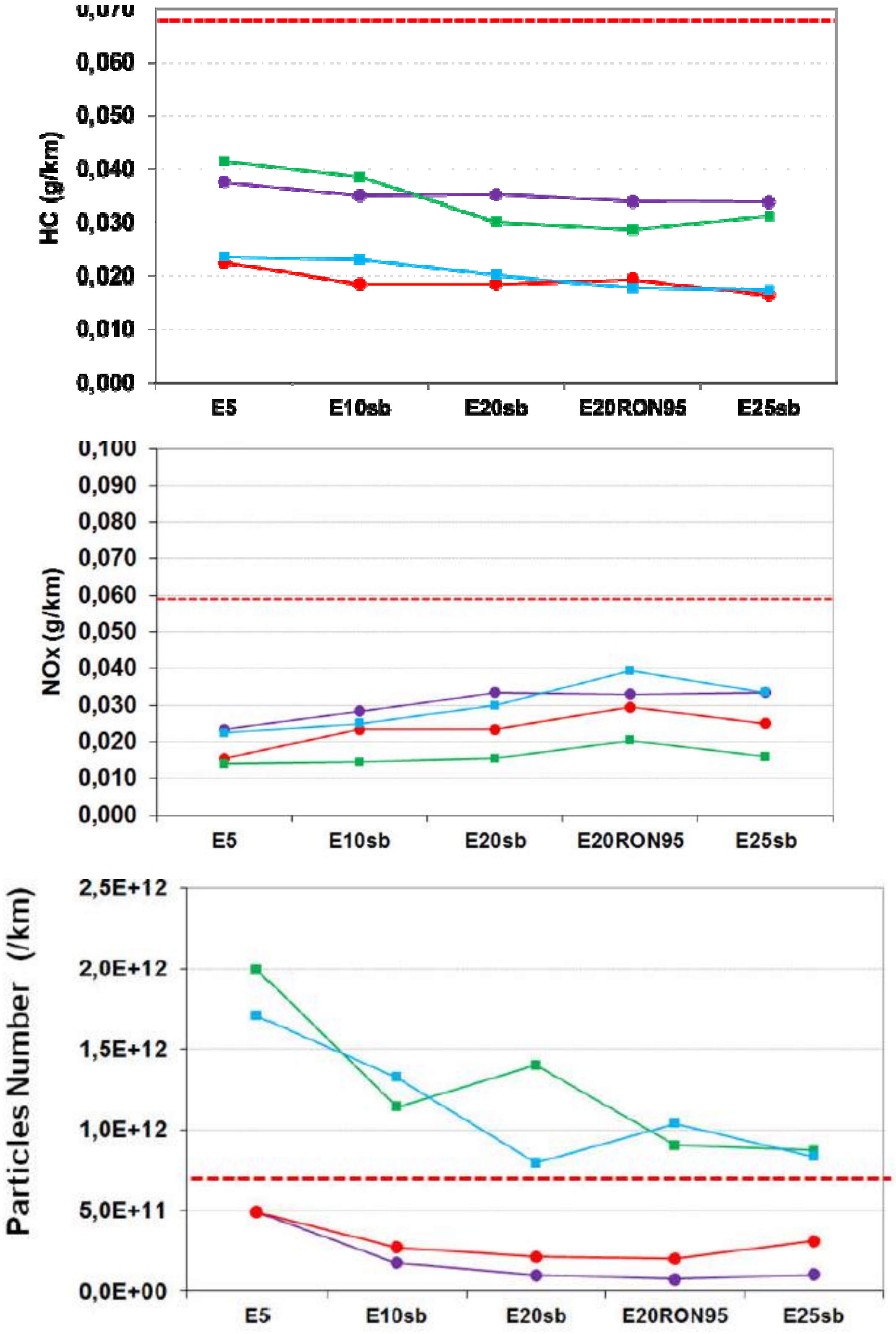


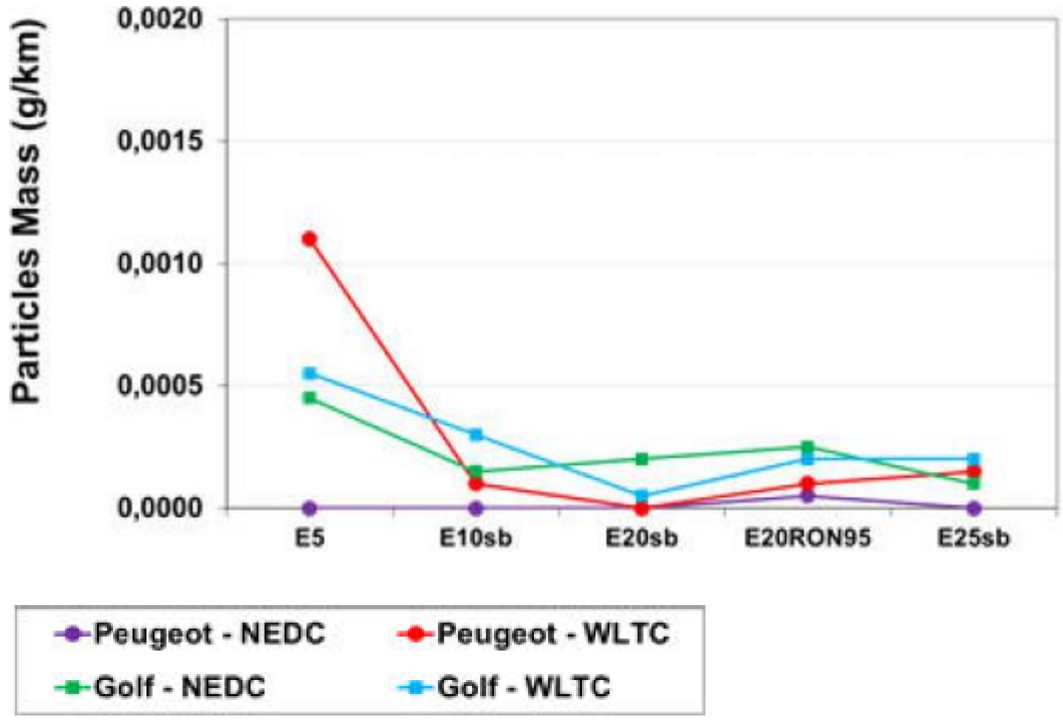
Source: Geringer, et al., 2014

The literature survey concluded that better results could be obtained if the engines were optimized for the higher octane number of the E20/25 fuels, and that the authors expected PM emissions to be reduced but the data was inadequate in the available literature. However, the zero change in NOx is not reported by other studies which show small absolute increases

The testing of two vehicles in the parallel study was conducted by the French Organization, IFP Energies Nouvelles (Fortunato, 2014). Tests were conducted on a 1.2L naturally aspirated, port fuel injected Peugeot 208 and a 1.4L turbocharged direct injected VW Golf. Fuels tested included commercial E5 and E10 blends, E20 and E25 splash blends and an E20 match blend where the base petrol was modified so the E20 also had a RON of about 95, similar to the E5 and E10 blends. Tests were conducted using the NEDC and WLTP test procedures. The results for HC, NO_x, particulate mass and particulate number are shown in Figure 2.6.

Figure 2.6 Emission test results from IFP testing (fuels designated 'sb' are splash blended)





Source: Fortunato, 2014

As can be seen from the figure, HC and particulate mass and number are reduced with higher ethanol content while there appears to be a slight upward trend in NOx emissions with increased ethanol content, but all NO_x emission values are well below Euro 5/6 standards. Toxics emissions were not investigated, except for benzene emissions which declined for all fuels relative to E5. CO_2 emissions were found to be proportional to the fuel hydrogen to carbon ratio while volumetric fuel consumption increased with increased ethanol content.

All of the CEN and JRC based test results are broadly consistent with the summary report from Ford and it can be concluded that increases in ethanol content of petrol ethanol blends in the E5 to E20 range will have either minor or favourable impacts on regulated and total toxic emissions from vehicles, although acetaldehyde emissions will increase significantly by around 10mg/km.

Vehicle test results

To assess and corroborate the literature review findings, a vehicle testing programme was implemented. Emission tests were conducted on a Euro VI compliant petrol vehicle, 1.2L Peugeot 308sw, to the World Harmonized Light Vehicles Test Cycle (WLTC). The vehicle was not optimised for the two fuels examined, E10 and E20.[68] Table 2.1 presents full details of the testing programme, including the approach, assumptions, and results.

Table 2.1 presents the average recorded figures for E10 and E20 test fuels. Each figure is an average of three test results on that fuel.

Table 2.1 Emission summary averages over WLTC cycles – Petrol

Test Fuel	NMHC (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)
E10	18	20	287	49	142.4	2.3	1.33E+12

[68] One of the key approaches to addressing air quality issues is to optimise vehicle engine settings according to the fuel (diesel or petrol) being used. Typically, automakers utilise a single set point for engine management, regardless of fuel composition. Consequently, fuel blends that are different to the optimised setting, could lead to poorer fuel utilisation and higher pollutant emissions.

Test Fuel	NMHC (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)
E20	17	20	458	32	139.9	1.3	1.28E+12
Diff (%)	-4%	0%	+60%	-33%	-2%	-44%	-4%

Overall, both E10 and E20 meet exhaust emission limits defined by the Euro 6 standard for passenger cars.[69] Specifically, total hydrocarbon (THC), particulate mass (PM) and particulate number (PM) are 80% lower than Euro 6 emissions limits, while non-methane hydrocarbon (NMHC) is over 70% lower. Carbon monoxide (CO) and Nitrogen oxides (NOx) vary between 50-70% and 18-46%, respectively, below Euro 6 emission limits. Nonetheless, the particulate emissions from this vehicle would struggle to meet the Euro 6 particulate number limit of 6,0 $x10^{11}$ that will be introduced in 2017. For CO_2, Regulation (EC) No 443/2009,[70] requires that only the fleet average is regulated. As such, all new cars in 2015 should not emit more than an average of 130 grams of CO_2 per kilometre (g CO_2/km). This target is set according to the mass of the vehicle, using a limit value curve, which means that heavier cars are allowed higher emissions than lighter cars. Consequently, although, it is not appropriate to compare the CO_2 test results to this average, for reference CO_2 emissions from both E10 and E20 were between 8 and 10% higher than the 130 g CO_2/km target.

The results indicate no change in the THC emissions between E10 and E20, and a slight decrease of 4% and 2% in NMHC and CO_2 emissions, respectively. PM emissions were between 1 and 2 mg/km; consequently, deviations in emissions between E10 and E20 are within measurement sensitivities.

Although the repeatability of emissions results was very good throughout the programme, as evidenced by low Coefficients of Variance (CoV) in fuel consumption over the WLTC cycles, in the case of NOx and CO, higher CoV were noted. For NOx, CoV figures of 45.6 and 39.3 were reported for E10 and E20, respectively. Although high, this was in part due to the low overall values of NOx produced (i.e., 49 mg/km (E10) and 32 mg/km (E20)), since a small change in mass will greatly affect the CoV values. Furthermore, on review of each tests' modal data, it was deduced that a large amount of NOx was produced during one acceleration period during the test, where the driver may have been overly aggressive. However, no driver violations were recorded with the drive trace being within legislative limits. For CO, the majority of the discrepancy, and reason for high CoV, was observed to be in phase 1 of the test Annex 5. Again, no other significant deviations in vehicle or driver traces were observed during the test period.

2.3.3.2 Fuel Consumption and Energy Efficiency

Ethanol has only two-thirds the energy per unit volume (nominal) of pure hydrocarbon petrol and an E5 blend will have about 1.7% lower energy content while an E10 blend while have about 3.4% lower energy content per unit volume than E0. E5 and E10 blends sold in the EU today uses a different base petrol blend-stock relative to E0 95 RON petrol so that the blend octane number remains at 95. There may be small differences in the energy content of the blend-stock relative to E0 95 RON fuel so the volumetric energy content of E10 maybe 3 to 4 % lower, while that of E5 may be 1.5% to 2 % lower.

When used in current petrol engines that tolerate E0 to E20 blends, the calibration of the engine does not change with the fuel type, although it is possible that higher latent heat of vaporization results in a slightly cooler charge in the engine. The engine may experience less heat transfer loss, and spark retard initiated by a knock limiter could be affected during normal driving. However, studies conducted by the US Department of Energy and the US EPA over the last 20 years (for example see website fueleconomy.gov) have concluded that energy efficiency of the engine remains near constant and the volumetric fuel consumption

[69] Regulation (EC) No 715/2007

[70] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009R0443-20130508

increases by the same amount as the decrease in energy density, so that efficiency benefits are lost in the noise. Studies on Flex Fuel Vehicles (FFVs) with higher ethanol blends like E75 and E85 have shown some modest energy efficiency benefits. For example, the testing at JRC (Dardiotis, et al., 2013and Suarez-Bertoa, et al., 2015) found that the fuel consumption increase was somewhat smaller with E85 than expected from the energy content difference with E5, and the paper concluded that the Turbo DI engine showed a 2.6% energy efficiency gain with E85 while the port fuel injected engine showed a 1.5% energy efficiency gain. The IFP test results (Fortunato, 2014) also showed that the VW Golf with the DI engine obtained some benefit with E20/25 blends in engine efficiency, while the port fuel injected Peugeot 208 had no change in efficiency. JRC testing (Suarez-Bertoa, et al., 2015) with E5, E10 and E15 blends showed no trend in CO_2 emissions or energy efficiency improvement, possibly because the effects are small and difficult to detect. Hence, the simple formulation that volumetric consumption varies inversely with the volumetric energy content of the blend is widely accepted as a good approximation for blends up to E25 when used in engines optimized for pure petrol or E5/10.

Vehicle test results

The 1.2L Peugeot 308sw that was used for the vehicle tests is tolerant to the higher ethanol blends; i.e., it can drive on these blends without technical or safety issues. Consequently, since it has not been optimised for the higher blends, it should, technically, receive no fuel efficiency benefit. As presented in Table 2.2, this observation was substantiated by the test results which indicated a decline in fuel consumption by 5% between E10 and E20.

Table 2.2 Fuel consumption averages over WLTC cycles – Petrol

Test Fuel	Fuel Cons (L/100km)
E10	6.25
E20	6.57
Diff (%)	+5%

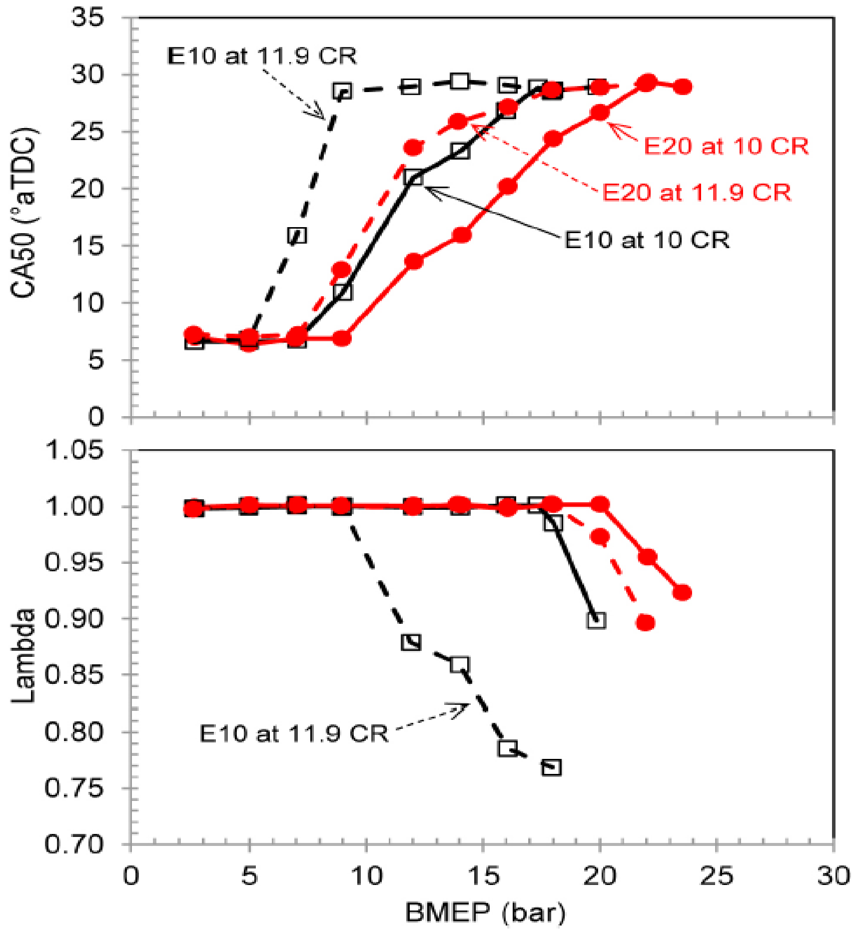
2.3.3.3 *Potential with E20 High Octane Fuel*

The issue of the fuel economy benefit possible from a purpose designed engine optimized to take advantage of E20 with 100 RON has been extensively investigated by Ford in conjunction with researchers from AVL and from the Oak Ridge National Laboratory. More recently, Ford conducted a study (Leone, et al., 2014) on a production 3.5L turbocharged DI engine, and conducted tests both at the stock 10 CR and with special pistons designed for 11.9 CR and 13.0 CR. The stock valve timing was used at all values of CR. This engine was tested with a variety of fuels and the base fuel was an E10 91.8 RON fuel for reference which is similar to a US specification regular petrol. Splash blended E20 and E30 fuels that has RON values of 96.2 and 100.7 as well as E20 and E30 blends matched to the 91 RON of the fuels were tested, along with an E85 rated at ~108 RON.

Tests conducted with the stock 10 CR engine and the 91 RON fuels with 10, 20 and 30 percent ethanol showed very little difference is spark advance requirements across fuels, and 17 bar BMEP was attained on all 3 fuels with only spark retard and no enrichment. With enrichment to an air-fuel ratio $\lambda = 0.75$, the E20 fuel allowed operation up to 23 bar, while the E10 fuel was a lower at 22 bar. (The E30 fuel was limited by low speed pre-ignition to 18 bar BMEP at 1500 RPM but had nearly equivalent performance as the E20 fuel at 2000 and 2500 RPM). These results show that the cooling effect has much more limited role in production engines' performance, and the fuel RON is the dominant factor controlling peak output.

Tests conducted with the splash blended fuels illustrate the benefits of the RON increase. While the E10 fuel became knock limited at BMEP over 7 bar, the E20 fuel extended the limit to over 9 bar and the E30 to 14 bar BMEP. Similarly, the E20 96 RON fuel could sustain operation to 22 bar and the E30 to 27 bar BMEP without enrichment. The study found that the combustion phasing for E10 at 10 CR was nearly equivalent to the phasing of the E20 fuel at 11.9 CR as shown in Figure 3-8. Similarly, the combustion phasing for E30 at 11.9 CR was similar to that of E20 at 10 CR. Tests at 13 CR were limited to the E30 101 RON fuel and the E85 fuel, but operation was limited by low speed pre-ignition.

Figure 2.7 Combustion Phasing and Equivalence Ratio for Load Sweeps at 1500 RPM



Source Leone, et al. 2014

The data suggests that a 4 point octane increase allows a 2 point CR increase in turbocharged engines, or alternatively a 4 bar increase in maximum BMEP. The latter effect is confirmed in today's production cars as boosted engines with 10 CR designed for regular petrol (95 RON) operate at 18 to 19 bar BMEP, while those designed for premium fuel (98+ RON) operate at 22 to 23 bar. Hence, the benefit to boost appears to be largely driven by the octane effect and no significant benefit from the high latent heat of vaporization of ethanol is shown in the production engine data.

Ford also explored the vehicle fuel economy benefits using the engine data and simulation modelling. Volumetric fuel economy for the 11.9 CR engine operating on E20-96 RON fuel was about 1% better than the fuel economy of the 10 CR engine operating on E10-91 RON fuel. Since the volumetric energy content for E20 is 3.6% lower than the energy content of E10, the net benefit in energy efficiency is about 4.6%. Based in this data, for E20 relative to a European 95 RON base fuel, the efficiency benefit would be about 3%. However, the energy content of E20 is 5.5% lower than that of E5, so volumetric fuel consumption would increase by 2.5%. (Note that these estimates have been adjusted for the difference between US and EU petrol RON)

An alternative strategy would be to keep the CR at 10 to 10.5 and increase boost so that the maximum BMEP is increased by 5 bar to 24 bar from 19 bar associated with 5 to 6 point increase in RON for E20. The engine can be downsized by 20% so that maximum torque is kept near constant. H-D Systems (2015) conducted a “matched pair” analysis of 23 models from model year 2014 spanning a wide inertia weight range and offering both Turbo and NA engines with the same transmission, using the 2014 official fuel economy data (Fuel Economy Guide, 2014). The analysis showed that the fuel economy (FE) ratio of turbocharged vehicles to naturally aspirated vehicles is very well explained by only the displacement reduction and torque change (which specifies the BMEP change) and the regression equation limited to situations where the torque ratio is between 0.7 and 1.4 is as follows :

FE Ratio = 1.48 – 0.32*Displacement Ratio – 0.16 * Torque Ratio

For a **20% displacement reduction**, the displacement ratio is 0.8, and at constant torque, the equation yields a FE ratio of 1.064 or a 6.4% efficiency benefit, so that this strategy could achieve even better results, and could actually improve volumetric fuel consumption with E20 by 1%. However, the above equation was derived for conventional hydrocarbon based premium fuels (98+ RON), and E20 of the same RON would have lower Motor Octane Number (MON) which may lead to other pre-ignition or hot spot ignition issues. In summary, the use of E20 with a 100+ RON rating offers the prospect for engine efficiency improvement from 3% to 6.4% depending on the path chosen, but this needs to be proven in production.

A key issue to be noted is that the E20 or E25 high octane fuel is intended as a premium fuel option (98+ RON) so that high octane pumps can be gradually converted to E20/E25 as more E20/E25 optimized vehicles are added to the fleet. The E20/E25 optimized vehicles can use available premium fuel (98+ RON) if E20/E25 is not available at a specific station so that transition issues are minimized. The main advantage of this option is that it captures the octane value of ethanol and allows manufacturers additional pathways to comply with the 2021 CO_2 standards for light vehicles

2.3.3.4 Costs Imposed by E10 and E20/E25 Blend Strategies

The strategy of using E10 blends as the base or protection fuel in the 2020+ time frame will affect only a fraction of the total fleet, including potentially vehicles manufactured before 1990 and a subset of vehicles manufactured in the 1990 to 2007 time frame. In 2020, the 1995 and earlier model year vehicles will be 25+ years old, and this sub-fleet will consist mostly of antique vehicles. The pre-2007 vehicles will be 13 to 25 years old but as noted, a fraction of the vehicles in this sub-fleet may be negatively affected by E10 blends. Unfortunately, no specific details of which vehicle models would be affected are available from the manufacturers, and the EU will have to request ACEA (the European Vehicle Manufacturers Association) to compile such information from its members. ACEA has provided data on the percent of E10 compatible vehicles in the EU and this is shown in Figure 2.8 below as summarized in a report from CE Delft (CE Delft, 2013), which indicates that 90% of vehicle are compatible with E10 for model years 2000 to 2005 and the fleet is 100% compatible from 2008 onwards.

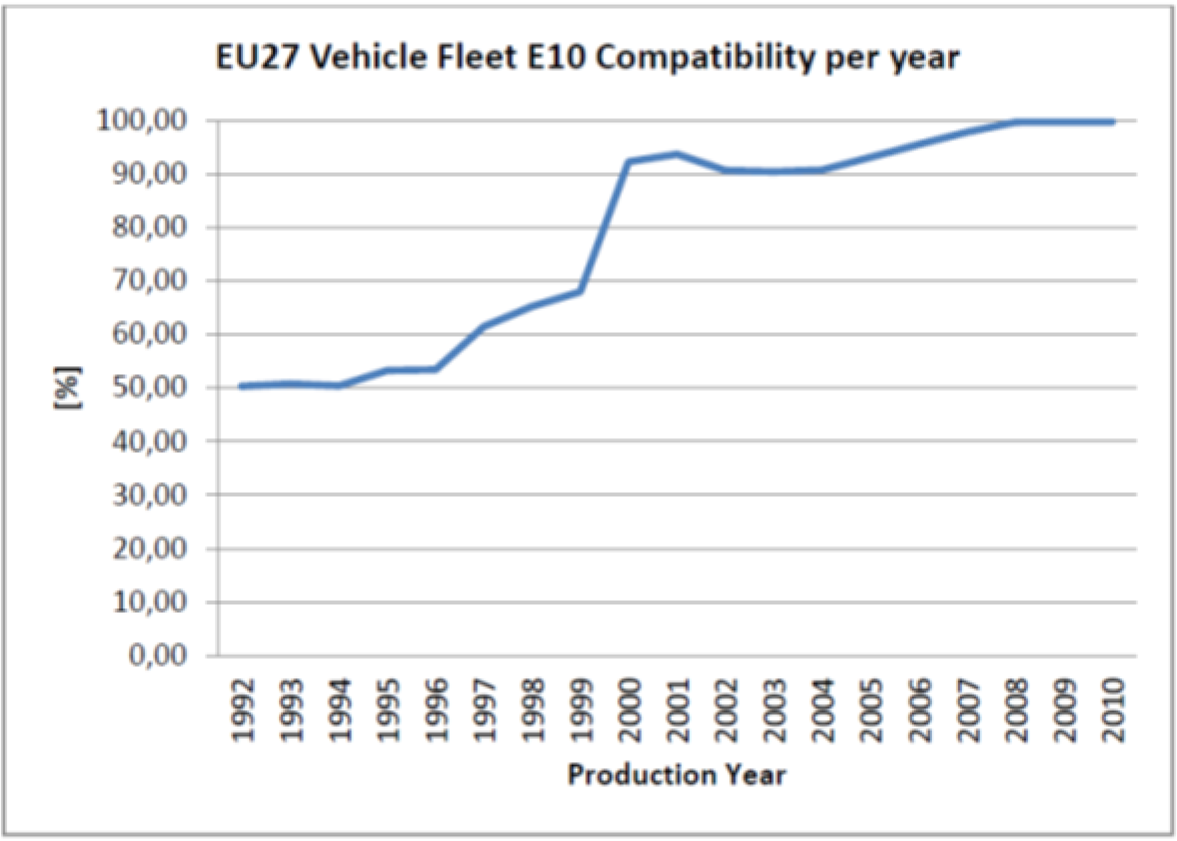
In general, most affected pre-2003 vehicles are expected to need only new fuel system gaskets. The gaskets themselves are not very expensive (~ Euro 20 to 30) but the labour cost of installation could be Euro 100 to 200, depending on the ease of access to injectors and fuel system hoses and seals. In a few cases, some components such as the high pressure injection pump may need modification or replacement and this can be a high cost item (in the range of Euro 400 to 500) for an aftermarket retrofit. These issues have been identified based purely on anecdotal comments made by manufacturers and suppliers during our meetings described in Section 2.3.2, and we have no quantitative data to make an assessment of total EU costs. The selected auto manufacturers who were interviewed during this study also stated that they would have to conduct some research internally to even identify which models would be significantly affected by E10 and E20. On the other hand, we should note that similar issues arose when E10 was introduced in the US in the late 1990s but actual problems encountered in the field were minor and did not cause any major public dissatisfaction. ACEA representatives state that E10 could cause engine fires due to fuel leaks in some cases, but the fraction of vehicles with problems having serious consequences is not known. Bosch has provided a figure of 365,000 vehicles which appear to be the total number of vehicles sold (not the 2020 fleet population) that could have serious problems.

Using the fleet registration distribution likely for 2020 based on 2010 registration distribution data and the ACEA ethanol compatibility data, we computed that 1.3% of the total gasoline fleet would be affected by E10 blends in 2020, although this figure includes vehicles affected in both a minor and major way. Alternately, analysis conducted using outputs of JRC's DIONE 2.0 model (Katsis, P., Ntziachristos, L. and Papageorgiou, T. (2014)) indicate that 6.8% of the 2020 EU passenger vehicle fleet could be non-compatible to E10, and thus potentially impacted. However, the registration fraction of vehicles over 20 years old is sensitive to economic conditions and difficult to estimate with accuracy; thus, the actual number is likely to fall within this range.

The need to retain a protection grade E5 fuel beyond 2020 has been stressed by some fuel system suppliers. The presence of E5 fuel however, will limit the transition to E10 and partially defeat the intent of this scenario. One option is for EU governments to offer a free upgrade of the fuel system to make the vehicles E10 tolerant, or pay for accelerated scrappage of the affected vehicles if the cost of the upgrade of an old vehicle exceeds its value. For example if the vehicle population of the seriously affected vehicles is about 100,000 vehicles (corresponding to the remaining 2000 to 2005 model year vehicles that Bosch suggests has serious issues) in 2020, then payments can be made to those select vehicles to have their owners scrap them.

The cost of a purpose built E20 capable vehicle is also very small if the changes are incorporated into the engine at design stage. Interviews with the selected manufacturers indicate that a lead time of 4 to 5 years will be required to design such engines. In a naturally aspirated engine, increasing the compression ratio from 10.5 to 11.5 or 12 is essentially a zero hardware cost item when the engine is being designed or upgraded for future production. In a turbocharged engine, increasing the turbocharger boost and raising BMEP by 5 bar can incur some costs for a larger intercooler, strengthened piston pins and crankshaft bearings and increased coolant flows, but the costs are only around 40 to 50 Euro for a 4 cylinder engine based on information received from suppliers and auto-manufacturers in analyses for the US Department of Energy (H-D Systems, 2015). Hence, this is a very cost effective strategy for auto-manufacturers to reduce CO_2 emissions by 4 to 7 percent.

Figure 2.8 E10 vehicle compatibility in the EU27 for vehicles produced in the years 1992-2010



2.4 Biofuel blend options for diesel engines

2.4.1 Future directions in diesel engine technology in the EU

Diesel engines are used in all heavy-duty commercial vehicles and most light duty commercial vehicles in the EU. In addition, almost half of all light duty vehicles are diesel powered, which is a level unique to the EU. Unlike the situation for petrol engines, we do not anticipate any fundamental changes in diesel combustion technology to 2030 based on the report to the American Petroleum Institute (ICF-HD Systems, 2013). However, engine specific output has been increasing over the last decade and many light duty engines now provide specific outputs of 80 kW/ litre (or average 100 hp per litre of displacement), with operating BMEP at 25 bar. In the future, we expect that average operating pressures will continue to increase as turbocharger boost is increased and sequential turbo-charging (now available in some BMW engines) is more widely deployed, and engines will be further downsized. By 2020, the API report anticipated that engine operating at 30 bar BMEP and having specific outputs of 100 kW/litre or higher will start to become the norm. The API report review of diesel technology suggested that diesel combustion improvements have made moves to any new form of combustion such as “HCCI” unlikely. The situation for heavy-duty engines is similar in that average BMEP is increasing with time and engines of up to 40 bar BMEP are likely by 2020, but combustion processes will not change. Hence, there will be no new requirements on diesel fuel quality or composition that will be helpful for manufacturers to attain their technology goals

Light Duty diesel engines did not rely on any exhaust after-treatment to meet emission standards until the advent of the Euro 4 standards in 2005. While these standards could be met without after-treatment, early introduction of PM traps by some manufacturers in 2002-03 led to consumer driven demand for traps and virtually all light duty diesels have been trap equipped since 2005. The traps have resulted in tailpipe PM emissions levels very close to zero. Euro 5 standards introduced in 2009 led to the introduction of some NO_x adsorbers in heavier diesel vehicles although most vehicles met the standards with only PM after-treatment. The imposition of Euro 6 standards in 2014 has required urea-SCR after-treatment on vehicles with engine of 2L displacement and larger, while NO_x adsorber technology is popular in smaller vehicles. At present, it appears that urea-SCR systems will be the likely choice for all vehicles if NOx standards are further tightened by 2030.

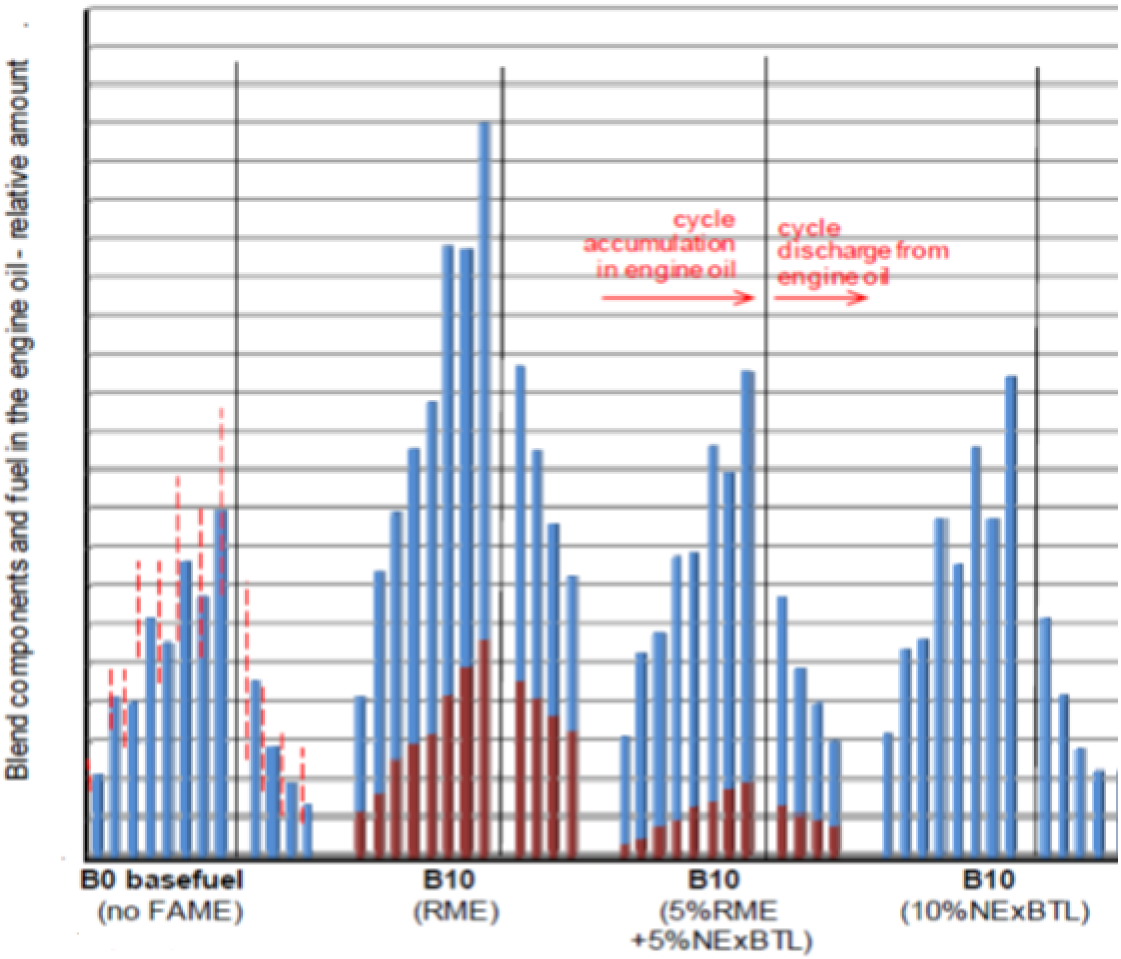
The market share of light-duty diesel hybrid and plug-in hybrids is expected to grow to 2030, and this could result in fuel staying in the vehicle tank for months (if much of the driving is powered electrically), which has raised concerns about the long term oxidation stability of bio-diesel fuel. This has increased concern about FAME blends but there is little data on long term effects since diesel plug-in vehicles have been introduced only in 2014.

EU heavy-duty vehicles also followed a nearly similar path in that PM traps were widely used since the imposition of Euro 4 standards in 2005, while the imposition of Euro 5 standards resulted in many but not all vehicles adopting urea-SCR systems as of 2009. The conversion to urea-SCR systems for NOx control is standard on all trucks following the imposition of Euro 6 standards in 2014.

2.4.2 Manufacturer Inputs on Blends

Interviews with selected auto-manufacturers suggest that they have accepted the use of B7 FAME blends only grudgingly and their main issue with FAME blends is that they cause oil dilution problems. In many PM trap equipped diesel engines, the trap regeneration is initiated by injection of fuel during the exhaust stroke, which in turn initiates ignition of the particulate matter collected on the filter. The exhaust stroke injection often results in some fuel wall wetting and subsequent dilution of the oil with fuel. Diesel fuel has a lower boiling point than FAME so that under the right combination of duty cycle (short trips where the engine never fully warms up) and low ambient temperature, the oil dilution becomes a serious problem. In recent testing, VW and Daimler reported on the oil dilution phenomenon (Baumgarten, et al., 2008) using FAME based B5 and B10 blends and compared these to HVO based B5 and B10 blends as well as a pure hydrocarbon diesel. VW bench tested engines, running for 40 hours with each fuel (with periodic PM trap regeneration), followed by oil analysis before and after every third regeneration of the trap. After 40 hours, the engine was run on hydrocarbon diesel (reference) fuel without trap regeneration. As shown in the figure below, the blends with FAME based on rapeseed methyl ester(RME) exhibit significantly higher oil dilution relative to pure diesel or the HVO blend labelled as NExBTL.

Figure 2.9 Oil dilution pattern with different fuels on the VW bench test



Source: Baumgarten, et al., 2008

Tests conducted by Mercedes using a slightly different procedure confirmed that FAME blends cause significantly higher oil dilution. As a result, manufacturers believe that oil drain intervals will need to be shortened (from current levels of 30,000 km drain intervals) to 20,000 km or lower. Other manufacturers concede that the oil dilution problems would be serious only for a subset of consumers with relatively short use duty cycles and would be more of a problem in winter, but these factors have made auto-manufacturers opposed to any increase in FAME blending beyond the B7 level accepted now.

In heavy-duty trucks, the short duty cycle may be less of an issue but oil dilution with FAME is still considered a significant problem. With more careful oil dilution monitoring and fuel quality monitoring, some captive fleets (both light and heavy duty) are operating with B20 and B30 FAME blends notably in Italy and France. During our discussions, Renault stated that the vehicles are specially prepared for B20/30 but we could not document any specific changes to the fuel system to use B20/ B30 blends. Although such information was requested from manufacturers, we did not obtain any specific data, and it is unclear if any hardware changes are required to enable engines to use B30.

Cold storage issues can be particularly acute for FAME blends. Both pure hydrocarbon diesel and FAME will gel at common winter temperatures; however, FAME's gel point may be much higher depending on the source of the FAME. Soy FAME, for example, has a cloud point (the temperature at which crystals begin to form) of 0ºC. In contrast, most petroleum diesels have cloud points of about -12º to -15º C. Blending with FAME can significantly raise the cloud point above that of the original diesel fuel. For example, a study by CRC (2008) showed that, when the soy FAME was blended into cold weather diesel fuel (cloud point of -38ºC), the cloud point of the B20 blend was -20ºC. Rapeseed based FAME has fewer issues, but manufacturers have complained about fuel filter plugging with FAME blends in winter.

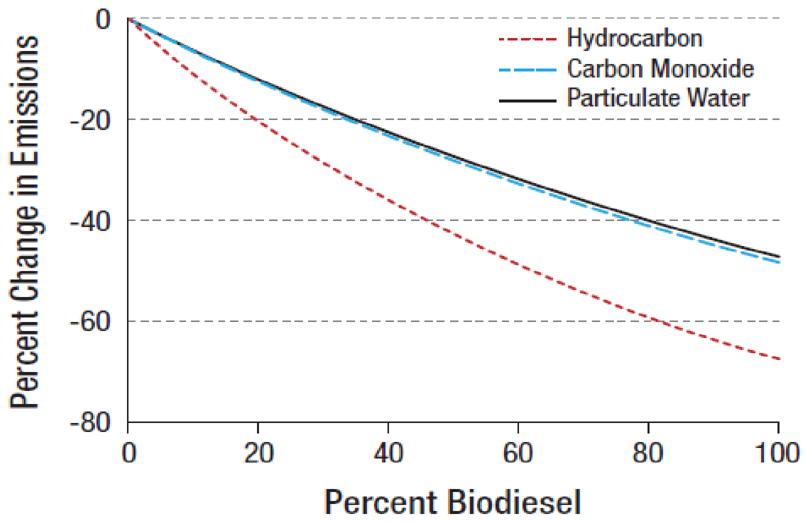
In contrast, manufacturers have no issues with HVO blends since HVO closely resembles diesel fuel. One option being considered in Germany is a blend of FAME and HVO called R33 which is 7% FAME and 26% HVO blended with diesel. This blend has been road tested by the University of Coburg in 250 vehicles since around September of 2013, and the website for the University states that the program was successful with no problems encountered. However, there is no formal or scientific report on the findings available publicly to date (March 2015).

2.4.3 Impact of higher biodiesel blends

Since FAME is the primary bio-diesel component in use today, its emission effects are explored for heavy-duty and light duty vehicles respectively.

FAME is an ester that contains 11 $\pm$ 1% oxygen by weight (Lopes, et al., 2014). Typically, when oxygen-rich fuels are combusted, a reduction of Particulate Matter (PM), Hydrocarbon (HC), and Carbon Monoxide (CO) is expected. One of the earliest analyses of the effects of FAME was completed by the US EPA in 2001. The agency reviewed 80 FAME emission tests on heavy-duty diesel engines from the 1990 to 2000 time frame corresponding approximately to Euro 1 and 2 emissions certification levels, and concluded that the emission benefits are predictable over a wide range of FAME blends.

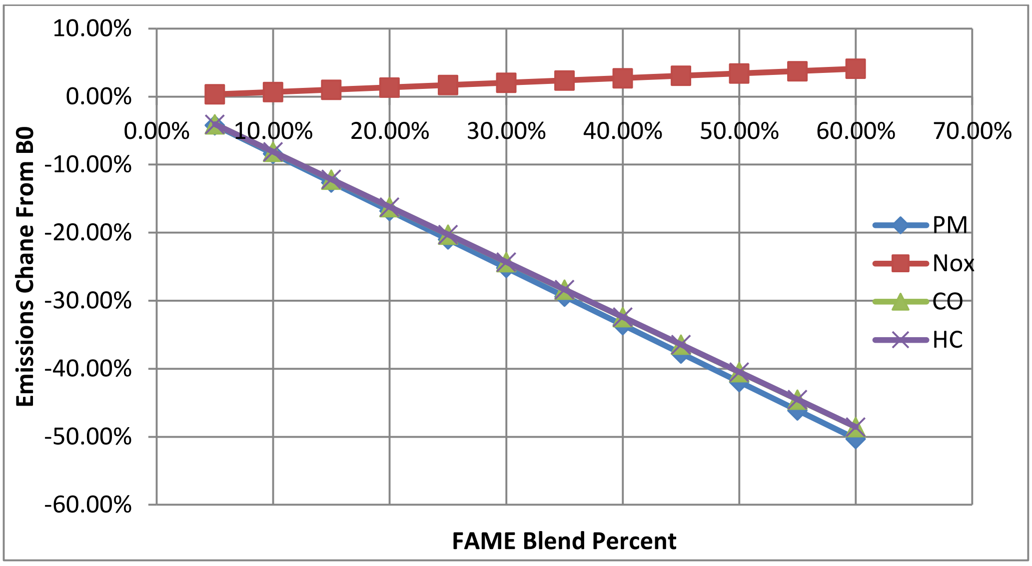
Figure 2.10 Emission Impacts of FAME Blends for 1991-2000 Heavy –Duty Diesel Engines.



Source: US EPA, 2002

The EPA data was collected through literature review using selective screening criteria and regression analysis was used to correlate the concentration of biodiesel in a conventional diesel fuel with changes in emissions. The results shown in Figure 2.10 indicate that a B20 blend would reduce PM and CO by 10% and HC emissions by 20%, with the curves being approximately linear to B30. NO_x emissions were found to increase and the EPA study noted that a B20 blend would increase NO_x by 2%. However, the EPA study is quite dated (from 2002) as the engine sample included 2 stroke engines that were no longer in production after 1995 and had few or no European and Japanese engines. In 2012, the National Technical University of Athens has published a statistical investigation of emissions reductions from bio-diesel blends, based on comprehensive literature review of published data (Giakoumis, 2012, p.273-291).

Figure 2.11 Emissions Reductions in Heavy-Duty Euro 3 and 4 Certified Engines with FAME Blends (Engine Based Transient Cycle Testing)



Source: Giakoumis, 2012

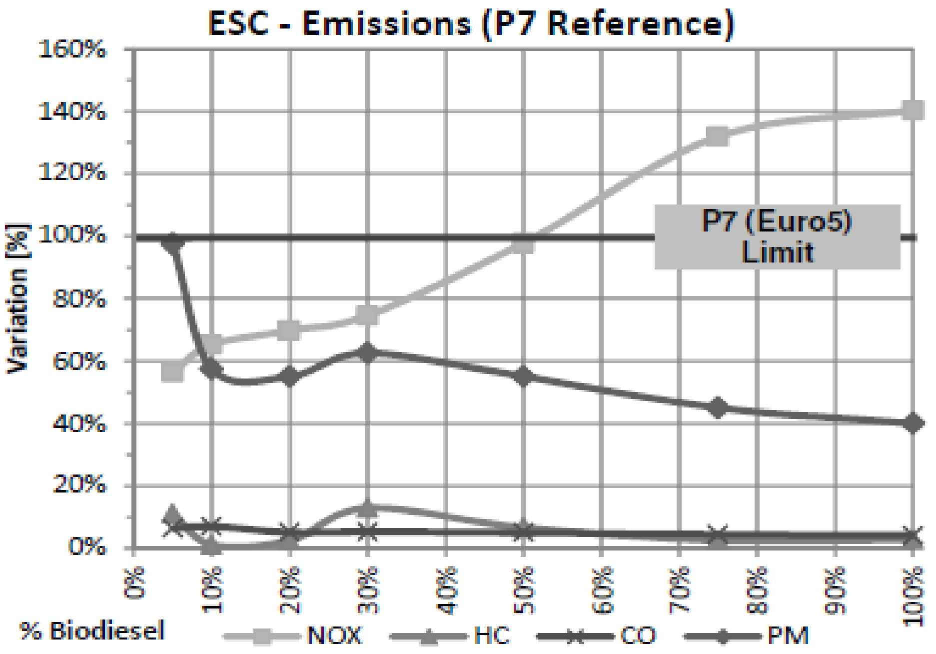
Data up to the end of 2011 was gathered and reported results were statistically analysed as a function of biodiesel content, test cycle, engine type (i.e., heavy or light-duty) and dynamometer schedule (chassis or engine). Separate best-fit curves were developed each case and for each exhaust pollutant. Although the sample included Euro 4 and Euro 5 certification engines with PM traps, only engine-out emissions were analysed. The sample did not contain any vehicles with NOx after-treatment devices.

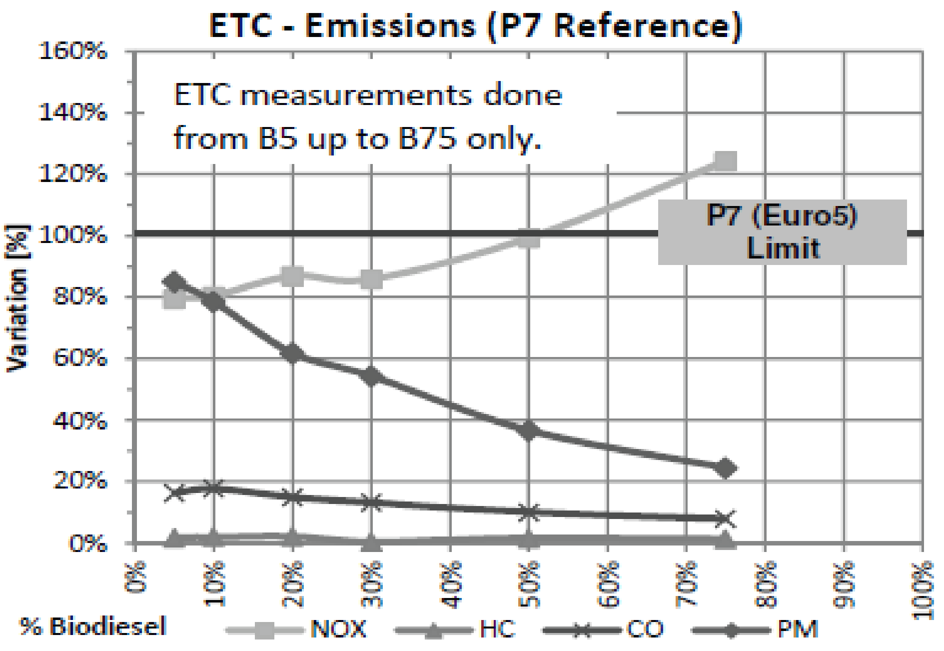
The emission trends, as represented by engine dynamometer testing data were established using published European Transient Cycle (ETC) and the World Harmonized Test Cycle (WHTC) results. The author concluded that the trends based on the heavy-duty engine dynamometer test results are consistent with EPA historical observations. The results for the heavy duty emissions regressions are shown in Figure 2.11. The regressions fitted were quadratic and while the square term coefficient is significant in some cases, it is quite small so that the results appear almost linear. The HC, CO and PM reductions with increased FAME blends are very similar to each other at about 16% reduction for a B20 blend and 24% for a B30 blend, (or about a 8% decrease for every 10% increase in FAME content) which are generally similar in magnitude to the results reported by EPA on older engines, except for PM emissions. The author thought the larger PM reduction observed by EPA was due to the high sulfur content of diesel fuel used in the older tests, so that sulfate PM reduction by FAME blending increased the PM reductions. The NO_x emissions increase is also quite linear, increasing by 0.7% for every 10% increase in FAME content, which is smaller than the increase reported by the EPA. Many, but not all, Euro 2 and 3 heavy-duty engines were equipped with an oxidation catalyst, which should result in significantly smaller benefits for HC and CO emissions, but only slightly lower PM emission benefits since the catalyst is not effective in oxidizing black carbon.

Tests of Euro 5 certified heavy duty engines with different bio-diesel blends are quite limited in the public literature. Mercedes-Benz Brazil published a paper with test results for biodiesel blends ranging from B5 to B100 (Machado, et al., 2013). The dynamometer test setup was equipped with Mercedes-Benz OM926LA Euro-5 certified heavy duty engine equipped with Urea Selective Catalytic Reduction (SCR) NO_x after-treatment system but no PM trap. The engine was tested following the ESC and ETC (EU Steady State Cycle and EU Transient Cycle) test methods, a B5 FAME blend was used as the reference fuel and B10, B20, B30, B50 and B75 blends were tested on both steady state and transient cycle tests.

Emission trends with increased FAME content were directionally similar on the two tests as shown in Figure 2.12. HC and CO emissions were far below standards on both tests with the base B5 blend, and showed some decline with increased FAME content. PM emissions were close to applicable standards with the B5 base fuel, and declined almost linearly with increased FAME content on the transient test. On the steady state test, PM emissions were near flat over the B10 to B50 range with a more modest decline for higher FAME blends. NOx emissions increased by about 20% on the transient test when FAME content increased from B5 to B50, but there was a larger increase on the steady state test between the B5 and B50 fuels. It should be noted that there was no adjustment of the urea dosing rate when tested with different fuels.

Figure 2.12 Emissions test results for various biodiesel blends versus B5 reference fuel on the Heavy-Duty ESC and ETC cycles.



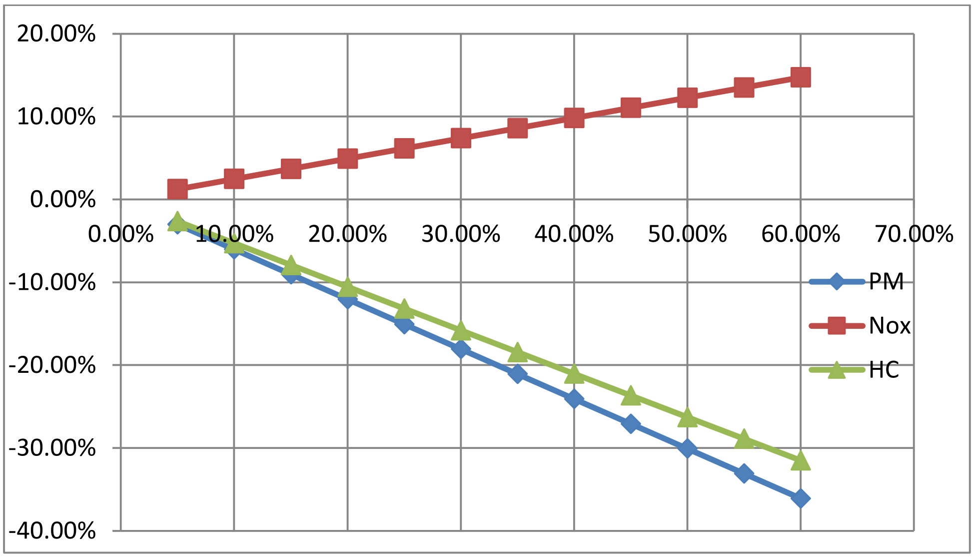


Source: Machado, et al., 2013

2.4.3.2 Light Duty Diesel Emissions with FAME Blends

As described in the heavy-duty Section, the National Technical University of Athens has published a statistical investigation of emissions reductions from bio-diesel blends, based on comprehensive literature review of published data (Gaikoumis, 2012, p.273-291) for light duty vehicles as well. Data was mostly on vehicles conforming to Euro 2, 3 and 4 certification gathered and reported results were statistically analysed as a function of biodiesel content, test cycle, and dynamometer schedule (chassis or engine). For light duty vehicles, most of the test results were chassis dynamometer based and most of the testing was on the NEDC cycle. Separate best-fit curves were developed each case and for each exhaust pollutant. Although the sample included Euro 4 and Euro 5 certification light vehicles with PM traps, only engine-out emissions were analysed. The sample did not contain any vehicles with NO_x after-treatment devices.

Figure 2.13 Changes in Light Duty Emissions (NEDC Cycle) with increasing FAME blends



Source: Gaikoumis, 2012, p.273-291

Emission reductions relative to B0 were modelled as a quadratic function of blend FAME content. The light duty regressions had much less explanatory power than the heavy-duty regressions, implying significantly higher car-to-car variation, and the regressions for CO emissions were not statistically significant. The light duty regression results are shown in Figure 2.13.

As in the case of heavy-duty emissions, the changes are almost linear with increased FAME content up to 60%, and PM emissions decrease by 6% for every 10% increase in FAME content, while HC emissions decrease by 5.2%. NOX emissions increase by 2.5% for every 10% increase in FAME. The PM and HC decreases are a little lower than those estimated for heavy-duty engines while the NO_x increase is somewhat larger. Other researchers have reported that NO_x emissions with bio-diesels made from saturated esters (such as animal fats) are lower than NO_x emissions from pure diesel.

Data from PM trap and urea-SCR after-treatment equipped vehicles certified to Euro 5 or 6 standards are less common. Researchers from the University of Aveiro (Lopes, et al., 2014) published results of emissions characterization from a Euro 5-certified passenger car using various biodiesel blends including B7 and B20. The tested vehicle was a MY2011 Renault Megane with a 1.5L Turbocharged Direct Injection diesel equipped with EGR and a catalyzed PM filter. The vehicle was tested on chassis dynamometer over the NEDC cycle, and tests were repeated four times for each fuel blend.

The criteria emissions results for CO and PM were found to have no specific direction with increased bio-diesel content in the fuel. The PM difference could not be established by weighing the PM filter after each test cycle, as the differences were at measurement noise levels. The CO difference could not be detected due to the exhaust measurement equipment resolution. The HC emissions factors were higher for all biodiesel blends, particularly for the B7 blend. However, HC emissions with B20, while higher than those with B0, were significantly reduced compared to the B7. The researchers attribute this decrease to higher cetane number and higher oxygen content for the B20 fuel, which leads to more complete combustion. The B7 emissions increase was related to specific HC species present in the low biodiesel blend versus pure diesel.

NO_x emissions were higher for the B7 relative to B0, but only slightly, by about 0.5%, and were still lower than the Euro 5 limits. Interestingly this study demonstrated that the NOx emissions were lower for B20 by 10.8% and 11.4% relative to the emissions with B0 and B7, respectively. The researchers speculated that the B20 result was due to higher EGR contribution to the combustion process which compensated for the higher oxygen content in the B20. The test results indicate that the emissions from PM trap and urea-SCR after-treatment equipped vehicles are much less sensitive to the presence of bio-diesel but large scale confirmatory testing of many vehicles is required to validate this conclusion.

Vehicle test results

Emission tests were conducted on a Euro VI compliant diesel vehicle, 2L Peugeot 508, to the WLTC. The vehicle was not optimised for the three fuels examined, B7, B10 and B30.

Table 2.3 presents the average recorded emissions, based on three vehicle tests, for the three test fuels. Further details of the test programme are presented in Annex 5.

Table 2.3 Emission summary averages over WLTC cycles – Diesel

Test Fuel	NO_2 (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)
B7	219	6	80	572	152	1	8.60E+09
B10	217	10	89	557	151	1	2.60E+10
B30	259	9	89	609	151	1	2.64E+10

Carbon monoxide (CO), particulate mass (PM) and number (PN) are approximately >80%, >75% and >95% lower, respectively, than the exhaust emission limits defined by the Euro 6 standard for passenger cars. More significantly, NOx emissions are over 7 times higher than Euro 6 limits. As noted earlier, CO_2 emissions targets for new cars (130 g/km) as defined by Regulation (EC) No 443/2009[71] are based on the car fleet, and not individual vehicles. Since CO_2 emissions will vary based on the power and size of the engine tested, the results presented in Table 2.3 are not comparable to the CO_2 regulated target.

Emissions for THC, CO, and PN increase from B7 to B30, while there is no noticeable change for PM. However, differences in emissions are within the standard deviation of the measurements; so they are not statistically different from zero. As such, no conclusions can be drawn on the emissions trends.

For NOx, the results were very high compared to the Euro 6b M1 limit of 80mg/km. Average NOx results were 572mg/km for B7, 557mg/km for B10 and 609mg/km for B30, which range from 7.2 to 7.6 times greater than the Euro 6b limits. However, the Euro 6b limits refer to a vehicle run over the New European Drive Cycle (NEDC) cycle, for this project the Worldwide Light-duty Test (WLTP) cycle was used. NOx is primarily produced during high load and high temperature combustion, and so more NOx is typically emitted during acceleration. As such, the higher emissions are likely due to the different acceleration profiles of the NEDC and WLTC cycles.

For reference, the Peugeot 508 2.0L BlueHDI diesel test vehicle achieved a NOx level of 57mg/km during type approval test work (data obtained from http://carfueldata.direct.gov.uk). Whilst the test vehicle achieved NOx levels in magnitudes higher than the type approval

[71] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009R0443-20130508

limit, it is likely that this behaviour is attributable to the diesel vehicle rather than the biofuels, as directionally similar results have been observed in other studies when running cycles other than the NEDC. For example, (J. May, 2014), noted that when testing 2 diesel vehicles, NOx emissions using WLTC was nearly 4 times greater than the Euro 6 limit. Furthermore, a recent study by (ICCT, April 2014), which tested 15 diesel cars from 6 different manufacturers, noted that using a Real Driving Emissions (RDE) test programme resulted in average NOx emissions which were 7.1 times greater than the Euro 6 limit. The variations in results between tests are likely due to the different vehicle/engine types, since outcomes will be dependent on engine design, engine calibration, and the after-treatment system.

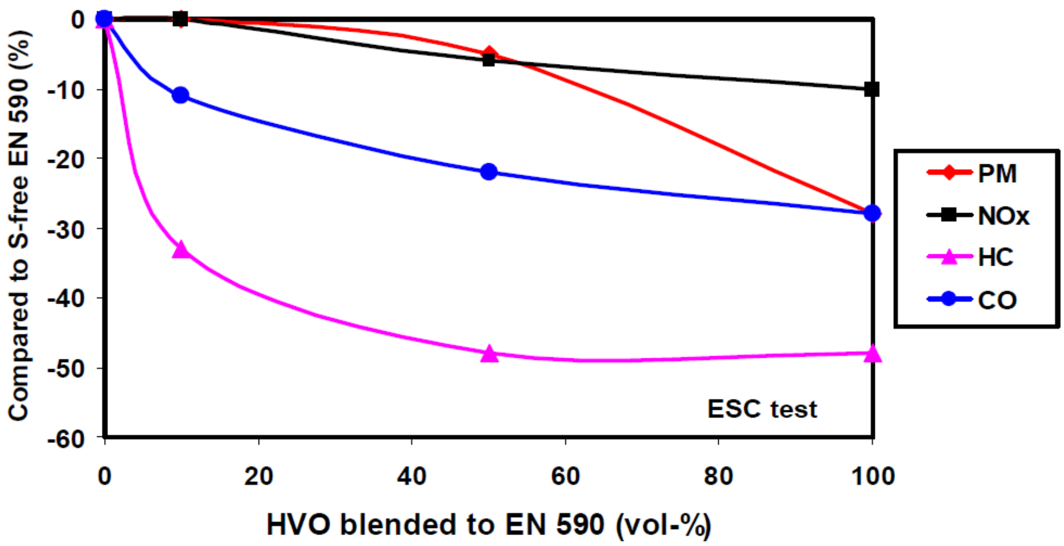
As a precaution, the vehicle was checked for any trouble codes (none were present), the Selective Catalytic Reduction (SCR) system was checked for distance remaining until refill of the AdBlue tank was required and found the level to be greater than required for project completion. The vehicle literature was also checked, which confirmed that it's AdBlue system warns when low levels are present and prevents the vehicle engine from starting if the SCR system is deemed not to be working (empty/faulty).

Overall, although the vehicle tests represent a small sample size, the results for NOx indicate a broader issue surrounding the impact of different test cycles on vehicle emissions. This warrants further investigation.

2.4.3.3 Emissions with HVO Blends

HVO has a different set of properties compared to FAME fuels. Neste Oil has researched the emissions implications for its blends extensively and the company claims that, compared to the neat diesel fuel, HVO reduces NO_x, CO, HC and PM emissions. However, the magnitude of reductions depends on EGR and exhaust after-treatment strategies (Neste Oil, 2014).Neste claims are substantiated by emissions tests for 32 heavy duty trucks and buses or their engines and several passenger cars. The tests results from a recent SAE paper are summarized in Figure 2.14.

Figure 2.14 HVO Heavy Duty Engine Emission Test Results over the ESC Cycle.as a Function of HVO Content

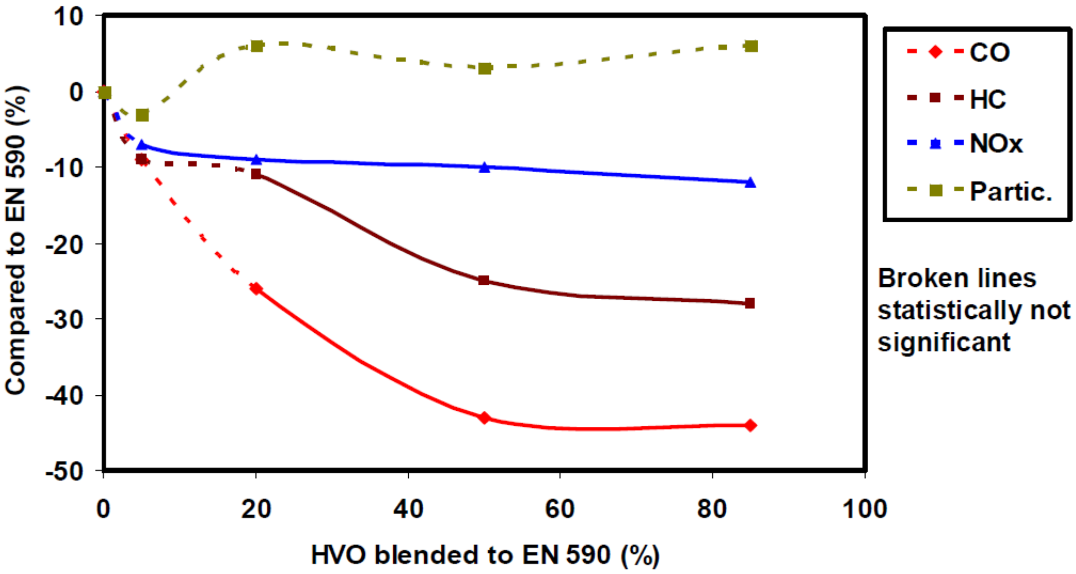


Source: Aatola, et al., 2008

The heavy duty results were obtained following the ESC test procedure. The engines were certified to Euro IV standards, equipped with EGR but had no PM or NO_x after-treatment. Neste observed that NO_x emissions were <u>reduced</u> linearly in proportion to the HVO blend content increase. The PM reduction for low level HVO blends was small but increased for mid-level blends. The CO and HC reduction was more significant for low level blends (Aatola, et al., 2008).

Passenger car data was obtained from New European Driving Cycle (NEDC) testing using test vehicles equipped with EGR and Diesel Oxidation Catalysts (DOC) but without a PM trap or urea-SCR after-treatment. The results indicate that, for low HVO blends the emissions changes were highly variable, hence the trends were deemed to be statistically insignificant. For higher blends the PM results remained “flat” indicating that HVO blending has little influence on PM emissions. Starting from the 5% blend level, the NOx reduction was statistically significant (reduction by about 7% for B10) and the benefit increased to 10% for HVO B20. The HC and CO emissions reductions were statistically significant starting from HVO B20 blends.

Figure 2.15 Passenger Car Emissions Test Results over the NEDC Cycle Compared to Regular EN590 Diesel as a Function of HVO Content



Source: Neste Oil.

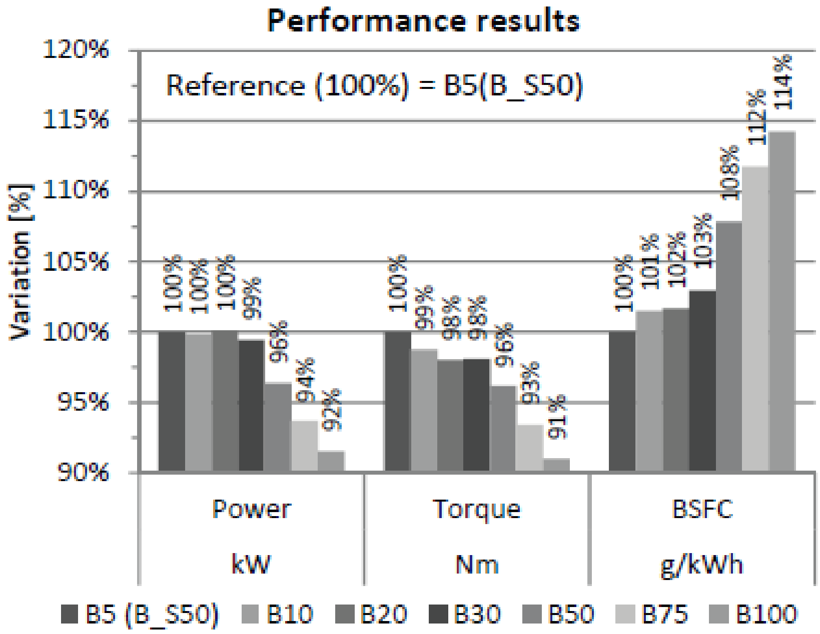
From this literature review it can be concluded that, for the light duty diesel vehicles, the use of modern after-treatment devices results in very small, if any, emissions penalty for low HVO blends such as B7. Recent tests indicate that PM and CO reduction cannot be easily confirmed due to measurement limitations. The NO_x emissions penalty appears to be detectable but the difference for low HVO blends is very small.

2.4.3.4 Fuel Consumption Effects

FAME has an energy content that is 10 to 12 percent lower than that of hydrocarbon diesel fuel, and a B7 FAME blend will have about 0.8% less energy per unit volume than the energy in B0. Historic test data has correlated bio-diesel blend energy content to volumetric fuel consumption although the small differences of 1% or less makes measurement accuracy an issue. Tests on newer engines such as those conducted by researchers at the University of Aveiro (Lopes, etal., 2014) showed fuel consumption impacts over NEDC, UDC and EUDC cycles. The data showed that, compared to pure hydrocarbon diesel fuel, fuel consumption for B7 increased from 5.86 l/100km to 5.92 l/100km or about 1% (the comparison represents average fuel consumption over the NEDC cycle). However, the tests performed with B20 revealed a decrease in fuel consumption by almost 1%, when compared to neat diesel. The researchers opined that B20 combustion in the EGR-equipped engine resulted in more efficient operation, although more data is needed to confirm this trend. Nevertheless, it should be noted that impacts of FAME blends on fuel consumption are quite small, in the range of 0 to 2%.

For the heavy-duty fuel efficiency assessment, the Mercedes-2013 study (Machado, et al., 2013) provides the Brake Specific Fuel Consumption (BSFC) performance using different biodiesel blends. The table above provides the results summary with B5 being the reference fuel (since Brazilian diesel fuel currently has 5% biodiesel content). The results for low-level blends B10, B20 and B30 seems to suggest that for each 10% increase in the biodiesel content, roughly 1% BSFC-based consumption penalty should be expected with about the same 1% degradation in available torque.

Figure 2.16 Nominal power, torque and BSCF for various biodiesel blends, when compared to B5 base fuel



(Results are presented an Index Format with B5 being 100% and other Blends ComparedRelative to B5).

Source: Machado, et al., 2013

Neste Oil has documented that the vehicle-level fuel consumption relationship for various HVO blends is basically linear with the measured caloric heating values (on MJ/l basis). Since HVO has about 3 to 4% lower energy per unit volume compared to diesel, a HVO 20 blend will have only 0.6% to 0.8% lower energy with similar volumetric fuel consumption increases.

In conclusion, the literature review for low-content biodiesel blends (in the B5 to B30 range) on fuel efficiency effects appears to indicate that fuel consumption is inversely related to blend energy content. There will be a volumetric fuel consumption penalty for both FAME and HVO fuel blends, as expected based on their lower energy content. For B5 to B20 blends the penalty will be small, in the order of 0.5% to 2% for FAME blends and about half that for HVO blends, versus conventional B0 diesel for both light duty and heavy-duty diesels.

Vehicle tests

As with the petrol vehicle, the 2L Peugeot 508 used for the vehicle tests was tolerant, but not optimised, to the higher biodiesel blends. Against the B7 reference fuel, a +1.5% and +1% improvement in volumetric fuel consumption was achieved by B10 and B30, respectively. These results are contrary to observations from literature, which indicate that fuel consumption will increase as the blend energy content decreases. Nonetheless, the impacts of FAME blends on fuel consumption are still very small.

Table 2.4 Fuel consumption averages over WLTC cycles – Diesel

Test Fuel	Fuel Cons (L/100km)
B7	5.81
B10	5.72
B30	5.75

2.5 Conclusions

2.5.1 Petrol blends

Future improvements in petrol engine technology is expected to progress in two directions. Both approaches would in principle not be negatively impacted by the use of higher ethanol blends. The first, favoured by European manufacturers, will rely on increased turbocharger boost and engine downsizing to improve fuel economy. The second, favoured by Japanese manufacturers, will use very high compression ratios (13 to 15) in combination with Atkinson or Miller cycles. Both approaches will not change the impact of ethanol blends relative to their impact on current engines, but can be assisted by the higher octane number of ethanol. The European approach of higher turbocharger boost pressures is likely to be more favourably impacted by higher octane fuel than the Japanese approach.

Expansion of E10 availability to all countries in the EU with E5 blend as the protection fuel maintained available. This is the least controversial option and there are no technical issues related to this option. There are small positive benefits for emissions of regulated pollutants and air toxics. This option would have no impact on the auto-manufacturers future products

Replacement of E5 as the protection fuel with E10 across the EU in 2020. This option will negatively affect between 1.3% and 6.8% of the 2020 EU passenger vehicle fleet; i.e., mostly older vehicles produced before 2003, in which fuel leaks or fuel system corrosion could occur. Upgrading these vehicles with new fuel system gaskets and elastomers could solve most issues satisfactorily but there will be a subset of these vehicles where there may be more serious consequences like engine fires, and these would require hardware changes. Unfortunately, there is no public data on affected models and the EU must work with auto-manufacturers to identify affected vehicles, upgrade costs and affected populations in 2020. There are small positive benefits for emissions of regulated pollutants and total air toxics associated with this strategy, although aldehyde emissions can increase significantly (see table below).

Manufacturers are favourably disposed towards E20, but only if the new E20 fuel is a tailored (“splash”) blend fuel rated at 100+ RON as a premium fuel that can be used by purpose designed cars starting in 2020. E20 fuel with the same octane rating as current E5 and E10 fuels will have a 6.5 to 7% increase in fuel consumption and would offer no benefit to the consumer in vehicle models not capable of exploiting the octane advantage of E20 . In contrast, the high octane E20 strategy would have the advantage of providing a 3% to 6.4% energy efficiency benefit potential for the auto-industry and provides value to the customer from the high octane rating of ethanol in vehicle models capable of exploiting the octane advantage of E20 (that auto-manufacturers would yet have to introduce). (Volumetric fuel consumption would change by -2.5% to +1%).

A high octane E20 fuel could slowly displace hydrocarbon based premium petrol (98+ RON) in the EU over the 2020 to 2030 period provided auto-manufacturers introduce more vehicle models capable of exploiting the octane advantage of E20. The intent of this scenario would be to introduce E20 as a premium fuel but work towards making it the mainstream fuel of choice for most consumers by 2030. The fuel would have negligible effects on regulated pollutants but could result in reduced toxics emissions. In purpose designed cars, the costs of this phasing in of E20 are near zero for naturally aspirated engines and estimated under Euro 50 for turbocharged engines if the changes are incorporated in the design stage. This strategy will affect future manufacturer product plans, which would need to be changed to accommodate the phasing in of E20 as engines will be modified to take advantage of the high octane of E20 splash blends. A lead time for 4 to 5 years will be required for manufacturers to design such engines. For non-E20 tolerant vehicles, optimisation costs will be significantly more; consequently, an E10 protection grade will be required.

A quantitative summary of the literature review (Section 2.3.3.1) is provided in the table below with values relative to E0 fuel for Euro 2 to Euro 5 certified vehicles except in the case of purpose designed E20 engines.

Table 2.5 Petrol blends - quantitative summary based on literature review

	E5	E10	E20 on current vehicles	E20 on purpose designed engine
Hydrocarbon (HC)	No trend	No trend	3 to 5% lower	No trend
Carbon monoxide (CO)	~ 5% lower	~ 10% lower	~ 20% lower	~ 20% lower
Nitrogen oxides (NO_x)	~ 1% higher (Euro 2/3), small* absolute increase for Euro 4/5	~ 1 to 2% higher (Euro 2/3), small* absolute increase for Euro 4/5	~ 2 to 3% higher (Euro 2/3), small* absolute increase for Euro 4/5	No change
Particulate mass (PM)	~ 5 to 10% lower	~ 10 to 20% lower	~20 to 30% lower	~20 to 30% lower
Toxics	Undetectable change	Lower benzene, higher (~5 mg/km) acetaldehyde	Lower benzene, ~+10 mg/km acetaldehyde	Lower benzene, but potentially similar aldehydes
Carbon dioxide (CO_2)	No change	No trend	~ 1 to 2% decrease	4% - 7% decrease potential
Other Issues	None	May cause problems in some pre-2003 models	Tolerated only by post-2011 models	Requires splash blend with RON of about 100

**Increase in the range of 10 to 20 mg/km*

Vehicle emissions testing results indicate that pollutant emissions from both E10 and E20 will meet exhaust emission limits defined by the Euro 6 standard for passenger cars.[72] Specifically, results indicate that total hydrocarbon (THC), particulate mass (PM) and particulate number (PN) are 80% lower than Euro 6 emissions limits, while non-methane hydrocarbon (NMHC) is over 70% lower. Carbon monoxide (CO) and Nitrogen oxides (NOx) vary between 50-70% and 18-46%, respectively, below Euro 6 emission limits. Particulate emissions from this vehicle would struggle to meet the Euro 6 particulate number limit of 6,0 $x10^{11}$ that will be introduced in 2017.

THC, NMHC, CO_2 and PM emissions trends between E10 and E20 agree directionally with observations from the literature review, but NOx and CO results were inclusive. Similar to the results presented in Table 2.5, there was no change in the THC emissions between E10 and E20, and a slight decrease of 4% and 2% in NMHC and CO_2 emissions, respectively. PM emissions decreased from E10 to E20; however, the percentage change was greater than that presented in Table 2.5 due to the low values reported and the emissions being within measurement sensitivities. NOx and CO data was subject to high Coefficients of Variance (CoV), in part due to low emissions values (NOx) and due slight

72 Regulation (EC) No 715/2007

changes in vehicle handling (NOx and CO), although, overall, the drive trace was within legislative limits.

2.5.2 Diesel blends

Future improvements in diesel engine technology is expected in principle not to be negatively impacted by the use of higher biofuels blends. Light and heavy duty diesel engine technology is expected to progress along a path of increased turbocharge boost pressures, and engines being further downsized. However, fundamental changes in diesel combustion technology are not expected in the 2030 timeframe. As such, current diesel fuel properties will be suitable for future diesel engines.

Expansion of B7 blend use to all countries in the EU with max. FAME content up to the allowed 7% requires no changes to vehicle technology and can be implemented immediately. Additional B7 use will result in decreases in PM, HC and CO emissions from most vehicles, although the PM decreases from trap equipped vehicles may be undetectable. NOx emissions could increase by zero to 1%. This option will have no impact on auto-manufacturers.

Use of B10 with 10% FAME blends instead of B7 will have emission effects similar, although slightly larger, to that of B7. However, vehicles with duty cycles having short trip lengths and many cold starts daily can experience significant oil dilution issues. The technical solution to this problem is improved monitoring of engine oil and more frequent oil change intervals. This option will not impact manufacturers new technology or require changes in product plans or but could result in the oil change interval being reduced from current levels of 25,000 to 30,000 km to less than 20,000 km. In addition, B10 use may not be allowed in winter months.

Expansion of B30 FAME bio-diesel use in "captive" fleets across the EU can be implemented by owners of large fleets in conjunction with an oil dilution monitoring program and more careful oversight of fuel quality. B30 FAME blends may not be suitable for consumer use. The duty cycle of these captive fleets should not include extensive low speed short trip operations. It is unclear if any upgrades of the fuel system are needed for modern (post-2010) vehicles to use B30, but vehicle hardware changes required, if any, are expected to be minor. The fleets can also use B7 seasonally if necessary, under cold winter weather conditions to avoid any filter plugging problems. With the use of B30, HC, PM and CO emissions from Euro 4 and earlier certification vehicles can decrease by 15% to 25%, while NO_x emissions and volumetric fuel consumption may increase by 1% to 2% relative to B7 fuel. In modern vehicles certified to Euro 5 and 6 standards, PM and HC emission declines and NO_x increases if any may be too small to be reliably detected. This option is more likely to affect heavy-duty diesel engine manufacturers who will have to coordinate the fuel use with improved oil dilution monitoring.

Addition of a new HVO+ FAME blend that could utilize 7% FAME-diesel with any level of HVO up to 26% is possible without any negative performance effects for all diesels. In general, HVO use with diesel or B7 FAME-diesel blends will result in emission declines for all regulated emissions, but volumetric fuel consumption could increase by about 0.5% for every 10% increase in HVO content in the blend. It is possible that with modern diesels with EGR, there may be no fuel consumption penalty with HVO, but this cannot be confirmed without more test data. This option will likely have no effect on auto-manufacturers, but fleet test data to confirm this is not yet available (but could be available later in 2015)

There are concerns about the oxidation stability of FAME when used in plug-in vehicles where the tank fuel can be present for several months if the vehicle is operated primarily in electric mode. Not much is known about this issue as plug-in diesels have entered the market in 2014, but is an area of manufacturer concern for the future.

The quantitative results of the literature review (Section 2.4.3.2) are summarized for all bio-diesel blends considered relative to pure hydrocarbon diesel or B0 in the Tables below.

Table 2.6 Summary of blend effects on light duty diesels

	B7 FAME	B10 FAME	B30 FAME	B30 HVO
Hydrocarbon (HC)	~ 4% reduction	~ 5% reduction	~ 15% reduction	~ 15% reduction
Carbon monoxide (CO)	~ 4% reduction	~ 5% reduction	~ 15 % reduction	~ 35% reduction
Nitrogen oxides (NO_x)	0 to 1% increase	0 to 1% increase	7 to 8% increase for Euro 2, 3 and 4, no change for Euro 5 vehicles	~ 10% decrease for Euro 2, 3, 4 no change for Euro 5, 6.
Particulate mass (PM)	~ 6% reduction for Euro 2, 3, 4, no change for Euro 5	~ 8% reduction for Euro 2, 3, 4, no change for Euro 5	~ 18% reduction for Euro 2, no change for Euro 3, 4 and 5	0 to 10% increase for Euro 2, no change for Euro 3, 4 and 5.
Carbon dioxide (CO_2)	No trend	No trend	No trend	No trend
Other Issues	FAME must meet EN14214 standards	Oil dilution by FAME can be a problem for some vehicles.	Careful check of fuel properties and oil dilution required.	No significant issues

Table 2.7 Summary of blends effects on heavy duty diesels

	B7 FAME	B10 FAME	B30 FAME	B30 HVO
Hydrocarbon (HC)	~ 6% reduction, 0 to 2% with oxidation cat.	~ 8% reduction, 0 to 2% with oxidation cat.	~ 25% reduction, 10 to 15% with oxidation cat.	~ 35 to 40 % reduction, 20 to 25% with oxidation cat.
Carbon monoxide (CO)	~ 6% reduction, 0 to 2% with oxidation cat.	~ 8% reduction, 0 to 2% with oxidation cat.	~ 25% reduction, 5 to 10% with oxidation cat.	~ 15% reduction, 3 to 5% with oxidation cat.
Nitrogen oxides (NO_x)	0 to 1% increase	0 to 1% increase	1 to 2% increase for Euro 2, 3 and 4, no change for Euro 5 vehicles	~ 0 to 1% decrease
Particulate mass (PM)	~ 6% reduction, no change for Euro 4/5	~ 8% reduction, no change for Euro 4 and 5	~ 25% reduction, no change for Euro 4 and 5	No change
Carbon dioxide (CO_2)	No trend	No trend	No trend	No trend
Other Issues	FAME must meet EN14214 standards	Oil dilution by FAME can be a problem for some vehicles.	Careful check of fuel properties and oil dilution required.	No significant issues

Vehicle emissions testing results indicate that CO, PM, and PN emissions from B7, B10 and B30 will meet Euro 6 exhaust emission limits for passenger cars.[73] Carbon monoxide (CO), particulate mass (PM) and number (PN) are approximately >80%, >75% and >95% lower, respectively, than the exhaust emission limits defined by the Euro 6 standard for passenger cars. Emissions for THC, CO, and PN increase from B7 to B30, while there is no noticeable change for PM. However, differences in emissions are within the

[73] Regulation (EC) No 715/2007

standard deviation of the measurements; so they are not statistically different from zero. As such, no conclusions can be drawn on the emissions trends.

NOx emissions were over 7 times greater than Euro 6 limits, due to issues associated with the test cycle rather than biofuel blends. Euro 6b limits are based on vehicles using NEDC tests. For type approval testing (NEDC), the test vehicle, Peugeot 508 2.0L BlueHDI, achieved a NOx level of 57mg/km (within the 80 mg/km Euro 6 limit). However, this study used the WLTC cycle, where NOx emissions on the order of 550-600 mg/km were observed. These test results are directionally similar to results from other studies which have compared NOx emissions from NEDC against other test cycles, such as WLTC and RDE. Overall, although the vehicle tests represent a small sample size, the results for NOx indicate a broader issue surrounding the impact of different test cycles on vehicle emissions. This warrants further investigation.

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3 Effects on air quality and implications for vapour pressure

Abbreviations/acronyms

API	American Petroleum Institute
CO	Carbon monoxide
CO_2	Carbon dioxide
DPVE	Dry vapour pressure equivalent
EEA	European Environment Agency
FFV	Flex fuel vehicle
HDV	Heavy duty vehicle
LDV	Light duty vehicle
NMHC	Non-methane hydrocarbons
NMVOC	Non-methane volatile organic compounds
NOx	Nitrogen oxides
PM	Particulate matter
RVP	Reid vapour pressure
SOx	Sulphur oxides
THC	Total hydrocarbons
VOC	Volatile organic compounds
VP	Vapour pressure

3.1 Summary

Increasing biofuel blends may result in air quality impacts at various points in the supply chain. Starting with the refining of biofuels, emissions will also occur at storage tanks, transport of the biofuel to the point of use, and during vehicle use. Although some emissions are likely during transport and storage (e.g., tailpipe, evaporative), the primary focus of Chapter 3 will be refinery emissions, and vehicles, both tailpipe and evaporative emissions.

Refinery emissions were calculated using refinery fuel consumption estimates from the EnSys WORLD model analyses and industry average emission factors[74]. Vehicle tailpipe emissions were developed using the results from vehicle emissions tests, literature and TREMOVE vehicle fleet projections. Evaporative emissions impacts were assessed based on literature review.

3.1.1 Refinery air quality impacts

In the refinery sector, emissions of air pollutants and CO_2 in the Base Case are expected to decline through 2030 from 2010/2013 levels. SOx, NOx and NMVOC emissions are about 55%, 45% and 35%, respectively, below 2013 levels. For CO and PM, emissions in 2030 are

[74] CONCAWE, "Air Pollutant Emission Estimating Methods for E-PRTR Reporting by Refineries," Report No. 3/15, Brussels (April 2015)

approximately 50% and 55%, respectively, lower than 2010 levels as reported by the European Environment Agency. These declines are directly linked to reduced refinery throughput, and associated lower refinery fuel consumption. However, for Scenarios A, B and C that assume the production of higher biofuel blends through 2030 (Chapter 1, Section 1.7.3), the emissions of NOx, SOx, CO, CO_2, PM and NMVOC are estimated to be 2-5% higher than the Base Case scenario. This increase is primarily due to increased biorefinery production.

Even though there is a slight increase in emissions in the higher biofuel scenarios, compared to the Base Case, there will not be a detrimental impact on air pollution from the refinery sector as emissions are still greater than 30% lower than current levels.

3.1.2 Vehicle use air quality impacts

In vehicles, the level of exhaust emissions that results from the burning of biofuels depends upon the fuel (e.g. feedstock and blend), vehicles technology, and vehicle tuning and driving cycles. Most studies agree that using biofuels can significantly reduce most pollutants compared to petroleum fuels, including reductions in controlled pollutant as well as toxic emissions. However, it has noted that biofuels can lead to a slight (~1-2%) increase tailpipe NOx and hydrocarbon emissions.

Modelling results, under the analysed scenarios, indicate that regardless of the blending ratio (E10, E20, E25, B7, B10 or B30), vehicle tailpipe emissions compared to a Base Case using current biofuel blending levels, do not negatively impact air pollution. Pollutant levels of THC, NMHC, CO, and PM decline with higher biofuel blends. In 2030, LDV emissions of these pollutants across each scenario were on average 3%, 3%, 6% and 8% lower than the base case. For NOx, emissions were on average 1% higher than the base case in 2030. However, in the context of issues reported during vehicle tests (Chapter 2, Section 2.4.3.2), where NOx emissions were over 7 times greater than Euro 6 limits, due to issues associated with the testing cycle, the biofuel-related increases are comparatively marginal. CO_2 emissions for scenarios A, B and C were the same in 2020, and 0.2% lower in 2030 than the base case. For HDV, the trends were similar, although no declines in CO_2 were noted through 2030.

3.1.3 Vapour pressure

Fuel vapour pressure (VP) directly affects the quality of ignition, atomization, and combustion of a fuel. Thus, low pressures can have detrimental impacts, including delayed ignition, poor atomization, and problematic combustion. Ethanol and biodiesel by themselves have low vapour pressures; consequently, the magnitude of this property depends upon the composition of the biofuel. During the summer, pollution is a frequent concern due to increased levels of smog and ozone. As such, summer blends have a lower VP to prevent excessive evaporation when outside temperatures rise. However, if temperatures remain low, a higher VP would be required because the fuel must be able to evaporate at low temperatures for the engine to operate properly, especially when the engine is cold.

Annex III of the Fuel Quality Directive (FQD; 2009/30/EC) sets out allowed VP waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. The vapour pressure of ethanol in petrol gradually declines as its concentration rises above 5 volume %. As a result, going to higher ethanol blends does not mean increases in the ethanol waiver, rather the required waiver (in kPa) gradually declines out to and beyond 30 volume % ethanol.

Furthermore, an assessment of literature indicates that there would be no appreciable adverse evaporative emissions impacts from raising ethanol concentration in petrol. Ethanol content has some effect on permeation emissions but little effect on diurnal, running loss, and hot-soak emissions. Studies indicate that diurnal, refuelling and hot-soak emissions were unaffected by higher ethanol content in petrol. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but not within the E10 to E25 range. Any reduction in VP from blends above E5 should tend to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

3.2 Introduction

Increasing biofuel blends will result in air quality impacts at various points in the supply chain; i.e., refining, storage tanks, transport of the biofuel to the point of use, and during vehicle use. Although some tailpipe and evaporative emissions are likely during fuel transport and storage, the primary focus of this analysis will be refinery and vehicle emissions. During refining, combustion products include sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2), carbon monoxide (CO), non-methane hydrocarbons (NMHC), and particulates. In vehicles, the level of exhaust emissions that results from the combustion of biofuels depends upon the fuel (e.g. feedstock and blend), vehicle technology, and vehicle tuning and driving cycles. Furthermore, evaporative emissions or non-combustion emissions derive from fuel vapour generated in the vehicle fuel tank and the fuel distribution system to the engine. The magnitude of evaporative emissions is generally a function of fuel vapour pressure.

Based on the scenarios discussed in Chapter 1, Section 1.7.3, an assessment of the potential impacts of biofuel blends on CO_2 and air pollution emissions from refining and vehicle use has been conducted. As mentioned previously, the scenarios that are described and used in this assessment are not intended to represent precise predictions of the future, but rather provide a means to assess a hypothetical situation rooted in a technically feasible reality. Furthermore, the assumptions of the variables used in the modelling are often quite crude (for simplicity, but also to improve transparency) and the modelling itself can only provide a rough approximation of reality (for the same reasons). Nevertheless, the results for the three scenarios provide useful insight into the potential impacts and trends through 2030. The next sections list the main assumptions and air emissions results during refining (Section 3.3) and vehicle use (Section 3.4). Section 3.5 discusses work undertaken to examine the effects on petrol vapour pressure of higher ethanol blends, leading to a proposed extension to the “Annex III” ethanol waiver table, and also to research into literature on the impacts of higher ethanol blends on petrol emissions of volatile organic compounds (VOC’s), toxics and other regulated compounds

3.3 Refining air quality impacts

Petroleum refineries are complex systems of multiple linked operations. The specific operations utilized at a refinery depend on the type of crude refined and the desired products. For this reason, no two refineries are exactly alike. Depending on the refinery age, location, size, variability of crude and product slates and complexity of operations, a facility can have different operating configurations. This will result in relative differences in the quantities of air pollutants emitted and the selection of appropriate emission management approaches.

Refinery air emissions can generally be classified as either hydrocarbons or combustion products. When handling hydrocarbon materials, there is always a potential for emissions through seal leakage or by evaporation from any contact of the material with the outside environment. Thus, the primary hydrocarbon emissions come from piping system fugitive leaks, product loading, atmospheric storage tanks and wastewater collection and treatment. In terms of combustion products, a refinery uses large quantities of energy to heat process streams, promote chemical reactions, provide steam and generate power. This is usually accomplished by combustion of fuels in boilers, furnaces, heaters and the catalytic cracker. Combustion-related emissions account for the majority of pollutant emissions within a refinery.

In addition to petroleum refineries, pollutant emissions will occur at biorefineries. The likely sources of emissions within these facilities, include cellulose enzyme production (i.e., bioreactor), boilers, storage, water treatment facilities, and product recovery and upgrading (e.g., preheater, hydrotreating process). However, the boiler has been noted by NREL, 2014 as likely the single largest emitting source for CO, NOx, PM, SO_2, and GHG within a biorefinery.

3.3.1 Assumptions

The changes in EU refinery operations to meet the Base and Scenario A, B and C assumptions will lead to varying refinery fuel demands, which will produce changes to refinery emissions of air pollutants.

Estimates of refinery air pollutant emissions have been based on the emissions associated with fuel combustion only. Based on the assumptions described in Chapter 1, Section 1.7.3, refinery fuel consumption for each of the scenarios has been estimated by the WORLD model. Table 3.1 presents a summary of the type and quantity of fuel consumed in European refineries for each of the scenarios.

Table 3.1 Refinery fuel consumption in million barrels of fuel oil equivalent from the WORLD model

Fuel	2020 Base	2020 Scenario A, B and C	2030 Base	2030 Scenario A	2030 Scenario B	2030 Scenario C
Natural Gas	0.43	0.43	0.39	0.39	0.39	0.39
Refinery fuel gas	0.38	0.37	0.30	0.30	0.29	0.29
Residual fuel oil	0.10	0.10	0.08	0.08	0.08	0.08
Fluid catalytic cracking (FCC) Coke	0.07	0.07	0.04	0.04	0.04	0.04
Natural Gas to Hydrogen	0.03	0.02	0.02	0.02	0.02	0.02

Nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxide (CO), particulate matter (PM), non-methane volatile organic compounds (NMVOC), and benzene pollutant emissions have been calculated by applying industry average emission factors from CONCAWE, “Air Pollutant Emission Estimating Methods for E-PRTR Reporting by Refineries,” Report No. 3/15, Brussels (April 2015), to the fuel consumption data in Table 3.1. Carbon dioxide (CO_2) emissions are directly calculated from the WORLD model analysis.

For biorefineries in the EU, fuel consumption is primarily renewable energy from its biomass feedstock (F Cherubini et al., 2013); however, there is a lack of information about the quantity and type of fuel consumed in Europe. Furthermore, biorefinery design specifications can vary significantly based on the feedstock and conversion technology, and include some novel unit operations; e.g., boiler using a combination of biogas, sludge, lignin and other residues. Since biorefinery-based emissions factors are not readily available from literature, a simplified, but conservative assumption has been applied to account for biorefinery air pollution emissions. That is, biorefinery pollutant emissions (e.g., tonnes of NOx, SOX, CO, PM) per unit of production (million barrels per day) is assumed to be the same as refinery emissions per unit of throughput (million barrels per day).

3.3.2 Results

Combustion source emissions at petroleum refineries and biorefineries have been projected to change in line with forecasts of EU refinery throughput and biorefinery production due to the impact of increasing biofuel blends. As discussed in Section 5.4.1, The 2020/2030 Base Case outlook embodies a substantial reduction in EU petrol demand in combination with some increase in diesel demand, which significantly aggravates the already problematic diesel:petrol ratio in the EU and so sets up 2020 and especially 2030 Base outlooks which strain EU refining and lead to projected lower regional refinery throughputs by 2030. This issue is further exacerbated by higher biofuel consumption, since a primary impact of higher biofuels is to reduce EU refining sector throughputs. The overall impact of this effect is a reduction in refinery pollutant emissions in both the Base and each of the alternate scenarios (A, B and C). Table 3.2 presents a summary of the pollutant emissions per scenario in 2020 and 2030 for the refinery sector only, as well as combined refinery and biorefinery emissions. Furthermore, 2010, and where available, 2013 European Environment Agency (EEA) data is presented for comparison.

Table 3.2 Refinery sector pollutant emissions per scenario in kilo tonnes per year

Pollutant	Assumption	Scenario	2010[a]	2013[b]	2020	2030
NMVOC	Refinery	Base	7.3	5.7	4.4	3.7
		Scenario A	7.3	5.7	4.3	3.7
		Scenario B	7.3	5.7	4.3	3.7
		Scenario C	7.3	5.7	4.3	3.7
	Refinery + Biorefinery	Base	7.3	5.7	4.6	3.9
		Scenario A	7.3	5.7	4.6	4.0
		Scenario B	7.3	5.7	4.6	4.0
		Scenario C	7.3	5.7	4.6	4.1
NOx	Refinery	Base	139.7	75.3	48.3	40.6
		Scenario A	139.7	75.3	47.2	40.6
		Scenario B	139.7	75.3	47.2	40.0
		Scenario C	139.7	75.3	47.2	40.0
	Refinery + Biorefinery	Base	139.7	75.3	50.1	42.7
		Scenario A	139.7	75.3	49.8	44.2
		Scenario B	139.7	75.3	49.8	43.6
		Scenario C	139.7	75.3	49.8	44.2
SOx	Refinery	Base	324.3	199.7	104.2	83.0
		Scenario A	324.3	199.7	103.7	83.0
		Scenario B	324.3	199.7	103.7	82.9
		Scenario C	324.3	199.7	103.7	82.9
	Refinery + Biorefinery	Base	324.3	199.7	107.9	87.3
		Scenario A	324.3	199.7	109.3	90.2
		Scenario B	324.3	199.7	109.3	90.4

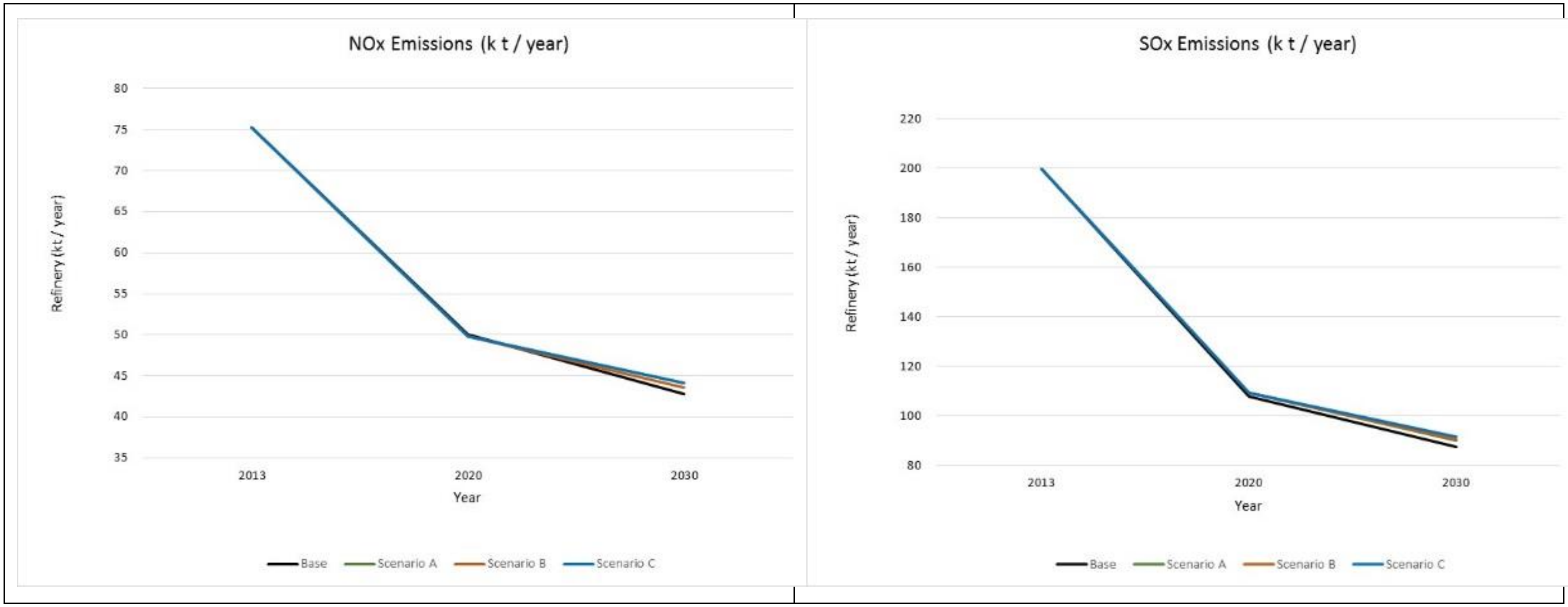
Pollutant	Assumption	Scenario	2010[a]	2013[b]	2020	2030
		Scenario C	324.3	199.7	109.3	91.6
PM	Refinery	Base	8.8		4.8	3.9
		Scenario A	8.8		4.7	3.9
		Scenario B	8.8		4.7	3.8
		Scenario C	8.8		4.7	3.8
	Refinery + Biorefinery	Base	8.8		4.9	4.1
		Scenario A	8.8		5.0	4.2
		Scenario B	8.8		5.0	4.2
		Scenario C	8.8		5.0	4.2
CO	Refinery	Base	35.2		21.2	17.8
		Scenario A	35.2		20.7	17.8
		Scenario B	35.2		20.7	17.6
		Scenario C	35.2		20.7	17.6
	Refinery + Biorefinery	Base	35.2		22.0	18.8
		Scenario A	35.2		21.9	19.4
		Scenario B	35.2		21.9	19.2
		Scenario C	35.2		21.9	19.4
CO2	Refinery	Base			326,714	296,787
		Scenario A			324,905	293,661
		Scenario B			324,905	293,568
		Scenario C			324,905	291,678
	Refinery + Biorefinery	Base			338,287	312,169
		Scenario A			342,315	319,188
		Scenario B			342,315	320,102
		Scenario C			342,315	322,161

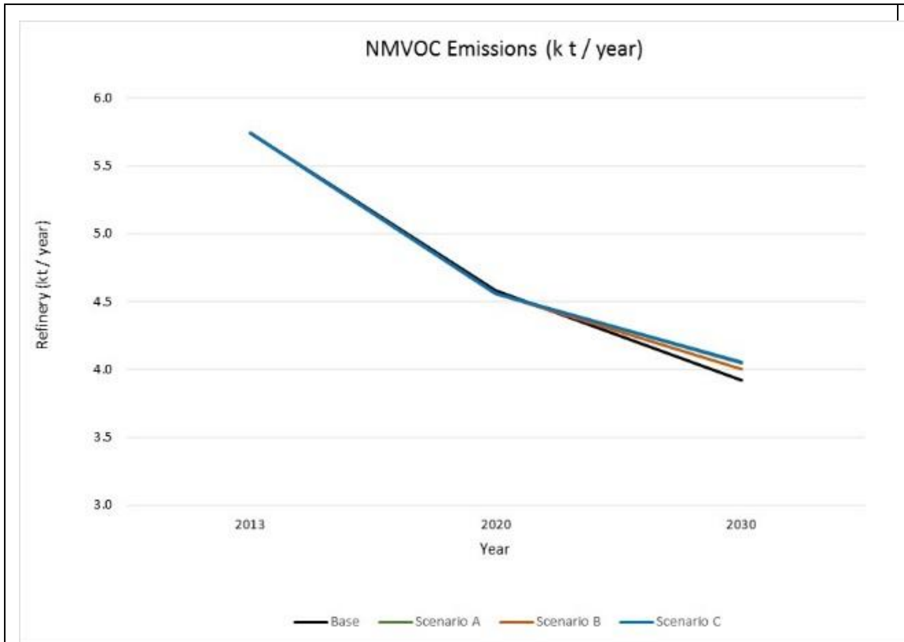
[a]*European Environment Agency (EEA), 2010 air pollutant inventory for refineries (sector code 1A1b); http://www.eea.europa.eu/data-and-maps/indicators/main-anthropogenic-air-pollutant-emissions/*

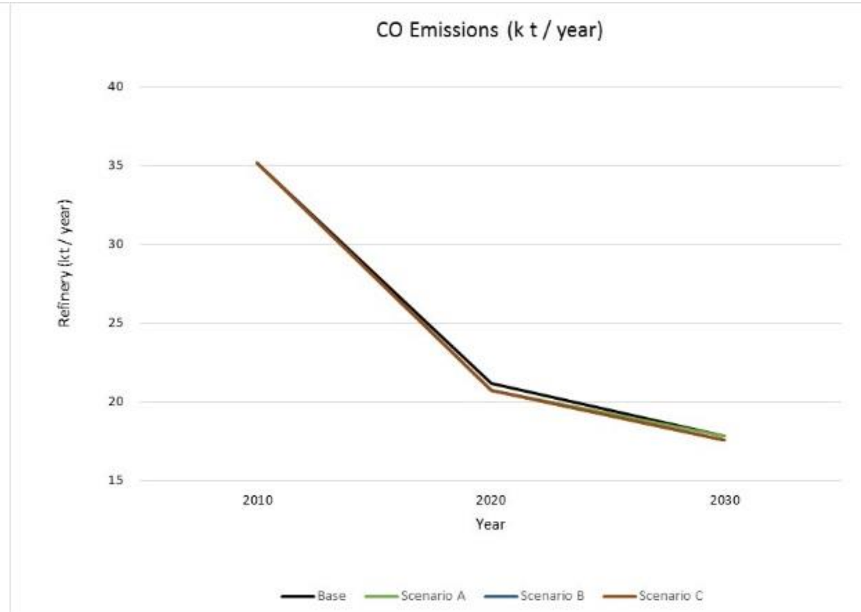
[b]*European Environment Agency (EEA), 2013 air pollutant inventory for refineries (sector code 1A1b); http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-nec-directive-viewer*

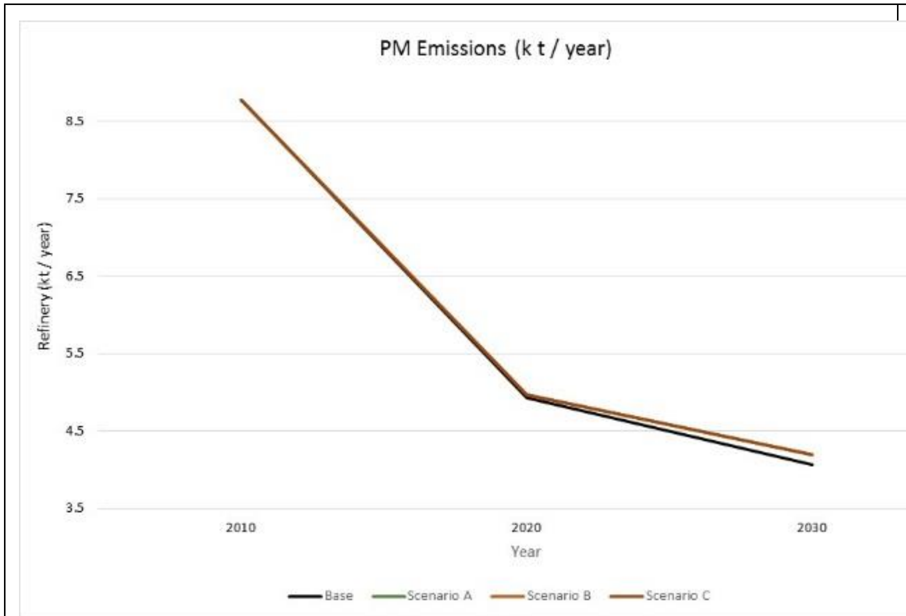
The results of this analysis are also presented in Figure 3.1.

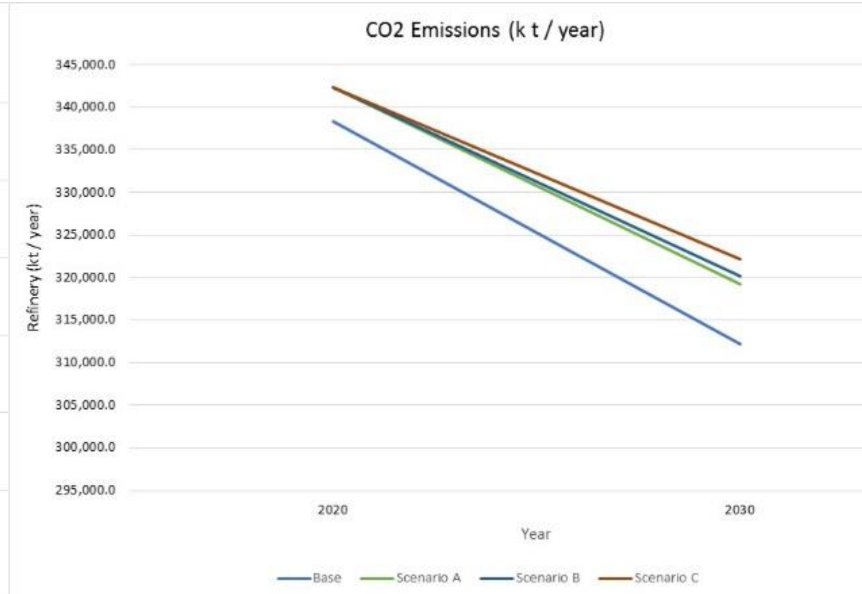
Figure 3.1 Refinery emissions per scenario (k tonnes/year)




NMVOC Emissions (k t / year)
Refinery (kt / year)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2013
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C


CO Emissions (k t / year)
Refinery (kt / year)
40
35
30
25
20
15
2010
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C


PM Emissions (k t / year)
Refinery (kt / year)
8.5
7.5
6.5
5.5
4.5
3.5
2010
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C


CO2 Emissions (k t / year)
Refinery (kt / year)
345,000.0
340,000.0
335,000.0
330,000.0
325,000.0
320,000.0
315,000.0
310,000.0
305,000.0
300,000.0
295,000.0
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C

In the Base scenario, there is a 65% reduction in NOx between 2010 and 2020, which continues the trend reported by EEA between 2010 and 2013 (i.e., over 45% reduction). Between 2020 and 2030, a further 9% reduction in NOx in the Base scenario occurs. In 2030, NOx emissions in Scenario A, B and C are 2-3% above the Base, as a reduction in refinery emissions is assumed to be offset by increases in the biorefinery sector. Nonetheless, sector emissions are still over 40% lower than 2013 pollutant levels.

Similar trends are observed for the other pollutants, SOx, CO, PM and NMVOC. In all cases, pollutant emissions in Scenarios A, B and C vary between 2-5% above the Base case in 2030. However, SOx and NMVOC emissions are still 50% and 30%, respectively, below 2013 levels[75]. For CO and PM, emissions in 2030 for Scenarios A, B and C are 45% and 50%, respectively, lower than 2010 levels as reported by the EEA.

For CO2, emissions reduce in the base and alternate scenarios between 2020 and 2030 by 6-8%. Again, this stems from a reduction in fuel consumption and associated combustion emissions within each scenario. In 2030, CO_2 emissions are estimated to be 2-3% greater than the base due to increased emissions from biorefineries, which offset reduced throughput in the refineries.

3.4 Vehicle tailpipe air quality impacts

Various factors affect the amount of emissions produced by vehicles, including vehicle class and weight, driving cycle, vehicle location, fuel type, engine exhaust after treatment, vehicle age, and the terrain travelled. In addition, engine control effects (such as injection timing strategies) on measured emissions can be significant. The following presents vehicle emissions for 2020 and 2030 for the Base scenario and three alternate scenarios (A, B and C) for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs). For the different biofuels considered in the analysis, emissions quantified include oxides of nitrogen (NO_X), total hydrocarbons (THC), non-methane hydrocarbons (NMHC) (for gasoline vehicles only), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM).

3.4.1 Assumptions

TREMOVES Model (TREMOVE 3.3.2)[76] outputs were used to define Base scenario emissions for 2020 and 2030 for light duty vehicles (LDVs) and heavy duty vehicles (HDVs).[77] It was also used to define the baseline transport demand; that is, the composition of LDV and HDV fleet by fuel type and average annual vehicle kilometres. The total number of vehicles and the annual vehicle kilometres were taken to be constant in all scenarios, and equal to the TREMOVE baseline.

Pollutant emission factors for petrol vehicles in the Base Case (i.e., E5 % v/v (equivalent to E3.4 % energy) were derived from literature (Suarez-Bertoa et al. 2015), while for diesel vehicles emission factors for B5.7 (B5.2 % energy) were estimated by linearly extrapolating vehicle test emission factors for B7 to B10 fuels based on their biodiesel content (7% and 10%, respectively). This is based on the assumption noted in literature (Section 2.4.3.2) that emissions are directly proportional to the biodiesel content of the fuel.

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[75] European Environment Agency (EEA), 2013 air pollutant inventory for refineries (sector code 1A1b);

[76] http://www.tmleuven.com/methode/tremove/home.htm

[77] For CO_2, Regulation (EC) No 443/2009 requires that only the fleet average is regulated; as such, it was assumed that EC mandatory 2020 emission reduction targets for new passenger cars and vans would be met[77]. As such, base case CO_2 emissions in 2020 were assumed to decrease in line with these targets. Since no CO_2 targets have been set for 2030, it was assumed that 2020 targets would remain constant through 2030.

Changes in pollutant and CO_2 emission factors from the base case for the different biofuel blend assumptions in scenario A, B and C were obtained literature, specifically the summation of data presented in Section 2.5.1, Table 2.5 for petrol; and Section 2.5.2, Table 2.6 and Table 2.7 for diesel LDV and HDV. These percent reductions for petrol and diesel-based biofuels described in were applied to the baseline emission factors to calculate emission factors for the higher biofuel blends for LDV and HDV. Although, the level of exhaust emissions is dependent on the vehicle and engine type, vehicle tuning and driving cycles, for this analysis, it has been assumed that these results apply to all vehicle types in the EU fleet. Furthermore, the changes in emission factors are assumed to be homogeneous across the EU.

The analysis assumes that emission factors remain constant over time; thus the key determinant driving emissions is the number of compatible vehicles and their use of higher biofuel blends in each scenario, which is described in Chapter 1, Section 1.7.3.

A detailed description of the modelling approach and calculations can be found in Annex 4.

3.4.2 Results

Table 3.3 presents a summary of the pollutant emissions per vehicle type and scenario for 2013, 2020 and 2030. Since the vehicle fleet assumptions in 2020 for scenarios A, B and C are the same, there is no difference between vehicle emissions for these scenarios in 2020. As previously discussed, the analysis has applied some simple assumptions to enable transparent comparison between scenarios. As such, the emissions represent a conservative estimate, as clearly, emissions will be expected to reduce significantly over time due to the tightening of EU emission regulations. Although we have attempted to address this for CO_2, where we have assumed that Base scenario emissions will decline in line with EC targets for new passenger cars and vans, for other pollutants we have maintained emissions outputs reported by TREMOVE.

Consequently, more useful when assessing the air emissions impact of higher biofuel blends is to compare the results against the base case scenario. Table 3.4 presents a summary of the pollutant emission reductions by scenario in 2020 and 2030 against the base case scenario. This information is also presented in Figure 3.2 and Figure 3.3. The results indicate that using biofuels can reduce pollutant levels of THC, NMHC, CO, and PM. In 2030, LDV emissions of these pollutants across each scenario were on average 3%, 3%, 6% and 8% lower than the base case. For NOx, emissions were on average 1% higher than the base case in 2030. CO_2 emissions for scenarios A, B and C were the same in 2020, and 0.2% lower in 2030 than the base case. For HDV, the trends were similar, although no declines in CO2 were noted through 2030.

Table 3.3 Summary of Emissions by Scenario

Vehicle/ Pollutant	Emissions by Calendar Year and Scenario (kilotonnes/year)								
	2013	2020				2030			
	Base	Base	Scenario A	Scenario B	Scenario C	Base	Scenario A	Scenario B	Scenario C
LDV									
CO_2	773,469	721,437	721,437	721,437	721,437	640,502	640,502	639,044	638,557
NOx	1,407.8	817.8	826.0	826.0	826.0	585.5	591.3	592.2	591.8
THC	843.6	532.6	519.5	519.5	519.5	506.3	493.9	489.6	486.5
NMHC[a]	765.1	485.4	473.5	473.5	473.5	462.4	451.1	447.2	444.4
CO	4,047.2	1,960.4	1,874.4	1,874.4	1,874.4	1,520.0	1,453.4	1,426.6	1,417.5

Vehicle/ Pollutant	Emissions by Calendar Year and Scenario (kilotonnes/year)								
	2013	2020				2030			
	Base	Base	Scenario A	Scenario B	Scenario C	Base	Scenario A	Scenario B	Scenario C
PM	63.6	30.6	28.6	28.6	28.6	21.7	20.2	19.8	19.7
HDV									
CO_2	178,955	189,613	189,613	189,613	189,613	201,657	201,657	201,657	201,657
NOx	1,318.6	941.4	950.8	950.8	950.8	901.0	910.1	910.1	909.2
THC	34.4	11.2	11.0	11.0	11.0	5.1	5.0	5.0	4.9
NMHC[a]	-	-	-	-	-	-	-	-	-
CO	203.7	83.8	82.2	82.2	82.2	45.9	45.0	45.0	44.7
PM	23.9	12.1	11.4	11.4	11.4	10.0	9.4	9.3	9.2
Total									
CO_2	952,423	911,050	911,050	911,050	911,050	842,159	842,159	840,701	840,215
NOx	2,726.5	1,759.2	1,776.8	1,776.8	1,776.8	1,486.5	1,501.4	1,502.2	1,501.1
THC	877.9	543.8	530.6	530.6	530.6	511.4	498.8	494.5	491.4
NMHC[a]	765.1	485.4	473.5	473.5	473.5	462.4	451.1	447.2	444.4
CO	4,250.9	2,044.2	1,956.5	1,956.5	1,956.5	1,565.9	1,498.3	1,471.6	1,462.2
PM	87.5	42.7	39.9	39.9	39.9	31.7	29.6	29.1	28.8
Notes: NMHC was estimated for gasoline vehicles only									

Table 3.4 Summary of emission reductions by scenario against the base case

Vehicle/ Pollutant	Emission Reductions Compared to Base Case Emissions (ktonne/year)[a]					
	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
LDV						
CO_2	0	0	0	0	1458	1944
NOx	8	8	8	6	7	6
THC	13	13	13	12	17	20
NMHC[b]	12	12	12	11	15	18
CO	86	86	86	67	93	103
PM	2	2	2	1	2	2
HDV						
CO_2	0	0	0	0	0	0
NOx	9	9	9	9	9	8
THC	0	0	0	0	0	0
NMHC[b]	-	-	-	-	-	-
CO	2	2	2	1	1	1
PM	1	1	1	1	1	1
Total						
CO_2	0	0	0	0	1458	1944

NOx	18	18	18	15	16	15
THC	13	13	13	13	17	20
NMHC[b]	12	12	12	11	15	18
CO	88	88	88	68	94	104
PM	3	3	3	2	3	3
Notes: Black = emission reductions; Red = emission increases. NMHC was estimated for gasoline vehicles only						

Figure 3.2 Summary of Emissions by Scenario for LDV and HDV Combined for 2020

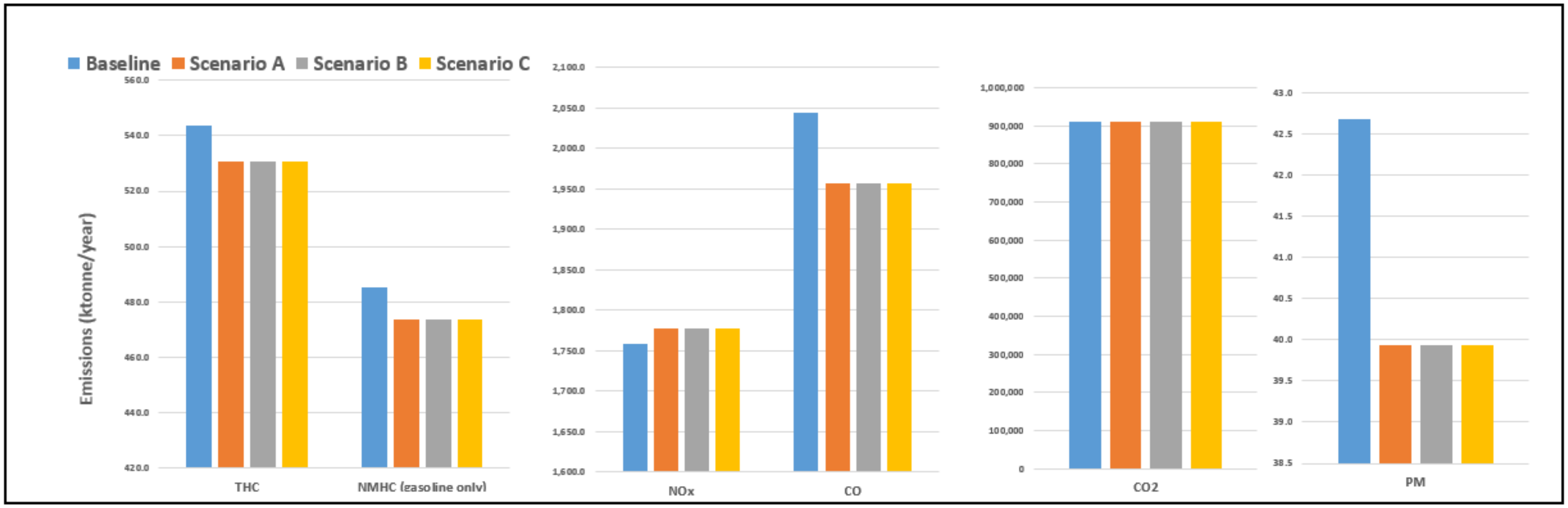
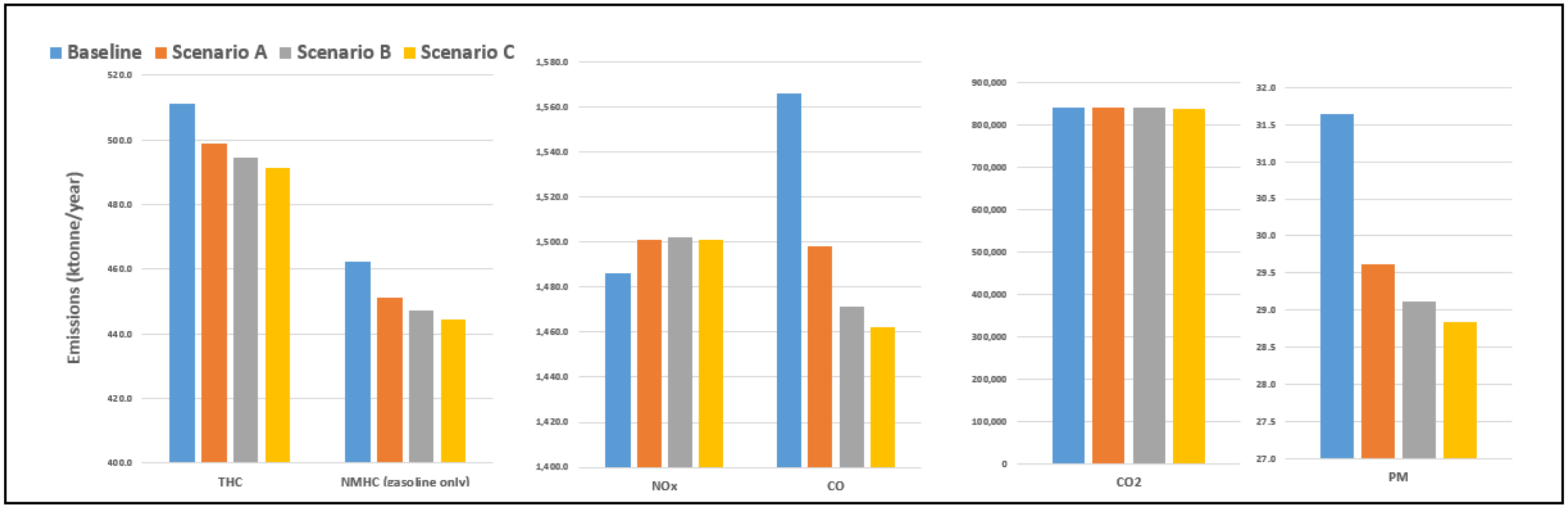


Figure 3.3 Summary of Emissions by Scenario for LDV and HDV Combined for 2030



3.5 Vehicle evaporative emissions impacts

3.5.1 Introduction

Evaporative emissions or non-combustion emissions are a form of emissions that derive from fuel vapours generated in the vehicle fuel tank and the fuel distribution system to the engine. The magnitude of evaporative emissions is generally a function of fuel vapour pressure. Several sources of data illustrate the instrumental effect that vapour pressure has in producing evaporative emissions at varying levels. For example, in the “Joint EUCAR/JRC/CONCAWE Study on: Effects of Gasoline Vapour Pressure and Ethanol Content on Evaporative Emissions from Modern Cars” (G. Martini, 2007), the authors assert that Dry Vapour Pressure Equivalent (DVPE)[78] is a key factor in assessing evaporative emissions; a higher DVPE value denotes higher volatility and is associated with a higher rate of fuel evaporation. Beyond vapour pressure, other factors such as vehicle design can play a role in the emissions impacts of higher ethanol content in petrol. In total, several specific emission types comprise the generalized category of evaporative emissions. Each is discussed below.

3.5.2 Ethanol blends and their effect on vapour pressure

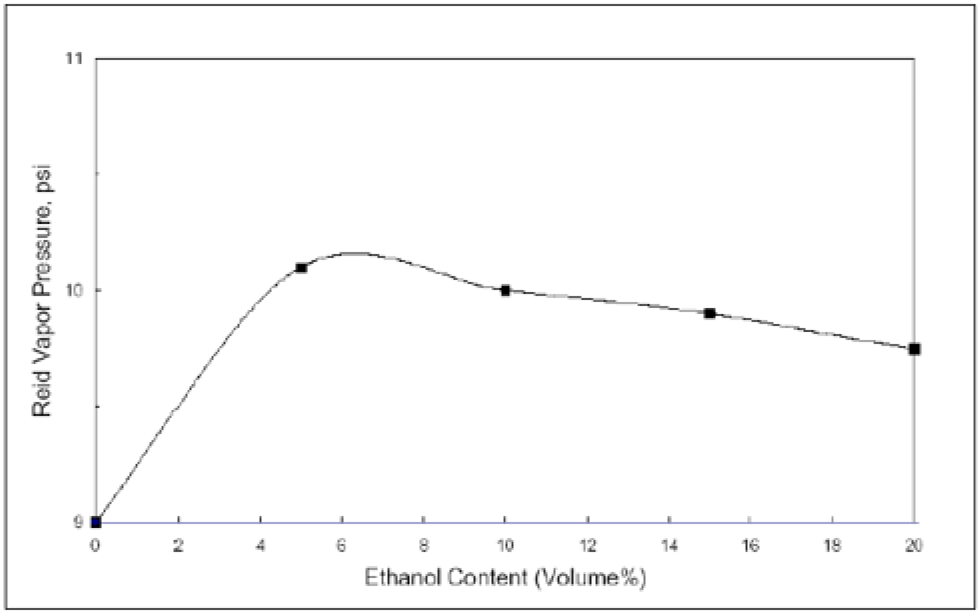
Because significant variation in total evaporative emissions occurs for different fuel blend vapour pressures, it is essential to examine the change in vapour pressure at different concentrations of ethanol in petrol. Figure 3.4 from the Joint Research Centre (JRC) report “Review of the European Test Procedure for Evaporative Emissions: Main Issues and Proposed Solutions” shows that the blend vapour pressure (VP) peaks near 5% ethanol blend concentration and then gradually declines as the effective vapour pressure of the ethanol blend decreases with increasing ethanol concentration (G. Martini, et al., 2012).

The interaction between petrol and ethanol in solution, taken at a molecular level, explains why ethanol in petrol blends first increase in vapour pressure (from E0 to E5) but then, beyond this level, increasing concentrations of ethanol in petrol result in decreased blend vapour pressure. While pure ethanol has a lower vapour pressure than petrol, when ethanol is added to petrol in low proportions (E0 to E5), the more numerous hydrocarbon molecules disrupt the attractive forces between the ethanol molecules, allowing the ethanol to more readily evaporate and this, in turn, raises the blend vapour pressure. Beyond the initial boost in vapour from adding ethanol, a trend emerges from E5 to E100 in which increasing concentrations of ethanol reduce the vapour pressure of the blend because the disruptive impact on the ethanol molecules diminishes. The effect of this phenomenon is that, after reaching a peak vapour pressure in the vicinity of E5, the petrol vapour pressure slowly trends downward thereafter with increasing ethanol concentration.

A key consequence of this phenomenon is that increasing ethanol concentration above 5% leads to minimal impacts on blend vapour pressure with consequently limited impacts on evaporative emissions, although, as discussed below, ethanol can have specific impacts on permeation and canister emissions depending in part on vehicle design and materials of construction.

[78] Reid Vapour Pressure, RVP, or what is more properly called the Dry vapor pressure equivalent (DVPE), or more simply called vapor pressure, is the vapor pressure of a fuel measured at 100 °F (37.8 °C) in a vessel with a vapor/liquid volume ratio of 4:1 by ASTM D5191 or similar method”(McCormick, Yanowitz, 2012). In absence of direct usage of the wording “DVPE” in supporting source material, the generalized wording “vapour pressure” is used throughout this section.

Figure 3.4 Effect of ethanol content on blend vapour pressure



Source: G. Martini, et al., 2012 – pg. 22

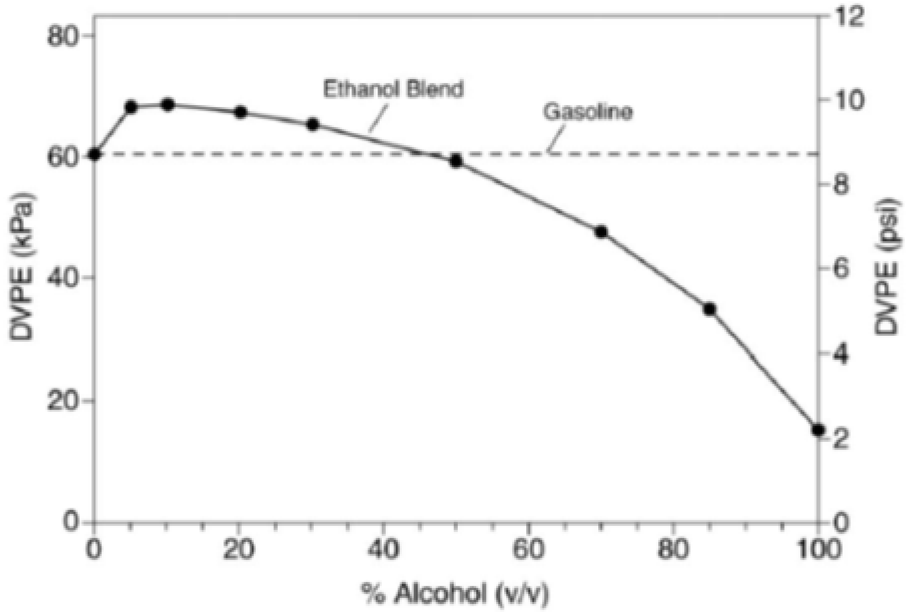
A study conducted by the U.S. National Renewable Energy Laboratory concluded that the RVP impact of a 15% ethanol blend of petrol on emissions is indistinguishable from that of a 10% ethanol blend (McCormick, Yanowitz, 2012). Recognizing that only a small ethanol blend RVP difference – indeed a decline - is depicted between the E10 and E15 blends in the graph above, this conclusion would be expected. Other studies of vapour pressure changes for E5 to E20 blends, such as NREL (2002)[79] and American Petroleum Institute (API) (2010)[80], reflect the same finding that the vapour pressure impact above E5 is marginal and trends down (as depicted in the above graph).

A March 2012 NREL letter to the US Renewable Fuels Association entitled "Discussion Document – Effect of Ethanol Blending on Gasoline RVP" provided extensive information on ethanol VP effects up to 100 vol%. The document references experimental results from a 2010 API report, which examined vapour pressure effects across a wide range of fuels and blendstocks with ethanol concentrations at 0, 10, 12.5, 15, 20 and 30% (Figure 3.5).

[79] Issues Associated with the Use of Higher Ethanol Blends (E17-E24), C. Hammel-Smith, J. Fang, M. Powders, and J. Aabakken, National Renewable Energy Laboratory, October 2002.

[80] American Petroleum Institute, Determination of the Potential Property Ranges of Mid-Level Ethanol Blends, Final Report, April 23, 2010.

Figure 3.5 Effect of ethanol blending on vapour pressure of gasoline

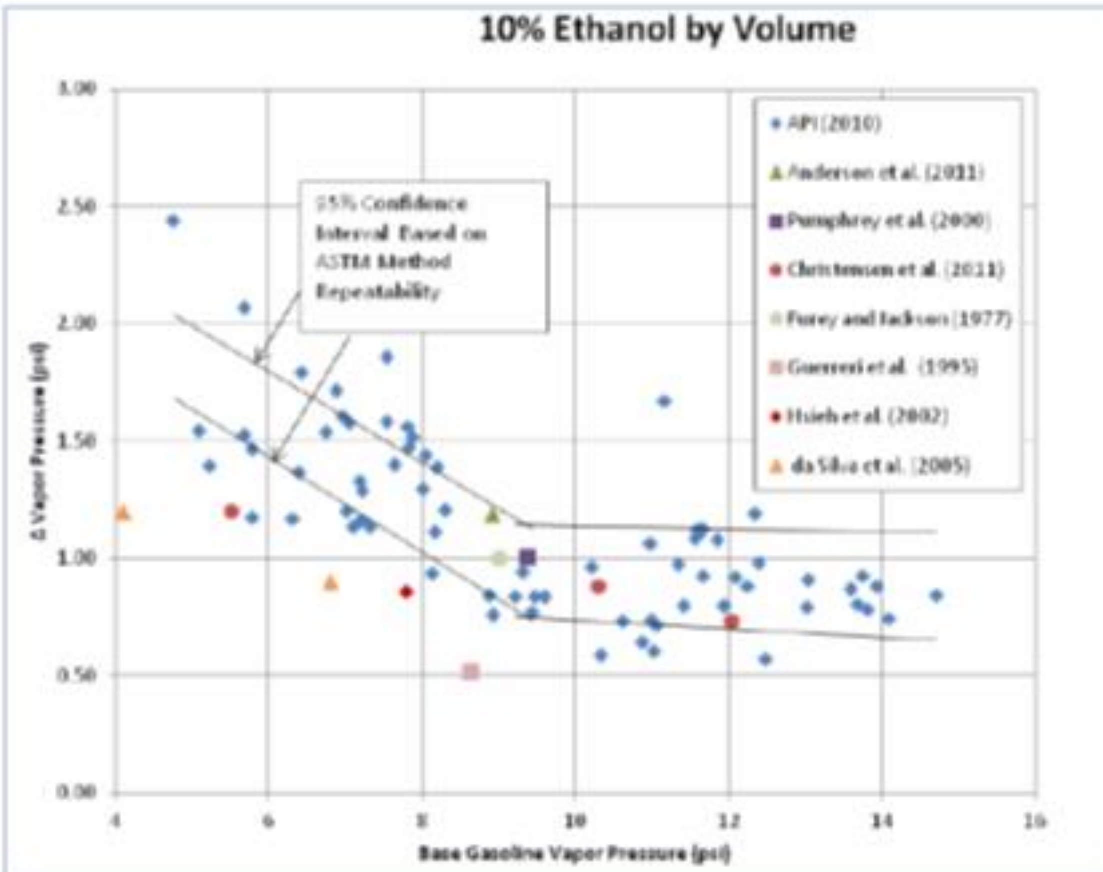


Because vapour pressure has been shown to have a profound effect on evaporative emissions, various studies have quantitatively assessed the impact that blend vapour pressure has on total evaporative emissions for a range of ethanol concentrations in petrol. For example, the JRC (2012) evaluated one of the highest levels of vapour pressure for a petrol blend, around 75 kPa (10.9 psi). The study concluded that ethanol blends with high vapour pressures around 75 kPa showed significantly higher evaporative emissions than lower volatility fuels in most of the vehicles; in short that – as would be expected – higher vapour pressure leads to higher evaporative emissions. Likewise, and again not surprisingly, a separate study by the Coordinating Research Council used the U.S. EPA's MOVES air emissions model and found that reducing summer RVP by 1 psi will reduce evaporative VOC emissions by 5% and total emissions (tailpipe plus evaporative) by approximately 2.5% (McCormick, Yanowitz, 2012).

JRC (2012) also found, however, that evaporative emissions differences were relatively small between ethanol-containing fuels with vapour pressures in the more typical range of 60-70 kPa (8.7 to 10.15 psi). This indicates that, for ethanol blends within the typical narrow (summer) petrol vapour pressure range, total evaporative emissions differences due to vapour pressure are likely to be small. In another study, evaporative emissions were tracked for four vehicles running E0, E10, and E20 blends. All three of the non-splash blended fuels were in the narrow vapour pressure range of 59.3 to 60.6 kPa (8.6 to 8.8 psi) and the differences in evaporative emissions from the fuel blends were found to be not statistically significant (Graham, Belisle and Baas, 2008).

NREL (2012) assessed the impacts of underlying blend composition on ethanol vapour pressure impact. Figure 3.6 illustrates that base gasoline vapour pressure and underlying blendstock composition do tend to have an effect on the level of vapour pressure increase at the 10% ethanol content examined but that the impact is mainly below 1 psi (6.895 kPa) except at low base blendstock vapour pressures where the impact can be 1.5 psi (10.3 kPa) or higher.

Figure 3.6 Change in RVP for blending 10% ethanol into gasolines and blendstocks



The JRC (2012) study examined whether the presence of ethanol in petrol blends could have additional impacts on evaporative emissions beyond purely the direct influence on blend vapour pressure. A series of extra tests was undertaken with same-vapour-pressure fuels. These indicated that ethanol-containing blends could lead to higher total evaporative emissions as a result of increased fuel permeation and/or reduced canister efficiency (see Section 3.5.5). There was significant variation in total evaporative emissions among test vehicles, as such effects are a function of vehicle design and materials of construction. Some vehicles evaporative emission control systems simply perform better than other systems in preventing evaporative emissions. Low permeation hoses, active purge systems, and carbon canisters are some of the components that can play a significant role in reducing emissions.

3.5.3 Vapour Pressure Waiver and Commingling Effect

3.5.3.1 Vapour Pressure Waiver

Because vapour pressure plays such a significant role in total evaporative emissions, the maximum vapour pressure for petrol is regulated. In Europe, the maximum summer season vapour pressure for petrol blends is 60 kPa (8.7 psi). By way of comparison, in the United States, the maximum summer vapour pressure ranges from 49.6 kPa (7.2 psi) to 62 kPa (9 psi) depending on the region (and attendant summer temperature level) and the fuel type – reformulated or conventional.

As discussed, adding ethanol at low concentrations increases the blend vapour pressure unless steps are taken to reduce the volatility of the base blend (pre ethanol addition). As a result of this, and in an effort to not discourage the use of blending of ethanol into petrol, regulations have been enacted to allow petrol with ethanol to have slightly higher vapour pressures. This is generally referred to as a vapour pressure waiver. Under the Fuel Quality Directive 2009/30/EC, EU Member States may apply for a relaxation of the summer vapour pressure limit for petrol blends with ethanol. To date, three EU Member States—Czech Republic, Poland, and Spain—have applied for and received the vapour pressure waiver. In the United States, there is also a waiver for “conventional gasoline” petrol blends with ethanol during summer months and many individual states also have their own regulations for allowing a 6.89 kPa (1 psi) increase in vapour pressure, enabling the petrol blend to reach up to 68.9 kPa (10 psi) versus the typical 62 kPa (9 psi) vapour pressure maximum.

Because evaporative emissions are largely a function of the vapour pressure, higher evaporative emissions generally result from petrol produced under the waiver. Several U.S. states have opted out of the waiver (e.g., New York, Pennsylvania and Texas), the waiver does not apply to reformulated (RFG) petrol (one-third of the US market in 2010) and the waiver will not apply to U.S. E15 fuel. If and when the U.S. does transition from E10 to E15 fuel, in regions that are currently utilizing the vapour pressure waiver for conventional gasoline, the RVP of the blend will decrease to conform to the “no-waiver” maximum RVP specification and, as a result, the evaporative emissions will be reduced (Air Improvement Resources, 2011).

The existence of waivers can be considered an indirect consequence of ethanol’s higher vapour pressure at relatively low ethanol concentrations in petrol. Whether the higher vapour pressure has any material impact is a function of the regulations for petrol vapour pressure. Where no waiver is allowed (e.g., as in the case of US RFG) the effect is for ethanol use to cause refiners to have to reduce the vapour pressure of the base blend stock, generally through the rejection of butane and other light streams. Since these streams are generally low value/price blend stocks, the effect is often a small increase in the produced cost of the petrol.

Section 3.5.6 discusses the implications of higher biofuel blends on the EU VP waiver.

3.5.3.2 Commingling

Even where all petrol grades have to comply with the same vapour pressure specification, (no waivers in place), blend vapour pressures will be higher in areas which have fuel blends at different ethanol concentrations, for example E0 and E10, than in areas with a uniform ethanol level. The effect of different ethanol-petrol blends being mixed with one another by motorists filling up their fuel tanks is dubbed the commingling effect. For example, if a motorist refuels a tank that is half full with E0 at a given DPVE, but adds a 10% ethanol blend at the same DVPE, the overall effect will be to turn the non-ethanol petrol into a 5% ethanol blend by volume. This situation would cause the DVPE of the non-oxygenated petrol to increase by about 1 psi; since that petrol represents 50% of the fuel in the tank, the average DVPE of all the fuel will increase by about half that amount, or about 0.5 psi. (JRC, 2012)

3.5.4 Splash Blending

Another consideration with regard to fuel vapour pressure and thus evaporative emissions is splash blending, or how the ethanol is blended into the petrol. The ethanol is either “splashed” into what is already a finished petrol grade, thus potentially impacting the fuel blend properties, or the ethanol is added to a specifically prepared petrol base stock so that the final blend has met a specified set of properties (Air Improvement Resources, 2011). Splash blending may result in increased evaporative emissions but the emissions difference is likely small. In the 2008 study by Graham, Belisle and Baas, evaporative emissions were tracked for four vehicles running E0 to E20 blends, differences between splash-based fuels were not found to be statistically significant. Another study, showed no statistically significant difference in evaporative emissions for E10 splash blended fuel vs. E10 non-splash blended fuel (Morris, Brondum, 2000).

Thus both studies reported a lack of any statistically significant differential in evaporative emissions. This lack of any observed emissions differential indicates that the base blendstock(s) may have been pre-configured for the addition of ethanol. As use of ethanol expands, the trend is generally to replace splash blending with the more rigorous preparation of specific blendstocks in order to optimize the total blend and minimize costs.

3.5.5 Specific Emission Forms

Evaporative emissions result from refuelling, diurnal temperature change, running loss, hot-soak, and permeation. At present the US has the most stringent evaporative emissions standards while those in the EU are similar to levels in force in the US in 1994. Most evaporative emissions derive from fuel vapours generated in the fuel tank and thus their magnitude is generally a function of fuel RVP. Ethanol added to petrol at low to moderate concentrations (E5-E30) increases fuel RVP and thus vapour generation, but the peak RVP occurs at a 5 to 10% ethanol blend. However, blend-stocks for ethanol-petrol blends are modified as needed to meet seasonal and regional fuel RVP limits. While petrol is regulated based on vapour pressure measured at 40º C, the fuel in the vehicle is exposed to both higher and lower temperatures. Vapour pressures of ethanol-petrol blends exhibit a greater change with temperature than petrol containing no ethanol. In addition, splash blending of E20 from an E5 base will reduce RVP.

The emissions from the different sources have been evaluated in various studies but it is important to note that there are often conflicting findings associated with the tracking of these specific emissions because small emission differences are difficult to accurately measure and the vehicle sample size of these studies is often small. The following paragraphs outline the different sources of evaporative emissions: permeation, diurnal, running loss, hot soak, and refuelling, their main drivers, and the conclusions regarding the particular emissions based on available literature.

3.5.5.1 Permeation Emissions

Permeation Emissions comprise fuel compounds that escape through the fuel tank and distribution system. Permeation emissions can be an important driver of total evaporative emissions and generally increase with blend vapour pressure, temperature, aromatic hydrocarbon content, and solubility in the fuel system materials. As a result, permeation emissions generally increase with increasing ethanol content in the very low concentration range (E0 to E5). JRC (2012) show that evaporative emissions increased 13 and 23 percent about two weeks after switching from E0 (vapour pressure 57.2 kPa) to E5 (vapour pressure 64.3 kPa), a switch the authors contend is due to fuel permeation. Additionally, for all test vehicles, permeation emissions increased in a statistically significant manner for E6 to E20 blends as compared to reference E0 blends (JRC, 2012). In a separate study, the Coordinating Research Council in 2010 found that permeation rates are higher with E10 or E20 fuels as compared to E0 fuel (Coordinating Research Council, Inc., 2010). This study noted a “trend” towards lower permeation emissions from E10 to E20 fuels, although the magnitude of the emissions difference and sample sizes for the vehicles tested was too small to firmly establish the decrease in permeation emissions from E10 to E20. However, when evaluating the transition all the way to E85, lower permeation emissions resulted as compared to reference E0 fuels because of decreased blend vapour pressure. (As illustrated previously, there is a constant yet slow trend towards lower vapour pressure beyond E5 blends. Pure ethanol has a vapour pressure of only 15.8 kPa (2.3 psi) at 100°F, 37.8°C).

Beyond the fuel used, permeation emissions are significantly driven by vehicle design (materials used for the tank and distribution system and layering[81], if any). JRC (2012) indicate that lower permeation emissions result from multilayer tanks or ones made of metal, as compared to the much more common plastic ones. In modern plastic multi-layer coextruded fuel tanks, ethanol can negatively interact with the ethylene vinyl alcohol barrier layer designed to control hydrocarbon permeation and increase hydrocarbon permeation. While multilayer tanks are common in the United States where stricter emission limits generally apply, about 35 percent of the vehicles in Europe are still equipped with monolayer tanks. Overall, higher permeation emissions result from having monolayer fuel tank designs and thus some European cars will continue to see higher permeation emissions directly as a result of having these monolayer tanks, regardless of whether ethanol has been added to the petrol. As one would expect, the usage of advanced evaporative systems (LEV II and PZEV1 systems), has been found to result in decreased permeations emissions compared to the usage of conventional systems. Study methodology is also a consideration in measuring permeation emissions: it takes up to 20 weeks to stabilize a low-permeation, multi-layer tank to steady state conditions and the U.S. tends to have stricter standards in measuring emissions (JRC, 2012).

3.5.5.2 Diurnal emissions

Diurnal emissions are those that result from fuel evaporation and escape (from a stationary vehicle) due to the temperature variation between day and night, **running loss emissions** are those that result from fuel evaporation and escape while the engine is running, and **hot soak emissions** are comprised of fuel that evaporates during the one hour period after the engine is shut-off (Tanaka, 2007). Diurnal emissions do not occur through a specific opening but, rather, individual molecules escape through areas such as fittings, openings, or plastic or rubber materials in the distribution system (California Environmental Protection Agency, 2008). Carbon canisters play a role in diurnal emissions, both in canister design and in how saturated the canister is before testing. Diurnal test results show higher evaporative emissions when the canister is fully saturated and, also, fuel vapour pressure plays a role because higher fuel vapour pressure reduces the time to saturate the canister. JRC (2012) indicates diurnal emissions did not change between E6 and E10 but appeared to increase in a non-statistically significant manner between E6 and E20. There remains a significant degree of uncertainty in quantifying the effect of particular emission forms though. In their 2009 Report, G. Martini, et al. state “What is not very well known is the contribution of the fuel permeation to the total evaporative emissions.”

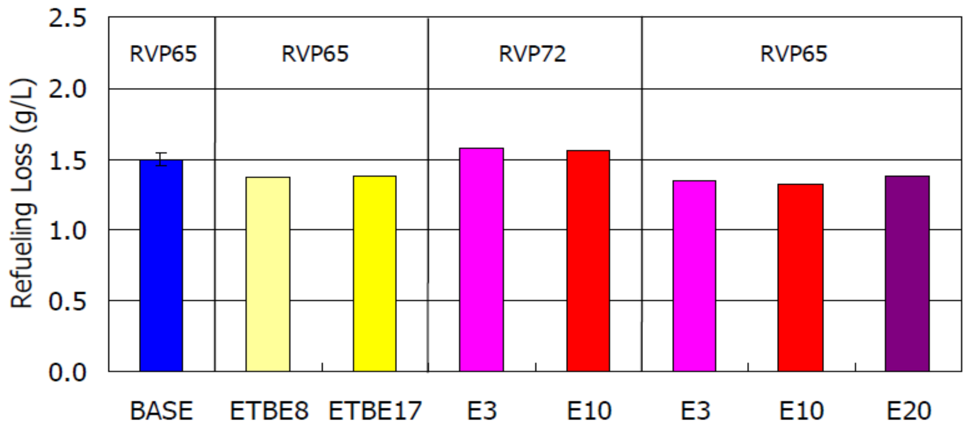
3.5.5.3 Refuelling Emissions

Refuelling Emissions result from liquid petrol flowing into the tank and displacing petrol rich vapour during the refuelling process. These emissions generally increase and decrease with petrol vapour pressure. Thus refuelling emissions will generally rise in the very low ethanol in petrol range, and then gradually decline with declining vapour pressure above the E5-E10 threshold, assuming that the blend vapour pressure is not re-adjusted to account for the presence of ethanol. Refuelling evaporative emissions tests are generally conducted at temperatures less than 40 °C, thus for E0 and E10 fuels with equal RVP, E10 yields lower refuelling emissions than E0. JRC (2012) showed that refuelling emissions increased because of reduced effectiveness of vapour recovery systems running fuels with higher vapour pressures. A Japanese study supports the finding that vapour pressure is the driving force. The graph below shows that refuelling loss emissions are very similar across fuel grades for a particular vapour pressure level. However, refuelling loss is greater for RVP72 (both E3 and

[81] Standard high density poly-ethylene (HDPE) tanks show higher emissions than multilayer tanks that are composed of HDPE and a film of ethylene-vinyl alcohol as one of the layers.

E10) as compared to RVP65 (E3, E10 and E20), indicating once again the importance of blend vapour pressure in determining evaporative emissions (Tanaka, 2007). However, this benefit may be offset by a greater frequency of refuelling events because of lower volumetric energy content of higher blends.

Figure 3.7 Effects of Ethanol or ETBE Blending in Petrol on Refuelling Loss Evaporative Emissions (Tanaka, 2007)



Recent published studies suggest that ethanol content has some effect on permeation emissions but little effect on diurnal, running loss, and hot-soak emissions. For example, in a Canadian government sponsored study (Graham, Baas and Belisle, 2008), diurnal and hot-soak emissions were unaffected by ethanol content using E0, E10, and E20 fuels with equal vapour pressure and an E10 splash blend with higher RVP.

A subsequent CRC study (Haskew and Liberty, 2011) examined evaporative emissions from four US certified MY2006-2007 FFVs with E6, E32, E59, and E85 with matched RVP. Running loss and hot-soak emissions did not show a trend with ethanol content. Diurnal emissions for E6 and E32 were similar, but an increase for the E59 and E85 fuels was indicated. The reactivity of these emissions showed no clear trends with ethanol content.

Hence mid-level ethanol blends (e.g., E20 or E30) with equal RVP are expected to have little impact on refuelling, diurnal, running loss, and hot-soak emissions. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but this is not directly relevant for the fuel choices considered here. Any reduction in RVP from blends above E5 should tend to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

3.5.6 EU vapour pressure waiver: Extension of Annex III

Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 sets out allowed vapour pressure (VP) waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. Annex III in that Directive tabulates allowed petrol vapour pressure waivers at ethanol concentrations from 1 to 10 volume percent. The following summarises the potential impacts on petrol vapour pressure of blends with ethanol contents above 10 % and proposes an extension to Annex III to cover such blends.

Table 3.5 below sets out Annex III values for volume percent of ethanol in the blend and the associated vapour pressure (VP) waivers at ethanol concentrations of 1 to 10 volume percent, (columns B and C) and then adds proposed waiver values for ethanol concentrations up to 30%. EnSys worked on the basis that the underlying base blend was at 60 KPa (column D) and used this assumption to compute the indicated blend vapour pressure (base plus waiver value), (column E).

We then applied the results from the sources discussed above which evaluated the effect of ethanol concentration on vapour pressure. EnSys used the data from Figure 3.5 and Figure 3.6 to trace out ethanol vapour pressures from 10 out to 100 volume %. Note that ethanol VP drops from some 425 kPa (61.6 psi) at 1% concentration to 15.9 kPa (2.3 psi) at 100% concentration. EnSys then used the ethanol vapour pressures to extend the Annex III table to ethanol concentrations up to 30 volume %. As part of this assessment, we plotted blend vapour pressure and vapour pressure waiver level against volume percent ethanol. The results are presented in Figure 3.8 and Figure 3.9. These plots were essential to ensure smooth progressions in the data points in the extended Annex III.

The net effect of this extension is that it shows, consistent with third party papers, that ethanol's effective vapour pressure in petrol declines as its concentration increases, initially sharply to about 10% concentration and then more slowly. As a result, for a given base petrol, the blend vapour pressure peaks at an ethanol concentration of around 5% and then steadily declines. Consequently, raising ethanol content from 0 to 5% has a marked upward impact on blend VP, but increasing concentrations further actually lowers blend VP, e.g. in the calculation used, from 68 kPa at 5% to 67.8 kPa at 10% and 66.8 kPa at 30%. Thus, going to higher ethanol concentrations beyond 5% does not cause increased pressure on petrol blend VP; rather the effect is to gradually reduce the vapour pressure waiver effect.

Table 3.5 Annex III waiver table – existing and draft proposed extension

	Volume content of ethanol in petrol - percent	Vapour pressure waiver permitted (kPa)	base petrol assumed kPa	blend kPa
A	B	C	D	E
	0	0	60	60
	1	3.65	60	63.65
	2	5.95	60	65.95
	3	7.2	60	67.2
	4	7.8	60	67.8
	5	8	60	68
	6	8	60	68
	7	7.94	60	67.94
	8	7.88	60	67.88
	9	7.82	60	67.82
original	10	7.76	60	67.76
new	*15*	*7.55*	*60*	*67.55*
	20	*7.31*	*60*	*67.31*
	25	*7.06*	*60*	*67.06*
	30	*6.82*	*60*	*66.82*
	40			
	50			
	70			
	85			

	Volume content of ethanol in petrol - percent	Vapour pressure waiver permitted (kPa)	base petrol assumed kPa	blend kPa
	100			

Figure 3.8 Petrol blend vapour pressure at different ethanol concentrations

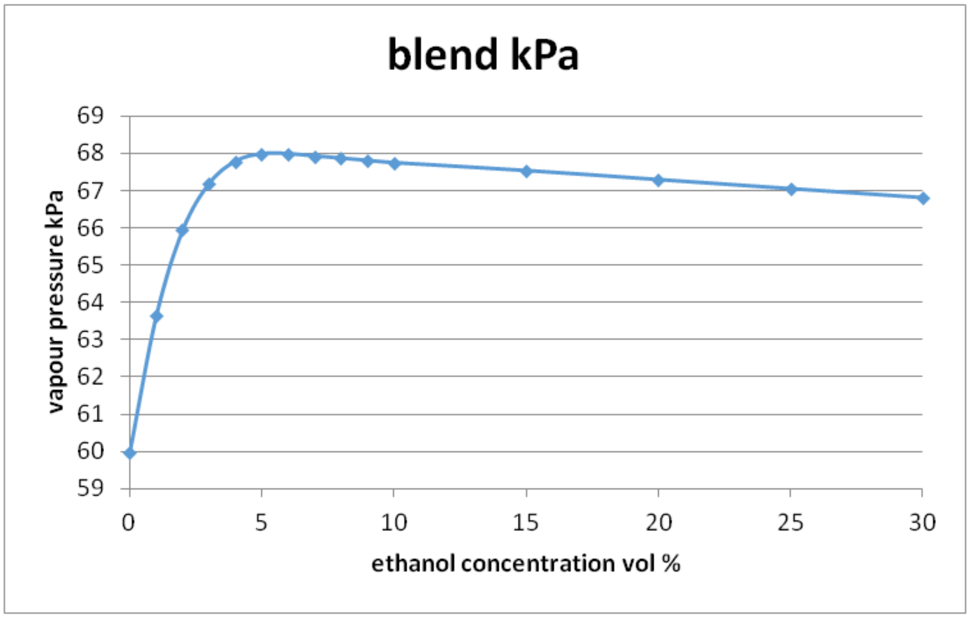
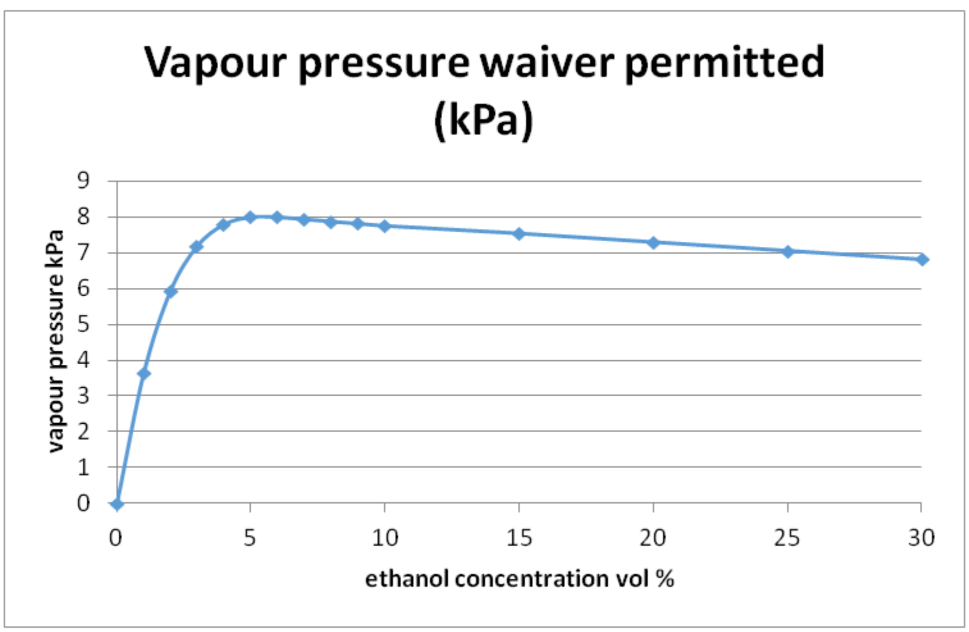


Figure 3.9 Petrol vapour pressure waiver permitted & proposed



There is an option in the EU for countries to apply for a vapour pressure waiver (increase) for blends which contain ethanol. As laid out in Annex III of the FQD, the allowed level of vapour pressure increase is a function of the ethanol concentration in the petrol blend. As also noted, to date, only three EU countries have requested a waiver under this programme. However, should ethanol content in EU petrol increase, it is possible more countries would apply for the vapour pressure waiver. If that happened, then the increasing ethanol content could indirectly lead to increased evaporative emissions as a consequence of more countries obtaining waivers which in turn bring increases in (summer) petrol vapour pressure.

3.6 Conclusions

Higher biofuel blends will not detrimentally impact air pollution from the refinery sector. In the refinery sector, through 2030, emissions of air pollutants are expected to continue their ongoing decline from 2010/2013 levels. These declines are directly linked to reduced refinery throughput, and associated lower fuel consumption, in the Base and all alternate scenarios (A, B and C) analysed in this study, even though biorefinery production will likely offset some of the air pollution reduction due to refinery throughput reduction. The refinery sector accounts for only a small fraction of pollutant emissions when compared to vehicle tailpipe emissions.

The use of the higher blends analysed will not negatively impact air pollution from vehicle tailpipe emissions. Modelling results illustrate that compared to a base case (i.e., current biofuel blending levels), pollutant levels of THC, NMHC, CO, and PM will decline with higher blends. In 2030, LDV emissions of these pollutants across each scenario were on average 3%, 3%, 6% and 8% lower than the base case. For NOx, emissions were on average 1% higher than the base case in 2030. CO_2 emissions for scenarios A, B and C were the same in 2020, and 0.2% lower in 2030 than the base case. For HDV, the trends were similar, although no declines in CO_2 were noted through 2030.

Moving to higher ethanol blends will not result in adverse evaporative emissions impacts in petrol. The upward impact is highest at around 5% ethanol concentration and then gradually declines as ethanol concentration is raised. Research shows that evaporative emissions do, as would be expected, increase potentially significantly with petrol blend vapour pressure—irrespective of whether ethanol is present in the blend. (For example, butane or other light streams could be added which would raise blend vapour pressure.)

Moving to higher ethanol blends does not mean increases in the ethanol waiver, rather the required waiver (in kPa) gradually declines out to and beyond 30 volume % ethanol. Annex III of the Fuel Quality Directive (FQD; 2009/30/EC) sets out allowed VP waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. The vapour pressure of ethanol in petrol gradually declines as its concentration rises above 5 volume %.

Ethanol content has some effect on permeation emissions but little effect on diurnal, running loss, and hot-soak emissions. Studies indicate that diurnal, refueling and hot-soak emissions were unaffected by higher ethanol content in petrol. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but not within the E10 to E25 range. Any reduction in VP from blends above E5 should tend to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

3.7 References

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4 Impacts on greenhouse gas emissions

Abbreviations/acronyms

API	American Petroleum Institute
CO_2	Carbon dioxide
GHG	Greenhouse gas
HVO	Hydrotreated vegetable oil
ILUC	Indirect land use change
MJ	Mega joule
RED	Renewable energy directive

4.1 Summary

The life-cycle GHG emissions impacts of higher biofuel demand was assessed using three key factors:

- The percent of biofuel blended with petrol and diesel. This factor accounts for both the increase in biofuel consumption as well as the decrease in petrol or diesel consumption, as is defined by the hypothetical scenarios presented in Chapter 1, Section 1.7.3 (Base Case, and Scenarios A, B, and C).
- The feedstock of biofuels blended with petrol and diesel. The feedstock determines the corresponding emissions factor to be used in the calculation–in terms of grams of carbon dioxide equivalent (CO2-eq) per unit energy (megajoule, MJ) of fuel, gCO2-eq/MJ. The feedstock also determines the impact of indirect land use change (ILUC). This factor was addressed via research and assessment of the EU's potential for producing and importing biofuels from various feedstocks.
- Projected changes in lifecycle emissions of biofuels over time as a result of process improvements. To the extent that there is potential to reduce GHG emissions over the lifecycle of biofuel production – from cultivation through to production at the biorefinery, this variable characterizes changes over time. This factor could also include other parallel impacts, such as changes in the emissions factor of petrol and diesel as a result in crude slate shifts, for instance. This factor was addressed by reviewing emissions estimates e.g., via differences between default and typical values, as well as other potential improvements in the lifecycle of biofuels.

The range of lifecycle GHG emissions under the scenarios in this study were estimated using the following two very different sets of assumptions:

- It is assumed that the carbon intensity of biofuels would significantly reduce over time as a result of future technological improvements made in the lifecycle. Emissions from indirect land use change (ILUC) were not included in the approach 1.
- The GHG emissions was estimated by applying the default values for biofuels as set out in current legislation (Fuel Quality Directive (2009/30/EC), Annex IV) and indirect land use change (ILUC) emissions (Directive 2015/1513) and the default factors were held constant over time.

The estimated benefits of biofuels are dependent on a) reducing the carbon intensity of biofuels over time as a result of improvements made in the supply chain of biofuels, b) expanded use of waste-based feedstocks, particularly for FAME and HVO production and c) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030,[82] including for ethanol, biodiesel, and renewable diesel. Assuming a reduction in the carbon intensity emission factors of biofuels over time and excluding indirect land use change (ILUC) GHG emissions, the analysis yields an estimated reduction in the range of 7.1 to 9.4% for the three higher blend limits and use scenarios in 2030. However, if no reductions in the carbon intensity of biofuels are assumed over time, and the emission factors as set out in current legislation are used, including default carbon intensity values for biofuels (included in FQD Annex IV) and indirect land use change factors (in the ILUC Directive), the analysis yields GHG emission reductions between 0.8 to 1.5% compared to the base case scenario.

4.2 Introduction

This chapter assesses the greenhouse (GHG) impacts of blending higher levels of bio components in transport fuels. Under the assumed scenarios of increases in the volume of biofuels blended in petrol and diesel, the life-cycle GHG emissions impacts are determined by three key factors:

1. **The percent of biofuel blended with petrol and diesel**. This factor accounts for both the increase in biofuel consumption as well as the decrease in petrol or diesel consumption. This variable was determined previously as part of the development of the Base Case Scenario, Scenario A, Scenario B, and Scenario C.
2. **The feedstock of biofuels blended with petrol and diesel**. The feedstock determines the corresponding emissions factor to be used in the calculation–in terms of grams of carbon dioxide equivalent per unit energy of fuel, gCO_2-eq/MJ. The feedstock also determines the impact of indirect land use change (ILUC).
3. **Projected changes in lifecycle emissions of biofuels over time as a result of process improvements**. To the extent that there is potential to reduce GHG emissions over the lifecycle of biofuel production – from cultivation through to production at the biorefinery, this variable characterizes changes over time. This factor could also include other parallel impacts, such as changes in the emissions factor of petrol and diesel as a result in crude slate shifts, for instance.

The first factor is described in Chapter 1, Section 1.7.3, where four biofuel blend scenarios are presented (Base Case Scenario and Scenarios A, B, and C) for the period through 2030. The second factor, focusing on the feedstock of biofuels blended with petrol and diesel, was addressed via research and assessment of the EU's potential for producing and importing biofuels from various feedstocks. The third factor was addressed by reviewing emissions estimates e.g., via differences between default and typical values, as well as other potential improvements in the lifecycle of biofuels.

4.3 Overview of the EU biofuels market: Current status and potential changes

The market for biofuel blending today is nearly exclusively linked to so-called first generation biofuels – those that are produced from conventional feedstocks or primary agrocommodities. More specifically:

- The biodiesel market is primarily supplied by rapeseed oil (~65%), palm oil (~20%),[83] and soybean oil (~10%). The balance of feedstocks come from sunflower oil, cotton seed oil, and pine oil.

[82] However, the factor of 10 growth in 2nd generation biofuels is still assumed to represent only 5% of total EU biofuel production capacity today, estimated at approximately 25,000 ktoe.

[83] Primarily imported from Southeast Asia.

- The ethanol market is primarily supplied by corn/maize (42%), wheat (33%), and sugar beet (17%). The balance of feedstocks come from cereals such as rye and barley.[84]
- The HVO market is dominated by a single supplier today, Neste Oil; Neste reports a mix of feedstocks, mostly palm oil and other virgin vegetable oils, and waste oils and residues.[85]

Moving forward, the biofuels market is constrained by a combination of policy and technical issues. Firstly, the EU has incentivized biofuel production and consumption through the RED, requiring 10% renewable content in transportation fuels by 2020. Recently, however, the EU agreed to cap the volume of biofuels from agricultural crops (which currently account for more than 90% of overall biofuel consumption) that can count towards the target at 7% of transportation fuels by 2020 (by energy content, not volume). Furthermore, the FQD includes sustainability provisions, namely that for biofuels to count towards the GHG emission reduction targets, the GHG emissions must be at least 35% lower than from the fossil fuel they replace. From 2017, this will increase to 50% and, from 2018, the saving must be at least 60% for newly installed production facilities.

It is important to note that while the aforementioned components of the RED and FQD incentivize low carbon intensity biofuels, and disincentivize higher carbon intensity biofuels, none of them explicitly prohibit the production, distribution, or sale of first generation biofuels between now and 2030.The imposition of a hard cap or firm limit on the types of biofuels that can be supplied to the EU market to help achieve the hypothetical blending scenarios outlined in this report becomes methodologically challenging. In other words, we are left with two broad methodological approaches regarding biofuel supply assumptions: 1) assume that RED and FQD will prevent the blending of conventional biofuels derived from agrocommodities *and* that there are drastic increases in second and third generation biofuel production in the next 15 years or 2) assume that the RED and FQD can be achieved with a mix of first generation biofuels and modest volumes of second generation biofuels, and that additional biofuel blending may not count towards RED or FQD compliance because of programmatic constraints. This analysis relies on the second approach. More specifically:

- For the purposes of this analysis, the deployment of biofuels from agrocommodities was *not* limited to 7% (by energy content). ICF assumed that the RED target of 10% would be met with a mix of biofuels from agricultural crops, waste-based biofuels, and 2nd generation biofuels. In 2020, only small volumes of 2nd generation biofuels are assumed to come online and account for less than 1% of all biofuels. By 2030, however, we assumed a five-fold increase (discussed in more detail below) in 2nd generation ethanol production, accounting for about 3–3.5% of all biofuels. In each case, ICF ensured that the analysis yielded RED compliance with a *maximum contribution* of 7% from biofuels via agricultural crops.
- ICF made similar assumptions and exceptions regarding the FQD. For instance, it is assumed that biofuels that do not achieve the 50% emissions reduction target will still enter the market place. Although these fuels may not contribute to FQD compliance because of the sustainability requirements, the biofuels with higher emission factors are required to achieve the higher blending scenarios outlined in this report. The alternative approach, which was *not* employed, would have been to assume that higher volumes of 2nd and 3rd generation biofuels would be available.

It is critically important to understand that the GHG emissions analysis laid out in this chapter is not a compliance-based optimization exercise. In that type of analysis, one would consider the costs (e.g., on a €/tonne basis) of various abatement options and optimize the solution based on supply constraints. In this analysis, however, the starting point is simply a specified

[84] Desplechin, E from ePURE. *Ethanol's role in meeting the EU 2020 targets – perspectives up to 2030*, 23 September 2015.

[85] For instance, palm fatty acid distillate (PFAD), and animal fats, used cooking oil, and in smaller volumes, tall oil pitch, technical corn oil, and spent bleaching oil

volume of liquid biofuel developed in the scenarios, and from there, ICF estimates the associated GHG emissions while ensuring FQD and RED compliance are achieved.

Consider Scenario A for illustrative purposes:

- The higher biofuel blends yield a renewable energy content of 14.2% for transport fuels in 2020 and 2030.
- ICF assumed that 7% of the total energy is attributable to biofuels from agrocommodities.
- ICF's assumed growth in waste-based biofuels (1st generation) and 2nd generation biofuels yields 1.6% of the energy. After accounting for the double-counting of these fuels, it yields a 3.2% contribution towards RED compliance.[86]
- At this point in the illustrative analysis, there is still a balance of 5.6% energy content in transport fuels that must be accounted for in some way. In this analysis, the additional energy content can be supplied by first or second generation biofuels, regardless of other considerations, such as feedstock, ILUC emissions or lifecycle GHG emissions. We fulfil that energy demand based on availability of first and second generation biofuels.

To develop feedstock shares into the future (namely 2020 and 2030), the analysis assumed modest changes to the share of biofuels from agricultural feedstocks (note: these fuels are assumed to have indirect land use change emissions, per the footnote on the previous page), including:

- A modest decrease in the share of biodiesel produced from rapeseed oil and sunflower oil, with an offsetting increase in biodiesel from waste feedstocks (e.g., used cooking oil) and palm oil.
- The modest decrease in biodiesel produced from rapeseed oil and sunflower oil is in part due to diverting those feedstocks to HVO production. HVO production is also increased from palm oil.
- An increase in sugarcane ethanol imports by 2030 because of the lower carbon intensity.

The amount of biodiesel and HVO from waste feedstocks (including used cooking oil and animal fats) was constrained based on assumptions presented by Chapter 1, Section 1.6.2.4, which estimates about 80–85 PJ of potential for biodiesel from used cooking oil and another 10–48 PJ of potential for biodiesel from by-products in the food industry (e.g., animal fats).

For second generation biofuels, growth was forecasted in each biofuel category, including second generation ethanol, biodiesel, and renewable diesel (which is akin to HVO; however, the feedstocks are not virgin oils). ICF assumed a doubling of capacity by 2020 yielding about 270 ktoe of biofuels; this growth is consistent with that expected in the U.S., Canada, and other markets that have incentives for advanced biofuel production[87] and is less than the 700 ktoe assumed by a report released by the JEC Biofuels Programme.[88] ICF assumed a five-fold increase from 2020 to 2030, yielding about 1.4 ktoe of 2nd generation biofuels. This is modest growth and only represents 5% of total EU biofuel production capacity today, estimated at around 25,000 ktoe.

[86] ICF notes that the RED also applies to electricity used in transport; most of which is currently used in rail applications. The 2010 NREAPs estimated a 1.4% contribution towards RED compliance, thereby putting downward pressure on the demand for advanced biofuels in meeting the 10% target. For the purposes of this analysis, we assumed that the 10% target would be met exclusively through deployment of liquid biofuels.

[87] EurObserv'ER, EU Biofuels Barometer, July 2014. Available online at: http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro222_en.pdf

[88] JRC, EU Renewable Energy Targets in 2020: Revised analysis of scenarios for transport fuels, 2014. Available online at https://www.concawe.eu/uploads/Modules/Publications/jec_biofuels_2013_report_final.PDF

4.4 Potential reductions in lifecycle GHG emissions

The range of lifecycle GHG emissions under the scenarios in this study were estimated using the following two very different sets of assumptions:

1. Approach 1: It is assumed that the carbon intensity of biofuels would significantly reduce over time as a result of future technological improvements made in the lifecycle. Emissions from indirect land use change (ILUC) were not included in the approach 1.
2. Approach 2: The GHG emissions was estimated by applying the default values for biofuels as set out in current legislation (Fuel Quality Directive (2009/30/EC), Annex IV) and indirect land use change (ILUC) emissions (Directive 2015/1513)[89] and the default factors were held constant over time.

Our assumptions of improvements to the carbon intensity of biofuels focused on changes to a) crop yield and b) processing efficiencies.

For crop yields we used yield improvements based on global averages of land-use efficiency of biofuels crops and expected yield improvements from the IEA, as shown in the table below.

Table 4.1 Average Crop Yield Improvements for Ethanol and Biodiesel Feedstocks

Biofuel	Feedstock	Average Improvement per year % litres per hectare	Main co-products, 2010 values (Kg/L biofuel)
Ethanol	Conventional (average)	0.70%	
	Sugar beet	0.70%	Beet pulp (0.25)
	Corn	0.70%	DDGS (0.3)
	Sugar cane	0.90%	Bagasse (0.25)
	Cellulosic -SRC	1.30%	Lignin (0.4)
Biodiesel	Conventional (average)	1.00%	FAME: Glycerine (0.1)
	Rapeseed	0.90%	Presscake (0.6)
	Soy	1.00%	Soy bean meal (0.8)
	Palm	1.00%	Empty fruit bunches (0.25)
	BtL - SRC	0.013%	Low temperature heat; pure CO_2
	HVO	1.30%	Same as for conventional biodiesel feedstock above

Source: IEA, 2011 analysis based on Accenture, 2007; BRDI, 2008; Brauer et al., 2008; E4Tech, 2010; ECN, 2009; FAO, 2003; FAO, 2008; GEMIS, 2010; IEA, 2008; Jank et al., 2007; Kusters, 2009; Kurker et al., 2010; and Schmer et al., 2008.

For process efficiency measures, ICF reviewed the so-called "typical" and "default" emission factors from Annex I of the Commission's 2011 proposal for a Directive laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC. ICF notes that the default values are derived from the typical values by adding an increase to the processing/refining emissions, thereby taking a conservative viewpoint of emissions. Absent more rigorous projections on the possible carbon intensity of biofuels that would be delivered to the EU to achieve the hypothetical blending scenarios, however, ICF used the difference between the default values and the typical values to characterize the type of changes that could occur over time to reduce emissions. More specifically:

[89] Available online at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:JOL_2015_239_R_0001&from=EN

- We assumed that all production matures to achieve "processing typical values" reported in the FQD and RED. This yields a 10–13% improvement.
- We assumed that processing emissions can be decreased mainly from energy efficiency and similar measures, leading to an additional reduction of 12–33%, depending on the fuel. These levels are consistent with improvements in plant efficiencies and conversion technologies. For instance, Table 4.2 below includes potential improvements in processing efficiencies (based on data from by the IEA)

Table 4.2 Biofuel plant efficiencies for large-scale energy pathways

Primary Energy Source	Process	Current Technology	Mature Technology
Oil-seed crops	Biodiesel	45%	52%
Grain crops	Ethanol / Alcohol	38%	42%
Sugar crops	Ethanol / Alcohol	36%	40%
Biomass from crops/waste products	Biodiesel	46%	53%
	Ethanol / Alcohol	34%	39%
	Methane	62%	69%

Source: IEA, Production Costs of Alternative Transportation Fuels, 2013. Available online at https://www.iea.org/publications/freepublications/publication/FeaturedInsights_AlternativeFuel_FINAL.pdf

- Emissions from processing sugarcane ethanol and wheat ethanol are assumed to remain constant 2020–2030.
- Finally, ICF's approach does *not* take into account reduction potential through co-products or improvements in transport and distribution.

It is likely that there will be changes in the carbon intensity of petrol and diesel over time as a result in crude slate shifts and adoption of upstream emission reduction strategies (e.g., flare reductions from associated petroleum gas in upstream oil and gas production). However, with a focus on the impact of higher biofuel blending, the emission factors for petrol and diesel were held constant over time for both scenarios. Furthermore, the feedstock shares remained the same for both approaches.

4.4.2 GHG emission factors

The table below includes the changes implemented for the GHG emissions from cultivation (Table 4.3) and processing (Table 4.4) between 2010 and 2030. GHG emission factors employed in the analysis and the corresponding ILUC factors that were used for sensitivity analysis are presented in Table 4.5.

The GHG emissions for petrol and diesel are calculated using 93.3 g/MJ and 95.1 g/MJ, respectively.

Table 4.3 Disaggregated values for emissions from cultivation of feedstocks for biofuel production

Biofuel and bioliquid production pathway	Carbon Intensity from FQD		Potential Improvement		Assumed Carbon Intensity (gCO2eq/MJ)	
	Typical	Default	10 years, %Liters/hectare	% Conversion	2020	2030
sugar beet ethanol	12	12	7.0%	10.0%	10.09	9.43
wheat ethanol	23	23	7.0%	9.5%	19.45	18.18
corn (maize) ethanol, Community produced	20	20	7.0%	9.5%	16.91	15.81
sugar cane ethanol	14	14	9.0%	10.0%	11.56	10.61
rape seed biodiesel	29	29	9.0%	13.5%	23.02	21.12
sunflower biodiesel	18	18	10.0%	13.5%	14.16	12.87
soybean biodiesel	19	19	10.0%	13.5%	14.95	13.59
palm oil biodiesel (process not specified)	14	14	10.0%	13.5%	11.01	10.01
palm oil biodiesel (process with methane capture at oil mill)	14	14	10.0%	13.5%	11.01	10.01
waste vegetable or animal oil biodiesel	0	0	0	13.2%	0.00	0.00
hydrotreated vegetable oil from rape seed	30	30	9.0%	13.5%	23.82	21.85
hydrotreated vegetable oil from sunflower	18	18	10.0%	13.5%	14.16	12.87
hydrotreated vegetable oil from palm oil (process not specified)	15	15	10.0%	13.5%	11.80	10.73
hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	15	15	10.0%	13.5%	11.80	10.73
pure vegetable oil from rape seed	30	30	9.0%	13.5%	23.82	21.85

Table 4.4 Disaggregated values for emissions from biofuels processing

Biofuel and bioliquid production pathway	Carbon Intensity from FQD		Potential Improvement	Assumed Carbon Intensity (gCO2eq/MJ)	
	Typical	Default	% Conversion	2020	2030
sugar beet ethanol	19	26	10.0%	23.40	19.00
wheat ethanol	32	45	9.5%	40.71	32.00
corn (maize) ethanol, Community produced	32	45	9.5%	40.71	32.00
sugar cane ethanol	21	30	9.5%	27.14	21.00
rape seed biodiesel	14	19	9.5%	17.19	14.00
sunflower biodiesel	1	1	9.5%	0.90	0.90
soybean biodiesel	15	21	9.5%	19.00	15.00
palm oil biodiesel (process not specified)	1	1	10.0%	0.90	0.90
palm oil biodiesel (process with methane capture at oil mill)	16	22	13.5%	19.04	16.00
waste vegetable or animal oil biodiesel	16	22	13.5%	19.04	16.00
hydrotreated vegetable oil from rape seed	18	26	13.5%	22.50	18.00
hydrotreated vegetable oil from sunflower	35	49	13.5%	42.40	35.00
hydrotreated vegetable oil from palm oil (process not specified)	13	18	13.5%	15.58	13.00
hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	9	13	13.2%	11.28	9.00
pure vegetable oil from rape seed	10	13	13.5%	11.25	10.00

Table 4.5 Carbon intensity values used in analysis for liquid biofuels

Biofuel and bioliquid production pathway	Carbon Intensity Values (gCO2eq/MJ)			ILUC (gCO2eq/MJ)
	2010	2020	2030	
Sugar beet ethanol	40	35	30	13
Wheat ethanol (process fuel not specified)	70	62	52	12
Wheat ethanol (lignite as process fuel in CHP plant)	70	62	52	12
Wheat ethanol (natural gas as process fuel in conventional boiler)	55	49	41	12
Wheat ethanol (natural gas as process fuel in CHP plant)	44	39	34	12
Wheat ethanol (straw as process fuel in CHP plant)	26	22	21	12
Corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant)	43	38	33	12
Sugar cane ethanol	24	21	21	12
FAME rape seed	52	43	38	55
FAME sunflower	41	34	30	55
FAME soybean	58	50	45	55
FAME palm oil (process not specified)	68	58	50	55
FAME palm oil (process with methane capture at oil mill)	37	32	28	55
Waste vegetable or animal oil biodiesel	14	12	10	0
Hydrotreated vegetable oil from rape seed	44	36	33	55
Hydrotreated vegetable oil from sunflower	32	26	24	55
Hydrotreated vegetable oil from palm oil (process not specified)	62	53	46	55
Hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	29	23	20	55
Pure vegetable oil from rape seed	36	29	27	55

4.4.3 Feedstock Shares

The GHG emissions are also dependent on feedstock shares assumed for biofuel production. Table 4.6 below includes ICF assumptions for 2010, 2020, and 2030; ICF notes that forecasting feedstock shares is non- trivial and dependent on parameters including but not limited to feedstock costs, agricultural policy, proximity to production facilities, ethanol imports, trade policy, and duties in place. The text following the table highlights ICF's assumptions regarding feedstock shares.

Table 4.6 Feedstock shares used in the analysis

Fuel	Feedstock	2010	2020	2030
Ethanol[90]	Sugar beet	18%	10%	7%
	Wheat (average)[91]	62%	40%	42%
	Corn	20%	45%	51%
	Sugar cane (import)	0%	6%	0%
FAME	Rape seed	73%	63%	52%
	Sunflower	2%	6%	10%
	Soybean	12%	11%	10%
	Palm oil (average)	5%	10%	15%
	Waste vegetable oil or animal oil	8%	10%	14%
HVO	Rape seed	37%	23%	10%
	Sunflower	1%	3%	6%
	Soybean	6%	4%	3%
	Palm oil (average)	3%	14%	23%
	Waste vegetable oil or animal oil	54%	56%	59%

ICF made the following assumptions related to feedstocks for ethanol:

- Corn shares increase consistent with recent trends based on feedstock availability, and its competitive pricing compared to wheat. The EU FAS posts forecast an annual increase in corn of 1%; however, data from ePURE indicate higher levels of corn utilization than the EU FAS documentation. ICF assumed 3% growth every five years moving forward.
- ICF assumes that wheat's contribution, along with other cereals, will stay in the range of 40%.
- Regarding imports, corn ethanol from the US is the most competitive import over the last several years. However, anti-dumping duty may disappear after 2017-2018, and sustainability criteria via FQD will encourage sugar cane. Current preferential trade is with Guatemala, Peru, and Pakistan; we characterize these as sugar cane
- With the market share for corn ethanol production increasing, wheat staying more-or-less constant, and the potential for imports, ICF assumes that sugar beets will decrease over time. This is in part linked to the abolishment of sugar production quotas in 2016/2017.

ICF made the following assumptions related to feedstocks for FAME/biodiesel:

- Rapeseed oil has an important share in the market that could be sustained to meet FAME biodiesel specifications. However, the feedstock has been displaced mostly due to higher use of palm oil and recycled vegetable oil. Palm oil has become the second most important

[90] Feedstocks shares for ethanol in 2010 come via Desplechin, E from ePURE. *Ethanol's role in meeting the EU 2020 targets – perspectives up to 2030*, 23 September 2015.

[91] ICF assumed that the emissions from wheat ethanol are similar to the emissions from ethanol produced with other cereals, including rye and barley.

feedstock because of Neste's renewable diesel plant; in 2013, increased palm oil use in conventional biofuel happened also because of palm oil price.

- Soybean oil use is limited due to EU biodiesel standard DIN EN 14214, which require the use of other biodiesel (rapeseed oil) to meet specifications. Inclusion of sustainability requirements might lead to an increase in rapeseed oil use at the expense of soybean oil.
- ICF assumed that the average annual increase in waste oil usage (and displacement of vegetable oils) is 1%, with a corresponding decrease in rapeseed oil of 1%. This is also linked to potential changes in palm oil prices.
- Attractive palm oil pricing and supply availability yields an average annual increase in palm oil 0.6%, and an annual average increase in sunflower oil of 0.4%. Note that from a GHG life cycle emissions perspective, the impact of this assumption is the same as assuming an increase in the share of rapeseed oil because the carbon intensity values for rapeseed and sunflower oils are similar.
- We also assume an average annual decrease in the share of soybean of -0.06% due to potential changes in palm oil prices and the introduction of sustainability criteria.

ICF made the following assumptions related to feedstocks for HVO:

- ICF assumed that the average annual increase in waste oil usage (and displacement of vegetable oils) is about 1%.
- We assumed an average annual decrease in rapeseed oil of about 3% due to potential changes in palm oil prices; other oils are to be displaced by rapeseed
- We assumed an average annual increase 2.5% and 0.6% for palm oil and sunflower oil, respectively. From a GHG life cycle emissions perspective, the impact of this assumption is the same as assuming an increase in the share of rapeseed oil as RED and FQD GHG values do not establish differentiate significantly between the processing and the transportation of these two type of feedstocks. This "additional increase of rapeseed oil" can be attributed to any impact sustainability requirements might lead to.
- We assumed an average annual decrease in the share of soybean of -0.3% due to potential changes in palm oil prices and the introduction of sustainability criteria.

4.5 Lifecycle Greenhouse Gas Impacts

Table 4.7 presents the GHG emissions of each biofuel blend scenario based on approach 1, where the carbon intensity of biofuels is assumed to reduce over time, and ILUC emissions are not included.

Table 4.7 GHG Emissions (million metric tonnes (MMT)) for each biofuel blend scenario

	2020		2030			
Feedstock	Base	Scenario A-C	Base	Scen A	Scen B	Scen C
Petrol	245	236	185	179	166	160
Diesel	827	776	840	745	743	724
Ethanol	4	8	3	6	11	15
FAME	21	25	19	24	33	42
HVO	1	19	1	31	25	25
Total	1,092	1,055	1,047	985	979	966
% change from Baseline	--	3.5%	--	7.1%	7.8%	9.4%

Table 4.8 presents GHG emissions estimates assuming default carbon intensity values and accounting for indirect land use change (ILUC) emissions.

Table 4.8 GHG Emissions (MMT) in for each biofuel blend scenario, with ILUC emissions

	2020		2030			
Feedstock	Baseline	Scenario A-C	Baseline	Scen A	Scen B	Scen C
Petrol	245	236	185	179	166	160
Diesel	827	776	840	745	743	724
Ethanol	5	11	3	7	15	18
FAME	43	50	39	50	69	87
HVO	2	43	2	81	64	64
Total	1,121	1,115	1,069	1,061	1,057	1,054
	--	0.5%	--	0.8%	1.2%	1.5%

The analysis indicates that the higher biofuel blending scenarios yield GHG benefits compared to the base case scenario, depending on the set of assumptions related to the emission factors for biofuels and ILUC emissions (2020 results in Figure 4.1 and 2030 results in Figure 4.2).The analysis yields GHG emission reductions of 7.1–9.4% for approach 1 with assumed significant improvements of the emission factor s and when not accounting for ILUC emissions. However in approach 2 when applying the default values for biofuels as set out in current legislation and taking indirect land use change (ILUC) emissions into account emission reductions of only 0.8–1.5% are estimated. It should be emphasised that these results are also significantly dependent on assumed a) expanded use of waste-based feedstocks, particularly for FAME and HVO production and b) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030, including for ethanol, biodiesel, and renewable diesel (chemically equivalent to HVO; but the term is inclusive of a broader set of production processes and feedstocks).

Figure 4.1 GHG emissions estimated for biofuel blending scenarios in approach 1 (left) and approach 2 (right; with ILUC emissions), 2020

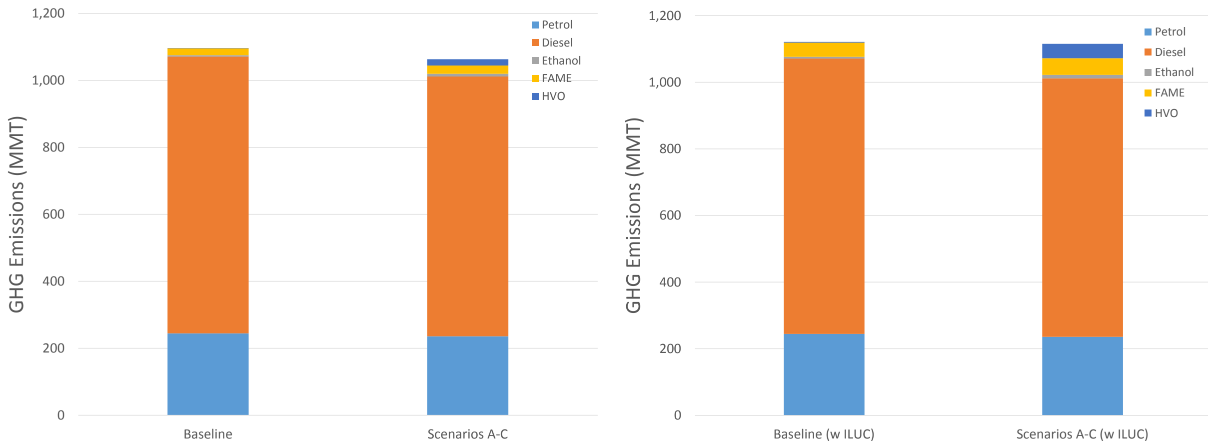
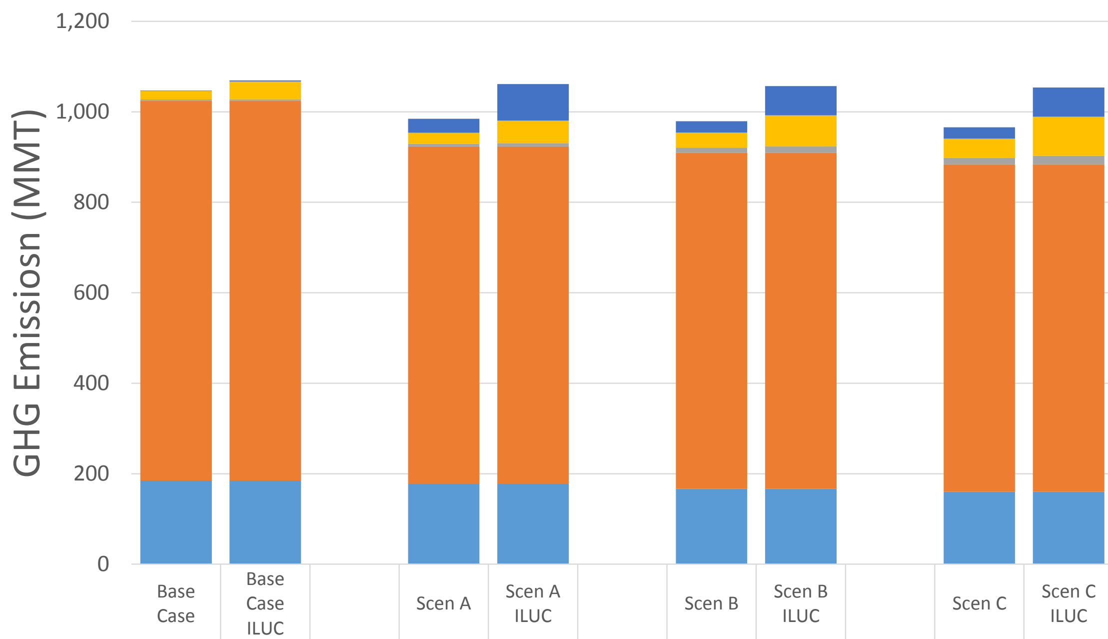


Figure 4.2 GHG Emissions (MMT) for each biofuel blend scenario, 2030



	Base Case	Base Case ILUC	Scen A	Scen A ILUC	Scen B	Scen B ILUC	Scen C	Scen C ILUC
HVO	1	2	31	81	25	64	25	64
FAME	19	39	24	50	33	69	42	87
Ethanol	3	3	6	7	11	15	15	18
Diesel	840	840	745	745	743	743	724	724
Petrol	185	185	179	179	166	166	160	160

4.6 Conclusions

Higher biofuel blending scenarios yield GHG benefits compared to the Base Case scenario, depending on applied assumptions related to the emission factors for biofuels and ILUC emissions.

The greenhouse gas (GHG) impact analysis of three hypothetical scenarios for higher bio blends suggests that these can yield benefits compared to the base case scenario. The estimated benefits are dependent on a) reducing the carbon intensity of biofuels over time as a result of improvements made in the supply chain of biofuels, b) expanded use of waste-based feedstocks, particularly for FAME and HVO production and c) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030, including for ethanol, biodiesel, and renewable diesel. Assuming a reduction in the carbon intensity emission factors of biofuels over time and excluding indirect land use change (ILUC) GHG emissions, the analysis yields an estimated reduction in the range of 7.1 to 9.4% for the three higher blend limits and use scenarios in 2030. However, if no reductions in the carbon intensity of biofuels are assumed over time, and the emission factors as set out in current legislation are used, including default carbon intensity values for biofuels (included in FQD Annex IV) and indirect land use change factors (in the ILUC Directive), the analysis yields GHG emission reductions between 0.8 to 1.5% compared to the base case scenario.

5 Impacts on refining and fuel supply

Abbreviations/acronyms

CTL	Coal to liquids
EIA	Energy information administration
FIMM	Full Industrial Market Model
GTL	Gas to liquids
IEA	International energy agency
IMO	International Marine Organisation
Ktoe	kilo tonnes of oil equivalent
Mb/d	Million barrels per day
MTBE	Methyl tert-butyl ether
NGL	Natural gas liquids
OECD	Organisation for Economic Co-operation and Development
PED	Price elasticity of demand
WEO	World energy outlook
WORLD	World Oil Refining Logistics & Demand model

5.1 Summary

Two different modelling methods were applied to evaluate the impacts of different biofuel blend scenarios (Chapter 1, Section 1.7.3) on the refinery sector and fuel supply in the EU.

1. EnSys Energy's WORLD model, which is a linear programming model that simulates the operation and economics of the world regional petroleum industry (Section 5.3 and 5.4); and
2. Vivid Economics' economic model of the EU refining market (Section 5.5 and 5.6)

While each model takes a different analytical route, their overarching messages are the same.

5.1.1 Impact of petrol and diesel projections in the Base Case

The 2020/2030 Base Case scenario (based on *EU Energy, Transport and GHG Emissions Trends to 2050, Reference Scenario 2013*) is itself significant since it embodies a further substantial reduction in EU petrol demand in combination with some increase in diesel demand. Under the Base Case outlook, EU diesel to petrol demand ratio continues to shift from 2:1 in 2007 and 2.4:1 in 2011 to 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis). This significantly aggravates the already problematic diesel:petrol ratio in the EU and so sets up 2020 and especially 2030 Base case outlooks which further strain EU refining and lead to projected lower regional refinery throughputs particularly by 2030.

Under the Base Case, petrol exports from and diesel/gasoil imports into the EU are far higher than has recently been the case. In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. The continuing distortion in projected regional demand ratio (petrol decline, diesel increase) relative to refinery yield capability contributes to reduced refinery throughputs while at the same time necessitating higher petrol exports in order to enable diesel production. As a part of this strained outlook, petrol prices in the EU and in non-EU regions are further depressed relative to crude price versus today's levels and – conversely – those for diesel and other distillates including jet fuel are elevated. Thus, at these depressed petrol prices, EU refiners find additional export markets for petrol, (The alternative would be for more extreme reductions in EU refinery throughputs and associated high levels of imports not only of diesel but also of other petroleum products. This would in turn necessitate added capacity and investments in non-EU refineries, raising costs of product supply into the EU and so creating even more price distortion, while EU refineries stood idle. It is thus an unlikely situation. The most economic / least uneconomic balance is projected to be for limited reduction in EU refinery throughputs and an expansion of petrol exports at depressed prices. This strained situation in turn affects the impacts from higher biofuels.

5.1.2 Impact of higher biofuel blend scenarios

EU ethanol and/or biodiesel supply was assumed to increase based on the higher biofuel scenarios in order to prevent significant increases in EU biofuels imports. The net effect of this approach was that the assessed EU biofuel supply increases were entirely biodiesel in 2020 for all Scenarios A, B and C, and predominantly biodiesel in 2030. Increases ranged from 0.2 million barrels per day (mb/d) in 2020 for all Scenarios to as high as 0.5 mb/d under 2030 Scenario C.

Mineral road fuels demand (petrol and diesel) is expected to decrease through 2030 with increasing biofuel demand. By 2020 (all scenarios), the EU mineral road fuels production could fall by 104,000 ktoe/yr (4.4 per cent) from its 2014 level due to the Base Case fuel supply projections, and by an additional 124,000 ktoe (5.5 per cent) due to higher biofuel demand. Mineral road fuels production could fall by 203,000 ktoe/yr (8.6 per cent) from its 2014 level due to Base Case assumptions, and, due to increasing biofuel demand, could fall by an additional:

- 209,000 ktoe/yr (9.7 per cent) in Scenario A;
- 240,000 ktoe/yr(11.1 per cent) in Scenario B; and
- 293,000 ktoe/yr (13.5 per cent) in Scenario C.

This assessment and premise has a key impact on the outlook. Because the European industry operates with a petrol/diesel imbalance which worsens under the Base Case scenario, a primary impact of higher biofuels is to reduce diesel/gasoil imports into the EU such that the bulk of the refinery impacts are projected to be felt in regions outside the EU. Put another way, in the 2020 and 2030 Base Case scenarios, and as stated under the Base Case impacts discussion above, the EU petrol:diesel imbalance is projected to be more severe than today, such that both diesel imports and petrol exports are higher. Since they incur added transport costs, the imports are generally the most expensive products supplied. Consequently, when EU biodiesel production is increased, as in the higher biofuels scenarios, the main impact is to reduce imports of diesel fuel into the EU. This reduction in imports means that production of diesel is reduced in one or more of the regions (Russia, USA etc.) that were exporting diesel to the EU. Consequently, it is in those regions that refinery throughputs drop and where, as a result, there is the potential for closures (relative to the Base Case scenario).

In contrast, increasing EU ethanol supply for use in petrol consumed in the EU leaves EU refineries with the choice of exporting yet more petrol (which is increasingly uneconomic to do since it must be further discounted in order to yet further increase flows into foreign markets) and/or of reducing throughputs to offset the increased ethanol supply. Given the premise that the higher biofuels scenarios increase primarily biodiesel production, the modelling results indicate the primary impact of higher EU biofuels supply is reduced diesel imports, as stated, and the secondary; i.e., smaller impacts are increases in petrol exports combined with limited reductions in EU refinery throughputs.

Implied refinery closures, relative to the Base Case, are driven by the increases in biofuels supply. Every barrel of increased EU biofuels supply reduces required global refinery throughputs by essentially one barrel. Since refineries are projected to be operating in the Base Case and higher biofuels scenarios at an average of around 80% of their capacity, a reduction of 1 barrel per day in throughput would imply approximately 1.25 barrels per day (1 ÷ 0.8) in closures. The modelling results reflect this. They indicate capacity closures due to higher biofuel supply could be 0.27-0.29 mb/d globally in 2020 (for all scenarios) and between 0.4 million barrels/day (mb/d) and 0.6 mb/d globally in 2030 under Scenario A and C, respectively. Of these, and for the reasons stated above, the majority of implied closures are indicated as occurring outside the EU with some 0.07 mb/d (2020; all scenarios) and between 0.08 mb/d and 0.2 mb/d (2030; Scenario A and C) inside the EU, as estimated by the WORLD model. These estimates are based on the assumption that refineries would maintain utilisations at around their 2014 levels (i.e., 79-80%). Conversely, if lower refinery utilisation levels were still considered sustainable, closures would be correspondingly lower. In addition, preliminary model cases indicated that the split of closures between EU and Non-EU regions is sensitive to how strained the Base Case scenario is. In a less strained scenario (meant here as EU petrol:diesel demand more in line with normal refinery yields) the indication is that total global throughput reductions and implied closures would not change but the proportion of capacity closures could be higher in the EU and lower in other regions.

Whether defined in terms of crack spread or refinery gross margins[92], the overall impact in the EU across the scenarios, compared to the Base Case, is estimated to be small, with a reduction on the order of 2-7% in 2020 and a change of +2% to -4% in 2030 on average. For example, for gross margins, which vary between refineries, the absolute impact is a reduction of 7 $¢/bbl in 2020 for all Scenarios (compared to a base case margin of 3.93 US$/bbl) and 11 $¢/bbl in Scenario A, 13 $¢/bbl in Scenario B and 16 $¢/bbl in 2030 for Scenario C (compared to a base case margin of 3.83 US$/bbl).

Impacts on product prices within the EU, relative to the Base Case, are projected to be limited. In 2020, adding in greater quantities of biofuels could reduce the aggregate cost of products in major demand centres although the effects would be small, about a 0.6% reduction in the EU and a global reduction of 0.3% (for all scenarios). Conversely in the 2030 scenarios, product supply cost hardly changes. This relates to the stresses inherent in the 2030 Base Case. As described above, the positive impact on EU refining of raising regional biodiesel production and thereby lowering diesel/gasoil imports with that the pressure to produce diesel, is negated by the further stresses placed on the EU refining system from the increase regional ethanol production and use. One move (more biodiesel) takes EU refiners a little closer to a situation that would be optimal, the second (more ethanol) does the opposite. The net effect is little change in overall costs of supplying products to major EU market centres.

The increase in consumer prices may be 2.3 €¢/l in 2020 (2 per cent) and, in 2030:

- 4.8 €¢/l (4 per cent) in Scenario A
- 5.0 €¢/l (4.1 per cent) in Scenario B and
- 5.8 €¢/l (4.8 per cent) in Scenario C.

Consumer prices are comprised of mineral road fuel wholesale prices, biofuel wholesale prices and the EU average current fuel duty and Value Added Tax. Mineral road fuel wholesale prices are 55.2 €¢/l for an 85 $/bbl crude oil price and biopetrol and biodiesel wholesale prices, which are weighted by their respective share in total biofuels, could be 91.9 €¢/l in 2020, rising to 97.8 €¢/l in 2030. Including taxes, the average price at the pump is 121.5 €¢/l in 2020 and 121.1 €¢/l

[92] Gross margins are the difference between the revenue derived from products and cost of raw materials, primarily crude but including other additives.

in 2030. The difference in biofuel and mineral road fuel prices drives the consumer price increase as the biofuel share increases from the baseline, as laid out above.

Higher crude oil prices would narrow the differential between mineral road fuel and biofuel prices and would make smaller the increase in consumer prices. At 124 $/bbl crude price, consumer prices increase by 1.0 €¢/l in 2020 across all scenarios and, in 2030, by 2.0 €¢/l in Scenario A; by 1.8 €¢/l in Scenario B and 1.9 €¢/l in Scenario C.

5.2 Introduction

This chapter focuses on the work undertaken by EnSys Energy and Vivid Economics to assess the impacts of higher biofuel scenarios in 2020 and 2030 on refining and fuel supply.

1. EnSys Energy utilised its proprietary World Oil Refining Logistics & Demand (WORLD) Model. WORLD captures and simulates the total global “liquids” downstream system from crudes and non-crudes supply through refining, transport and demand and which can be used to address a wide range of strategic questions. It marries top down oil price/supply/demand outlooks, such as are developed by the IEA, EIA, OPEC and others, with bottom up detail: around 200 crude oils, non-crudes breakdown (NGL’s, biofuels, GTL/CTL etc.), data on every refinery worldwide with aggregation into regional or sub-regional groups, multiple products and product quality detail, detailed marine, pipeline and minor modes transport representation, refining sector GHG emissions, projects, investments. This combination is used to model any current or future horizon out to (currently) 2040, simulating how the industry is likely to operate and react under any given scenario and capturing the interactions and competition inherent in the global downstream.
2. Vivid Economics’ Full Industrial Market Model (FIMM) estimates competitiveness impacts quantitatively. The model allows analysis of interactions between rival firms and consumers within capital-intensive industries. The model depicts firms in individual economic markets and captures the impact of changes in market structure, including the entrance or exit of individual firms, changes in the nature of demand, and changes in production costs. The model is well-suited to industrial sectors where firms have high fixed costs, such as energy-intensive industries. The model is based around the Cournot model of oligopoly, and is conceptually similar to the qualitative Porter’s Five Forces model, widely used in corporate strategy analysis. It is a partial equilibrium model, solved algebraically. The results span the changes in: consumer prices, EU mineral road fuel (diesel and petrol) production, mineral road fuel imports, EU refining gross profit margins, and potential utilisation decline and/or exit of EU refining capacity.

The conclusions from this analysis reflect the outcomes of two models that each take a different analytical route to assessing the impacts of higher biofuel blends.

- Section 5.3 provides a review of the EnSys WORLD modelling methodology and assumptions.
- Section 5.4 presents the key results and findings from the WORLD modelling analysis.
- Section 5.5 presents a summary of the methodology and assumptions of Vivid’s FIMM
- Section 5.6 discusses the consumer price, gross profit margins and refinery capacity results from FIMM
- Section 5.7 integrates the main findings from sections 5.4 and 5.6 and presents the overarching conclusions from this analyses.

5.3 WORLD model methodology and assumptions

This section provides an overview of the modelling tool used by EnSys Energy (EnSys) and then focuses on the premises applied in the analysis of higher biofuel scenarios.

5.3.1 Model inputs and outputs

As illustrated in Figure 5.1 (below), model inputs combine top down and bottom up data covering:

- Supply/demand
  - Overall world oil price/supply/demand scenario for case year e.g. from EIA or IEA projection
    - Includes marker crude price
  - Supply projection detail (crudes, non-crudes) matched to supply scenario
  - Crude oil supply detail
  - Non-crudes comprise NGLs, petchem returns, biofuels, methanol, GTL, CTL
  - Product demand projection detail by region based on historical data plus growth rates tuned to demand projection
    - Multiple product grades:
    - Gasoline, distillates, residual fuels, other products
- Transport
  - Trade movement detail:
  - Crudes, non-crudes, products, intermediates
  - Marine, pipeline, minor
  - Built up freight rates / tariffs / duties
  - Pipeline and tanker fleet capacities / projects
- Refining
  - Base/current refinery capacity data
    - By refinery by unit worldwide
    - Regionally aggregated
  - Announced refinery projects
    - Categorized by stage of development
    - Selection of projects considered firm
  - Refinery closures
    - Firm announced closures plus optionally assessed additional potential closures
  - Refinery technology database
    - Multiple processes
    - Yields, utilities, OVCs

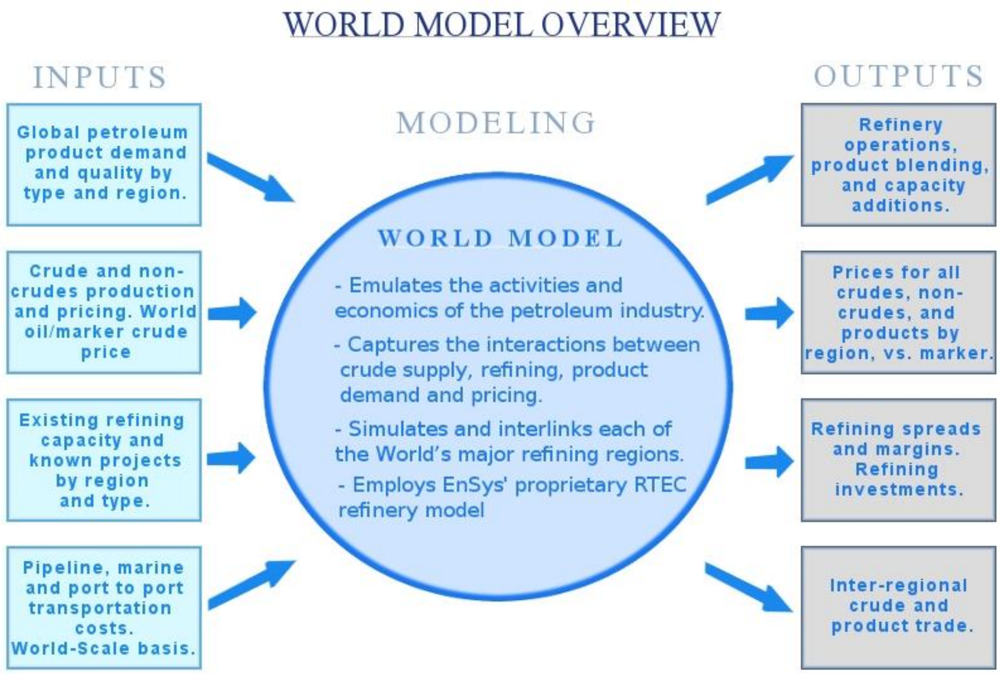
    - Current technologies but can accommodate/evaluate new processes
    - Merchant processes: MTBE, GTL, CTL
  - Product blending & specifications

Outputs comprise a combination of physical and economic parameters:

- Main results - physical:
  - Refinery throughputs, operations, capacity additions
  - Product blending & qualities
  - Crudes, non-crudes, products, intermediates inter-regional trade movements & pipeline throughputs
- Main results - economic:
  - Refining investment costs
  - Marginal costs / prices of all crudes, products by region
    - relative to marker crude
  - Total product costs (price * volume) delivered to major market centres regional and global
  - Refining margins / crack spreads

In summary, each WORLD Model case provides a summary of the way the global industry is projected as likely to operate under a given scenario and captures key physical and economic parameters. Much of the power of the approach lies in the ability to assess the impacts of changes off a base case, in this instance higher biofuels use in Europe, and the resulting refining and trade consequences both directly in the region(s) immediately affected and also worldwide.

Figure 5.1 Model inputs and outputs



5.3.2 Model regional formulation

Table 5.1 summarises the regional formulation of the WORLD Model as used for this study. As can be seen, Europe is represented as three regions. WORLD Europe regions are defined geographically and do not correspond to either the EU28 or OECD Europe. Constraints of timescale and budget did not allow for Model reformulation. Consequently data on EU28 (e.g. petrol and diesel demand) were ratioed up to fit the WORLD Europe definition and vice-versa. Available data from the Energy Information Administration on total petroleum product demand by country were used to establish the ratio. As shown on Table 5.2, this was estimated as a factor of 1.077 to go from EU28 to WORLD Europe and 1/1.077 to go in the opposite direction (e.g. in translating WORLD results on trade flows and refining operations – but not prices – back to their EU28 equivalent). This approach necessarily introduced a degree of approximation but was considered the best option available given the constraints noted. It was also the approach used in the *Impact Analysis of Options for Implementing Article 7a of Directive 98/70/EC (Fuel Quality Directive)*, ICF, August 2013.

In the Model reports generated for this study, refining activity and trade flows were reported at the level of 9 aggregate regions as set out in Table 5.1. Summary results were presented mainly at the level of "Europe" and "Global" for simplicity. References to "Europe" are marked as either WORLD Europe or EU28.

Table 5.1 WORLD Model Regional Formulation

Standard WORLD Model 23 Region Formulation	
Regional aggregations for reporting	Primary model supply / demand / refining regions
USA & Canada	US East Coast (PADD1)
	US Mid West (PADD2)
	US Gulf Coast (PADD3)

Standard WORLD Model 23 Region Formulation	
Regional aggregations for reporting	Primary model supply / demand / refining regions
	US Rocky Mountain (PADD4)
	US West Coast (PADD5)
	Canada East
	Canada West
Latin America	Mexico
	Greater Caribbean
	South America
Africa	Africa North & Eastern Med
	Africa West
	Africa South/East
Europe	Europe North West
	Europe South
	Europe East / EurAsia
Russia / Caspian (FSU)	Russia (or Russia/FSU) (1)
	Caspian
Middle East	Middle East
Pacific Industrialized	Pacific Industrialized (Japan / Australasia)
China	China
Other Asia / Pacific	Pacific Industrializing (High Growth)
	India / Rest of Asia
Note: Some users require Russia split out as its own region, others to stay with the FSU formulation.	

Table 5.2 European Countries Total Petroleum Consumption

European Countries Total Petroleum Consumption and Allocation to Regional Groups (http://www.eia.gov/countries/data.cfm)				
(Thousand Barrels Per Day)				
European Country	**2011**	**EU 28**	**WORLD Europe**	**OECD Europe**
Albania	38.4		E	
Armenia	45.3			
Austria	264.5	U	N	O
Azerbaijan	152.9			
Belarus	188.8			

European Countries Total Petroleum Consumption and Allocation to Regional Groups (http://www.eia.gov/countries/data.cfm)

(Thousand Barrels Per Day)

European Country	2011	EU 28	WORLD Europe	OECD Europe
Belgium	647.4	U	N	O
Bosnia and Herzegovina	27.5		E	
Bulgaria	112.7	U	E	
Croatia	93.0	U		
Cyprus	58.4	U		
Czech Republic	192.4	U	E	O
Denmark	160.2	U	N	O
Estonia	26.3	U		O
Faroe Islands	4.9			
Finland	209.1	U	N	O
Former Czechoslovakia	--			
Former Serbia and Montenegro	--			
Former Yugoslavia	--			
France	1824.0	U	N	O
Georgia	17.3			
Germany	2423.0	U	N	O
Gibraltar	24.9			
Greece	336.8	U	S	O
Hungary	141.4	U	E	O
Iceland	17.4		N	O
Ireland	144.2	U	N	O
Italy	1455.5	U	S	O
Latvia	31.3	U		
Lithuania	70.4	U		
Luxembourg	62.2	U	N	O
Macedonia	17.5		E	

European Countries Total Petroleum Consumption and Allocation to Regional Groups (http://www.eia.gov/countries/data.cfm)				
(Thousand Barrels Per Day)				
European Country	2011	EU 28	WORLD Europe	OECD Europe
Malta	19.5	U		
Moldova	18.1		E	
Montenegro	4.4		E	
Netherlands	1005.7	U	N	O
Norway	245.0		N	O
Poland	579.3	U	E	O
Portugal	260.7	U	S	O
Romania	218.2	U	E	
Serbia	81.4		E	
Slovakia	80.6	U	E	O
Slovenia	52.9	U	E	O
Spain	1383.2	U	S	O
Sweden	328.4	U	N	O
Switzerland	236.1		N	O
Turkey	679.9		S	O
Ukraine	320.6			
United Kingdom	1602.1	U	N	O
TOTAL		**13783.3**	**14850.1**	**14358.1**
Ratio WORLD Europe to EU 28 Demand			**1.077**	
Count - number of countries		28	32	25

5.3.3 Model base case premises

The following summarises key premises proposed for the WORLD Model 2020 and 2030 base and higher biofuels cases developed and run to examine impacts of high biofuels scenarios for EU transport fuels. As noted in the table, key steps in the Model set up were to:

1. Build in IEA WEO New Policies world crude price profile and top down supply and demand outlook and tune WORLD bottom up numbers to these
2. Adjust global marine fuel demand to fit with latest IMO outlook (which differs from IEA) and assume MARPOL Annex VI global fuel standard goes ahead in 2020

3. Build in projected 2020 and 2030 Europe demand numbers for petrol and diesel and for ethanol and biodiesel supply which override the original WEO-based numbers - but leave all other WEO-based numbers unchanged.

Table 5.3 Key model base case premises

Premise	Value(s) Used	Comment
Global price/supply/demand outlook		
Top down outlook	IEA Nov 2014 World Energy Outlook (WEO) New Policies case.[93] This outlook was selected because (a) it originated from the IEA as distinct the US-based EIA or other organisations and (b) because it included projections to 2030 which were needed for the study. The IEA states in the WEO that New Policies is their "central" case. New Policies includes progressive worldwide implementation of efficiency and alternative fuel technologies such that global oil demand growth gradually slows. The oil price path has a moderate increase (versus the Current Policies case). Price reaches $118/barrel in 2025 and $132/barrel in 2040 (in real terms). Global oil demand reaches 101.3 mb/d in 2030 to which IEA adds 3.4 mb/d (oil energy equivalent) of biofuels. Translating the latter into volume barrels leads to a total 2030 volume "liquids" demand of just over 106 mb/d. This outlook is broadly in line with those from other agencies such as the EIA and OPEC (unlike the Current Policies and 450 Scenarios).	Note, the WEO New Policies case is a "high" price outlook that did not fully take into account the recent crude price drop, i.e. effectively it assumes a return to high prices for the 2020 – 2030 time frame. (See below.) The Nov 2014 WEO is however the latest available IEA outlook that goes beyond 2020. Overall, the WEO New Policies scenario presented the most plausible available outlook which also covered to 2030. In addition, the WEO New Policies scenario provides more detail on supply and demand for the New Policies than for the other two scenarios. The Feb 2015 IEA Medium Term Oil Market Report (MTOMR) includes projections from 2015 to 2020. These were used as a cross-check.
Crude price	Per WEO basis. WEO New Policies prices ($2013) are $112/barrel for 2020 and $122.67/barrel for 2030. These are adjusted for input to WORLD (a) for quality differential versus Saudi Light which is used as the marker crude in the WORLD Model and (b) to subtract off estimated freight to arrive at a Saudi Light FOB (loading port) price.	Basis for the WEO price is understood to be average IEA member import (landed) price.

93 Based on IEA data from © 2014 World Energy Outlook, OECD/IEA, IEA Publishing. Modified by EnSys Energy. Licence: www.iea.org/t&c/termsandconditions.

Premise	Value(s) Used	Comment
Global supply / demand	WEO total supply and demand for 2020 under New Policies scenario is 99.0 mb/d including biofuels in volume barrel terms and 106.1 mb/d for 2030 on the same basis. The WEO New Policies tables include data for OPEC and non-OPEC crude, NGL's and non-conventional supply and for the same breakdown of supply by major world region. EnSys used these to tune embedded bottom up WORLD detail to the WEO top down numbers.	As noted above, WEO projections show biofuels supply/demand stated as barrels of equivalent gasoline/diesel. Since WORLD works on volume barrels, the biofuels volumes are adjusted to their estimated volume barrels equivalent and global volume supply and demand correspondingly adjusted. WEO Tables 3.1 through 3.9 and tables in Annex A contain New Policies scenario supply and demand projections.
Global biofuels supply	WEO New Policies projects biofuels at 2.2 mb/d 2020 and 3.4 mb/d 2030 oil equivalent volume. EnSys adjusted these to respectively 3.08 and 4.76 mb/d total volume barrels. Embedded WORLD data and cross checking with MTOMR were used to establish the regional splits and the splits of ethanol versus biodiesel.	IEA 2015 MTOMR Tables 5 and 5A provide a detailed regional breakdown for each of ethanol and biodiesel production 2014 - 2020. EnSys used this as a basis for regional breakdown for 2020 and 2030 but EU biofuel supply was adjusted to fit projections for the EU from Chapter 1, Section 1.7.3.[94] (See below.)
Crudes supply	Within WORLD, "top level" regional supply of oil liquids is taken from a third party projection, as above, and then broken down to first subtract out non-crudes supplies (often these are split out in the projection). Total crude supply for a given region is then split out between the relevant crude grades based on extensive in-house research and data on current and projected crude production by main crude grade. This process includes both conventional and non-conventional crude oils. In any WORLD case, production levels are fixed for all individual crude grades except for the balancing marker/marginal crude (generally Saudi Light is used). An input price is assigned to the marker crude based on the projection for world crude price.	

[94] Based on IEA data from © 2015 Medium Term Oil Market Report, OECD/IEA, IEA Publishing. Modified by EnSys Energy. Licence: www.iea.org/t&c/termsandconditions.

Premise	Value(s) Used	Comment
Non-crudes supply	Non-crudes supplies for all except methanol (for MTBE feed) and natural gas (for hydrogen plant feedstock and refinery fuel) are also projected and fixed in any given case. (Prices are assigned to methanol and natural gas.)	
Product demand	Product demands are worked up in a similar way (tuning embedded bottom up detail to top down numbers) and are fixed for all except the refinery by-products of sulphur and fuel grade petroleum coke (which are given prices and allowed to float).	The effect is that, within any one case, the prices of every crude except the marker and of every non-crude and product are outputs from the case – not inputs.
Global marine fuels demand	For 2020 and 2030, total global demand was based on the average of International Marine Organisation (IMO) 3rd GHG Study scenario cases (which run to 2050); these as the most authoritative available source. (The IMO 3rd GHG Study was released in July 2014. It summarized comprehensive assessments of historical demand based on AIS vessel tracking. It also included a matrix of projections for global demand through 2050 across 16 scenarios.)	IEA data are known to understate marine fuels consumption (notably international). The IMO 3rd GHG discusses this at length. EnSys has built in methodology for adjusting to accommodate IMO-based marine fuels demand outlook.
EU/Europe Specific Demand & Affected Fuels & Biofuels		
Europe regional formulation in WORLD Model	WORLD covers Europe geographically with all countries included in one of three regions plus Eurasia and Russia regions. As described in the main text, WORLD Europe formulation does not correspond to either EU or OECD Europe, therefore an adjustment procedure used.	2012 approach was to use historical demand data by European country to establish a ratio between WORLD Europe demand and EU demand and to apply that in reports. That process was repeated as described in the body of the text. Resulting factor to go from EU28 demand to WORLD Europe demand was 1.077.
EU petrol and diesel demand	On-road demands by scenario (see Table 5.4).	
EU ethanol supply and demand	Required volumes to meet EU demand levels 2020 and 2030 (see Table 5.4).	Based on client guidance, Europe ethanol demand under higher biofuel scenarios was assumed to be met by increasing European ethanol production as necessary to ensure no significant increase in ethanol imports.

Premise	Value(s) Used	Comment
EU biodiesel supply and demand	Required volumes to meet EU demand levels 2020 and 2030 (see Table 5.4).	Based on client guidance, Europe biodiesel demand under higher biofuel scenarios was assumed to be met by increasing European biodiesel production as necessary to ensure no significant increase in biodiesel imports.
EU Base and higher biofuels scenarios	See Table 5.4	For 2020, all the higher biofuels scenarios were in fact the same so treated as one All Scenarios case in the WORLD modelling. For 2030, Scenarios A, B and C represented different levels of higher biofuels use and were modelled separately
Differences between EU and WEO supply and demand projections	The projections for EU ethanol and biodiesel production volumes and for petrol and diesel demand used in this study were different from those in the WEO. These were handled by introducing them as “overrides” that replaced the corresponding WEO numbers. All other WEO-based supply and demand numbers were left unchanged	
EU demand for products aside from petrol and diesel	Internal WORLD data were used adjusted to IEA New Policies	
Product Quality / Regulatory		
Product blending and quality / specifications	Internal WORLD data and projections taking account of actual blended qualities versus specifications. Progressive trend to low sulphur (LS)/ ultra-low sulphur (ULS) standards in non-OECD regions	
Marine fuels	Global 0.5% standard assumed implemented in 2020. Projection of volume of high sulphur IFO to be shifted to 0.5% sulphur compliant fuel taken from IEA Feb 2015 MTOMR which projected a shift volume of 2.2 mb/d. HS IFO assumed shifted to 0.5% sulphur marine distillate. There is uncertainty over the critical question of what role onboard scrubbers will play and by when – and hence what volume of HS IFO would actually need to be shifted to 0.5% sulphur fuel. EnSys considers the IEA MTOMR outlook to	

Premise	Value(s) Used	Comment
	be a "mid-level" projection in this regard. No new ECA's by 2020 beyond existing Europe (2) and Canada/USA. Additional ECA's by 2030. EU 2012 directive to use 0.5% sulphur fuel in 2020 in all EEZ waters recognized	
EU petrol and diesel specifications	Internal WORLD data used. EU petrol vapour pressure allowed for ethanol vapour pressure waiver	
EU Carbon regime / cost	WORLD Model embodies carbon costs for refineries. For Europe, EU ETS prices taken as €10/ tCO2E 2020 and €35/ tCO2E 2030 based on *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013, Figure 11.	Note, an energy efficiency trend is allowed for in WORLD but the option to "buy" more energy efficient means to generate steam/power and/or to consume fuel/steam/power more efficiently is not built in to the Model
Other carbon regimes	No other major regimes assumed except for California Low Carbon Fuel Standard (LCFS) and then only to extent of blocking Western Canadian oil sands crudes from being processed in the state	
Refining		
Base capacity	Internal WORLD data basis January 2015 used based on review completed May 2015	Note, in current WORLD model, total refining capacity is aggregated in each of the 3 European Model regions
Closures	Recent refinery closures incorporated into January 2015 base capacity. Firm announced closures in 2015 and 2016 also incorporated together with additional assumed closures for a total of 2 mb/d worldwide by 2020. No further closures built in beyond 2020	2020 and 2030 base cases and especially higher biofuels cases were expected to and did lead to lower Europe refinery utilisations hence implied further closures which can be estimated from Model results (as amount needed to get back to a sustainable utilisation level)
Projects	Internal WORLD data based on review completed May 2015	
Process technology and economics	Internal WORLD data based on recent (2Q 2015) technology review and update	

Premise	Value(s) Used	Comment
Logistics & Trade		
Marine routes, tanker types, freight rates	Extensive movements for crudes and products embodied in WORLD with freight rates based on WorldScale. Gradual return assumed to balanced tanker markets by around 2020 (from recent extremely low rates) Panama Canal expansion by 2016 (reduces freight rates for tanker routes that transit the Canal).	Movements generally not constrained other than where there are clear known situations that force or prevent specific movements e.g. for geo-political reasons or where crudes are known to be refined locally. Examples that are actively incorporated within the WORLD Model include: Venezuelan crude to China, no Iranian crude to USA, requirements that selected crude oils in oil-producing countries be refined locally based on knowledge of the refineries there.
Pipelines & Rail – USA & Canada	Inter-regional pipelines, basis WORLD internal data/projections, including USA/Canada pipelines and rail. Trans Mountain expansion to 890,000 b/d assumed by 2020; Northern Gateway by 2025 (affects volumes of WCSB crudes moving to BC and Asia versus into US/eastern Canada). Energy East assumed 2020 at 0.8 million bpd and post 2020 at 1.1 million bpd. Keystone XL assumed online pre 2020. Rail costs assumed raised because of new regulations but that in 2020/2030 rail will act in balancing role after pipelines are filled.	Basis is extensive and regular monitoring through EnSys' Monthly North America Logistics service.
Canadian crude to Europe	Shipping allowed from Canada East at levels dependent on pipeline capacity. (Movements to Europe from Montreal already exist.) No restriction on oil sands crudes into Europe based on recent EU announcement	
Pipelines - ESPO	Expansion plans assumed trimmed to 1.3 mb/d 2020 and 1.5 mb/d 2030	Affects volumes of Russian crude moving east
FSU product exports	New laws passed in Russia are likely to lead to higher exports of product from Russia and less crude oil – although there is uncertainty. Historical trends and also data and commentary from the IEA and others used to set potential 2020 and 2030 exports within a range.	In the WORLD Model, Former Soviet Union (FSU) exports are an exception in that EnSys has found it necessary to extrapolate trends and assume future export levels (within a range).

Premise	Value(s) Used	Comment
Notes: WORLD marries "top down" projections as from the IEA, EIA, OPEC or others with "bottom up" detail. The details in the WORLD Model used for this case have been built up from multiple sources (and 25 years of experience with the Model) including recent studies with and for the U.S. Departments of Energy and State, EPA, American Petroleum Institute, International Maritime Organisation, World Bank and OPEC Secretariat, with whom EnSys undertakes a joint annual study of the global downstream outlook that is now published as part of the annual OPEC World Oil Outlook.		

5.3.4 Model biofuel scenario premises

The specific volumes used for the Base and alternate scenarios for European biofuel supply and demand and for total petrol and diesel demand are shown in Table 5.4. These projections incorporate data from Table 1.18 and projections from *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013 (Table 5.5). The figures were transposed from ktoe to million bpd for use in WORLD and also factored up (by 1.077) to translate from EU28 to WORLD Europe basis.

The higher biofuels case premises were examined to assess in which instances either ethanol or biodiesel demand exceeded base level supply. Based on client guidance, in those situations where the EU scenario demand exceeded the available base EU supply, the EU supply of the affected biofuel was raised to match the EU demand. The intent behind this was to avoid a situation where a higher EU biofuels demand scenario would have necessitated "pulling" either ethanol or biodiesel away from other world regions. Put another way, the intent was to avoid any significant need to increase biofuel imports into the EU.

Table 5.4 summarises base and incremental ethanol and biodiesel volumes across the various scenarios in both ktoe/yr and mb/d. Figure 5.2 and Figure 5.3 illustrate the volumes of respectively ethanol and biodiesel against each scenario. Figure 5.4 summarises total ethanol plus biodiesel in each scenario and expresses the numbers in volume terms.

Table 5.4 EU Biofuels Supply Base Case and Higher Biofuels Scenarios

EU Biofuels Supply Base Case and Higher Biofuels Scenarios						
ktoe/yr	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol base	4521	4521	4882	4882	4882	4882
Ethanol incremental	0	0	0	0	1510	3140
ktoe/yr	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Biodiesel base	15179	15179	20530	20530	20530	20530
Biodiesel incremental	0	10170	0	17258	17305	22064
Total incremental	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol	0	0	0	0	1510	3140
Biodiesel	0	10170	0	17258	17305	22064
Total	**0**	**10170**	**0**	**17258**	**18815**	**25204**

EU Biofuels Supply Base Case and Higher Biofuels Scenarios						
mb/d	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol base	0.098	0.098	0.106	0.106	0.106	0.106
Ethanol incremental	0.000	0.000	0.000	0.000	0.033	0.068
mb/d	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Biodiesel base	0.299	0.299	0.405	0.405	0.405	0.405
Biodiesel incremental	0.000	0.200	0.000	0.340	0.341	0.435
Total incremental	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol	0.000	0.000	0.000	0.000	0.033	0.068
Biodiesel	0.000	0.200	0.000	0.340	0.341	0.435
Total	**0.000**	**0.200**	**0.000**	**0.340**	**0.374**	**0.503**
Grand total	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol base	0.098	0.098	0.106	0.106	0.106	0.106
Ethanol incremental	0.000	0.000	0.000	0.000	0.033	0.068
Biodiesel base	0.299	0.299	0.405	0.405	0.405	0.405
Biodiesel incremental	0.000	0.200	0.000	0.340	0.341	0.435
Total	**0.397**	**0.597**	**0.510**	**0.850**	**0.884**	**1.013**

Figure 5.2 EU Base & Incremental Ethanol Production

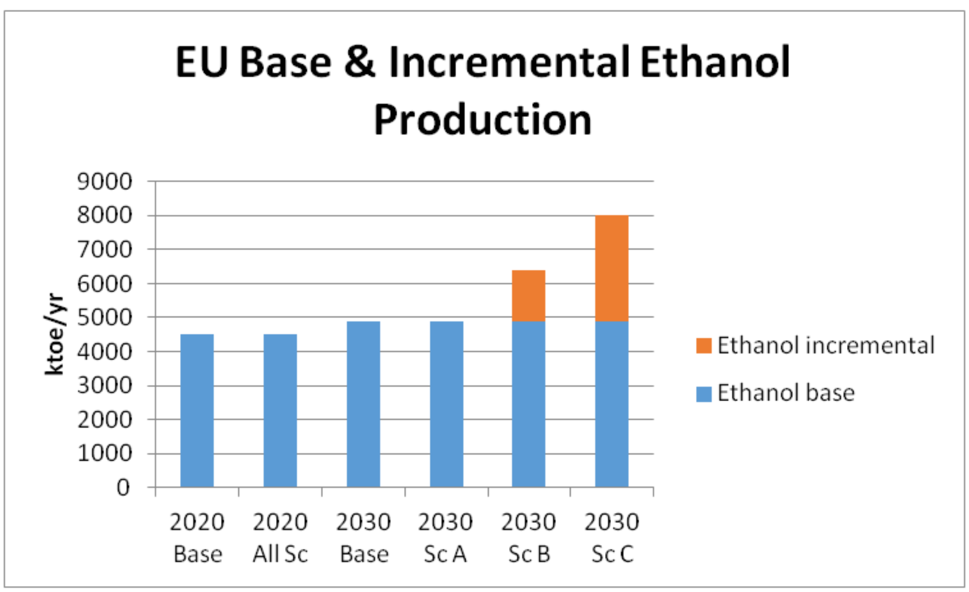


Figure 5.3 EU Base & Incremental Biodiesel Production

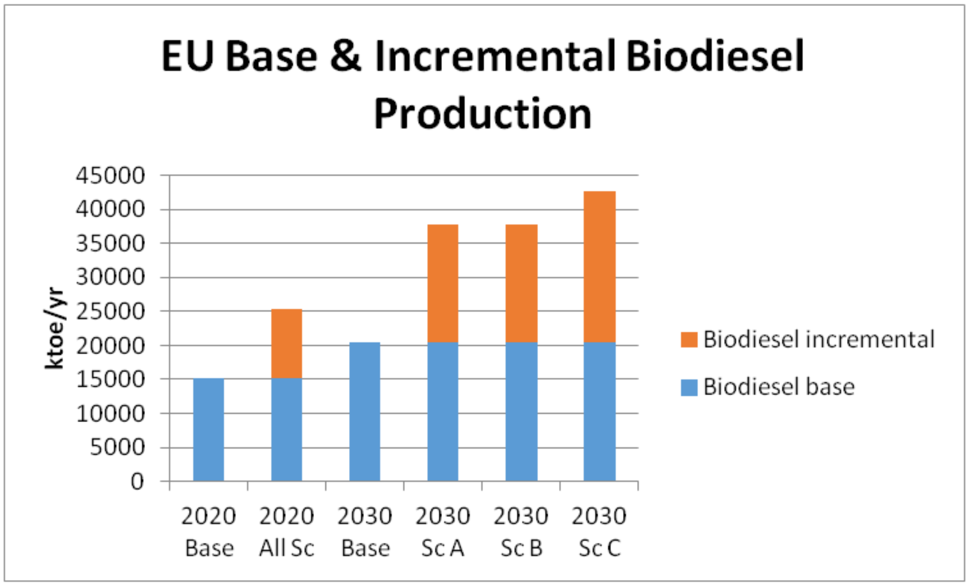
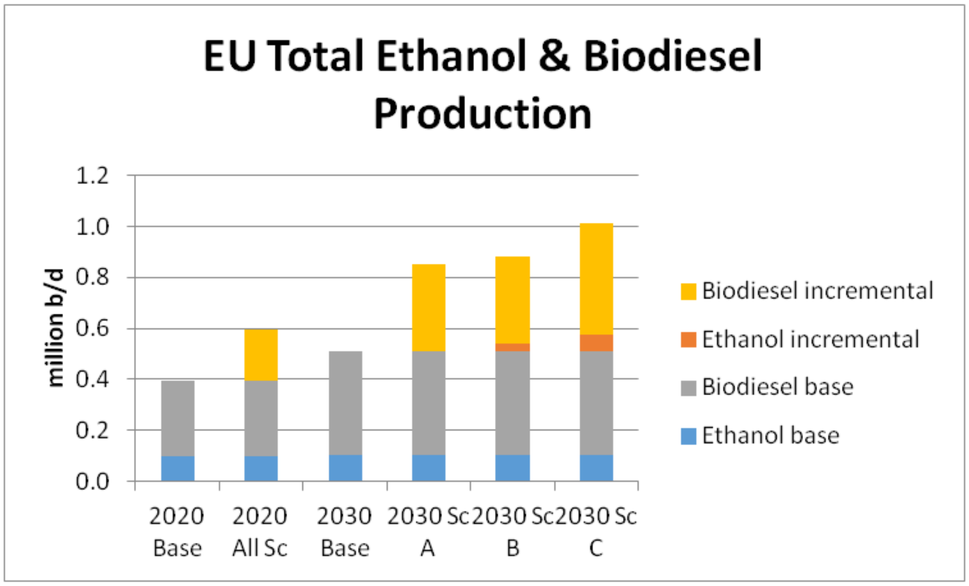


Figure 5.4 EU Total Ethanol & Biodiesel Production



What is evident from the figures above is that the major increases are in biodiesel production. This is because of the increases in biodiesel requirement in each higher biofuel scenario relative to the Base biodiesel availability. No incremental ethanol is projected as needed except in the 2030 Scenarios B and C and then the highest increment is 3140 ktoe/yr (0.068 mb/d). In contrast significant incremental biodiesel was projected as needed in every higher biofuel scenario 2020 and 2030. The largest required increment is just over 22,000 ktoe/yr (0.435

mb/d) in the 2030 Scenario C. The highest total incremental biofuel is just over 25,000 ktoe/yr (0.5 mb/d) in 2030 Scenario C.

The high proportion of incremental biodiesel in the total and the aggregate incremental production volume of up to 0.5 mb/d are key factors influencing the modelling results for the higher biofuels scenarios.

Table 5.5 EU petrol diesel and biofuel demand used in base cases and scenario A, B and C

EU petrol and diesel demand by scenario (ktoe/yr)						
ktoe/yr	**Base**	**All scenarios**	**Base**	**Scenario A**	**Scenario B**	**Scenario C**
	2020	**2020**	**2030**	**2030**	**2030**	**2030**
Petrol	62,564	60,376	47,354	45,696	42,619	40,994
Diesel	207,589	194,805	210,849	187,142	186,552	181,789
EU biofuel demand by scenario (ktoe/yr)						
ktoe/yr	**Base**	**All scenarios**	**Base**	**Scenario A**	**Scenario B**	**Scenario C**
	2020	**2020**	**2030**	**2030**	**2030**	**2030**
Ethanol	2,202	4,390	1,667	3,325	6,402	8,027
Fame	10,817	13,620	10,987	13,836	18,713	23,476
HVO	569	10,551	578	21,437	17,150	17,150
Biodiesel	11,387	24,171	11,566	35,273	35,863	40,626
EU Total Oil + Biofuel Demand (ktoe/yr)						
ktoe/yr	**Base**	**All scenarios**	**Base**	**Scenario A**	**Scenario B**	**Scenario C**
	2020	**2020**	**2030**	**2030**	**2030**	**2030**
Petrol	64,766	64,766	49,021	49,021	49,021	49,021
Diesel	218,976	218,976	222,415	222,415	222,415	222,415

5.4 WORLD model results

This section provides a review of the main results from the modelling of 2020 and 2030 Base and higher biofuels scenarios.

5.4.1 Base case outlook

As indicated in Table 5.5 above, the Base Case outlook embodies a sustained reduction in EU petrol demand through 2030 while diesel demand is projected to slowly increase over the period. Figure 5.5 further illustrates this by comparing the Base Case demand projections with recent demand history[95]. Thus these projections, taken from the *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013, constitute an assumed continued dieselisation in Europe, i.e. a continued decline in the ratio of gasoline to diesel demand[96].

The strains that the current dieselisation programme has placed on the European refining system and the consequences for petrol/diesel imbalance in Europe and more broadly in the Atlantic Basin are well known; equally the resulting large exports from Europe of excess petrol and imports of diesel[97]. The Base Case outlook has EU petrol demand (including any biofuel content) dropping to approximately 65,000 ktoe/yr (1.5 mb/d) by 2020 and to 49,000 ktoe/yr (1.1 mb/d) by 2030; this from around 103,000 ktoe/yr (2.4 mb/d) in 2007 and 87,000 ktoe/yr (2 mb/d) in 2011. In contrast, the Base Case outlook has EU diesel demand rising from around 205,000 ktoe/yr (4.2 mb/d) on average 2007-2013 to 219,000 ktoe/yr by 2020 and over 222,000 ktoe/yr by 2030, respectively just under and just over 4.5 mb/d.

In other words, the Base Case outlook is for the EU diesel to petrol demand ratio to continue to shift from 2:1 in 2007 and 2.4:1 in 2011 to 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis) as shown in Figure 5.6. Put another way, petrol demand drops from 50% of diesel demand in 2007 to 30% of diesel demand in 2020 and 22% in 2030. Since, in many refineries, the yield ratio of petrol to diesel is closer to 1:1, this outlook sets up further exacerbated yield and economic strain on European refineries moving forward to 2020 and 2030[98]. The resulting WORLD Model Base Cases indicate relatively flat European refining throughputs to 2020 but thereafter further declines to around 10 mb/d in 2030 versus 11.9 mb/d in 2012[99]. As illustrated in Figure 5.7, the Base Case outlook is for an overall continuing downward trend.

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[95] The demand history data were taken from Interim Report Figure 3.2 Temporal trends in EU fuel sales (Ricardo AEA, to be published).

[96] Recent energy/fuel tax proposals in the EU may act to shift consumer pricing advantage away from diesel and back somewhat toward petrol which, over time, could reduce or even reverse the dieselization trend. In addition, current concerns over NOx and particulates emissions from diesel and associated health impacts could have the same effect.

[97] Refining is a co-product industry and, generally, refiners in Europe have to produce a certain amount of petrol (which is relatively unprofitable since it must be exported) in order to produce diesel (which is comparatively profitable since its pricing is based on import parity).

[98] In addition, all modelling cases included EU ETS allowance costs at €10/tonne of CO2e in 2020 and €35/tonne in 2030 again based on the EU Trends to 2050 report (Figure 11). Based on modelled European refinery fuels consumptions, these equated to approximately $0.80/barrel of added European refinery operating cost in 2020 and $2.80/barrel in 2030.

[99] There was a sharp drop in 2013 to around 11.2 mb/d. In addition, there have been substantial refinery closures in Europe in the past two years and more are planned.

Figure 5.5 EU Petrol & Diesel Consumption History and Base Case Outlook

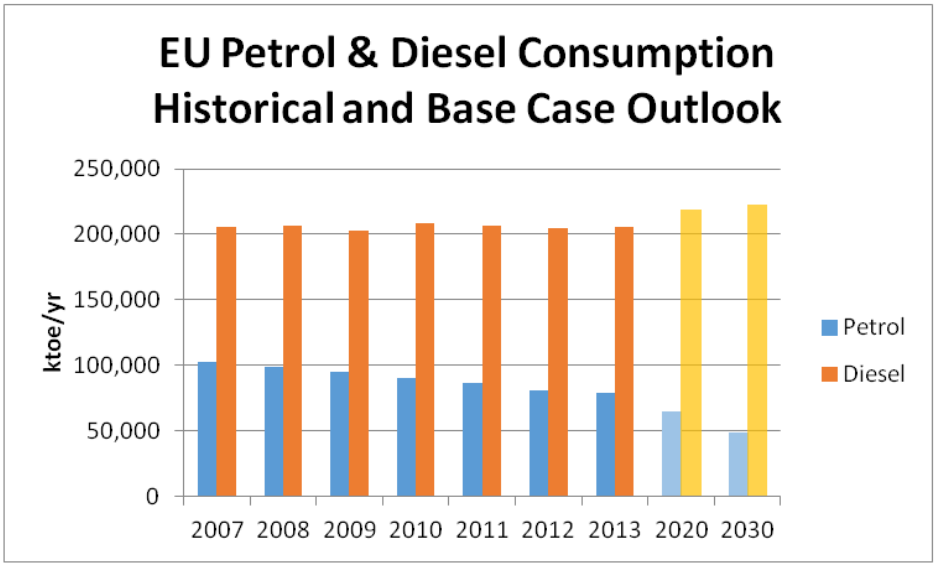


Figure 5.6 EU Petrol to Diesel Ratio History and Base Case Outlook

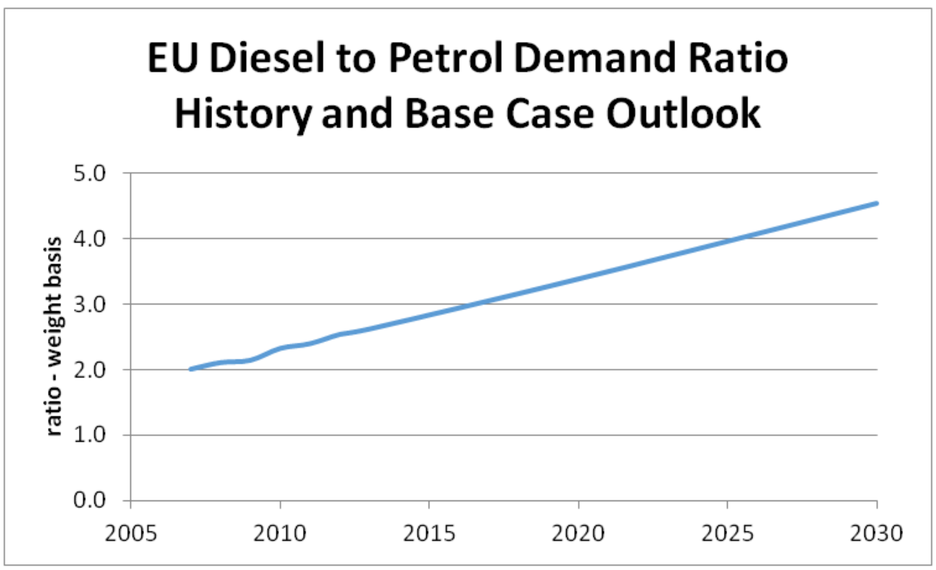
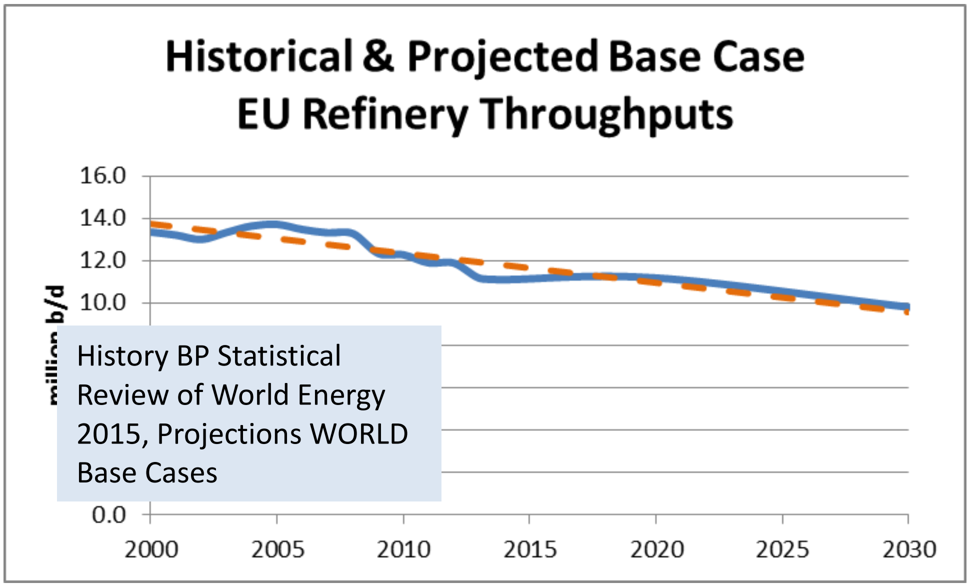


Figure 5.7 Historical and Base Case EU Refinery Throughputs



The strain in the European refining system is evident in the levels of petrol exports and diesel imports projected in the Base cases. For 2020, petrol exports are projected at nearly 54,000 ktoe/yr (1.24 mb/d) and distillate (diesel/gasoil) imports at 71,000 ktoe/yr (1.44 mb/d). For 2030, the corresponding figures are petrol 56,000 ktoe/yr (1.3 mb/d) and distillate (diesel/gasoil) 104,000 ktoe/yr (2.1 mb/d). In comparison, in 2013, Europe's refineries were reported as having excess petrol production at a level of around 34,000 ktoe/yr (0.8 mb/d) and a diesel/gasoil deficit of around 33,000 ktoe/yr (0.67 mb/d).[100]

In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. The continuing distortion in projected regional demand ratio (petrol decline, diesel increase) relative to refinery yield capability contributes to reduced refinery throughputs while at the same time necessitating higher petrol exports in order to enable diesel production. Figure 5.10 compares Base Case and Higher Biofuels projections for EU petrol exports and diesel/gasoil imports with reported 2013 levels. Versus 2013, the Base Case outlook leads to a 50 – 60% increase in petrol exports and a doubling by 2020 then tripling by 2030 in diesel/gasoil imports.

In short, the Base Case outlook is for a highly strained situation for European refiners which both reduces throughput and leaves little flexibility remaining.

5.4.2 Higher biofuel scenarios

Figure 5.8 through Figure 5.13 and Table 5.6 through Table 5.8 summarise key results from the higher biofuel scenarios. The primary impact (Figure 5.8) is that total global refinery throughputs drop by approximately the volume of the EU biofuel supply increases that were assumed in the higher biofuel scenarios. This is to be expected since the added biofuel correspondingly reduces the amount of refined product needed.[101] Thus the assumed biofuels supply increases

[100] http://www.hydrocarbonprocessing.com/Article/3321653/European-refiners-hit-by-diesel-deficit-gasoline-glut.html.

[101] The match between biofuel supply increase and crude supply/processing reduction is not exact since the two have different qualities.

in the EU of just over 0.2 mb/d (2020 All Scenarios) up to just over 0.5 mb/d (2030 Scenario C) lead to broadly equal reductions in refinery throughputs and crude production.

A related key aspect is the split of the refining impacts between the EU and Non-EU regions. The results indicate the majority of the throughput reductions would occur in Non-EU regions – some 70-85%. Why is this the case? The answer lies in the case premises and Base Case outlook. As previously described, the bulk of the increases in biofuels supply across the Higher Biofuels cases were assessed to be for biodiesel. As also shown, and expanding on what is happening today, in the 2020 and 2030 Base cases, the EU is projected to be importing significantly more diesel/gasoil than today. Since the bulk of the assessed biofuel increase is biodiesel and since it is diesel/gasoil that is imported, the primary impact of the higher EU biodiesel supply is to back out diesel/gasoil imports. These imports by definition would have been produced in regions outside the EU, therefore it is in those regions that the bulk of the refinery throughput reductions occur[102].

Increases in biodiesel supply thus tend to help EU refiners by reducing some of the strain to produce diesel/gasoil in competition with imports. Increases in regional ethanol supply have the opposite effect. They exacerbate an already strained situation in which EU refiners have to coproduce and export petrol in order to co-produce diesel. While raising EU biodiesel production if anything eases the situation for EU refiners, increasing ethanol production leaves refiners with the option of either maintaining throughputs or exporting additional petrol – to offset the additional ethanol now feeding in to EU petrol – and/or to accommodate to the increased ethanol supply by reducing refinery production of petrol and thus refinery throughputs. What was evident in the modelling cases was a mix of both adjustments coming into play – some increases in petrol exports in conjunction with some reductions in refinery throughputs.

The results obtained were dependent on the degree of petrol:diesel stress inherent in the Base Case scenario and the volume and mix of incremental EU biofuel supply. Given the premises that were required for the Base case scenario, EU refinery throughputs are projected to drop by 0.15 mb/d in 2030 Scenario C and around 0.05-0.06 mb/d in 2020 All Scenarios and 2030 Scenarios A and B. Again, given the premises applied, the bulk of the refinery throughout reductions are shown as occurring outside the EU, 0.35 mb/d under 2030 Scenario C. This is because, as stated, EU biodiesel supply increases reduce EU diesel/gasoil imports essentially with the consequence that throughputs must necessarily drop in the regions whose exports to the EU have dropped.

Table 5.6 sets out these results and also the implied refinery closures that could occur see also Figure 5.9. (These were estimated by taking the change in refinery throughput and dividing that by 0.8, equating to an assumed roughly 80% utilisation.) These are indicated as 0.27 mb/d global under 2020 All Scenarios and as lying in the range of 0.4 to 0.63 mb/d global in the 2030 Scenarios A through C. Of these some 70-86% are projected to occur outside the EU. So one key implication is that raising EU regional biofuel production, with the primary emphasis on biodiesel, would be expected to have substantial impacts on refineries outside the EU as well as inside. As discussed further below, these projections are sensitive to the assumptions used (Section 5.4.2.2).

Figure 5.10 illustrates the reductions in diesel/gasoil imports into the EU. In addition, it illustrates how the higher biofuel scenarios could be expected to lead to higher EU exports of petrol, this to partially offset the reduction in refined petrol needed for regional EU markets because of the increase in regional ethanol supply. The Figure also shows the scale of the

[102] The model results project diesel/gasoil imports would be flowing in from Russia followed by USA & Canada, Latin America, Middle East and Africa. All these regions would be affected by the increases in EU biodiesel production.

projected increases in both petrol exports and diesel/gasoil imports by 2020 and 2030 versus the situation in 2013.

Figure 5.11 shows the projected associated impacts on refinery investments. Again, because it is projected the bulk of the refinery throughput impact would be on refineries outside the EU, it is Non-EU regions where the bulk of corresponding reductions in investments (less refinery plant needed). For global refinery investments, the changes equate to reductions in the range of 2.4-3.3%. For the EU, the reductions are indicated as around 3.5-3.9% (off an already low total investment as shown in Table 5.6).

Figure 5.8 Effects of Higher Biofuels Scenarios on Refinery Throughputs

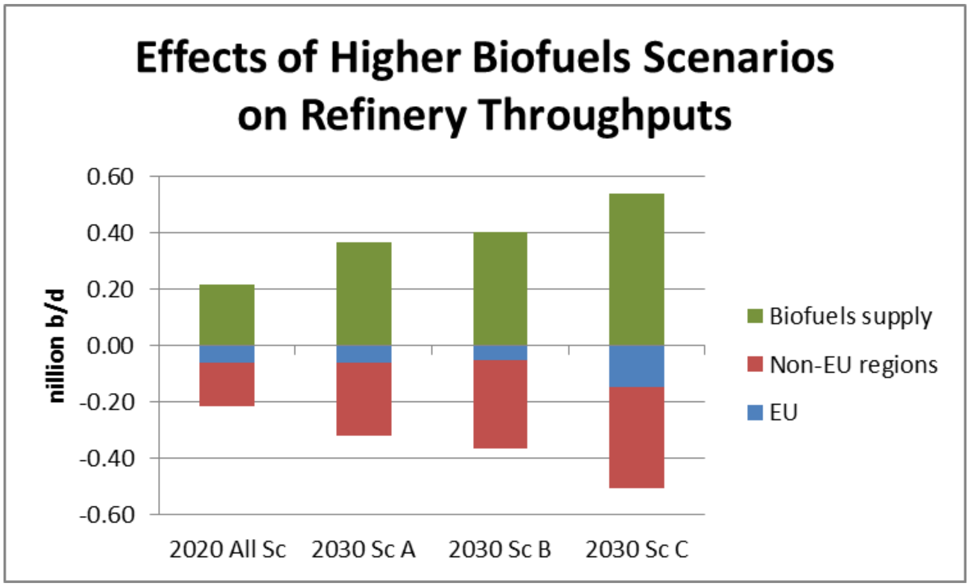


Figure 5.9 Potential Refinery Closures from Higher Biofuels

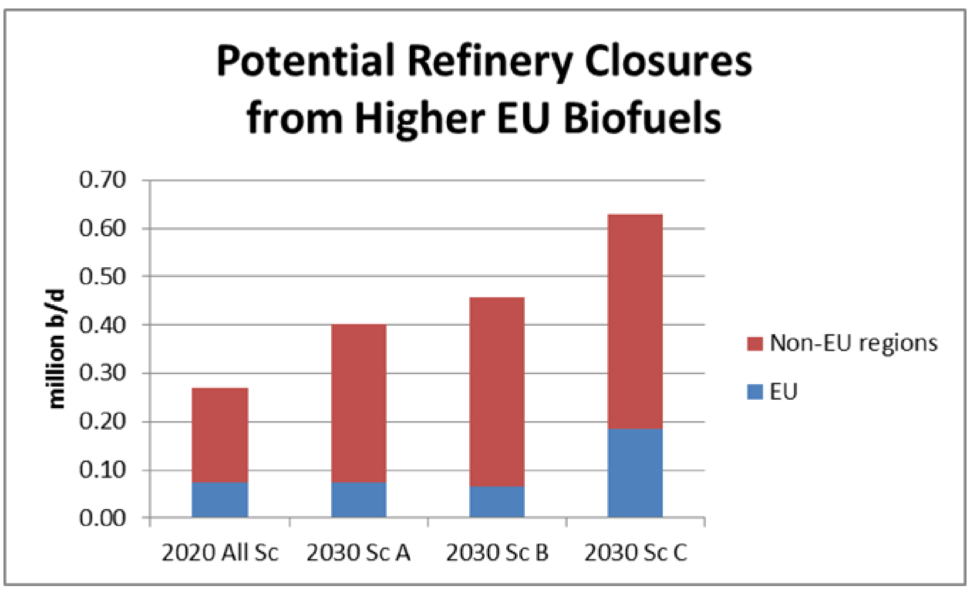


Figure 5.10 Effects of Higher Biofuels Scenarios on EU Imports and Exports

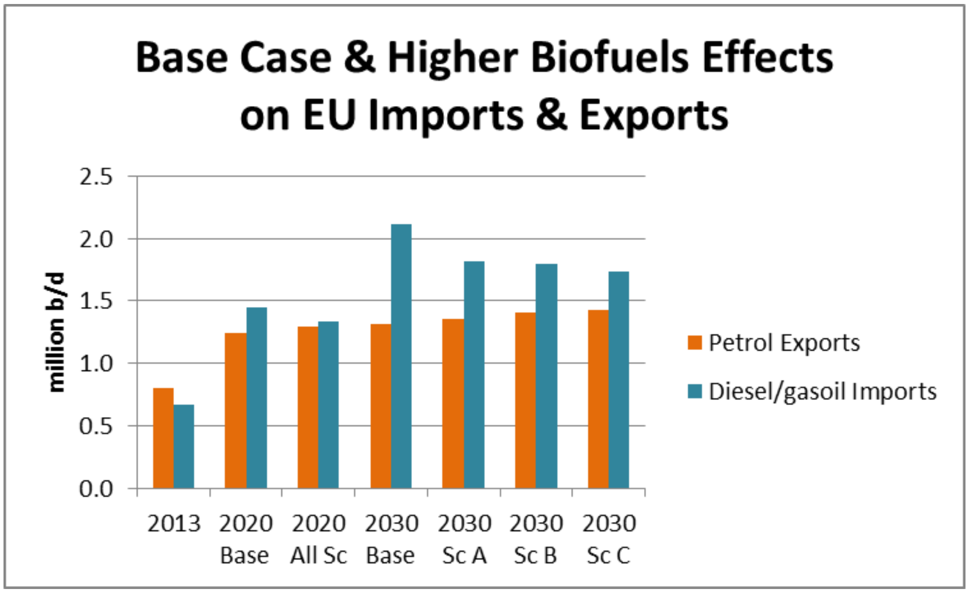


Figure 5.11 Effects of Higher Biofuels Scenarios on Refinery Investments

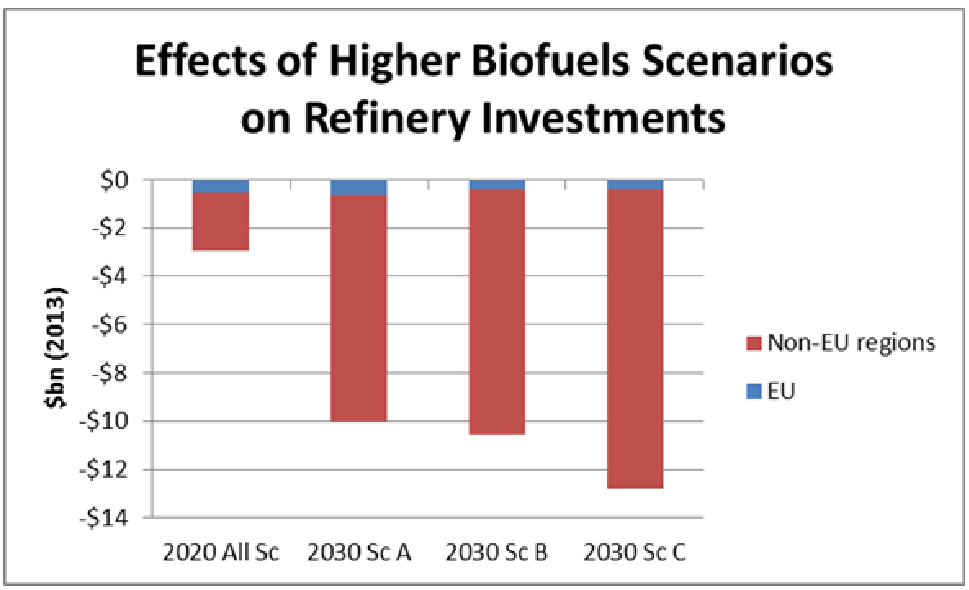


Figure 5.12 illustrates the impacts of the higher biofuel scenarios on refinery margins – with details in Table 5.7 which also summarises key price impacts. The refinery margins are expressed simply in terms of what are in the industry are referred to as "crack spreads":

- The margin for a complex refinery oriented toward gasoline is represented by a 3-2-1 crack spread wherein the price of 3 barrels of crude (Brent) is deduced from the revenue from (price of) 2 barrels of petrol plus 1 of diesel and then expressed as $/barrel of crude

- The margin for a complex refinery oriented toward diesel is represented by a 2-1-1 crack spread wherein the price of 2 barrels of crude (Brent) is deduced from the revenue from (price of) 1 barrels of petrol plus 1 of diesel
- The margin for a less complex refinery is represented by a 5-2-2-1 crack spread corresponding to revenue from 2 barrels of petrol plus 2 barrels of diesel plus 1 of residual fuel minus the cost of 5 barrels of crude, again expressed as $/barrel of crude.

Firstly, the crack spread margins are projected as a whole to be markedly lower in 2030 than in 2020 (this with a top down projection for higher crude prices in 2030 than in 2020 which *a priori* would tend to support refinery margins). There are a number of underlying causes. Key is the projected continuing overall demand decline in Europe, (most notably for petrol), under the Base Case scenario. Another factor is that EnSys did not build in any firm refinery closures for the period post 2030. EU refinery utilisations are projected to drop from the 80% range in 2020 to the 70% range in 2030 – with clear implications for further Base Case closures by 2030 (before considering the higher biofuel scenarios). These closures were left implied in the results although clearly a 70% level is unsustainable; therefore the Base Case outlook implies significant closures before considering the added effects of higher biofuels. Had EnSys enacted further closures in the 2030 cases then we would have expected the reported margins to be somewhat higher. Similarly, EnSys did not build in any assumed closures post 2020 for Non-EU refining regions. As a result, global utilisations are projected to average 79.9 – 79.6% in the 2030 cases versus 81.9-81.7% in the 2020 cases.

A second effect is that relative margins on the gasoline oriented refinery (3-2-1 crack spread) drop significantly between 2020 and 2030. This is because of a projected global slowing in petrol demand growth by 2030 in which the projected EU reduction plays an important role.

The third effect visible in Figure 5.12 (and Table 5.7) is that in 2020 introducing higher biofuels cuts margins across all three refinery types considered whereas, in 2030, the impacts are minimal. EnSys believes this is because, in the 2020 scenarios, the EU refining industry still has a measure of flexibility but that, under the 2030 scenario with its substantial further reduction in petrol demand, the industry is operating in a highly strained manner in the Base Case and has little flexibility to react to further changes. In 2020, both the biodiesel and the ethanol supply increases act to ease the costs of supplying diesel and petrol. Conversely, in 2030 and as explained above, the already severely strained Base Case situation means adding more ethanol has an adverse effect on strained petrol supply and exports which negates the benefit increasing biodiesel supply has in backing out diesel imports.

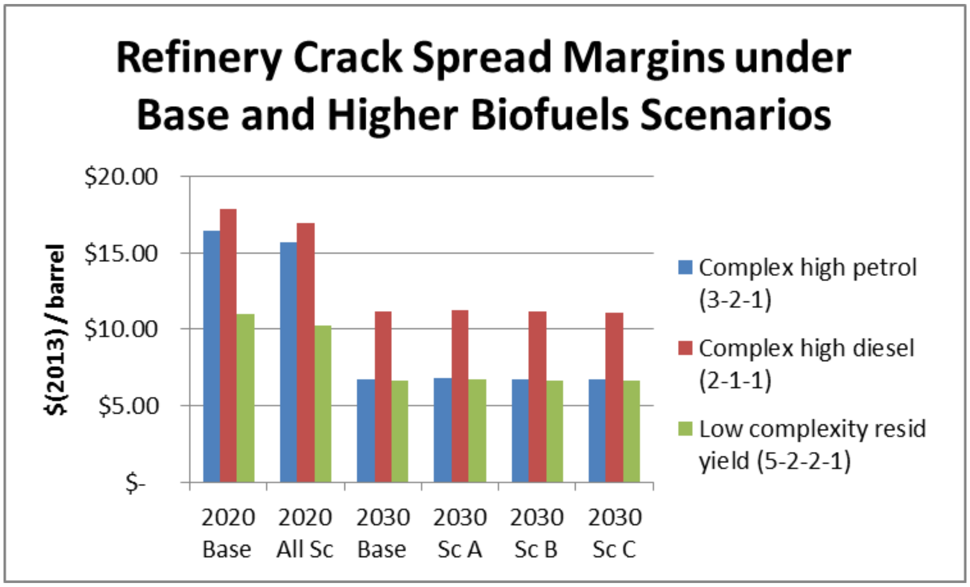
A similar story would appear to apply to projected product prices (Table 5.7) and delivered costs (the prices of each product at a major market centre times its demand volume then summed across all products), Figure 5.13 and Table 5.8. In 2020, delivered costs are projected to drop when more biofuel is introduced (in the EU) although the effects would be small, about a 0.6% reduction in the EU and a global reduction of 0.3%. Conversely in the 2030 scenarios, product supply cost hardly changes.[103] Again we believe this relates to the stresses inherent in the 2030 Base Case which then lead to the offsetting impacts from further biofuels additions.

[103] The WORLD modelling cases were undertaken using the same world crude oil price in each 2020 case ($2013 112/bbl) and in each 2030 case ($2013 122.67/bbl). Given the higher biofuels cases reduce crude oil demand by up to 0.5 mb/d, it could be argued that, therefore, crude oil prices and hence product prices would drop and that this price elasticity of demand should be allowed for in the assessment – essentially by lowering world crude price in line with the increase in biofuels supply. EnSys briefly examined the situation. Applying a (long run) price elasticity of demand for crude oil of -0.23 (taken from The Impacts of U.S. Crude Oil Exports on Domestic Crude Production, GDP, Employment, Trade, and Consumer Costs, March 31, 2014, by ICF International and EnSys Energy for the

Overall, our finding is that higher biofuels supply and use in the EU has adverse impacts on the refining sector in terms of throughputs – and hence implied further closures – but also that, because the European industry operates with a petrol/diesel imbalance which worsens under these scenarios, a primary impact is to reduce diesel/gasoil imports into the EU such that the bulk of the refinery impacts are projected to be felt in regions outside the EU.

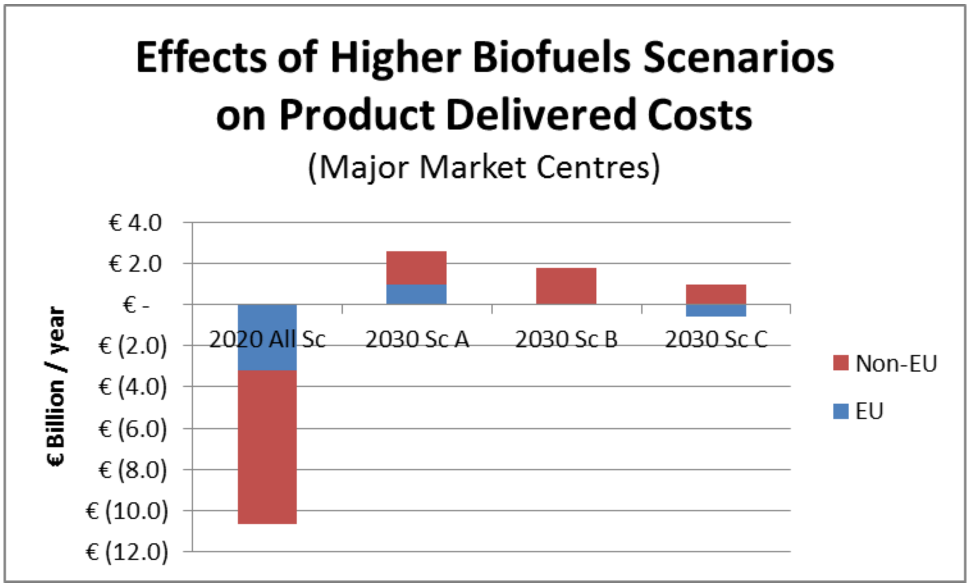
Impacts of higher biofuels on EU crack spread margins are negative in 2020, narrowing them by 4.5-7%. Under the more strained conditions projected for 2030, the positive impact of additional biodiesel is offset by the negative impact of additional ethanol with the result that crack spread margins are only minimally impacted. They vary by around +2 to -1%.

Figure 5.12 Refinery Crack Spread Margins under Base & Higher Biofuels Scenarios



American Petroleum Institute) implies that a 0.5 mb/d crude oil demand reduction would (given a global system running roughly 83 mb/d of crude – 2030 Scenario C) equate to a crude oil price reduction of around 2.5%. Recognising that the price of finished products includes other costs aside from just crude oil, the implied maximum change in product price (again 2030 Scenario C) would be of the order of 2% as a result of the reduction in crude oil demand and price. This equates to maximum effect of approximately 2 €¢/litre, i.e. a small impact.

Figure 5.13 Effects of Higher Biofuels Scenarios on Product Delivered Costs



5.4.2.2 Sensitivity of Results

The projections are sensitive to the premises used for the Base case outlook. As discussed above, this outlook embodies a severe reduction in Base case EU petrol demand by 2030. This, together with a projected predominance of global distillates demand growth (jet/kerosene plus gasoil/diesel) versus more moderate petrol demand growth by 2030 leads to a tightening in the market for distillates and a slackening in that for petrol. This can be seen in, for example, the trends in Northwest Europe petrol and diesel price differentials versus Brent crude oil. In the first 8 months of 2015, Brent price averaged $55.69/barrel, Northwest Europe 95 RON petrol $70.35 and Northwest Europe ultra-low sulphur diesel $71.08/barrel.[104] The corresponding price differentials versus Brent were thus $14.66/barrel for petrol and $15.39/barrel for diesel. By way of comparison, the corresponding modelled 2020 Base case differentials were petrol $13.26 and diesel $20.92/barrel, reflecting a gradual trend to tighter diesel demand. The corresponding projected Base case differentials for 2030 were negative almost $3/barrel for petrol and positive almost $24/barrel for diesel. Thus these Base case differentials reflect the projected extreme Base case surplus of petrol in the EU and extreme deficit for diesel – that is also reinforced by global trends. The high premium for diesel over crude (Brent) reflects the need to build high-cost incremental hydro-cracking and related process units at the margin in order to meet marginal distillate demand.[105] As discussed, those facilities are projected as being built in 2030 in Non-EU regions. They represent the highest-price forms of diesel supply (delivered cost to Europe) and thus are the sources of supply which are cut when biodiesel supply in Europe is raised in the Higher Biofuel cases.

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[104] Source Bloomberg.

[105] The analysis indicates that, because of a combination of flat to declining regional demand and high operating costs, there is essentially no incentive or ability to invest within EU refineries to try to resolve the projected extreme 2030 petrol:diesel imbalance. Since EU refineries are also constrained by their ability to produce petrol, and consequently diesel since there is a limit to their feasible diesel:petrol ratio, the investment to product incremental diesel necessarily comes from Non-EU refineries.

The extreme price differentials in the 2030 Base case beg the question of whether such a scenario would indeed occur but they represent the EU demand outlook presented in *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013. Because of the extremely depressed EU petrol prices projected for 2030, EU refiners are – in the model cases - able to find expanded export markets for petrol. It is appropriate to question whether such exports would in fact exist. However, should they not be found, the situation that would apply would be one where, in 2030, EU refineries would be heavily constrained by their ability to produce petrol. Versus the levels of close to 10 mb/d projected in the 2030 cases, EU refinery throughputs would have to drop dramatically, potentially to as low as around 5 mb/d. In that scenario, Non-EU refineries would have to export around 5 mb/d of additional products to the EU, not only diesel but jet fuel and a range of other products from lubricating oils to asphalt. The Non-EU refineries would have to be expanded by at least 5 mb/d, with attendant major investment costs, while existing EU refineries sat idle. In the authors' view, such a scenario is not realistic – barring closure of EU refineries on a massive scale. Such major investments and import flows would not occur as long as there is EU refinery capacity available. Thus exporting large volumes of petrol while importing large volumes of diesel represents the most economic (or least un-economic) option as signified by the modelling results.

The European Commission Joint Research Council "refinery fitness test" analysis concluded that, in 2012, EU refineries suffered from severe competitive disadvantages versus refineries in several other regions, because of a combination of additional regulatory but especially energy costs. Natural gas prices in 2012 were some 3-4 times higher in Europe that in the USA (or Middle East). With the recent large drop in crude oil prices, the ratio has shrunk to around 2:1. While the IEA WEO used for this study comprised a "high price" outlook, the gaps between natural gas prices across the major regions of the world were assumed to slowly and partially narrow over the long term to 2030; this based on a gradual increase in international natural gas trade including an expansion of natural gas sources flowing into Europe. Thus the severe competitive energy cost disadvantage that EU refineries have been suffering at recent $100/barrel crude price levels was projected to have moderated to some degree by 2030. This in turn affected, to a limited degree, the projected long term relative energy costs for EU refiners.

The modelling analysis did indicate that the split in projected refinery throughput and implied capacity losses in 2030 is very sensitive to the projected ratio for EU petrol to diesel demand. In preliminary model cases, EnSys inadvertently set 2030 EU diesel demand at the correct level but EU petrol demand (including biofuel) close to recent levels of around 2 mb/d, i.e. at approximately twice the 1.1 mb/d called for in the 2030 Base case. The results obtained indicated that, since EU refineries would be less strained, (have the ability to produce petrol and diesel in somewhat more normal ratios without resorting to major expansion of petrol exports), they would correspondingly "share" more in the impacts of adding in higher biofuels supplies. EU refinery throughput reductions and implied closures would be higher than in the final model cases run with the correct (much lower) 2030 petrol demand. The indicated share of throughput reduction was closer to 50:50 between EU and Non-EU refineries.

5.4.2.3 Use of ETBE

As discussed, the higher biofuel scenarios were analysed on the basis that ethanol would be blended directly into petrol. The analysis did not assess the potential differences in outlook should ethanol be first processed into ETBE and the latter then blended into petrol in the EU. Such analysis is feasible to undertake but was beyond the scope of the current project. Processing ethanol into ETBE would entail an additional processing step to etherify ethanol into

ETBE by reacting it with iso-butylene.[106] This step would be undertaken either within a refinery of within a separate processing facility. Either way, the resulting ETBE would then be blended into petrol (in place of the ethanol). Using ETBE instead of ethanol would incur additional capital, operating and energy costs and associated GHG emissions for the etherification step but would ease the refinery petrol blending in part because ETBE has a vapour pressure much below that for ethanol. Thus, versus use of ethanol, there could potentially be reduced refinery capital/operating costs and or emissions which would help offset the increases from ETBE production. Again, this study did not include any examination of these trade-offs or whether there would be potential net benefits.

[106] The MTBE process entails reacting methanol with iso-butylene.

Table 5.6 Summary of Key Case Results – Refining & Trade

	2020 Base		2020 Scenario A		2030 Base		2030 Scenario A		2030 Scenario B		2030 Scenario **C**	
	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe
Total Investments (b$ 2013)	124.01	14.39	121.08	13.89	385.46	11.04	375.40	10.39	374.91	10.63	372.68	10.61
Refinery Throughput (mmbpd)	81.10	11.20	80.88	11.14	83.63	9.82	83.31	9.76	83.27	9.77	83.13	9.67
Refinery Utilization (%)	81.91%	80.37%	81.72%	79.94%	79.94%	70.59%	79.72%	70.17%	79.69%	70.21%	79.57%	69.53%
Implied Additional Closures (change in throughput divided by 80%)												
EU				0.07				0.07		0.07		0.19
Non-EU			0.19				0.33		0.39		0.44	
Global			0.27				0.40		0.46		0.63	
Percent Non-EU			72%				82%		86%		70%	
Net Imports into Europe (WORLD Europe Countries ratioed back to EU28)												
USLD (mmbpd)		1.21		1.08		1.55		1.29		1.29		1.24
Biodiesel (mmbpd)		0.00		0.00		0.01		0.07		0.08		0.07
Ethanol (mmbpd)		-0.05		0.00		-0.07		-0.03		0.00		0.00
Biodiesel Production (mmbpd)	0.68	0.30	0.89	0.50	1.33	0.40	1.69	0.74	1.69	0.74	1.79	0.84
Ethanol Production (mmbpd)	1.84	0.10	1.84	0.10	2.44	0.10	2.44	0.10	2.48	0.14	2.52	0.17
Total Biofuel Producton (mmbpd)	2.51	0.40	2.73	0.60	3.77	0.51	4.14	0.85	4.17	0.88	4.31	1.01
Change versus Base Case			0.22	0.20			0.37	0.34	0.40	0.37	0.54	0.50
Refinery Fuels												
Total Refinery Fuel Oil (mmboepd)	6.451	0.909	6.427	0.902	6.436	0.759	6.403	0.754	6.397	0.754	6.383	0.747

Table 5.7 Summary of Key Case Results – Crude, Product & Biofuel Prices, Refining Margins

Summary of WORLD Model Results for EC - Europe Higher Biofuel Cases

Note - results below are for WORLD Model definition of Europe countries but with volume results converted to EU28, by dividing by 1.077

	2020 Base		2020 Scenario A		2030 Base		2030 Scenario A		2030 Scenario B		2030 Scenario **C**	
	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe
CRUDE PRICES FOB												
SAUDI LIGHT (input marker crude price $/barrel)	$ 109.15		$ 109.15		$ 119.58		$ 119.58		$ 119.58		$ 119.58	
Brent ($/barrel) - output	$ 115.69		$ 115.66		$ 124.35		$ 124.32		$ 124.33		$ 124.31	
CRACK SPREADS - Output $/bbl												
NW Europe 3-2-1 Brent		$ 16.45		$ 15.69		$ 6.70		$ 6.83		$ 6.76		$ 6.72
NW Europe 2-1-1 Brent		$ 17.88		$ 16.91		$ 11.20		$ 11.22		$ 11.16		$ 11.11
NW Europe 5-2-2-1 Brent		$ 11.00		$ 10.22		$ 6.68		$ 6.71		$ 6.67		$ 6.63
EU ETS Allowance Prices - Input €/tonne CO2												
Source EU Trends to 2050 Fig 11		€ 10		€ 10		€ 35		€ 35		€ 35		€ 35
Key Product Prices (Output) €/litre												
Europe North												
Petrol (95 RON)		€ 0.739		€ 0.737		€ 0.698		€ 0.700		€ 0.699		€ 0.699
Diesel (ULS)		€ 0.788		€ 0.779		€ 0.852		€ 0.850		€ 0.850		€ 0.850
Europe South (Med)												
Petrol (95 RON)		€ 0.732		€ 0.731		€ 0.690		€ 0.692		€ 0.692		€ 0.692
Diesel (ULS)		€ 0.774		€ 0.767		€ 0.846		€ 0.843		€ 0.843		€ 0.842
Europe East												
Petrol (95 RON)		€ 0.740		€ 0.739		€ 0.691		€ 0.693		€ 0.692		€ 0.692
Diesel (ULS)		€ 0.781		€ 0.774		€ 0.846		€ 0.840		€ 0.840		€ 0.838
Key Biofuel Prices (Blending Value - Output) €/litre												
Europe North												
Ethanol		€ 0.781		€ 0.784		€ 0.681		€ 0.686		€ 0.691		€ 0.690
Biodiesel		€ 0.785		€ 0.804		€ 0.850		€ 0.850		€ 0.849		€ 0.849
Europe South (Med)												
Ethanol		€ 0.772		€ 0.783		€ 0.563		€ 0.679		€ 0.692		€ 0.690
Biodiesel		€ 0.770		€ 0.785		€ 0.840		€ 0.838		€ 0.838		€ 0.837
Europe East												
Ethanol		€ 0.792		€ 0.795		€ 0.692		€ 0.697		€ 0.700		€ 0.698
Biodiesel		€ 0.783		€ 0.798		€ 0.849		€ 0.849		€ 0.849		€ 0.849

Table 5.8 Product Delivered Costs

Summary of WORLD Model Results for EC - Europe Higher Biofuel Cases

Note - results below are for WORLD Model definition of Europe countries but with volume results converted to EU28, by dividing by 1.077

	2020 Base		2020 Scenario A		2030 Base		2030 Scenario A		2030 Scenario B		2030 Scenario **C**	
	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe
TOTAL EXTERNAL PRODUCT COST (EXCLUDES INTERNAL REFINERY CONSUMPTION)												
(demand times open market price (from model) summed across all products by region and global)												
TOTAL COST - € BILLION / YEAR												
Petrol	€ 1,037	€ 65	€ 1,035	€ 65	€ 987	€ 46	€ 989	€ 46	€ 989	€ 46	€ 989	€ 46
Distillates (Jet/Kero,Gasoil/Diesel)	€ 1,642	€ 334	€ 1,636	€ 332	€ 1,902	€ 376	€ 1,901	€ 377	€ 1,900	€ 376	€ 1,899	€ 376
Residual Fuels	€ 157	€ 14	€ 157	€ 14	€ 217	€ 23	€ 217	€ 23	€ 217	€ 23	€ 217	€ 23
Other Products	€ 670	€ 90	€ 669	€ 90	€ 719	€ 95	€ 721	€ 95	€ 721	€ 95	€ 721	€ 95
Total	€ 3,507	€ 504	€ 3,497	€ 500	€ 3,825	€ 540	€ 3,828	€ 541	€ 3,827	€ 540	€ 3,826	€ 540
TOTAL COST - € MILLION /DAY	€ 9,609	€ 1,380	€ 9,582	€ 1,371	€ 10,480	€ 1,480	€ 10,487	€ 1,483	€ 10,485	€ 1,480	€ 10,481	€ 1,479

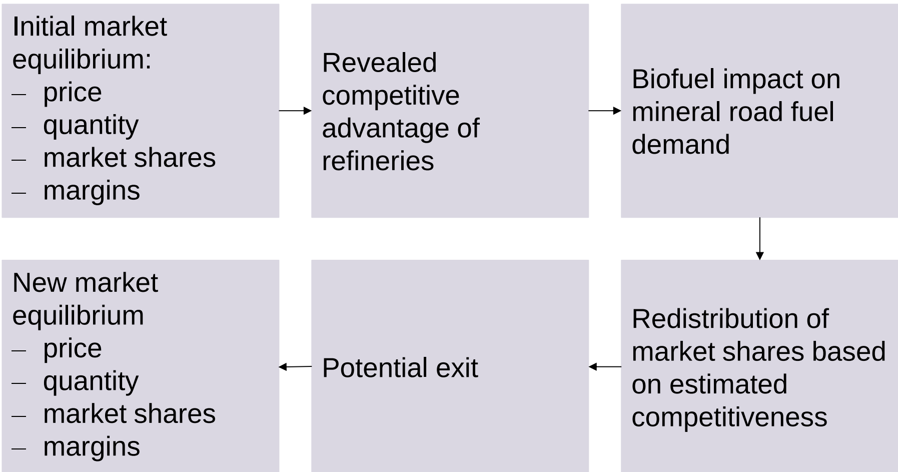
5.5 FIMM methodology and assumptions

This section presents a description of the methodology including input data and a market description

5.5.1 Methodology

Vivid Economics' (Vivid) Full Industrial Market Model (FIMM) was applied to the petroleum refining sector, in order to estimate competitiveness impacts quantitatively. Vivid's FIMM estimates the impact of the displacement of mineral fuel demand by biofuels. Figure 5.14 explains how the demand change works through the model.

Figure 5.14 Vivid's FIMM estimates the market impacts changes based on market shocks



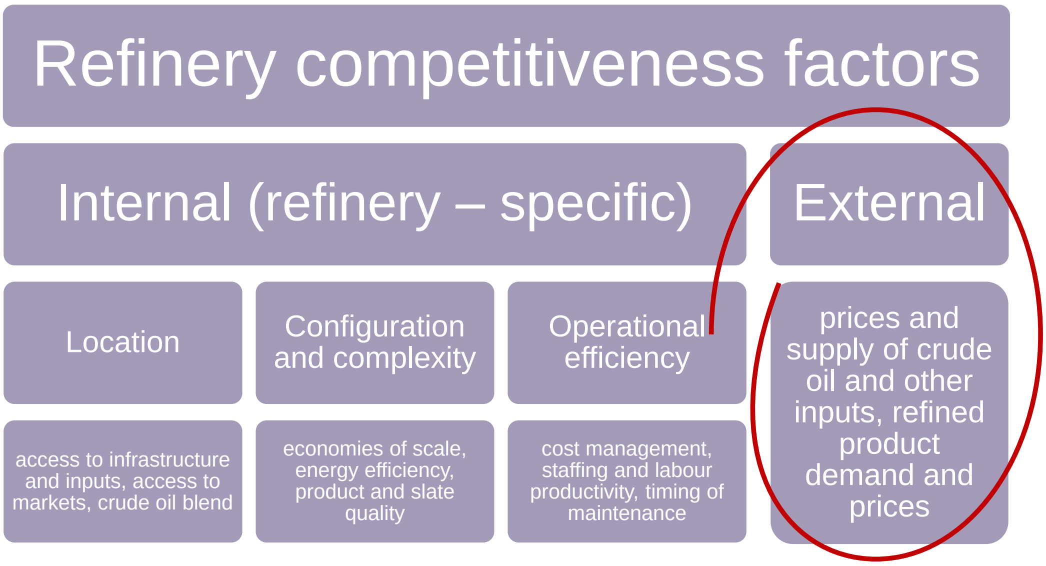
Source: Vivid Economics

The strength of competition in refining is determined from market data and largely drives the resulting sectoral cost pass-through rate. Competition in refining is a function of gross profit margins, the price elasticity of demand, and the market shares of firms (meaning the market shares of individual installations). . In conjunction with the absolute size of the shock that the industry is subject to, the strength of competition and price elasticity of demand determine the impact on quantity of production and market price. The impact on production can in turn be broken down into:

- the fall in production resulting from the decline in consumption as prices rise; and
- the loss of a refinery's market share to other refineries as profit margins decrease.

Refinery profitability is an outcome of the interplay between multiple drivers. Among the factors that influence a refinery's competitiveness, one can distinguish between variables that are within the control of an individual refinery and those that are external and apply to any refinery, independently of how it is constructed and managed. Among such external factors are, for example, general requirements on product and process specifications, or global market conditions determining the prices of crude oil and refined products. In turn, within the factors that can be controlled by a refinery, some are related to location (access to infrastructure and relevant markets; costs of inputs such as labour and energy; crude oil blend), others to refinery's configuration and complexity (economies of scale; energy efficiency; product slate and quality achievable), and some fall under operational efficiency (cost of management; staffing levels and labour productivity; timeliness of maintenance). These factors are schematically summarized in Figure 5.15. The internal factors are captured by the market shares in Vivid's analysis and are constant across scenarios.

Figure 5.15 Vivid's analysis looks at changes in the external factors affecting refinery competitiveness between scenarios



Source: European Union (2015), Refinery Fitness Check

5.5.2 Inputs

5.5.2.1 Assumptions

Table 5.9 lists the assumptions used in the model. Section 5.5.2.2 and 5.5.2.3 provide details on the price elasticity of demand and biofuel price assumptions respectively.

Table 5.9 Assumptions

Assumption	Units	Value	Source
Refinery utilisation in 2014	%	79%	European Union (2015), Refinery Fitness Check
Carbon price	€/tCO_2	5 in 2014; 10 in 2020; 35 in 2030	European Commission (2013), EU Trends to 2050
Average EU fuel duty in 2013*	€/l	0.53 (petrol) 0.41 (diesel)	European Environment agency (2013)
Average EU fuel duty in 2020 and 2030*	€/l	Same as 2014	Vivid assumption
Average EU VAT in 2013*	%	21%	DG Ener (2015)
Average EU VAT in 2020 and 2030*	%	Same as 2014	Vivid assumption
Wholesale road fuel price in 2014 in Member States	€/l	0.51 (petrol) 0.57 (diesel)	Eurostat (2014)
FQD baseline compliance cost level	€/tCO_2	10	Vivid Assumption based on 2013 FQD work
Share of petrol in EU in 2014 (in mineral road fuels)	%	30%	Internal report
Share of diesel in EU in 2014 (in mineral road fuels)	%	70%	Internal report
FQD baseline compliance cost level	€/tCO_2	10	Vivid Assumption based on 2013 FQD work
Petrol and diesel production shares for EU Member States throughout analysis	%	Assumed to be same in 2020 and 2030 as in 2012	UN (2012)

Assumption	Units	Value	Source
Crude oil price	$/bbl	85	2014 Brent average price

*Note: *Fuel duty and VAT do not influence the results of refinery competitiveness but the final consumer price level*

Source: Vivid Economics

5.5.2.2 Price elasticity of demand

The consumer price elasticity of demand (PED) for road fuels influences the interaction between supply and demand and resulting consumer market price and quantity, is obtained from Espey (1998), and takes the value -0.58. For refineries, the PED at the refinery gate is what determines their market response. It is lower than the PED for consumers because a fixed fuel duty is added to the pump price. Hence a change in refinery cost does not change the pump price one to one, but instead by a lower amount. Table 5.10 shows the calculation of price elasticity of demand at the refinery gate used in the FIMM, and its value is -0.32.

Table 5.10 Price elasticity of demand for the FIMM

Variable	Unit	Value	Calculation	Source
PED for consumers	unitless	-0.58	N/A	Espey (1998)
Price without taxes	€/l	0.55	diesel price * diesel share + petrol price * petrol share	prices: Eurostat (2014)
Price with fuel duty	€/l	1.00	road fuel price without taxes + average fuel duty	prices: Eurostat (2014)
Price with VAT	€/l	1.20	road fuel price with fuel duty * (1+VAT)	VAT: DG Ener (2015)
PED at the refinery gate	unitless	-0.32	PED for consumers * price without taxes / price with fuel duty	Calculation

Source: Vivid Economics

5.5.2.3 Price of biofuels

The biofuel prices for 2014, 2020 and 2030 shown in Table 5.11 are taken from the OECD FAO agricultural outlook 2014-23. The OECD ethanol and biodiesel price projections end in 2023, and in the calculations that follow, it has been assumed that the prices remain unchanged between 2023 and 2030.

Table 5.11 Biofuel prices

EUR/litre	2014	2020	2030*
Ethanol	0.57	0.68	0.73
Biodiesel	0.84	0.97	1.00

*Note: *The OECD ethanol and biodiesel price forecast end in 2023, which have been used as forecasts for 2030 prices.*

Source: Vivid Economics based on OECD FAO agricultural outlook 2014-23

5.5.2.4 Scenario inputs

Scenario inputs for demand of mineral road fuel were obtained from *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013. Table 5.12 shows the biofuel content in road fuels increasing from 14 per cent to 18 per cent by energy content on movement from scenario A to C in 2030. The consumption of mineral petrol and diesel in the EU decreases by 0.1 mb/d on each 2 per cent increase in biofuel content.

Table 5.12 Scenarios – consistent across tasks

	2020	2030		
	A/B/C	A	B	C
Biofuel share in road fuels by (energy)	10%	14%	16%	18%
EU consumption of mineral petrol and diesel (mbl/d)	4.9	4.5	4.4	4.3

Note: *The model uses biofuel shares by energy content and not volume since the energy content impacts the demand for mineral road fuels*

Source: Vivid Economics

The model was updated with the most recent input data and draws inputs from Chapter 1, Chapter 2 and Chapter 4 on biofuel availability and price. The model further accounts for expected changes in demand for refined products between today and 2020 and 2030, a period of projected demand decline. The changes in demand were be obtained from PRIMES-TREMOVE, and are consistent with projections presented in *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013. Consistency with other chapters is ensured by working on the same biofuel and mineral road fuel mix for 2014 and base case and scenarios in 2020 and 2030, as shown in Table 5.12 and Table 5.13.

Table 5.13 Biofuel mix

	2014	2020				2030			
		Base	A	B	C	Base	A	B	C
Ethanol	20%	14%	16%	16%	16%	8%	8%	14%	16%
Biodiesel	80%	86%	84%	84%	84%	92%	92%	86%	84%

Source: Vivid Economics

Table 5.14 Mineral road fuel mix

	2014	2020				2030			
		Base	A	B	C	Base	A	B	C
Petrol	30%	25%	26%	26%	26%	20%	21%	20%	18%
Diesel	70%	75%	74%	74%	74%	80%	79%	80%	82%

Source: Vivid Economics

5.5.3 Market description

Table 5.15 describes the EU refining industry in 2014, which is used to set up the 2014 base case scenario of the model.

Table 5.15 2014 EU refining industry

Variable	Value	Note
Total refining capacity (bbl/d)	14.2 million	15% of world refining capacity

Consumption of light and middle distillates* (bbl/d)	9.3 million	14.6% of world consumption, second largest in the world after US
of which petrol and diesel (bbl/d)	5.1 million	
Number of refineries producing petrol and diesel	90	Oil and Gas Journal (2014)
Average gross refining margins (€/bbl)	4	North West Europe average refining margins $4/bbl in 2014 (BP, 2015)
Ethanol share in petrol consumption (energy)	5.2%	Chapter 1, Table 1.7
Bio-diesel share in diesel consumption (energy)	3.4%	Chapter 1, Table 1.8

Note: ** 'Light distillates' consists of aviation and motor petrol and light distillate feedstock (LDF). 'Middle distillates' consists of jet and heating kerosene, and gas and diesel oils (including marine bunkers).*

Gross margins are margins after variable costs, that is it is price minus unit variable cost

Source: *Vivid Economics, BP (2015)*

5.6 FIMM results

This section presents the results of Vivid Economic's analysis of the impacts of biofuels scenarios on the profit margins of refineries (Section 5.6.1), consumer prices (Section 5.6.2) and refinery production and capacity reduction (Section 5.6.4). The results are presented as comparisons to the base case, which is explained in sub-section 5.6.1.

5.6.1 Base case

Demand for mineral road fuels falls even though biofuels content does not increase. Under the base case scenario, the biofuel energy content in road fuels does not change from 2014 levels. Consequently, 2020 and 2030 both have biofuel consumption at 5 per cent of road fuel energy content. However, due to a trend of declining mineral fuel demand, consumption of mineral petrol and diesel falls by 7.5 per cent between 2014 and 2030. This results in an estimated EU refinery capacity decline of 0.2 mb/d (2 per cent) by 2020 with a slightly reduced average margin, and no further EU capacity declines thereafter, coming at the cost of a reduction in the average margin. Imports of mineral road fuels also decline slightly. The reduction in mineral road fuel demand lowers mineral road fuel prices by 0.2% between 2014 and 2030, as some refining capacity becomes unprofitable and exits while margins fall for surviving capacity. All base case scenario results are summarised in Table 5.16.

Table 5.16 Under the base case scenario, demand for mineral road fuels falls even when biofuel content does not increase

Variable	Input/output	2014	2020 - base	2030 - base	Percentage change between 2030 and 2014
Consumption of mineral petrol and diesel (mb/d)	Input	5.5	5.3	5.1	-7.5%
Biofuel share in road fuels by (energy %)	Input	5%	5%	5%	no change
EU average gross margin ($/bbl)	Output	4.00	3.96	3.86	-3.5%
Average mineral road fuel price (€¢/l)	Output	55.2	55.1	55.1	-0.2%

Variable	Input/output	2014	2020 - base	2030 - base	Percentage change between 2030 and 2014
EU refinery capacity (mb/d)	Output	13.9	13.7	13.7	-1.5%

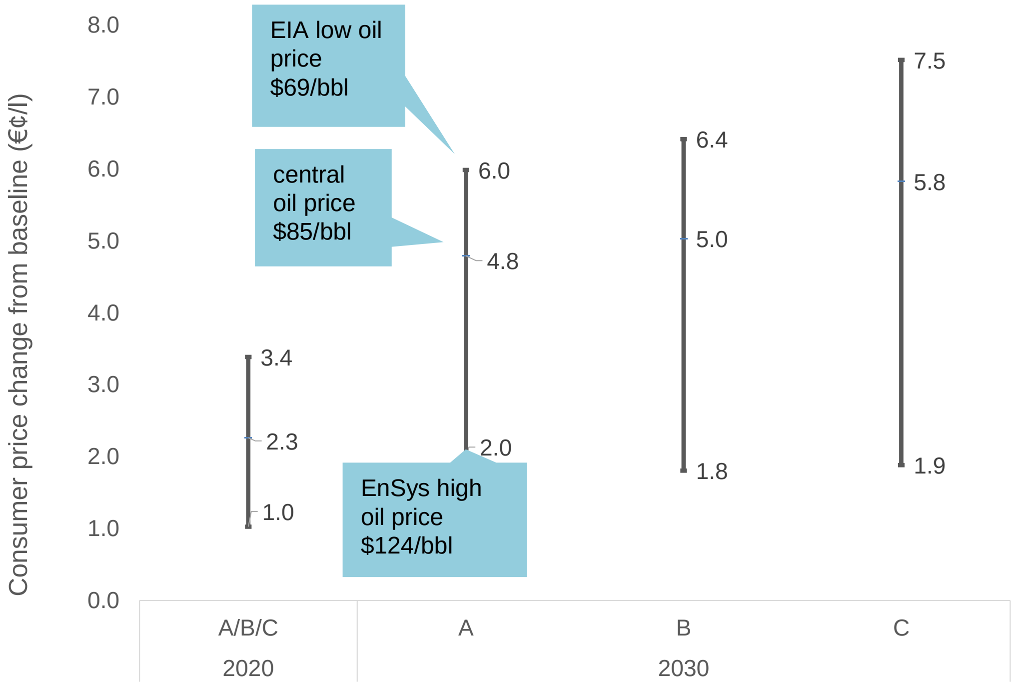
Source: Vivid Economics

5.6.2 Impact on consumer price

In Vivid's analysis, the consumer prices, including fixed fuel duty and VAT, increase by 2.3 €¢/l (2 per cent) in 2020 and up to 5.8 €¢/l (5 per cent) in 2030 relative to the base case scenario, as shown in Figure 5.16. The consumer prices are calculated as follows:

$$\text{consumer prices}(€/l) = [\text{mineral fuel price}(€/l) * \text{mineral fuel share }(\%) + \text{biofuel price}(€/l) * \text{biofuel share}(\%) + \text{fuel duty}] * (1 + \text{VAT})$$

Figure 5.16 The average consumer price might increase by 2.3 €¢/l in 2020 and up to 5.8 €¢/l in 2030 for a $85/bbl oil price



Note: Average mineral fuel price and average biofuel price are weighted by petrol and diesel and ethanol and bio-diesel shares, respectively, produced by the WORLD model. Average consumer price is weighted by mineral fuel and biofuel shares in road fuels. Taxes include average fixed fuel duty and VAT.

Source: Vivid Economics

Mineral fuel wholesale prices are 55.2 €¢/l in the base case and change negligibly between scenarios, as shown in Table 5.17. Biofuels are more expensive than mineral road fuels with an average wholesale price of 92.6 €¢/l in 2020, rising to 97.8 €¢/l in 2030, based on the prices and shares of biodiesel and ethanol shown in Sections 5.5.2.3 and 5.5.2.4. As the share of biofuels grows, from 5 per cent energy content in the base case to 10 per cent in 2020 scenario and up to 18 per cent in the 2030 scenario, and the relative shares of biodiesel and ethanol change, the consumer prices increase in response. Table 5.17 shows the calculations for consumer prices.

Table 5.17 Consumer price calculations

Unit: €¢//l	2020		2030			
	Base	A/B/C	Base	A	B	C
Mineral fuel price*	55.0	54.9	55.1	54.9	54.9	54.8
Biofuel price	92.6	91.9	97.8	97.8	96.1	95.7
Share of biofuels in road fuels (%)	5%	10%	5%	14%	16%	18%
Consumer price without taxes	56.8	58.6	57.1	60.9	61.3	62.1
Consumer price with fixed fuel duty and VAT	121.5	123.7	121.1	125.9	126.1	126.9

*Note: * For a crude price of $85/bbl. Average mineral fuel price and average biofuel price are weighted by petrol and diesel and ethanol and bio-diesel shares, respectively, produced by the WORLD model. Average consumer price is weighted by mineral fuel and biofuel shares in road fuels. Taxes include average fixed fuel duty and VAT.*

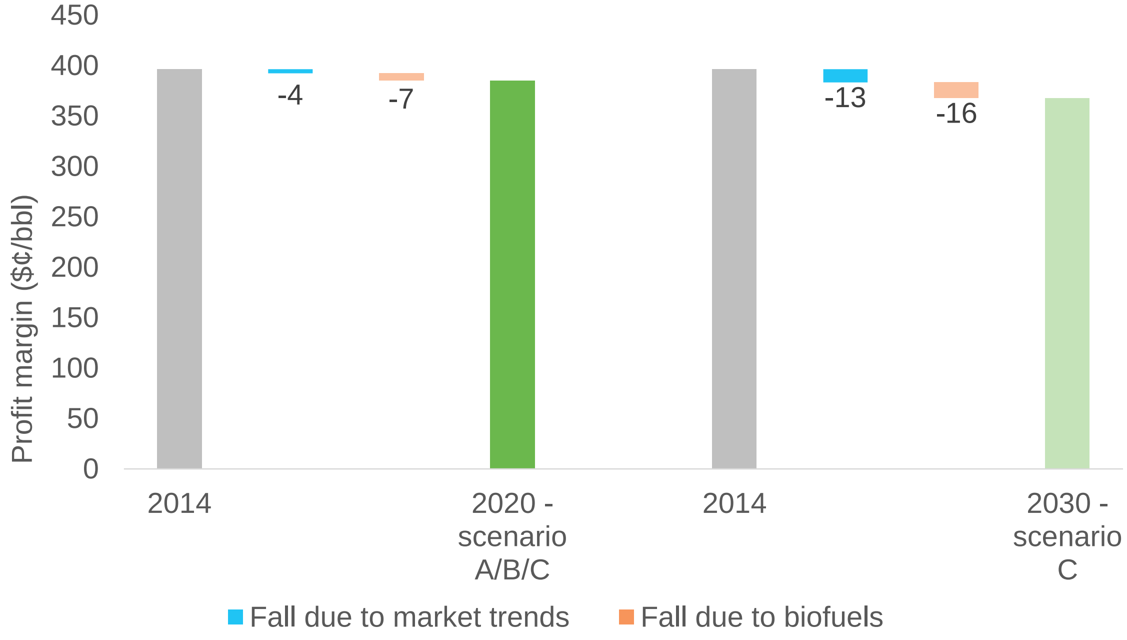
Source: Vivid Economics

Consumer price changes are sensitive to the crude oil price assumption. At a lower crude oil price, based on the EIA (2015) low oil price scenario of $58/bbl in 2020 and $69/bbl in 2030, the blending of a greater proportion of biofuels increases consumer prices by up to 7.5 €¢/l in 2030. If the oil price were higher, the price increase caused by sourcing a higher share of biofuels in the energy mix would be lower. For example, at the EnSys oil price of $116/bbl in 2020 and $124/bbl in 2030, which has been taken as the high oil price scenario, price increases are only 1 €¢/l in 2020 and up to 2 €¢/l in 2030.

5.6.3 Impact on refinery gross profit margins

Refinery gross profit margins decline by 7 US$¢/bbl in 2020 and up to 16 US$¢/bbl in 2030 due to biofuels. The decline is relative to the respective base case margin of 3.96 US$/bbl in 2020 and 3.87 US$/bbl in 2030 and represents the maximum declines in the highest biofuel energy share scenario (C). Margins decline as biofuels crowd out mineral road fuels and refineries compete for a smaller overall market. In scenarios A and B in 2030, the margins fall by 11 US$¢/bbl and 13 US$¢/bbl respectively relative to the base case scenario.

Figure 5.17 Profit margins decline by 7 US$¢/bbl in 2020 and up to 16 US$¢/bbl in 2030 due to biofuels



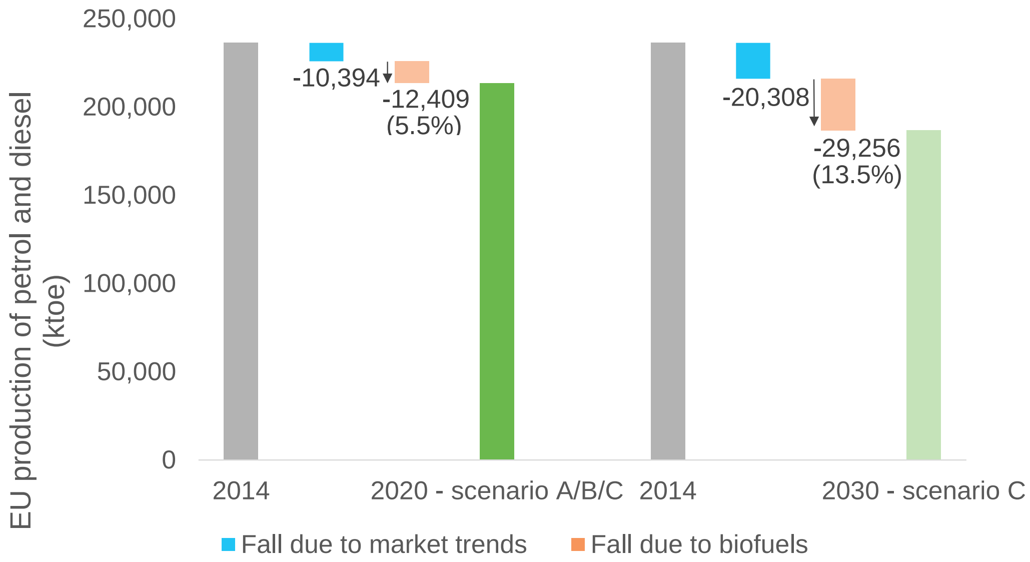
Note: North West Europe average refining margins were $4/bbl in 2014 (BP, 2015)

Source: Vivid Economics

5.6.4 Impact on production and capacity

Mineral petrol and diesel production in the EU falls by 5.5 per cent in 2020 and up to 13.5 per cent in 2030 due to biofuels. In comparison, underlying market trends (as described in the Base Case) shave off 4.4% of mineral road fuels demand in 2020 and 8.6% in 2030, as shown in Figure 5.18.

Figure 5.18 Petrol and diesel production falls by 5.5 per cent in 2020 and up to 13.5 per cent in 2030 due to biofuels



Source: Vivid Economics

Vivid Economics' Full Industrial Market Model (FIMM) estimates that the impact is felt by both EU refineries and importers. The absolute impact falls largely on EU refineries and they currently produce the majority of EU fuel supply. The FIMM is an economic model that estimates the value of mineral road fuels and the current share of imports. In contrast to the WORLD model, the FIMM is a top-down partial equilibrium model and does not model individual processes. As such, it does not account for the effects changes in the diesel/petrol ratio over time on the costs of refining. The WORLD model estimates a lower competitiveness of imports, that is, a higher cost of imports than is estimated by FIMM, and hence the WORLD model estimates a larger absolute and relative impact on importers than EU refineries, whereas the FIMM estimates impacts between the group of importers and the group of EU producers that are roughly in proportion to the market shares of those two groups.

The FIMM estimates an exit of 0.21 mb/d of EU refining capacity between 2014 and 2030. The FIMM estimates zero exit due to increasing biofuel shares in 2020 and 2030. EU refinery utilisations do not fall enough to force refineries to exit, when moving from the 2020 and 2030 base case scenario to the high biofuel blend scenarios. The fall in utilisation can be absorbed in margins. Some further EU refinery exits might occur, depending on market trends in refined product demand and import competition. If utilisation were to be sustained at its 2014 level of 79%, EU and import refining capacity would fall by 0.29 mb/d in 2020 and 0.69 mb/d in 2030.

5.7 Conclusions

The 2020/2030 Base Case scenario (based on EU Trends to 2050) will lead to a substantial reduction in EU petrol demand in combination with some increase in diesel demand. In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. Considering that the EU diesel to petrol demand ratio is projected to shift from 2:1 in 2007 and 2.4:1 in 2011 to 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis), an already problematic diesel:petrol ratio in the EU will be aggravated further by the impacts from higher biofuel demand. This will put a strain on EU refining and lead to projected lower regional refinery throughputs by 2030.

The impacts on refineries of increases in biofuel energy share are greater than the impacts of expected general trends in road fuel demand. By 2020, the EU mineral road fuels production could fall by 104,000 ktoe/yr (4.4 per cent) from its 2014 level due to market trends, and by an additional 124,000 ktoe/yr (5.5 per cent) due to biofuels (all scenarios). By 2030, mineral road fuels production could fall by 203,000 ktoe/yr (8.6 per cent) from its 2014 level due to market trends, and, due to increasing biofuel energy shares, by an additional:

- 209,000 ktoe/yr (9.7 per cent) in Scenario A
- 240,000 ktoe/yr (11.1 per cent) in Scenario B and
- 293,000 ktoe/yr (13.5 per cent) in Scenario C.

A primary impact of higher biofuel demand in the analysed scenarios is to reduce diesel/gasoil imports into the EU such that depending on assumptions the impacts may also be felt in refineries outside the EU. Because the European industry operates with a petrol/diesel imbalance which worsens under the Base case scenario, higher biofuels supply and demand in the EU has adverse throughput impacts on the EU and Non-EU refining sectors. In 2030, the implied further closures due to the higher biofuel scenarios could be over 0.6 million barrels per day (bbl/d) globally of which 0.2 million bbl/d might occur in the EU. The split of impacts between EU and Non-EU refining regions is, however, dependent on Base case scenario assumptions (e.g., a higher petrol demand in the EU, will result in a greater proportion of the total refinery throughput reductions and implied closures occurring in the EU than in Non-EU regions).

Impacts on product prices within the EU are projected to be limited. In 2020, biofuels could reduce the aggregate cost of products in major demand centres although the effects would be small, about a 0.6% reduction in the EU and a global reduction of 0.3%. Conversely in the 2030 scenarios, product supply cost hardly changes. It is assumed that this relates to the stresses inherent in the 2030 Base Case scenario which negates any positive blending value impacts from further biofuels additions.

Consumer prices increase as the biofuel energy share rises. For the analysed scenarios the increase in consumer prices may be 2.3 €¢/l in 2020 (2 per cent) and, in 2030:

- 4.8 €¢/l (4 per cent) in Scenario A
- 5.0 €¢/l (4.1 per cent) in Scenario B and
- 5.8 €¢/l (4.8 per cent) in Scenario C.

Consumer prices are comprised of mineral road fuel wholesale prices, biofuel wholesale prices and the EU average current fuel duty and Value Added Tax. Mineral road fuel wholesale prices are 55.2 €¢/l for an 85 $/bbl crude oil price and biopetrol and biodiesel wholesale prices, which are weighted by their respective share in total biofuels, could be 91.9 €¢/l in 2020, rising to 97.8 €¢/l in 2030. Including taxes, the average price at the pump is 121.5 €¢/l in 2020 and 121.1 €¢/l in 2030. The difference in biofuel and mineral road fuel prices drives the consumer price increase as the biofuel share increases from the baseline, as laid out above. (Chapter 5, Section 5.6.2).

Higher crude oil prices would narrow the differential between mineral road fuel and biofuel prices and would make smaller the increase in consumer prices. At 124 $/bbl crude price, consumer prices increase by 1.0 €¢/l in 2020 across all scenarios and, in 2030, by 2.0 €¢/l in Scenario A; by 1.8 €¢/l in Scenario B and 1.9 €¢/l in Scenario C.

Whether defined in terms of crack spread or refinery gross margins[107], the overall impact in the EU across the scenarios, compared to the Base Case, is estimated to be small, with a reduction on the order of 2-7% in 2020 and a change of +2% to -4% in 2030 on average. For example, for gross margins, which vary between refineries, the absolute impact is a reduction of 7 $¢/bbl in 2020 (for all scenarios) and between 11 $c/bbl and 16 $¢/bbl in 2030 for Scenario A and C, respectively. The decline is relative to the respective Base Case margin of 3.93 US$/bbl in 2020 and 3.83 US$/bbl in 2030. Margins decline as the demand for mineral road fuels falls and refineries compete for a smaller overall market

[107] Gross margin is the margin after variable cost, that is, price minus unit variable cost

Annexes

Annex 1 List of interviews conducted

In the context of this task, face-to-face or telephone interviews have been conducted with the following companies, organisations and governments:

- Argos Oil
- FuelsEurope (including Shell, Total, OMV, Exxon Mobil)
- Abengoa
- NesteOil
- Shell
- UPEI (Union of European Petroleum Independents, including member organisations from Germany, UK and Belgium)
- BMU (German government)
- Finnish government
- French government

In addition, a questionnaire was sent out by email to a wider range of stakeholders. Written responses were received from

- AS Olerex
- Austrian Petroleum Industry Association (APIA)
- Romanian Oil Association
- Unione Petrolifera
- UPEI (Union of European Petroleum Independents)

Annex 2 Description of main type of biofuels and conversion routes[108]

A2.1 FAME as diesel replacer

Fatty Acid Methyl Esters are the most common type of "bio-diesel" used in the EU. Production of fatty acid methyl esters concerns transformation of refined[109] natural vegetable or animal fats – in essence esters of fatty acids with glycerol – to methyl esters by a catalysed reaction with methanol. Types of fats applied include rapeseed, sunflower, soy, palm oil, coconut oil, tallow, used cooking oil and residual fats from meat processing.

In the reaction glycerol is replaced by three methanol molecules. The reaction yields three methyl fatty acid esters per molecule of fat with glycerol as a by-product.

FAME is a substitute for diesel in view of its boiling point or distillation curve.

The produced 'biodiesel' is however non fungible and can be added up to 7vol% to conventional diesel in view of the deviating properties (compared to conventional diesel).

- Lower energy density, higher cloud point and melting point (-15°C)
- Biodiesel acidity and related deterioration of lubricating oil and of elastomers (e.g. rubber) in the car fuel distribution system;
- Biodiesel tends to be less stable in storage and combustion processes. The reduced thermal stability results in formation of soot during combustion and may result in formation of deposits in the engine.

In order to establish better control of fuel properties, the European standards organization, CEN, has published a standard (EN 14214) for FAME to be used as an automotive fuel. The standard establishes specifications for the FAME as a final fuel in engines designed or adapted for its use. The same standard also specifies the parameters for FAME to be used as the blend stock for conventional diesel fuel.

Thermal stability is expressed by the so called Iodine number of the FAME. Europe's EN14214 specification allows a maximum of 120 for the Iodine number, Germany's DIN 51606 tops out at 115. In practice only rapeseed methyl ester (97) or rapeseed ethyl ester (100) can meet this criterion. As a consequence FAME has to contain at least approximately 60% rapeseed methyl ester to meet these criteria.

A2.2 HVO as diesel replacer

Hydro-treated Vegetable Oils (HVO) such as vegetable oils may be processed by variations of petroleum refining processes including hydro-treatment. These refining methods can produce hydrocarbons with closely controlled and desirable fuel properties such as low aromatic levels and a very narrow distillation range. HVO production utilizes the same types of fats used for production of FAME. In addition, fatty acids isolated from tall oil are utilized in Scandinavia. Tall oil is a by-product of sulphate pulping of wood for pulp production and contains up to 40% fatty acids.

In HVO production these refined vegetable or animal oils and fats are treated with hydrogen (hydrogenated) and subsequently isomerized.[110] During hydrogenation oxygen, sulphur and

[108] Source: (Kampman et al, 2011) (Bacovsky et al, 2013), Croezen, 2008

[109] Refining of fats concerns removal of components which may have negative effects on taste, stability, appearance or nutritional value.

[110] **Isomerisation** refers to a process by which a hydrocarbon molecule is transformed into another molecule which has exactly the same atoms, but the atoms have a different arrangement. In case of isomerization of fatty acids the straight hydrocarbon molecules produced during hydro deoxygenation are converted into branched molecules. This has the effect that the melting point of the molecules and hence the cloud point of HVO is lowered.

nitrogen are removed as water, H_2S and NH3 and unsaturated bonds are saturated. The glycol present in the vegetable oil is hydrogenated into propane.

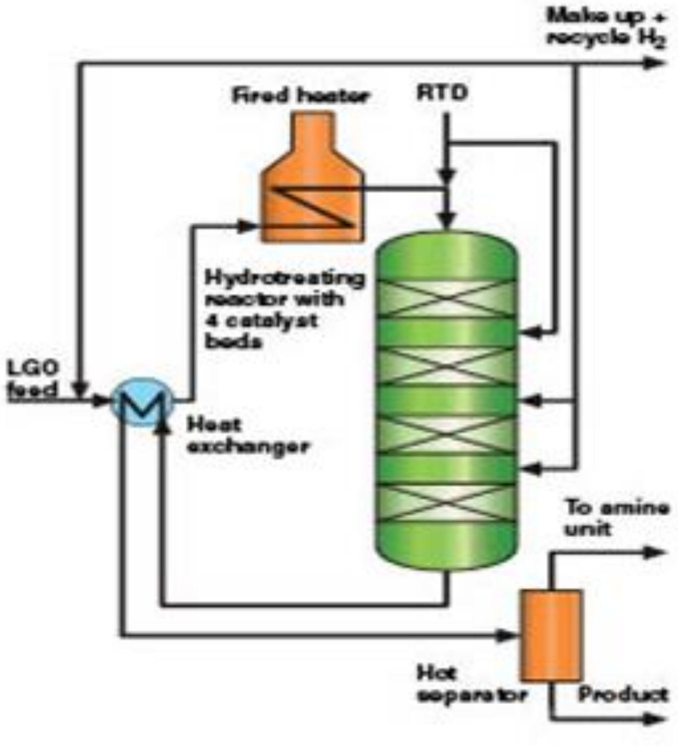
Products assay is a function of feedstock composition and operational conditions and may range as indicated below:

- Propane (2-4% weight)
- Naphta (1-10% weight)
- Diesel (88-98% weight)

Unlike FAME, refining vegetable oils usually yields paraffinic middle distillate fuel oils that can be indistinguishable from conventional fuel components derived from petroleum, but the average density is slightly lower than that of conventional diesel fuel. Therefore, it can be blended with conventional diesel fuel with very few issues up to B30 blends, beyond which the blend density would be below the diesel specification requirement (EN590). Consequently, engine and vehicle manufacturers widely support the development of hydro-treated renewable fuels. However, according to VW and Renault, Neste in Finland is the only major supplier of HVO at present and its penetration in the EU is not high (i.e., <5% of all bio-diesel sold in the EU in 2014).

The cetane number of HVO is higher in comparison to diesel, which result in some advantages, such as easier ignition, more efficient combustion and less NOx emissions. As HVO contains virtually no sulphur and aromatics, it can be considered a premium fuel. A disadvantage is the lubricity of HVO, which is not as good as the lubricity of diesel.

Figure A2.1 Hydrotreating of vegetable oils as implemented by PREEMs Gothenburg refinery



Source: http://www.topsoe.com/sites/default/files/novel_hydrotreating_technology_for_production_of_green_diesel.ashx_.pdf

LGO = Light Gas Oil, RTD = Raw Tall-oil Diesel. The RTD is injected at four points in the hydrotreater, between the individual catalysts beds.

HVO is primarily produced with dedicated installations such as realised in Rotterdam and Porvoo. As an alternative tall oil can be co-processed with conventional diesel in a retrofitted diesel hydrotreater, as e.g. has been implemented at PREEM's Gothenburg refinery, where a 85%/15% blend of conventional and tall oil based diesel is processed. Higher percentages may not meet cloud point specifications, because of the high molecular weight of the tall oil acids.

A2.3 Diesel and bio-diesel properties

Table A2.1 Properties of Diesel and Bio-diesel

	HVO	EN590 (summer grade)	FAME (from rape seed oil)
Density at 15 ºC (kg/m^3)	775 … 785	≈ 835	≈ 885
Viscosity at 40 ºC	2.5 … 3.5	≈ 3.5	≈ 4.5
Cetane number	≈ 80 … 99	≈ 53	≈ 51
Distillation rangeºC	≈ 180 … 320	≈ 180 … 360	≈ 350 … 370
Cloud pointºC	-5 … -25	≈ -5	≈ -5
Heating value, lower (MJ/kg)	≈ 44.0	≈ 42.7	≈ 37.5
Heating value, lower (MJ/l)	≈ 34.4	≈ 35.7	≈ 33.2
Total aromatics (wt-%)	0	≈ 30	0
Polyaromatics (wt-%)[1]	0	≈ 4	0
Oxygen content (wt-%)	0	0	≈ 11
Sulfur content (mg/kg)	<10	<10	<10
Lubricity HFRR at 60º (µm)	<460[2]	<460[2]	<460
Storage stability	Good	Good	Very challenging

(1) European definition including di- and tri+ -aromatics

(2) With lubricity additive

Source: Environmental Protection Agency, 2002

Table A2.1 provides a summary of the important characteristics of bio-diesel types contrasted to pure diesel fuel meeting the European EN590 specification. The data shows that FAME has a volumetric energy content 8% lower than that of diesel while the energy of HVO is about 4% lower than that of diesel.

A2.4 Ethanol as petrol replacer

Ethanol is the only bio-fuel considered for blending with petrol. While other components derived from bio-ethanol and bio-methanol have been considered, ETBE is the only other fuel that has any commercial scale production in the EU and is used with petrol, or ethanol and petrol.

A2.4.1 Feedstocks used

Typical feedstocks include sugar crops (sugar cane, sugar beet, sweet sorghum) and starch containing commodities (grains - corn (maize), wheat, barley – and tuber crops, e.g., potato, cassava).

Technological innovation aims at utilization of cellulose as is present in ligno-cellulosic feedstocks such as wood, fast-growing grasses (e.g., giant cane) and crop residues such as straw. In practice, wood proves to be a difficult feedstock that is more suitable for thermochemical production.

A2.4.2 Biochemical production route

Ethanol is produced biochemically by fermentation of C6 sugars (glucose and fructose), as present in starch and saccharose, by yeast. Sugar is used in yeast metabolism and growth and is converted into 50 weight% CO2 and 50 weight% ethanol.

Fermentation of disaccharides requires no pre-treatment. Starch and cellulose need to be hydrolysed by cooking in boiling water into disaccharides and monosaccharides. Hydrolysis of cellulose must be promoted by microorganisms (cellulase), hydrolysis of starch has a sufficiently high reaction rate by itself. An alternative approach has been implemented in the USA for wood processing: the wood is gasified and the produced CO is fermented into ethanol.

Fermentation of C5 sugars, part of the sugars in hemicelluloses, is still under development and requires genetic modification of yeast.

Fermentation typically takes place in warm water as a reaction medium, in part to avoid intoxication of the yeast at elevated ethanol concentrations. As a consequence, the produced ethanol has to be isolated by distillation. Sugar syrup or low grade exhausted molasses from the sugar process are used to feed the bioethanol plant

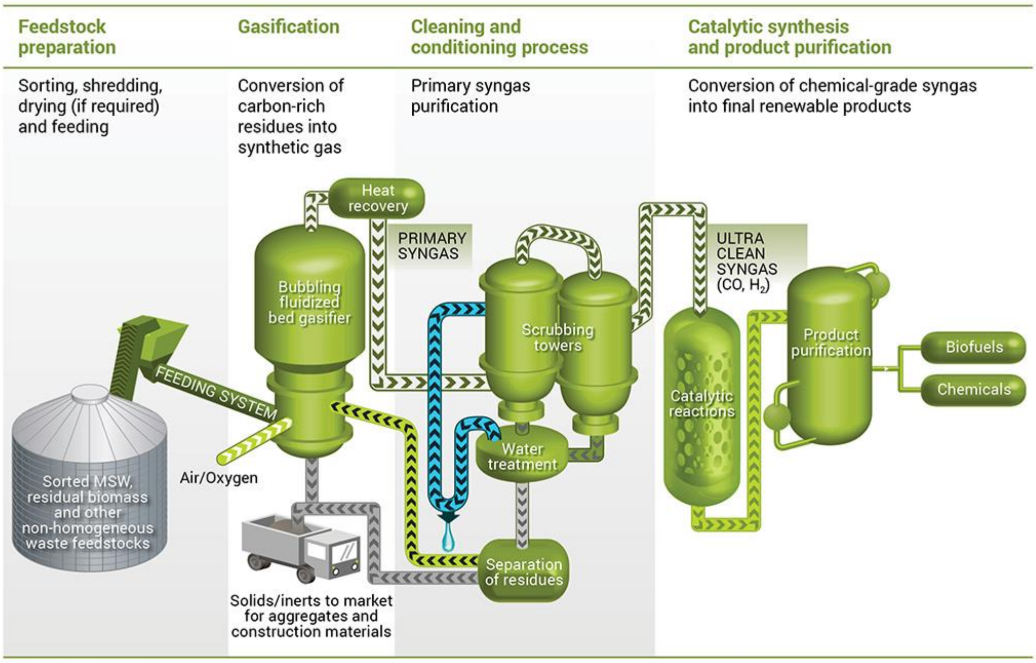
A2.4.3 Thermochemical production

An alternative production route for ethanol concerns catalysed synthesis from CO and H2, produced by biomass gasification. This route is especially suitable for woody biomass with low ash content. Produced CO and H2 are next converted with a catalysed process into ethanol.

The thermochemical production route has been developed into a commercial scale technology by Enerkem. The Enerkem technology platform involves a fluidized bubbling bed gasifier. Clean syngas is catalytically converted to mixed alcohols. A first commercial, MSW processing plant with an ethanol production capacity of 38 million litres per year was inaugurated in Edmonton, Canada on June 4th 2014.

Enerkem partners with AkzoNobel to jointly explore development of waste-to-chemicals facilities in Europe, aimed at production of bio-based methanol and acetic acid.

Figure A2.2 Enerkem production process flow sheet



** Municipal solid waste*

Source: Bacovsky et al, 2013

A2.4.4 Bio-ethanol utilization

Bio-ethanol is typically used in passenger cars, as low blends of around 5-10% bio-ethanol can be used in unmodified petrol engines. Higher blends require adapted engines. In colder climates E85, a mix of 85% bio-ethanol and 15% petrol, should be used to avoid cold start problems in view of the reduced vapour pressure of ethanol. In warmer climates pure bio-ethanol (E100) can be used in adapted petrol engines. Petrol vehicles with adapted engines are so-called flex-fuel vehicles (FFVs), which run either on petrol or on an ethanol blend up to 85 vol%. Like FAME, E85 reacts differently with certain materials (plastic and rubber) compared to regular petrol. Therefore some materials in the existing infrastructure and engines need to be replaced to avoid technical problems.

Ethanol can also be applied in heavy duty vehicles as ED95, a blend containing up to 95% ethanol and as so-called E-diesel, an ethanol-diesel blend containing up to 10-15% ethanol[111]. While ethanol does not readily mix with diesel, it is possible to provide a semi-stable blend with the use of dispersants. E-diesel fuel lowers the blend flashpoint, which is well below the minimum limit set by diesel fuel standards. Such flashpoint levels basically can result in fuel handling related fire safety issues comparable to those for neat ethanol or petrol. E-diesel advocates believe that safety risks can be mitigated by adopting the storage and refuelling methods commonly used by methanol producers, for example. Equipping all storage tank vents and the vehicle tank vent and fill openings with flame arresters can eliminate some of these concerns (Waterland, Venkateshand Unnasch, 2003). In addition to the refuelling infrastructure concerns, vehicle manufacturers have reported (ACEA, et al., 2013) that e-diesel may damage vehicle parts, especially fuel injectors, and cause other types of vehicle failure due to low lubricity. In addition, ethanol separates from diesel during injection into the engine and the combustion process is affected. For these reasons, e-diesel has no support at all with auto-manufacturers.

The energy content of bio-ethanol is around 35% - 40% lower compared to petrol diesel. This means that (much) more ethanol is needed to cover the same distance. On the contrary the octane number of ethanol is higher resulting in a higher energy efficiency, because a higher compression rate can be used.

A2.5 Potential future biofuels under development

Alternative advanced production routes applied at limited scale or being on the brink of demonstration on commercial scale include:

- **Production of methanol** via gasification of glycerol by Bio MCN in The Netherlands; The glycerol used by Bio MCN is a by-product of biodiesel production and the production process is hence directly linked to biodiesel production.
- **Synthetic Fuels from Bio-mass** can be created using processes such as Fischer-Tropsch, which has been around for almost 100 years. Similar processes are used today and their aim is to convert feedstock of biomass, as well as methane (captured from agricultural wastes) into fuels, including diesel. The processes are commonly referred to as BTL (Biomass-To-Liquids) or GTL (Gas-To-Liquids). Regardless of the feedstock, these processes involve a gasification step (synthetic gas production) and a second step of gas synthesis to various liquid hydrocarbons.The synthetic diesel fuel can be tailored to be used as a “drop-in” (or interchangeable) fuel with conventional diesel. Due to parafinnic nature of this fuel, there could be an issue with lubricity although traditionally it can be overcome with appropriate additives (Neste Oil, 2006). However, there are no commercial scale BTL facilities operating in the EU today although there is pilot production in the Netherlands.
- **The bioforming process:** a two-step catalytic process in which sugars and cellulosic biomass are first converted in a reaction at elevated pressure and water into low oxygen

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[111] Pure Energy Corporation, Website http://www.oxydiesel.com/oxyindex.html, Accessed August 4, 2014.

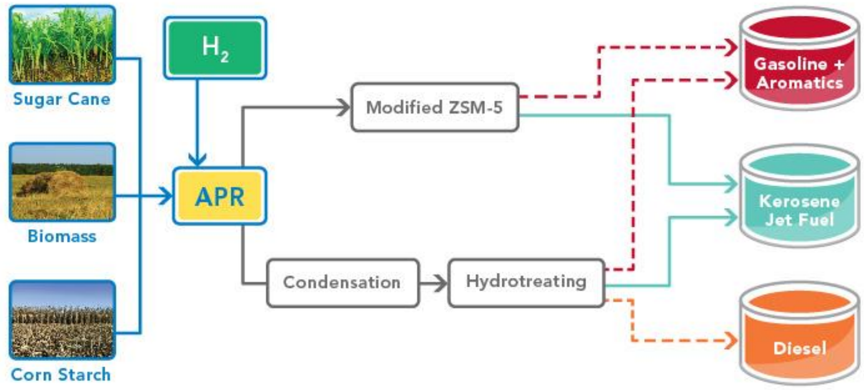
content hydrocarbons[112], which can next be converted into fuels and chemicals utilizing standard petrochemical processes (see Figure A2.3).

- **Hydropyrolysis:** fast pyrolysis of biomass in a hydrogen atmosphere.

The last two processes have been adopted by Shell, which is sponsoring further development by respectively Virent and subsidiary CRI. Shell expects to be producing advanced biofuels at scale, in US, by end of decade with both technologies.

With Virent, Shell has developed a petrol made from sugars that has this year been registered by EPA for blending in petrol at up to 40% and a jet product that can be blended at 15%. The jet fuel product is currently going through the certification process.

Figure A2.3 Bioforming process flow sheet



Source: Bacovsky et al, 2013

[112] The aqueous phase reforming step utilizes heterogeneous catalysts at moderate temperatures and pressures to reduce the oxygen content of the carbohydrate feedstock. Some of the reactions in the APR step include: (1) reforming to generate hydrogen; (2) dehydrogenation of alcohols/hydrogenation of carbonyls; (3) deoxygenation reactions; (4) hydrogenolysis; and (5) cyclization.

Annex 3 A first-order assessment of future availability of biofuels from sustainable, non-food biomass

In this Annex a broad analysis is presented evaluating availability of sustainable feedstocks in the EU that can be used above the 7% cap, based on existing literature. The recent ILUC decision and relevant EU directives imply that the future biofuels marketed have to meet the following criteria:

- Not produced from cultivated feedstock
- ILUC-free or low-ILUC
- Retaining soil fertility, SOC-levels
- Retaining surface and ground water quality
- Matching the no net biodiversity loss target

This leads to the following possible route for feedstock provision:

- utilization of by-products and residues from various economic sectors that do not have other useful applications
- utilization of biomass from landscape management

As discussed in the previous Annex, the technology to use these feedstocks to produce bioethanol is currently the most advanced, but efforts are ongoing to develop a number of alternative conversion processes that could produce both petrol and diesel replacements from these feedstocks.

Note that the potential availability of these types of low-ILUC feedstocks is one of the key drivers for these R&D efforts: if the share of sustainable biofuels in transport fuels is to be increased significantly in the future, both the fuels suppliers and the biofuels industry needs to be able to rely on routes with sufficient and reliable sustainable biomass supply (source: interviews with these stakeholders, and literature).

The ILUC decision does, however, leave an option to also include ILUC-free or low-ILUC, cultivated biomass as a possible feedstock which does not fall under the cap, at a later stage. As this may be an interesting option to expand the feedstock base for biofuels in the EU, the is also included in this analysis. This could concern cultivation of more productive crops on land already utilized previously for biofuels feedstock cultivation, without intensification of cultivation, and intensified cultivation of cover crops may also have significant potential for low-ILUC. However, the definition of low-ILUC cultivated biomass is difficult to implement and monitor.

There are two important issues to consider when interpreting the data presented in this Annex:

- As noted in the remarks Section of the table and mentioned above, many of these feedstocks can also be used for other applications. The waste and residues can typically also be used for electricity and heat production, and as renewable feedstock for the chemical industry. The cultivated low-ILUC biofuels can also be used for food and feed. To derive a realistic estimate of potential availability for the biofuels sector thus requires a much more extensive and complex assessment of future availability and demand from all sectors involved. This competition is also realised in the ILUC decision recently adopted in by the European Parliament, which included the provision to the RED that support schemes that promote the use of renewable energy shall not distort the markets in raw materials of other manufacturing sectors in which the same raw materials are traditionally used.
- As mentioned before, the uncertainties regarding future success of the R&D efforts in the various advanced biofuels routes are still significant. Especially the advanced biodiesel processes still seem to be relatively far away from commercial application

The criteria possibly exclude production of biofuels feedstock by intensification of cultivation, as recently explored by Ecofys. In Ecofys, 2015 several case studies are analyzed for 'low ILUC' biofuels produced from agro commodities cultivated using highly intensive cultivation practices, compared with reference cultivation systems. The idea behind this approach is that intensification and yield increases per hectare will reduce land requirements for food and feed production and will hence make arable land available for cultivation of biofuels feedstocks. As intensification of crop cultivation will very likely result in biodiversity decrease, as illustrated by the low level of biodiversity on arable land in the Netherlands, compared with e.g. low input or subsistence arable land in Eastern Europe. This loss in biodiversity is in itself not contradictory to the RED sustainability criteria, but is at odds with the EU's no net loss principle as defined in the EU Biodiversity Strategy to 2020.

Next to biodiversity loss, a number of other sustainability issues may be relevant in case of intensification, such as

- loss of soil carbon and nutrients,
- increased leaching of nutrients and associated impacts on surface and ground water quality.

In all, 'ILUC free' or 'low ILUC' biofuels from more intensively cultivated arable land seem to be less desirable and have hence been ignored.

A3.1 Biofuels from cultivated raw materials

A3.1.1 Increased utilization of crops with higher biofuels yields per hectare on current biofuels feedstock cultivation area

For current production of biofuels in the EU a total area of 8 - 9 Mha of arable land is utilized (EC, 2014f):

- approximately 6.0 - 6.5 Mha for cultivation of rape seed and smaller volumes of sunflower utilized in biodiesel production;
- approximately 2.0 - 2.5 Mha for cultivation of sugar beets and cereals utilized in bio-ethanol production.

This area is spread out over the entire EU land area.

Feedstock availability for biofuels production may be increased without or with only limited indirect land use change by cultivating crops that allow higher biofuel yields per hectare.

The most easily implementable type of crop that gives increased feedstock yields while it can also be grown almost anywhere in the EU is the sugar beet. This crop yields 5.5 tonnes of ethanol per hectare on average in the EU (CEFS, 2013). This is in terms of biofuel energy content approximately 3 times more (EC, 2014f) than rape seed (1.2 tonnes/ha of vegetable oil) or cereals (1.7 tonnes/ha of ethanol)[113].

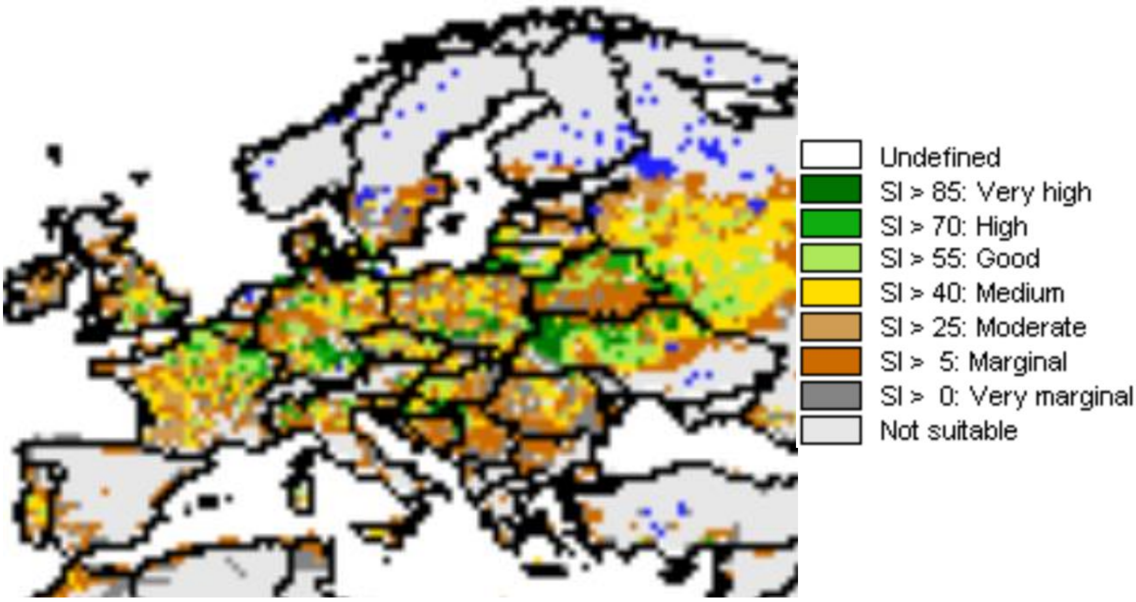
Total amount of bio-ethanol that could be produced on the currently utilized 8 – 9 Mha is estimated at 45 – 50 Mtonnes/year or 28 – 30 Mtoe/year assuming:

- all arable land currently utilized for cultivation of biofuels feedstock is suited for sugar beet cultivation
- sugar beets can be integrated in the rotations currently producing cereals and rape seed for biofuels production

This is approximately twice the amount of bio-ethanol required for meeting total petrol demand in the EU in 2024 with E20.

[113] Lower heating value of ethanol amounts to approximately 26.8 GJ/tonne, the LHV of vegetable oil to approximately 37 GJ/tonne.

Figure A3.1 Suitability of soil and climate for sugar beet cultivation in the EU



Source: GAEZ, 2002

The disadvantage of utilization of sugar beets is that beets cannot be stored as the sugar content rapidly declines during storage. Hence processing has to take place during the harvesting campaign. A second potential disadvantage is that production costs for sugar beet ethanol seem to be somewhat higher than production costs for cereals based ethanol.

On the other hand sugar beets produce less impact per unit of product, compared with cereals require beets less water and nutrients per unit of ethanol.

Alternative feedstocks for sugar beet might be fodder beet, chicory or Jerusalem artichoke or another crop with high sugar production per hectare that can be cultivated within the EU. A more in-depth analysis taking into account climatic aspects, soil characteristics and farm management aspects to determine the best suited crops per region is recommended.

Sugar isolated from sugar beets may also be utilized for production of chemicals. Whether this happens will depend on renewable fuel policy and other relevant policies.

A3.1.2 Cover crops cultivation during autumn and winter

A second option for supply of ILUC free or low ILUC feedstock may be increased cultivation of cover crops and green manure during autumn and winter, seasons during which food and feed crops are normally not grown.

This option will however probably only allow cultivation of fresh biomass such as leaves and stems as crops normally do not produce oil seeds or grains in autumn and winter.

That in turn means cover crops are only suitable as a feedstock for 2^{nd} generation biofuels production or require biomass refining – e.g. for isolation of fermentable sugars from the fresh biomass. Refining technologies are currently under development and are being demonstrated at commercial scale in e.g. the Grassa grass refining initiative in The Netherlands. The Grassa initiative is based on mobile refineries in which biomass is separated by milling, pressing and sieving into juices with dissolved sugars and proteins and fibres. The dissolved sugars could be utilized in conventional ethanol production utilizing sugar fermentation.

A first order potential of 30 – 60 Mtonnes/year of ethanol was estimated on the basis of following basic assumptions:

- Fresh stem and leave yields for cover crops amount to 2 – 4 tonnes d.m./ha/year.

- The ethanol / feedstock ratio is assumed similar with the ratio for straw (1 / 4 – JEC, 2014). Yield would amount to 0.5 – 1.0 tonne of ethanol per hectare.
- Cover crops may be cultivated in combination with crops harvested before mid-September – early October, such as corn maize, maize silage, winter wheat. Total area of cereals and silages cultivated in the EU amounts to approximately 60 Mha (EC, 2014f).

The estimate is a first rough estimate.

- It is based on one cover crop, while for The Netherlands alone there are 15 – 20 relevant cover crops (Timmer, 2004). Some of these can potentially produce significantly more biomass per hectare than winter rye. But possibilities for application of these crops may be limited by e.g. promotion of pests and diseases by certain cover crops for value crops or by the period of the year in which they can be grown. Winter rye is a known cover crop for land cover after a maize silage cultivation and has the advantage that it can sequester nitrogen.
- Yields for the considered cover crop have been based on experiences in The Netherlands (Timmer, 2004). The assumed yield is comparable with yields obtained during trials in Flanders[114]. But in different climate zones yields may differ.

Isolation of sugars by crop refining would make cover crops multi-applicable in the sense that fibres and proteins could be utilized for livestock feeding. Production of solid board from grass fibres has been demonstrated in The Netherlands[115].

A3.2 Biofuels from by-products and residues

A3.2.1 Residual fats and fatty acids

Residual fats and fatty acids are often considered as being low ILUC feedstocks for biodiesel and HVO. This is however questionable for some categories of fats. Residual fats and fatty acids include:

- Used cooking oil;
- Fats from meat processing and animal waste processing;
- Tall oil fatty acids

Based on the information collected during the project following characteristics were composed for the different by-products.

Table A3.1 Estimated availability and pricing of residual oils in the EU

	TOFA from chemical paper pulp	Waste fats from meat processing industries	Waste fats from consumers and catering
Price, €/tonne	900 - 1,000	450 - 550	900 - 1,000
Potential volume, kilotonnes	600 (EU)	650 (EU)	650 (EU)
Current application	Chemicals, fuel, biodiesel	biodiesel, co-combustion	biodiesel
Added value when processed into naphtha	modest to significant	significant	significant

[114] See: http://lib.ugent.be/fulltxt/RUG01/001/789/777/RUG01-001789777_2012_0001_AC.pdf

[115] See: http://grassa.nl/

	TOFA from chemical paper pulp	Waste fats from meat processing industries	Waste fats from consumers and catering
Required effort to contract	low	low	high
Type of contract required	medium term	medium term	long term

Source: Ecofys, 2013a, Ecofys, 2013b, Pelkmans, 2014, Baumassy, 2014

The total of these categories is somewhat less than the amount of residual vegetable and animal oils projected by the EU to be utilized for biofuels production in 2024. According to the EU publication “Prospects for EU agricultural markets and income 2014-2024” the amount of residual oils utilized in 2024 will amount to approximately 3.5 Mtonnes/year, approximately 1 Mtonne/year more than the estimated size of the three categories described below. The EU projection may include e.g. fatty acid distillate, technical corn oil, and spent bleaching oil.

Animal fats are fats from slaughtered animals that are rendered into a variety of products, which can be classified by their degree of quality, from high to low:

- Animal fats intended for human consumption.
- Category 3: fats that can be used for animal feed and cosmetics. For example parts of slaughtered animals, which are fit for human consumption in accordance with EU legislation, but are not intended for human consumption for commercial reasons.
- Category 2: fats that can be used for soil enhancement and for technical purposes, such as oleochemical products and special chemicals[116].
- Category 1: fats that have a high risk for human health, for example animals suspected of being infected by a TSE[2] or in which the presence of a TSE has been officially confirmed; specified risk material. category can be used for energy purposes or biodiesel production and are not allowed to enter the human or animal food chains.

Table A3.2 Waste fats production from meat processing

	2010	2009	2008	2007	2006
Germany	689	669	652	637	600
Spain	381	371	396	402	376
France	333	323	345	345	346
Poland	279	258	300	328	325
Italy	290	283	287	289	282
Netherlands	224	215	208	206	210
UK	155	147	151	152	147
Denmark	144	139	147	154	151
Belgium + Lux	132	126	125	126	120
Austria	109	108	108	108	107
Romania	89	86	84	92	86
Ireland	73	67	70	75	75

[116] Examples of this category ABPs include manure and digestive tract content, (parts of) animals that have died from other causes than by being slaughtered for human consumption, including animals killed to eradicate an epizootic disease

	2010	2009	2008	2007	2006
Hungary	45	41	46	50	48
Other	224	222	244	247	228
Total	**3167**	**3055**	**3163**	**3211**	**3101**

Source: Ecofys, 2013b

Fats categorized as being of quality 3 to 1 are produced by rendering companies, such as:

- Rendac in the Netherlands and Belgium
- Saria Group in Germany, France, Spain, Poalnd and Austria

Both companies own biodiesel producing facilities, both for C3 fats as for C1 fats.

Total EU production of fats amounts to 3,100 - 3,200 ktpy of which approximately 650 ktpy of C1 and C2 waste fats[117].

The produced fats are primarily applied for:

- Co-combustion (520 ktpy) and biodiesel production (410 ktpy);
- Feed (730 ktpy) and pet food (360 ktpy);
- Oleochemical feedstock (600 ktpy).

In theory the total volume of residual fats could be utilized for biodiesel (or HVO) production. As large amounts already have an application, utilization for biodiesel production would lead to market disturbances and possibly ILUC due to the requirement of cultivating primary crops for production of the feedstocks required in the competing industries.

A3.2.2 Straw

According to a JRC analysis (see Alterra, 2012), a total of 45 – 50 Mtoe[118] of straw could be utilized for biofuels production annually without sustainability issues such as deterioration of soil quality. Associated costs are estimated at €40/tonne straw.

The estimation includes straw from a wide range of crops delivering straw including all cereals, rice, and maize, sunflower and oil seed rape. the amount of straw that should be left on the land for conservation of soil quality were estimated to be 40% for wheat, rye, oats and barley and at 50% for the other 4 crops. Estimated demands for straw for competitive uses such as bedding in specific livestock systems (including horses) and for mushroom production have also been subtracted from the bioenergy potential.

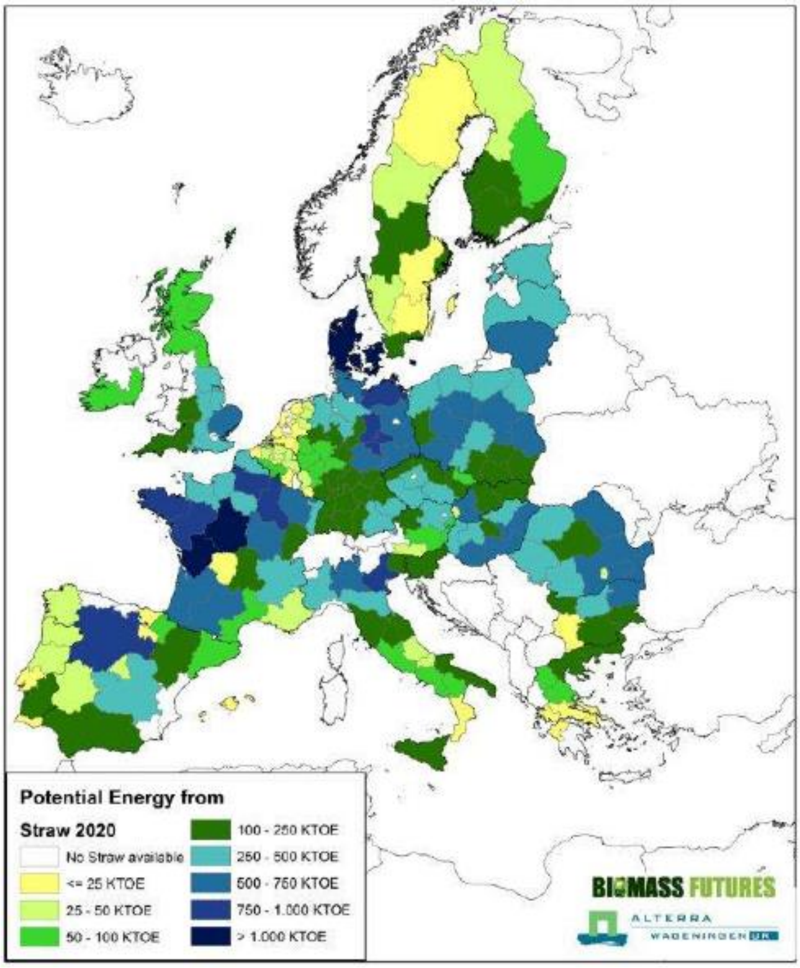
A more detailed disquisition of the analysis conducted by JRC can be found in (Alterra, 2012).

In this study the potential of straw has been recalculated into a potential production volume of bio-ethanol assuming the ethanol / dry straw ratio of 1 / 4 assumed in JEC, 2014.

[117] Mail exchange with Ralph Brands, Sales Manager Energy at Ecoson / Rendac / Vion Ingredients

[118] A toe = ton oil equivalent = 41.86 GJ/tonne LHV. Straw has a LHV of approximately 14 MJ/kg.

Figure A3.2 Geographical sustainable availability of straw in the EU



Source: Alterra, 2012

A3.3 Other residues from agricultural land utilization

According to Alterra, 2012 pruning's and cuttings in permanent crops plantations with soft fruit, citrus, olives but also vineyards can supply up to 10 Mtoe of biomass.

Utilization for biofuels production in practice competes with utilization for heat and/or power generation.

A3.3.1 Woody biomass from forests, other wooded land and from industry and consumers

According to the EU Wood study (EU Wood, 2010) intensification of wood mobilization in European forests could sustainably produce a total amount of 36 Mtoe of round wood (thinning) and 19 Mtoe of forests residues (branches and tops). The estimate refers to a scenario in which forests with high biodiversity are excluded from harvesting and more measures are taken to prevent loss of site productivity and soil erosion.

In addition landscape care may an additional 11 – 11.4 Mtoe, while increased mobilization of forest wood and residues may yield another 10 Mtoe of woody biomass, compared with current production and utilization. The considered residues include black liquor, saw dust and other sawmill residues, other industrial residues and consumer waste wood.

Utilization for biofuels production in practice competes with utilization for heat and/or power generation.

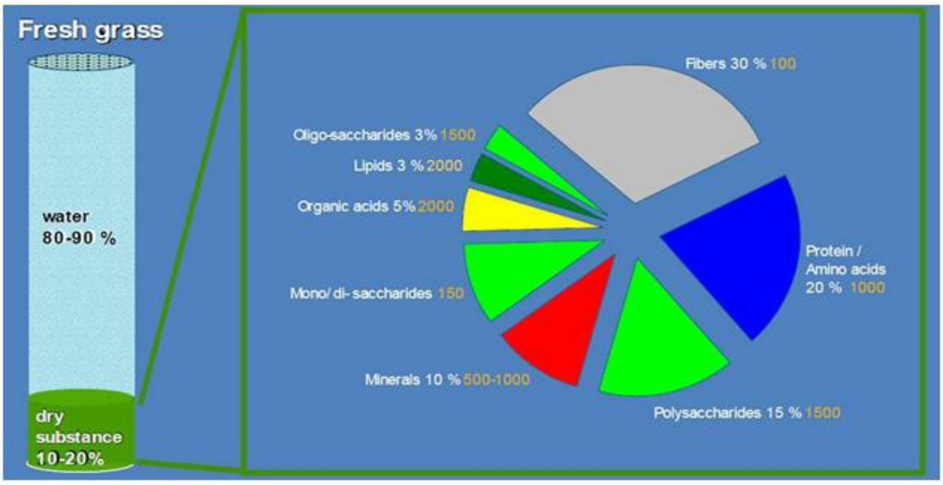
A3.3.2 Grass

In regions with intensive dairy cattle and other bovine husbandry part of the grass cultivated for feeding these animals is lost because it is too wet. Especially in spring and wet summers a lot of grass can be lost. Availability of surplus grass in the EU is estimated at 15 Mton dry matter per year from fertilized grasslands.

Next to this an indicated amount of 15-20 Mton dry matter per year from natural sources and unfertilized lands (Van Zijderveld, 2012).

Grass can be separated into different components, a wet component which can be used as feed, and fibres which can be used to produce e.g. graphic board component or paper, fertilizer and a residue which can be processed into biogas through anaerobic digestion (Courage2025).

Figure A3.3 Average composition of grass from fertilized grasslands



Source: see footnote[119].

The technology has meanwhile been demonstrated at industrial scale with a mobile installation, allowing surplus grass processing at the point where it is released.

Assuming an availability of 30 Mton (dry matter) of surplus grass in the EU per year, grass refinery could potentially produce 6 Mton protein, 9 Mton fibre, 1 Mton fat, 14 Mton sugars (Van Zijderveld, 2012). The high-protein concentrate can substitute soy as animal feed. The sugars and fat can be utilized as biofuels feedstock. The fibres may also be used for (2nd generation) biofuels production or as fuel in coal fired power plants.

As the grass is very wet, storage by means of silaging is impossible by definition (otherwise the grass would be utilized as silage for cattle) and utilization for anaerobic digestion and other production routes for heat and/or power are secluded.

A3.3.3 Biodegradable consumer waste

Around 50 Mton of bio-municipal solid waste (MSW) is landfilled in the EU-27 every year (based on EC, 2012). Incineration with energy recovery, as electricity and heat, provides a useful alternative for what would otherwise be waste. Composting also is a valuable application of bio-waste, a little over 60 Mton of bio-waste is already recovered (in another way than energy recovery; EC, 2012).

[119] See: http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/Presentatie__7__Grasraffinage_Courage_WS_061207.pdf and http://www.kcpk.nl/kees-van-zijderveld

A3.3.4 Palm oil from degraded soils

WWF has analyzed the possibilities of oil palm cultivation on degraded soils, such as Alang-Alang grasslands on Kalimantan (WWF, 2009). The reason for WWF to study such a possibility is twofold:

- Production of additional palm oil for food applications and indirect avoidance of land use
- Land restoration by removal of the grass

Such a cultivation scheme may be considered to be ILUC free and sustainable as the land aimed at has already been degraded due to previous economic activities (e.g. timber fellings) (WWF, 2009).

For oil palms cultivated on grass land the reference is limited to unutilized grasslands with limited carbon stocks in vegetation (± 10 metric tons of carbon per hectare) and soils (45 – 60 metric tons of carbon per hectare).

Planting and cultivating oil palms on such lands results in additional sequestration of carbon in both the growing oil palms and the soils. Sequestration in soils occurs because the oil palms give more biomass to the soils as leafs, twigs and fruit residues than the original grass vegetation, resulting in built up of additional humus.

The net effect is an increase in sequestered carbon of approximately 14 metric tons of CO2/ha/year (WWF, 2009).

Annex 4 Modelling methodology to estimate vehicle emissions

A4.1 Introduction

For the hypothetical scenarios described in Chapter 1, Section 1.7.3 for increasing the limits of the bio-content of petrol and diesel fuels, a calculation model was developed with which the biofuel market uptake could be calculated, and the associated impact on vehicle pollutant (oxides of nitrogen (NOX), total hydrocarbons (THC), non-methane hydrocarbons (NMHC) (for petrol vehicles only), carbon monoxide (CO), and particulate matter (PM)) and carbon dioxide (CO2) emissions in 2020 and 2030.

The following describes the methodology used for these calculations.

A4.2 Methodology

The following overall approach was used to calculate emissions. Each of these steps is described in greater detail below.

Step 1. Establish base case emissions and base case emission factors

Step 2. Calculate the percent reduction in emission factors for each pollutant and fuel type using base case emission factors calculated in step 1 and vehicle test results for each type of fuel.

Step 3. Determine the vehicle populations using each fuel under each scenario and analysis year

Step 4. Determine total activity levels by vehicle type, fuel type, and year

Step 5. Determine total emissions for each vehicle type, fuel type, and year for each scenario.

A4.2.1 Step 1: Base case Emissions and Emission Factors

Under this step, base case emissions for each year and base case emission factors (for the base case fuel types) were established. This allows comparison to emissions for the fuel blend scenarios. The following approach, along with key assumptions, was used.

1. Determine base case emissions:
    a. Outputs from the TREMOVES model (version 3.3.2)[120] were used to determine total base case emissions for 2010, 2020, and 2030 for light duty vehicles (LDVs) and heavy duty vehicles (HDVs).
    b. Emissions for 2013 were determined by linearly interpolating values from 2010 to 2020 (TREMOVES does not have year 2013 data).
    c. For non-methane volatile organic compounds (NMVOC), as reported in TREMOVES, was converted to NMHC and THC using conversion factors from the Environmental Protection Agency, assuming that NMVOC is equivalent to VOC (US EPA, 2010).
    d. For CO_2, Regulation (EC) No 443/2009 requires that only the fleet average is regulated; as such, it was assumed that EC mandatory 2020 emission reduction targets for new passenger cars and vans would be met[121]. As such, base case CO_2 emissions in 2020 were assumed to decrease in line with these targets. Since no CO_2 targets have been set for 2030, it was assumed that 2020 targets would remain constant through 2030.

[120] http://www.tmleuven.com/methode/tremove/home.htm

[121] http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

2. Determine base case emission factors for petrol vehicles:
   a. Pollutant emission factors for E5 and E10 were obtained from *Impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the Worldwide Harmonized Light duty Test Cycle (WLTC)* (Suarez-Bertoa et al. 2015). These data are the basis for data provided graphically in Chapter 2, Figure 2.3 and Figure 2.3Figure 2.4. Emission factors for the WLTC and hydrous fuels (e.g. HE10) have been used. WLTC data has been used since vehicle emissions tests described in Chapter 2 and Annex 55 were also based on the WLTC test, and WLTC will become the EU type-approval procedure for fuel consumption and CO_2 in 2017.
   b. Emission factors for E5 and E10 for PM were estimated from Chapter 2, Figure 2.6. Emission factors represent the Peugeot - WLTC.
   c. The base case petrol fuel is E5 (5% v/v ethanol), equivalent to 3.4% energy from Chapter 1, Table 1.8.
3. Determine base case emission factors for diesel vehicles:
   a. The percent reductions for B7 and B10 fuels compared to B0 were obtained from Chapter 2, Table 2.6 (LDVs) and Table 2.7 (HDVs). Where ranges in percent reductions were presented, the mid-range values were used.
   b. Assumed all vehicles comply with Euro 5 or Euro 6 standards (reduction percentages for NO_X and PM vary based on Euro standard compliance). This assumption is supported by TREMOVES data: 70% of vehicles comply with Euro 5 or 6 standards in 2020 and 100% comply with Euro 5 or 6 standards in 2030.
   c. Assumed all HDVs have oxidation catalysts (reduction percentages for THC and CO vary based on the presence of oxidation catalysts).
   d. The base case diesel fuel is B5.7 (5.7% v/v biodiesel), equivalent to 5.4% energy from Chapter 1, Table 1.7.
   e. Emission factors for B5.7 fuel were determined by linearly extrapolating emission factors for B7 to B10 fuels based on their biodiesel content (7% and 10% v/v, respectively). This assumes that emissions are directly proportional to the biodiesel content of the fuel.
   f. The change in emission factors from B7 to B5.7 was applied to emission factors for B7 determined by (Suarez-Bertoa et al. 2015) to estimate the base case emission factors.

Emission factors are presented in Table A4.1 below.

Table A4.1 Emission Factors

Vehicle/ Fuel / Pollutant	Emission Factors[a]			
Petrol - LDV	**E5[b]**	**E10[c]**	**E20[c]**	**E25**
CO_2	151.00	151.00	148.74	147.98
NOx	62.00	62.62	63.24	63.24
THC	93.00	93.00	89.28	89.28
NMHC	82.00	82.00	78.72	78.72
CO	394.00	374.30	334.90	334.90
PM	0.00110	0.00102	0.00091	0.00091
PN	5.00E+11	1.33E+12	1.28E+12	1.28E+12
Diesel – LDV	**B5.7[b]**	**B7[c]**	**B10[c]**	**B30[c]**
CO_2	152.40	152.40	152.40	152.40
NOx	570.88	576.59	582.36	582.36
THC	6.33	6.08	5.78	4.91

Vehicle/ Fuel / Pollutant	Emission Factors[a]			
CO	80.12	76.92	73.07	62.11
PM	1.10	1.03	0.95	0.78
PN	8.60E+09	8.58E+09	2.59E+10	7.93E+10
Diesel – HDV	**B5.7[b]**	**B7[c]**	**B10[c]**	**B30[c]**
CO_2	152.40	152.40	152.40	152.40
NOx	570.88	576.59	582.36	582.36
THC	6.31	6.18	6.06	5.30
CO	79.81	78.21	76.65	70.90
PM	1.10	1.03	0.95	0.71
PN	8.60E+09	8.58E+09	2.59E+10	7.93E+10
Notes: Units are milligrams per vehicle-kilometer (mg/km) for all pollutants except PM, where units are grams per vehicle-kilometer (g/km), and PN, where units are number of particles per vehicle-kilometer (g/km) Base case fuels				

A4.2.2 Step 2: Percent Reduction in Emissions

Using the base case emission factors estimated under Step 1, the percent reduction in emission factors for each pollutant and fuel type compared to the base case fuels was estimated. The following approach, along with key assumptions, was used.

1. The base case emission factors for each pollutant and fuel as calculated under Step 1 were compared with data presented in Chapter 2, Table 2.5, Table 2.6 and Table 2.7.
2. The percent reductions for petrol and diesel-based biofuels described in Chapter 2, Table 2.5, Table 2.6 and Table 2.7 were applied to the base case emission factors to calculate emission factors for the higher biofuel blends for LDV and HDV.

A4.2.3 Step 3: Vehicle Populations by Scenario

Vehicle populations using each fuel type under each analysis scenario were estimated using the following approach.

1. Scenarios analysed are based on the Chapter 1, 1.7.3.
2. For Scenario C, it was assumed that vehicles compatible with E20 are also compatible with E25 and vehicles compatible with B10 are also compatible with B30 (Chapter 2).
3. Vehicle populations by model year, calendar year, and fuel compatibility were obtained from TREMOVES model outputs.
4. To determine the number of LDV vehicles using petrol versus diesel, vehicle activity (kilometers traveled) from TREMOVES by vehicle type and fuel type were used.
5. Based on TREMOVES outputs, a small percentage of LDVs and HDVs use natural gas; these vehicles were not included in the analysis.

Vehicle populations by scenario are presented in Table A4.2 below.

Table A4.2 Vehicle Populations by Scenario (Thousands)

Vehicle / Fuel Type	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
LDVs						
E10	10,791	10,791	10,791	11,865	7,208	7,208
E20	0	0	0	0	4,657	0
E25	0	0	0	0	0	4,657
B7	17,076	17,076	17,076	18,817	11,431	11,431
B10	0	0	0	0	7,386	5,540

Vehicle / Fuel Type	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
B30	0	0	0	0	0	1,847
HDVs						
B7	10,921	10,921	10,921	12,343	7,849	7,849
B10	0	0	0	0	4,495	3,371
B30	0	0	0	0	0	1,124

A4.2.4 Step 4: Vehicle Activity by Scenario

Total activity levels by vehicle type, fuel type, and analysis year were calculated as follows.

1. The vehicle populations by scenario and fuel type as calculated under Step 3 above was used to determine the percentage of total vehicle activity (kilometers traveled).
2. It was assumed that vehicle population equals activity (kilometers traveled), and therefore also equals emissions.

The percent vehicle activity by scenario are presented in Table A4.3 below.

Table A4.3 Percent Vehicle Activity by Scenario

Vehicle / Fuel Type	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
LDVs						
E10	39%	39%	39%	39%	23%	23%
E20	0%	0%	0%	0%	15%	0%
E25	0%	0%	0%	0%	0%	15%
B7	61%	61%	61%	61%	37%	37%
B10	0%	0%	0%	0%	24%	18%
B30	0%	0%	0%	0%	0%	6%
All Fuels	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
HDVs						
B7	100%	100%	100%	100%	64%	64%
B10	0%	0%	0%	0%	36%	27%
B30	0%	0%	0%	0%	0%	9%
All Fuels	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

A4.2.5 Step 5: Emissions by Scenario

Total emissions for each vehicle type, fuel type, and year for each scenario were calculated as follows.

1. For each pollutant, year, vehicle type, and fuel type, total base case emissions from Step 1 were multiplied by the percent reductions from Step 2 and the vehicle activity percentages from Step 4 to determine emissions for each scenario.
2. Emission reductions were calculated by comparing emissions for each scenario to the base case emissions determined in Step 1.

Annex 5 Millbrook Vehicle Test Report

Test Report

MILLBROOK

Customer	ICF International
Vehicle	Euro 6 Diesel and Gasoline vehicles
Test	Evaluation of Bio Fuels on Emissions and Fuel
Millbrook Report No.	MBK15/0621
Millbrook Project No.	PT0270-001-01

Author: A. Shepherd
Senior Engineer - Powertrain

Approved for Issue: P. Stones
Head of Emissions & Fuel Economy

Date: 06 August 2015

Test Report

Executive Summary

The project detailed in this report was conducted to produce emission data for test fuels with varying levels of Bio-content to allow further analysis to be conducted which is not covered in this report. The following Diesel and Gasoline fuels were considered

- Diesel Reference B7
- Diesel B10
- Diesel B30
- Gasoline Reference E10
- Gasoline E20

Tests were conducted on Euro 6 compliant vehicles running on a chassis dynamometer (Dyno) with emissions sampled using a Constant Volume Sampler (CVS) system, Peugeot 508 (2.0L Diesel) and Peugeot 308 (1.2L Gasoline).

Testing was completed successfully with a full set of results obtained.

Distribution

Organisation	Recipient	Format	Qty
ICF International Watling House, 33 Cannon Street, London, EC4M 5SB	Mr Ravi Kantamaneni	PDF	1
Millbrook Proving Ground Ltd Millbrook Bedford MK45 2JQ	Contract file Andrew Shepherd	PDF Paper	1 1

Report Revision History

Rev.	Revision Description	Date	Author	Approver	Pages
0	Preliminary release	06 August 2015	A.Shepherd	-.-	All

Contents

Section	Page Nos.

Appendices

Emissions results	Appendix A
Vehicle details	Appendix B
Fuel Analysis Certificates	Appendix C
Description of test cycles	Appendix D
Carbon Balance Method	Appendix E

List of Figures

Objectives

1. Conduct emission tests on two vehicles, 1 gasoline and 1 diesel, to the World Harmonized Light Vehicles Test Cycle (WLTC) in a repeatable manner.
2. Present the differences in fuel consumption and emissions results from the different fuels being tested containing various levels of bio-content. For the gasoline vehicle two fuels were examined, E10 and E20. Three fuels were evaluated using the diesel vehicle, those being B7, B10 and B30.

Conclusions

1. Two vehicles were successfully run in a repeatable manner to the WLTC cycle resulting in Coefficients of Variance (CoV) below 0.35% for all test fuels.
2. Emissions results for test fuels with varying levels of bio content were produced for further analysis along with modal data.

Test Facility and Date

The WLTC tests on two test vehicles were performed between the 24th June 2015 and 12th July 2015 in the Vehicle Emissions Laboratory (VEL) facility at Millbrook Proving Ground Ltd.

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Contact: Mr. Andrew Shepherd - Powertrain Engineer.
Telephone: 01525 408423
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Test Material/Vehicle

Item	Identification
Test Vehicle 1 - Peugeot 308sw	
Registration Number	*LP64AEW*
Chassis OEM	*Peugeot 308sw*
Engine OEM & Model	*1.2L PureTech e-THP 130*
Power Rating	*96 kW @ 5500 rpm*
Torque Rating	*230 Nm @ 1750 rpm*
Engine Size	*1199 cc*
Euro Standard	*Euro 6*
Transmission OEM	*6 Speed Manual*
Fuel type & Spec	*Gasoline*
Odometer at start of test	*3,606 miles*
Test Vehicle 2 - Peugeot 508	
Registration Number	*LT64OVG*
Chassis OEM	*Peugeot 508*
Engine OEM & Model	*2.0L BlueHDi 150 S&S*
Power Rating	*110 kW @ 4000 rpm*
Torque Rating	*370 Nm @ 2000 rpm*
Engine Size	*1999 cc*
Euro Standard	*Euro 6*
Transmission OEM	*6 Speed Manual*
Fuel type & Spec	*Diesel*
Odometer at start of test	*10,212 miles*
2 x 50L barrels of E20 fuel (Millbrook supplied)	“E20 Gasoline”, CAF-W15/438
2 x 50L barrels of B10 fuel (Millbrook supplied)	“B10 Diesel”, CAF-G15/313
2 x 50L barrels of B20 fuel (Millbrook supplied)	“B20 Diesel”, CAF-G15/314

Full vehicle details are documented in Appendix B.

Dynamometer Settings

	Vehicle 1 (Peugeot 308sw)	Vehicle 2 (Peugeot 508)
Mass (kg)	1,360	1,700
F0 (N)	7.10	7.9
F1 (N/kmh)	0	0
F2 (N/kmh^2)	0.04810	0.05360
F3 (N/kmh^3)	0	0

The parameters above were used in the dynamometer settings to take into account vehicle inertia, rolling resistance, frictional and aerodynamic resistance. These have been taken from UNECE Regulation 83 for the applicable vehicle mass.

Test Procedure

Gear shift schedule

A gear shift schedule was constructed for each vehicle during start of the test program as detailed by the procedure set out in the WLTP regulation. The vehicles were driven to these shift schedules on each test to ensure repeatability.

Test Steps

For each test the vehicle's stop-start function for engine control was disabled to ensure each test was as repeatable as possible. The study is concerned about test repeatability to highlight any measurable differences in vehicle emission data due to varying levels of bio-content and not the overall emission levels produced by the test vehicles in relation to legislative limits.

The main procedural steps of the test programme were carried out in the below order:

Gasoline vehicle – Peugeot 308sw

- Fuel flush to E10 Reference fuel
- Run 3xWLTC emissions tests

- Fuel flush to E20 Gasoline fuel
- Run 3xWLTC emissions tests

Diesel vehicle – Peugeot 508

- Fuel flush to B7 Reference fuel
- Run 3xWLTC emissions tests

- Fuel flush to B10 Diesel fuel
- Run 3xWLTC emissions tests

- Fuel flush to B30 Diesel fuel
- Run 3xWLTC emissions tests

Fuel flush procedure

The vehicles were flushed onto each fuel using the following procedure:

- Drain existing fuel from the tank
- Fill with 15L of the test fuel
- Drive for 15 minutes
- Drain remaining fuel from the tank
- Fill with 45L of test fuel (Retain a 5L sample of the test fuel)
- Vehicle driven for 250 miles to a Public Road Simulation (PRS) schedule of 1/3 urban, 1/3 rural and 1/3 motorway on Millbrook's tracks.

Before each emissions test, the vehicle was prepared using the following procedure:

- Tyre pressure check/adjustment
- Exhaust leak check
- Pre-conditioning drive cycle on chassis dynamometer:
    - Gasoline (1xECE followed by 2xEUDC drive cycles)
    - Diesel (3xEUDC drive cycles)
- Vehicle soak with battery on charge inside laboratory (23°C ± 2°C for 6 hour minimum)

To ensure repeatability, each vehicle had a dedicated driver that completed all tests on that vehicle. A set of emissions tests for each fuel consisted of:

- Three cold-start WLTC emissions tests with 1Hz Modal Analysis

The laboratory was conditioned to a constant 23°C ± 2°C throughout the test period.

Descriptions of the pre-conditioning cycle and WLTC test cycle can be found in Appendix D.

Fuel consumption was calculated using the Carbon Balance Method detailed in Appendix E.

Instrumentation

Pollutant		Measurement technique	Frequency	Analysis technique
Regulated	Total hydrocarbons (HC)	Bag	Per phase	Flame ionisation
	Carbon monoxide (CO)	Bag	Per phase	Non-dispersive IR
	Nitrogen oxides (NO_x)	Bag	Per phase	Chemiluminescence
Unregulated	Carbon dioxide (CO_2)	Bag	Per phase	Non-dispersive IR
	Total hydrocarbons (HC)	Continuous modal tailpipe and engine	1 Hz	Flame Ionization
	Carbon monoxide (CO)	Continuous modal tailpipe and engine	1 Hz	Non-dispersive IR
	Nitrogen oxides (NO_x)	Continuous modal tailpipe and engine	1 Hz	Chemiluminescence
	Carbon dioxide (CO_2)	Continuous modal tailpipe and engine	1 Hz	Non-dispersive IR

Item	Ser. No.	Calibration due date
Vehicle Weigh scales	4-9820-46	18 Feb 2016

Test Results and Discussion

Test Repeatability

Test result repeatability was very good throughout the test project.

For comparisons to be valid, the driven cycle and force on the dynamometer should be comparable. Figure 1 shows an overlay of dynamometer roller speed from all cold WLTC tests carried out on the Diesel vehicle in the programme. Figure 2 shows the same parameters for the Gasoline vehicle.

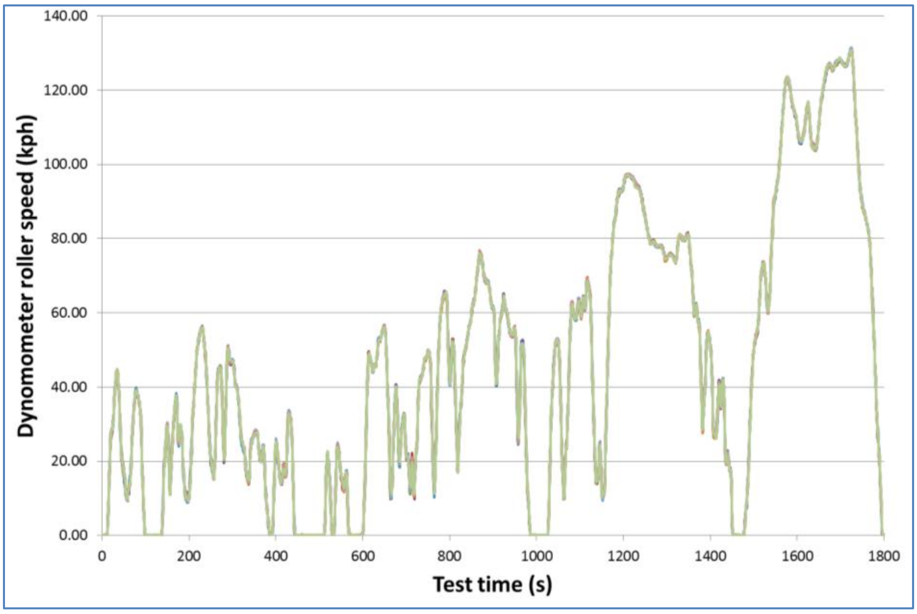

Figure 1. Graph showing Dyno roller speed over all WLTC cycles - Diesel

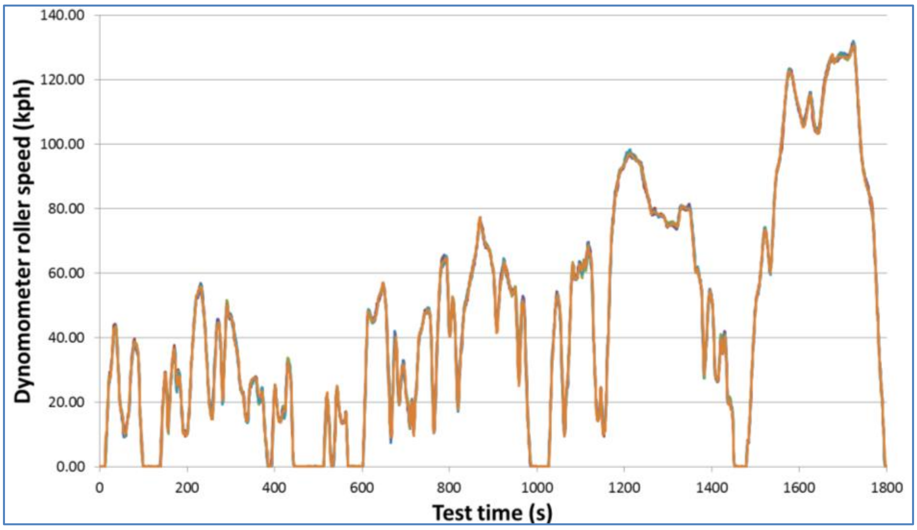

Figure 2. Graph showing Dyno roller speed over all WLTC cycles - Gasoline

All of the tests conducted were driven according to the drive trace in a repeatable manner. The drive trace specifies a tolerance of ±2km/h and ±1 second from the required speed before highlighting a driver violation.

Figure 3 shows an overlay of dynamometer force from all WLTC tests carried out in the programme on the Diesel vehicle. Dynamometer force applied to the vehicle over the WLTC cycles was observed to be very repeatable.

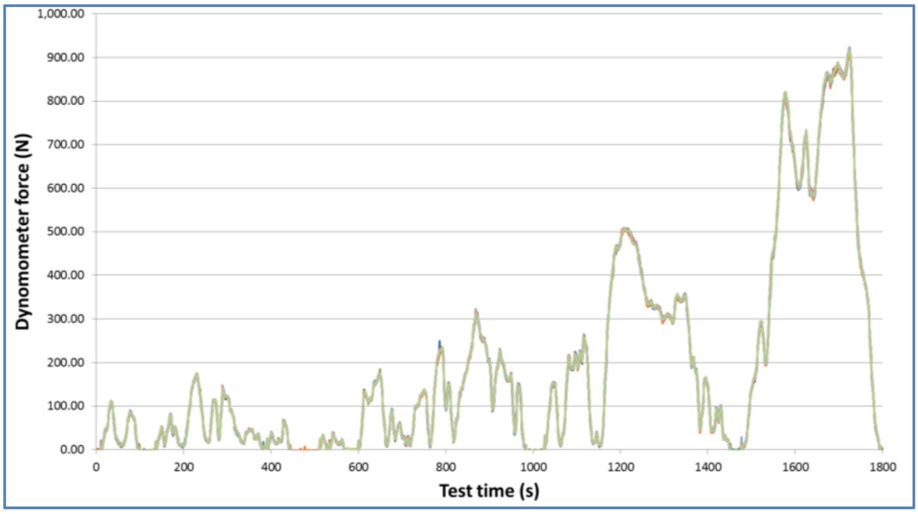

Figure 3. Graph showing Dyno force over all WLTC cycles – Diesel

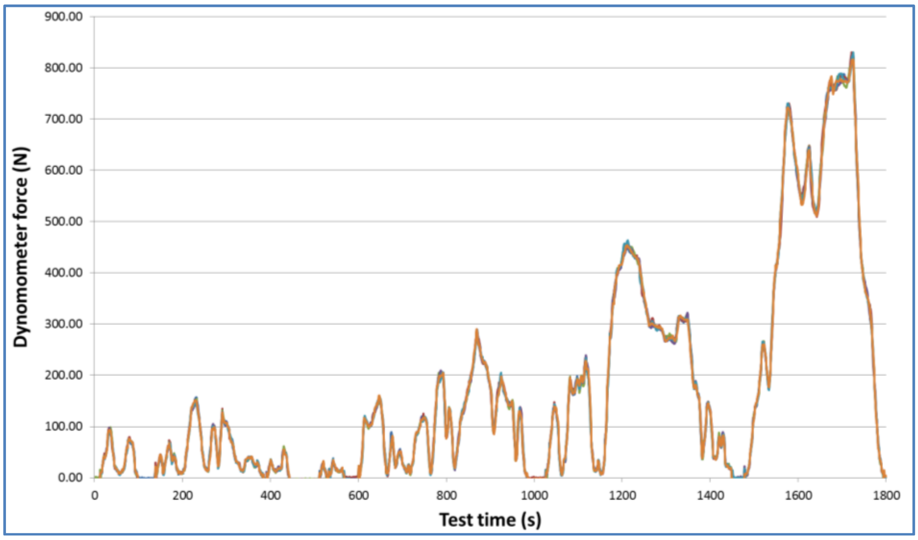

Figure 4. Graph showing Dyno force over all WLTC cycles – Gasoline

Repeatability of emissions results was very good throughout the programme, evidenced by low Coefficients of Variance (CoV) in fuel consumption over the WLTC cycles shown in Table 1.

Test Fuel	Diesel B7	Diesel B10	Diesel B30	Gasoline E10	Gasoline E20
Coefficient of Variance	0.34%	0.14%	0.16%	0.29%	0.33%

Table 1. Coefficient of Variance of fuel consumption over WLTC cycles

Emission results

Tables 2 and 3 show the average recorded figures for each test fuel. Each figure is an average of three test results on that fuel. The full set of emissions test results can be found in Appendix A.

Test Fuel	NO_2 (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)	Fuel Cons (L/100km)
B7	219	6	80	572	152	1	8.60E+09	5.81
B10	217	10	89	557	151	1	2.60E+10	5.72
B30	259	9	89	609	151	1	2.64E+10	5.75

Table 2. Emission summary averages over WLTC cycles – Diesel

Test Fuel	NMHC (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)	Fuel Cons (L/100km)
E10	18	20	287	49	142.4	2	1.33E+12	6.25
E20	17	20	458	32	139.9	1	1.28E+12	6.57

Table 3. Emission summary averages over WLTC cycles – Gasoline

Fuel consumption was calculated using the carbon balance method outlined in Appendix E, the carbon weight fraction and specific gravity of each fuel is given in Table 4.

Test Fuel	Carbon Weight Fraction (CWF)	Specific Gravity
B7	0.860	0.833
B10	0.859	0.841
B30	0.843	0.851
E10	0.833	0.749
E20	0.789	0.741

Table 4. CWF and SG of test fuels

Emission Results Discussion - Gasoline

Whilst the CoV of CO_2 and Fuel Consumption figures of the test conducted on the gasoline vehicle were low, in the region of 0.3% (CO_2 being the main contributor to fuel consumption figures), it was identified that several other gases saw much higher CoV values. Tests on both E10 and E20 fuels returned CoV figures for NO_x of 45.6 and 39.3 respectively. Due to low overall values of NOx produced (averages of 49 and 32 mg/km) a small change in mass greatly affects the CoV values. Checking modal data from each test it can be seen that there was a large amount of NO_x produced during one acceleration on test ML01014616 at 1564 seconds. The trace of tailpipe CO_2 mass shows that the acceleration during test ML01014616 might have been more aggressive, however, no driver violations were recorded with the drive trace being within legislative limits. A similar observation was made for NO_x values when the modal data was checked for the E20 test fuel, although the level of deviation was not to the same extent.

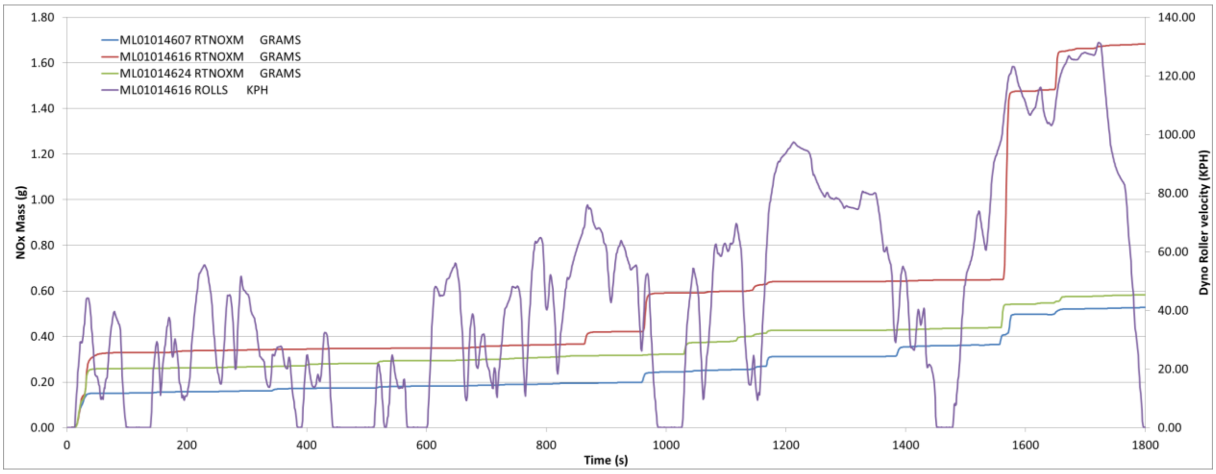

Figure 5. Graph of cumulative NOx mass (g) modal data – E10 Gasoline

In the same set of tests for the E10 fuel a high CoV (24.67) was noted in the CO results. The majority or the discrepancy was observed to be in phase 1; this can be seen in the modal data referenced in Figure 6. Whilst traces diverge slightly over the test period, it is during the acceleration of the first hill where the main deviation occurs. No other significant deviations in vehicle or driver traces were observed during this time period.

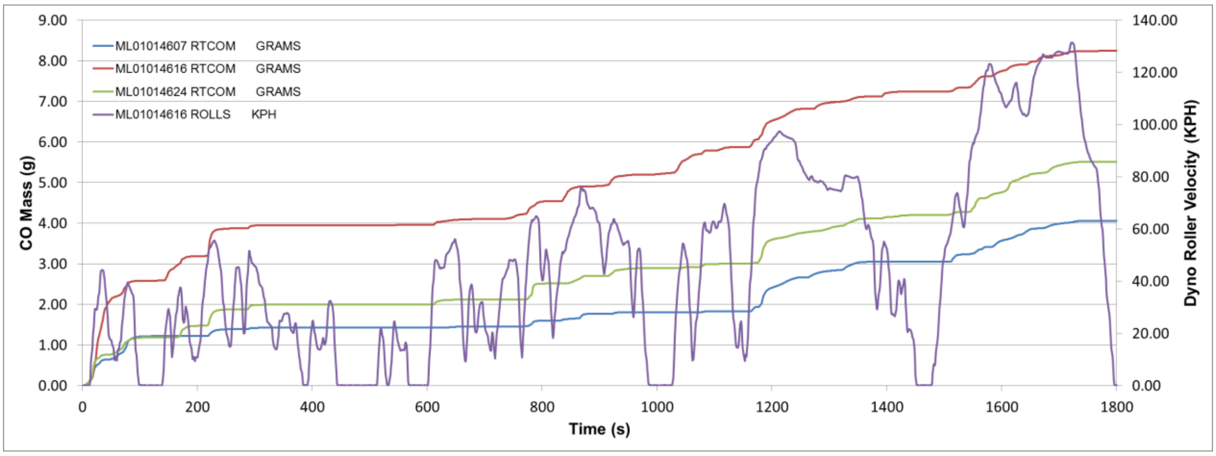

Figure 6. Graph of cumulative CO mass (g) modal data – E10 Gasoline

Emission Results Discussion - Diesel

It is noted that the NO_x results on the diesel vehicles are very high compared to the Euro 6b M_1 limit of 80mg/km. Average NO_x results were seen at 573mg/km for B7, 557mg/km for B10 and 607mg/km for B30, which range from 716% to 759% of the Euro 6b limits. However, the Euro 6b limits refer to a vehicle run over the NEDC cycle, for this project the WLTP cycle was used. The Peugeot 508 2.0L BlueHDI diesel test vehicle achieved a NO_x level of 57mg/km during type approval test work (data obtained from http://carfueldata.direct.gov.uk). Whilst the test vehicle only achieved NO_x levels in magnitudes higher than the type approval limit, it is behaviour attributed to diesel vehicles that is widely recognised in the industry when running cycles other than the NEDC.

As a precaution, the vehicle was checked for any trouble codes (none were present), the Selective Catalytic Reduction (SCR) system was checked for distance remaining until refill of the AdBlue tank was required and found the level to be greater than required for project completion. The vehicle literature was also checked which confirmed that it’s AdBlue system warns when low levels are present and prevents the vehicle engine from starting if the SCR system is deemed not to be working (empty/faulty). No concerns were raised during the checks and the vehicle was considered to be running correctly.

Appendices

Appendix A. Emission Results

DIESEL WLTC

EMISSIONS TEST SUMMARY SHEET

MILLBROOK

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**

Vehicle No:	***LT64OVG***	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	***Peugeot 508***	Deterioration Factors		INERTIA	1700 kg
Engine:	***2.0L Diesel BlueHDI***	CO	N/A	F_0	7.90 N
Transmission:	***6-Spd Manual***	THC+Nox	N/A	F_1	0.0000 N/kmh
Fuel Type:	***Euro 6 B7 Reference Diesel***	NOx	N/A	F_2	0.05360 N/kmh^2
Fuel Batch No:	***CAF-G14/580***	PM / PN	N/A	F_3	0.00000 N/kmh^3
Millbrook Project No:	***PT0270-001-01***				

Test No: ***ML01014594***		***24-Jun-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT:	**10714**	UNITS								
Phase 1	*Low*	mg/km	64.504	32.349	508.133	295.722	182.6	NA	4.91E+10	6.99
Phase 2	*Medium*	mg/km	122.068	4.467	4.620	264.735	141.7	NA	7.71E+09	5.40
Phase 3	*High*	mg/km	47.338	1.515	27.081	105.443	128.8	NA	5.59E+09	4.91
Phase 4	*Extra High*	mg/km	504.495	1.622	8.509	1221.253	169.1		3.41E+09	6.45
Combined result		**mg/km**	**227.769**	**6.288**	**80.258**	**561.308**	**153.0**	**1.06**	**1.11E+10**	litres/100km
										5.84

Test No: ***ML01014600***		***25-Jun-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT:	**10748**	UNITS								
Phase 1	*Low*	mg/km	54.316	29.828	532.428	324.970	170.3	NA	5.75E+10	6.53
Phase 2	*Medium*	mg/km	100.976	3.316	30.548	331.476	137.3	NA	4.04E+09	5.23
Phase 3	*High*	mg/km	34.424	3.100	16.133	111.700	130.6	NA	2.38E+09	4.98
Phase 4	*Extra High*	mg/km	489.070	1.663	10.947	1178.917	171.1		1.28E+09	6.52
Combined result		**mg/km**	**212.688**	**6.207**	**86.218**	**565.813**	**151.8**	**1.15**	**9.67E+09**	litres/100km
										5.79

Test No: ***ML01014610***		***26-Jun-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT:	**10779**	UNITS								
Phase 1	*Low*	mg/km	45.112	29.504	469.216	351.722	169.2	NA	1.31E+10	6.48
Phase 2	*Medium*	mg/km	102.874	5.224	15.338	326.037	137.9	NA	6.23E+09	5.26
Phase 3	*High*	mg/km	40.344	2.481	7.674	136.167	131.5	NA	4.05E+09	5.01
Phase 4	*Extra High*	mg/km	498.343	1.638	10.836	1215.251	171.8		2.22E+09	6.55
Combined result		**mg/km**	**216.959**	**6.357**	**72.052**	**588.685**	**152.3**	**1.05**	**5.06E+09**	litres/100km
										5.81

Average of Combined Tests (mg/km)	219.139	6.284	79.509	571.935	152.4	1.087	8.60E+09	5.81
Standard Deviation/Mean x100	2.90	0.98	7.30	2.10	0.34	4.14	29.83	0.34

Comments:

Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.860 and a Specific Gravity (SG) of 0.833

Phase 3 and 4 Emissions split by mass from single bag using modal analysis.

Compiling Engineer	Date: 29/06/2015	Approving Engineer:	Date: 29/06/2015

Issue No.	Effective Date:	POF003
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Test Report

DIESEL WLTC
EMISSIONS TEST SUMMARY SHEET

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**
Vehicle No:	***LT64OVG***
Vehicle Type:	***Peugeot 508***
Engine:	***2.0L Diesel BlueHDI***
Transmission:	***6-Spd Manual***
Fuel Type:	***B10 Diesel Fuel***
Fuel Batch No:	***CAF G15/313***
Millbrook Project No:	***PT0270-001-01***

Site No.	1	DYNAMOMETER SETTINGS	
Deterioration Factors		INERTIA	1700 kg
CO	N/A	F°	7.90 N
THC+Nox	N/A	F₁	0.0000 N/kmh
NOx	N/A	F₂	0.05360 N/kmh ²
PM / PN	N/A	F₃	0.00000 N/kmh ³

Test No: ***ML01014628***	***01-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **11090**	UNITS								
Phase 1 *Low*	mg/km	12.850	41.239	437.821	228.031	170.8	NA	2.54E+11	6.48
Phase 2 *Medium*	mg/km	4.749	9.124	39.959	82.972	139.3	NA	1.32E+10	5.26
Phase 3 *High*	mg/km	82.679	5.748	23.523	176.127	128.9	NA	8.71E+09	4.87
Phase 4 *Extra High*	mg/km	462.842	2.457	12.463	1095.659	170.7		4.72E+09	6.45
Combined result	**mg/km**	**192.742**	**9.998**	**78.109**	**491.946**	**151.6**	**0.89**	**4.09E+10**	litres/100km
									5.73

Test No: ***ML01014636***	***02-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **11121**	UNITS								
Phase 1 *Low*	mg/km	62.379	50.177	515.692	368.278	173.0	NA	1.62E+11	6.57
Phase 2 *Medium*	mg/km	114.127	9.766	48.578	300.785	139.6	NA	6.11E+09	5.28
Phase 3 *High*	mg/km	103.765	5.583	17.537	242.358	128.2	NA	4.17E+09	4.84
Phase 4 *Extra High*	mg/km	507.477	4.809	6.877	1241.587	169.8		2.21E+09	6.41
Combined result	**mg/km**	**244.189**	**12.125**	**86.636**	**627.659**	**151.4**	**1.19**	**2.49E+10**	litres/100km
									5.72

Test No: ***ML01014645***	***03-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **11153**	UNITS								
Phase 1 *Low*	mg/km	48.032	28.687	539.853	302.047	171.0	NA	7.06E+10	6.49
Phase 2 *Medium*	mg/km	99.283	3.867	68.934	288.341	137.7	NA	5.00E+09	5.20
Phase 3 *High*	mg/km	57.827	2.894	28.265	124.482	128.8	NA	3.42E+09	4.87
Phase 4 *Extra High*	mg/km	478.051	2.660	16.435	1157.981	170.0		1.93E+09	6.42
Combined result	**mg/km**	**214.645**	**6.469**	**100.903**	**550.523**	**151.1**	**1.42**	**1.22E+10**	litres/100km
									5.71

Average of Combined Tests (mg/km)	217.192	9.531	88.549	556.709	151.4	1.167	2.60E+10	5.72
Standard Deviation/Mean x100	9.71	24.48	10.62	9.98	0.15	18.60	45.11	0.14

Comments:
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.859 and a Specific Gravity (SG) of 0.841
Phase 3 and 4 Emissions split by mass from single bag using modal analysis.

Compiling Enginee	Date: 03/07/2015	Approving Engineer:	Date: 10/07/2015

Issue No. 4 | Effective Date: 07-Jan-13 | POF003 Page 1 of 1

Test Report

MILLBROOK

DIESEL WLTC
EMISSIONS TEST SUMMARY SHEET

MILLBROOK

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**

		Site No.	1	DYNAMOMETER SETTINGS	
Vehicle No:	***LT64OVG***	Deterioration Factors		INERTIA	1700 kg
Vehicle Type:	***Peugeot 508***	CO	N/A	F°	7.90 N
Engine:	***2.0L Diesel BlueHDI***	THC+Nox	N/A	F_1	0.0000 N/kmh
Transmission:	***6-Spd Manual***	NOx	N/A	F_2	0.05360 N/kmh ²
Fuel Type:	***B30 Diesel Fuel***	PM / PN	N/A	F_3	0.00000 N/kmh ³
Fuel Batch No:	***CAF G15/314***				
Millbrook Project No:	***PT0270-001-01***				

Test No: ***ML01014659***	***08-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN Nb / km	Fuel Cons (Carb Bal)
Odo at SOT: **11453**	UNITS								
Phase 1 *Low*	mg/km	63.268	44.274	553.775	322.475	170.5	NA	2.89E+11	6.53
Phase 2 *Medium*	mg/km	121.746	5.955	18.463	314.013	138.3	NA	1.08E+10	5.27
Phase 3 *High*	mg/km	125.142	4.539	4.988	284.631	127.4	NA	2.99E+09	4.85
Phase 4 *Extra High*	mg/km	548.837	3.753	6.102	1245.497	170.9		1.63E+09	6.51
Combined result	**mg/km**	**267.032**	**9.882**	**81.713**	**638.931**	**151.1**	**1.29**	**4.24E+10**	litres/100km
									5.76

Test No: ***ML01014666***	***09-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN Nb / km	Fuel Cons (Carb Bal)
Odo at SOT: **11484**	UNITS								
Phase 1 *Low*	mg/km	75.315	29.601	526.790	362.720	171.3	NA	1.44E+11	6.55
Phase 2 *Medium*	mg/km	126.193	4.910	39.352	323.606	136.7	NA	6.85E+09	5.21
Phase 3 *High*	mg/km	130.152	2.396	16.162	253.287	128.4	NA	4.34E+09	4.89
Phase 4 *Extra High*	mg/km	521.035	1.413	7.243	1166.809	169.0		2.46E+09	6.43
Combined result	**mg/km**	**261.359**	**6.199**	**85.962**	**608.921**	**150.5**	**1.77**	**2.29E+10**	litres/100km
									5.73

Test No: ***ML01014676***	***12-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN Nb / km	Fuel Cons (Carb Bal)
Odo at SOT: **11545**	UNITS								
Phase 1 *Low*	mg/km	45.521	43.391	599.972	282.825	169.7	NA	9.33E+10	6.50
Phase 2 *Medium*	mg/km	113.226	7.333	78.504	313.847	137.9	NA	3.30E+09	5.25
Phase 3 *High*	mg/km	102.578	4.223	5.191	222.787	127.5	NA	1.53E+09	4.85
Phase 4 *Extra High*	mg/km	525.951	2.735	7.748	1148.842	170.7		9.44E+08	6.50
Combined result	**mg/km**	**248.035**	**9.564**	**100.528**	**580.422**	**150.8**	**0.70**	**1.39E+10**	litres/100km
									5.75

Average of Combined Tests (mg/km)	258.809	8.549	89.401	609.425	150.8	1.253	2.64E+10	5.75
Standard Deviation/Mean x100	3.08	19.49	9.01	3.92	0.15	34.91	45.04	0.16

Comments:
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.843 and a Specific Gravity (SG) of 0.851
Phase 3 and 4 Emissions split by mass from single bag using modal analysis.

Compiling Enginee	Date: 13/07/2015	Approving Engineer:	Date: 13/07/2015

The data on this summary sheet shall not be reproduced without the written approval of Millbrook Proving Ground Ltd.

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PETROL WLTC
EMISSIONS TEST SUMMARY SHEET

Customer:	ICF Consulting Services				
Customer Address:	Watling House, 33 Cannon Street, London, EC4M 5SB				
Test Purpose:	Bio components level study for transport fuels				
Vehicle No:	*LP64AEW*	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	*Peugeot 308sw*	Deterioration Factors		INERTIA	1360 kg
Engine:	*1.2L Petrol PureTECH*	CO	N/A	F_0	7.10 N
Transmission:	*6-Spd Manual*	THC / NMHC	N/A	F_1	0.0000 N/kmh
Fuel Type:	*Euro 6 E10 Reference Fuel*	NOx	N/A	F_2	0.04810 N/kmh ²
Fuel Batch No:	*CAF W14/395*	PM / PN	N/A	F_3	0.00000 N/kmh ³
Millbrook Project No:	*PT0241-002-01*				

Test No: *ML01014607*	*26-Jun-15*	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons
Odo at SOT: 2533	UNITS								(Carb Bal)
Phase 1 *Low*	mg/km	110.010	122.519	712.986	85.854	172.033	N/A	5.64E+12	7.59
Phase 2 *Medium*	mg/km	1.685	2.408	73.958	30.075	124.372	N/A	8.28E+11	5.45
Phase 3 *High*	mg/km	0.559	1.074	180.780	20.430	118.816	N/A	6.14E+11	5.21
Phase 4 *Extra High*	mg/km	1.048	2.014	125.807	25.294	163.570	N/A	9.30E+11	7.17
Combined result	**mg/km**	**15.743**	**17.792**	**209.886**	**32.831**	**143.061**	**2.51**	**1.44E+12**	litres/100km
									6.28

Test No: *ML01014616*	*27-Jun-15*	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons
Odo at SOT: 2550	UNITS								(Carb Bal)
Phase 1 *Low*	mg/km	135.649	156.310	1489.371	131.710	168.081	N/A	5.05E+12	7.48
Phase 2 *Medium*	mg/km	2.996	4.158	268.555	52.494	126.728	N/A	7.05E+11	5.57
Phase 3 *High*	mg/km	0.968	1.379	281.502	8.669	119.355	N/A	5.08E+11	5.24
Phase 4 *Extra High*	mg/km	2.183	3.111	120.655	137.256	160.564	N/A	7.50E+11	7.04
Combined result	**mg/km**	**20.005**	**23.043**	**381.111**	**79.860**	**142.072**	**2.25**	**1.23E+12**	litres/100km
									6.25

Test No: *ML01014624*	*30-Jun-15*	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons
Odo at SOT: 2772	UNITS								(Carb Bal)
Phase 1 *Low*	mg/km	122.5934	138.746	921.233	136.946	174.864	N/A	5.63E+12	7.74
Phase 2 *Medium*	mg/km	0.4681	1.172	162.666	7.427	125.117	N/A	6.77E+11	5.49
Phase 3 *High*	mg/km	0.4277	1.093	189.027	18.875	117.141	N/A	5.28E+11	5.14
Phase 4 *Extra High*	mg/km	1.3663	3.493	162.401	21.189	160.466	N/A	7.86E+11	7.03
Combined result	**mg/km**	**17.255**	**20.129**	**270.797**	**32.942**	**141.960**	**2.10**	**1.33E+12**	litres/100km
									6.23

Average of Combined Tests (mg/km)	17.668	20.321	287.265	48.545	142.4	2.29	1.33E+12	6.25
Standard Deviation/Mean x100	9.98	10.57	24.67	45.62	0.35	7.41	6.21	0.29

Comments:

* NO_2 values below measurable range.

Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.833 and a Specific Gravity (SG) of 0.749

Phase 3 and 4 emissions split by mass from single bag using modal analysis. CH4 split using phase 3 to 4 THC mass ratio.

Compiling Engineer	Date: 01/07/2015	Approving Engineer:	Date: 01/07/2015

Issue No. 4 | Effective Date: 07-Jan-13 | POF003 Page 1 of 1

PETROL WLTC

EMISSIONS TEST SUMMARY SHEET

MILLBROOK

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**

Vehicle No:	***LP64AEW***	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	***Peugeot 308sw***	Deterioration Factors		INERTIA	1360 kg
Engine:	***1.2L Petrol PureTECH***	CO	N/A	F_0	7.10 N
Transmission:	***6-Spd Manual***	THC / NMHC	N/A	F_1	0.0000 N/kmh
Fuel Type:	***E20 Gasoline***	NOx	N/A	F_2	0.04810 N/kmh^2
Fuel Batch No:	***CAF W15/438***	PM / PN	N/A	F_3	0.00000 N/kmh^3
Millbrook Project No:	***PT0270-001-01***				

Test No: ***ML01014655***	***07-Jul-15***	NMHC	THC	CO	NO_x	CO_2	PM	PN	Fuel Cons
Odo at SOT: **2769**	UNITS					(g/km)		(Nb/km)	(Carb Bal)
Phase 1 *Low*	mg/km	113.156	134.069	2111.38	98.504	170.049	N/A	4.37E+12	8.12
Phase 2 *Medium*	mg/km	3.452	4.602	432.235	7.947	124.166	N/A	7.00E+11	5.83
Phase 3 *High*	mg/km	0.966	1.798	244.664	7.416	117.118	N/A	4.25E+11	5.49
Phase 4 *Extra High*	mg/km	3.910	7.276	166.429	42.481	157.073	N/A	8.36E+11	7.35
Combined result	**mg/km**	**17.976**	**21.802**	**501.809**	**32.125**	**140.014**	**1.270**	**1.15E+12**	litres/100km
									6.58

Test No: ***ML01014658***	***08-Jul-15***	NMHC	THC	CO	NO_x	CO_2	PM	PN	Fuel Cons
Odo at SOT: **2788**	UNITS					(g/km)		(Nb/km)	(Carb Bal)
Phase 1 *Low*	mg/km	100.127	117.827	1513.55	83.669	169.909	N/A	4.29E+12	8.06
Phase 2 *Medium*	mg/km	3.320	4.495	429.476	8.252	124.328	N/A	7.01E+11	5.84
Phase 3 *High*	mg/km	0.713	1.291	323.682	2.923	116.463	N/A	5.18E+11	5.46
Phase 4 *Extra High*	mg/km	2.629	4.759	160.276	9.089	158.639	N/A	1.00E+12	7.42
Combined result	**mg/km**	**15.508**	**18.520**	**443.524**	**16.850**	**140.365**	**1.030**	**1.23E+12**	litres/100km
									6.59

Test No: ***ML01014663***	***09-Jul-15***	NMHC	THC	CO	NO_x	CO_2	PM	PN	Fuel Cons
Odo at SOT: **2807**	UNITS					(g/km)		(Nb/km)	(Carb Bal)
Phase 1 *Low*	mg/km	116.299	135.980	1847.88	91.210	167.576	N/A	4.43E+12	7.98
Phase 2 *Medium*	mg/km	3.1704	4.454	242.460	21.479	125.771	N/A	1.18E+12	5.89
Phase 3 *High*	mg/km	0.6055	1.138	309.691	4.299	114.000	N/A	6.40E+11	5.35
Phase 4 *Extra High*	mg/km	1.9550	3.675	108.954	84.194	157.803	N/A	1.25E+12	7.38
Combined result	**mg/km**	**17.404**	**20.528**	**427.392**	**47.908**	**139.287**	**1.520**	**1.47E+12**	litres/100km
									6.54

Average of Combined Tests (mg/km)	16.963	20.284	457.575	32.294	139.9	1.273	1.28E+12	6.57
Standard Deviation/Mean x100	6.22	6.66	6.99	39.26	0.32	15.71	10.67	0.33

Comments:
* NO_2 values below measurable range.
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.789 and a Specific Gravity (SG) of 0.741
Phase 3 and 4 emissions split by mass from single bag using modal analysis. CH4 split using phase 3 to 4 THC mass ratio.

Compiling Engineer	Date: 13/07/2015	Approving Engineer:	Date: 13/07/2015

Issue No. 4 | Effective Date: 07-Jan-13 | POF003 Page 1 of 1

Appendix B. Vehicle details

MILLBROOK VEHICLE EMISSIONS LABORATORY

Vehicle Details Sheet

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**
Test Vehicle	**Passanger Car Emissions - Euro 6**

Vehicle Information	Vehicle Registration No.	LT64OVG
	VIN	VF38DAHXMEL030599
	Year of Registration	2014
	Make & Model	Peugeot 508
	Model Varient	2.0 BlueHDi 150
	Body Type	Saloon
	Tyre Make/Size	Michelin Primacy HP - 235/45 R18
	Mileage	10212
Technical Specification	Fuel	Diesel
	Transmission	6-Spd Manual
	Engine Type/Code	2.0 BlueHDi 150
	Engine Size	1997 cc
	Number of Cylinders	4
	Fuel System Type	2.0L Diesel with CAT, SCR and DPF
	Aspiration	Turbocharged
	Euro Level	6
	Maximum Power@rpm	110 Kw @ 4000 rpm
	Maximum Torque@rpm	370 Nm @ 2000 rpm

Type Approval Information	Euro Level	HC+Nox mg/km	CO mg/km	NOx mg/km	CO2 g/km	PM mg/km	Fuel Cons l/100km
	EC Stage VI	67	157	57	109	0.1	4.20

Photographic

Comments: Emissions and Fuel Consumption data taken from www.carfueldata.direct.gov.uk/

Compiling Engineer:	DATE:	Approving Engineer:	DATE:

Test Report

MILLBROOK VEHICLE EMISSIONS LABORATORY

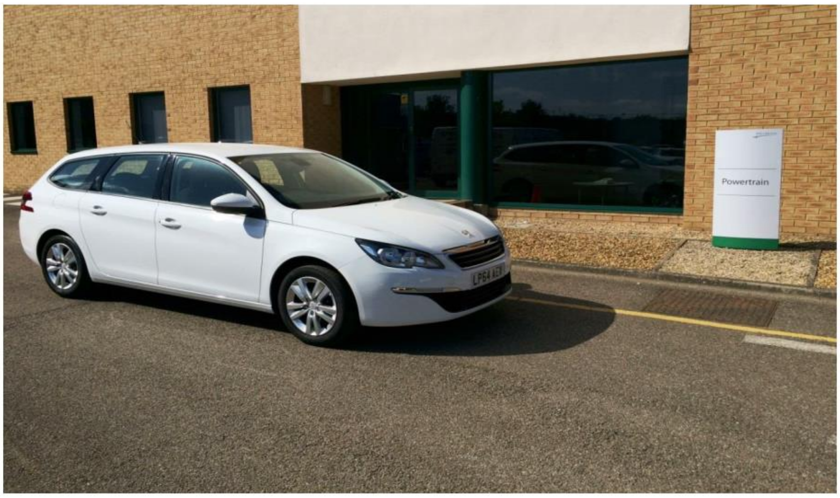
Vehicle Details Sheet

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**
Test Vehicle	**Passanger Car Emissions - Euro 6**

Vehicle Information	**Vehicle Registration No.**	**LP64AEW**
	VIN	**VF3LRHNYHES182421**
	Year of Registration	**2014**
	Make & Model	**Peugeot 308sw**
	Model Varient	**PureTech 1.2 130 S&S**
	Body Type	**Estate**
	Tyre Make/Size	**Michelin Energy Saver - 205/55 R16**
	Mileage	**3603**
Technical Specification	**Fuel**	**Gasoline**
	Transmission	**6-Spd Manual**
	Engine Type/Code	**PureTech 1.2 130 S&S**
	Engine Size	**1199 cc**
	Number of Cylinders	
	Fuel System Type	
	Aspiration	**Turbocharged**
	Euro Level	**6**
	Maximum Power@rpm	**96 Kw @ 5500 rpm**
	Maximum Torque@rpm	**230 Nm @ 1750 rpm**

Type Approval Information	**Euro Level**	**HC+Nox mg/km**	**CO mg/km**	**NOx mg/km**	**CO2 g/km**	**PM mg/km**	**Fuel Cons l/100km**
	EC Stage VI	N/A	196	23	109	N/A	4.70

Photographic



Comments: Emissions and Fuel Consumption data taken from www.carfueldata.direct.gov.uk/

Compiling Engineer:	DATE:	Approving Engineer:	DATE:

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Test Report

Appendix C. Fuel Certificate of Analysis

Euro 6 Gasoline – E10

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-W14/395	**Contact:**	Andy Inskip
Fuel Type:	Euro 6 Gasoline	**Order No:**	PO3054146
Customer:	Millbrook	**Date:**	05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
Appearance @ -7°C	Visual		Report		C&B
RON	EN ISO 5164		95.0	98.0	96.6
MON	EN ISO 5163		85.0	89.0	86.2
Density @ 15°C	EN ISO 12185	kg/L	0.7430	0.7560	0.7488
DVPE @ 37.8°C	EN 13016-1	kPa	56.0	60.0	58.2
Sulfur	EN ISO 20846	mg/kg	-	10.0	1.0
Water Content	EN ISO 12937	% v/v	-	0.050	0.029
Aromatics	ASTM D1319	% v/v	Report		28.8
Olefins	ASTM D1319	% v/v	Report		10.2
Saturates	ASTM D1319	% v/v	Report		51.8
PIONA			Report		
Paraffins	ASTM D6730 mod	% v/v	Report		10.0
Isoparaffins	ASTM D6730 mod	% v/v	Report		33.1
Olefins	ASTM D6730 mod	% v/v	6.0	13.0	9.8
Naphthenes	ASTM D6730 mod	% v/v	Report		6.8
Aromatics	ASTM D6730 mod	% v/v	25.0	32.0	29.8
Benzene	ASTM D6730 mod	% v/v	-	1.0	<0.1
Oxygenates			Report		
Methanol	ASTM D6730 mod	% v/v	Report		<0.1
Ethanol	ASTM D6730 mod	% v/v	9.0	10.0	9.3
MTBE	ASTM D6730 mod	% v/v	Report		<0.1
ETBE	ASTM D6730 mod	% v/v	Report		<0.1
Oxidation Stability	EN ISO 7536	min	480	-	>480
Copper Corrosion (3h at 50°C)	EN ISO 2160	Rating	Class 1	-	1A
Existent Gum - Washed	EN ISO 6246	mg/100mL	-	4	<1
Lead	EN 237	mg/L	-	5.0	<2.5
Phosphorus	ASTM D3231	mg/L	-	1.30	<0.20
Carbon	ASTM D6370 mod	% m/m	Report		83.30
Hydrogen	ASTM D6370 mod	% m/m	Report		13.30
Oxygen	ASTM D6730 mod	% m/m	3.30	3.70	3.40
C/H Ratio	Calculation		Report		0.526
C/O Ratio	Calculation		Report		32.635

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MILLBROOK

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-W14/395	**Contact:**	Andy Inskip
Fuel Type:	Euro 6 Gasoline	**Order No:**	PO3054146
Customer:	Millbrook	**Date:**	05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Distillation (Evaporated)			Report		
E70	EN ISO 3405	% v/v	34.0	46.0	42.6
E100	EN ISO 3405	% v/v	54.0	62.0	59.9
E150	EN ISO 3405	% v/v	86.0	94.0	90.4
IBP	EN ISO 3405	°C	Report		35.1
10% Volume Evaporated	EN ISO 3405	°C	Report		56.9
20% Volume Evaporated	EN ISO 3405	°C	Report		61.0
30% Volume Evaporated	EN ISO 3405	°C	Report		63.4
40% Volume Evaporated	EN ISO 3405	°C	Report		66.3
50% Volume Evaporated	EN ISO 3405	°C	Report		86.0
60% Volume Evaporated	EN ISO 3405	°C	Report		100.1
70% Volume Evaporated	EN ISO 3405	°C	Report		114.6
80% Volume Evaporated	EN ISO 3405	°C	Report		130.2
90% Volume Evaporated	EN ISO 3405	°C	Report		149.0
95% Volume Evaporated	EN ISO 3405	°C	Report		164.9
FBP	EN ISO 3405	°C	170.0	195.0	189.4
Residue	EN ISO 3405	% v/v	-	2.0	1.0
Recovery	EN ISO 3405	% v/v	Report		99.0

Notes:

Date:	05/03/2015
Authorised by: C L Goodfellow *Operations Director*	

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Registered in England & Wales
Registered Company No. 7232065
Registered Office Address: The Manorway, Stanford-le-Hope, Essex. SS17 9LN

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Test Report

MILLBROOK

Gasoline – E20

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-W15/438	**Contact:**	Andy Shepherd
Fuel Type:	E20 Gasoline	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	10/06/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
RON	EN ISO 5164		Report		101.8
MON	EN ISO 5163		Report		87.6
Density @ 15°C	EN ISO 12185	kg/L	Report		0.7411
DVPE @ 37.8°C	EN 13016-1	kPa	Report		86.8
Sulfur	EN ISO 20846	mg/kg	Report		4.2
VLI	Calculation		Report		1199
Aromatics	ASTM D1319	% v/v	Report		21.4
Olefins	ASTM D1319	% v/v	Report		12.8
Saturates	ASTM D1319	% v/v	Report		45.1
Benzene	ASTM D6730 mod	% v/v	Report		0.77
Oxygenates					
Methanol	ASTM D6730 mod	% v/v	Report		<0.1
Ethanol	ASTM D6730 mod	% v/v	Report		20.7
i-Propanol	ASTM D6730 mod	% v/v	Report		<0.1
i-Butanol	ASTM D6730 mod	% v/v	Report		<0.1
t-Butanol	ASTM D6730 mod	% v/v	Report		<0.1
MTBE	ASTM D6730 mod	% v/v	Report		<0.1
ETBE	ASTM D6730 mod	% v/v	Report		<0.1
Ethers (5 or more C atoms)	ASTM D6730 mod	% v/v	Report		<0.1
Oxygenates - Total	ASTM D6730 mod	% v/v	Report		20.7
Oxidation Stability	EN ISO 7536	min	Report		>360
Copper Corrosion (3h at 50°C)	EN ISO 2160	Rating	Report		1A
Existent Gum - Washed	EN ISO 6246	mg/100mL	Report		<1
Lead	EN 237	g/L	Report		<0.0025
Carbon	ASTM D6730 mod	% m/m	Report		78.87
Hydrogen	ASTM D6730 mod	% m/m	Report		13.42
Oxygen	ASTM D6730 mod	% m/m	Report		7.70
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		45.99
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		43.08

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Test Report

MILLBROOK

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No: CAF-W15/438
Fuel Type: E20 Gasoline
Customer: Millbrook
Contact: Andy Shepherd
Order No: PO3056199-1
Date: 10/06/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Distillation (Evaporated)			Report		
E70	EN ISO 3405	% v/v	Report		47.3
E100	EN ISO 3405	% v/v	Report		71.9
E150	EN ISO 3405	% v/v	Report		93.8
E180	EN ISO 3405	% v/v	Report		99.9
IBP	EN ISO 3405	°C	Report		27.3
10% Volume Evaporated	EN ISO 3405	°C	Report		46.3
20% Volume Evaporated	EN ISO 3405	°C	Report		54.4
30% Volume Evaporated	EN ISO 3405	°C	Report		61.5
40% Volume Evaporated	EN ISO 3405	°C	Report		67.1
50% Volume Evaporated	EN ISO 3405	°C	Report		71.1
60% Volume Evaporated	EN ISO 3405	°C	Report		74.2
70% Volume Evaporated	EN ISO 3405	°C	Report		78.2
80% Volume Evaporated	EN ISO 3405	°C	Report		121.4
90% Volume Evaporated	EN ISO 3405	°C	Report		140.2
95% Volume Evaporated	EN ISO 3405	°C	Report		156.1
FBP	EN ISO 3405	°C	Report		172.8
Residue	EN ISO 3405	% v/v	Report		1.0

Sample Received Condition: Good (No Seal)
Date Sample Received: 03/06/2015

Notes:

Date:	10/06/2015
Authorised by: M Rodriguez *Blend Formulator*	

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Euro 6 Diesel – B7

Certificate of Analysis

Fuel Blend No: CAF-G14/580 **Contact:** Andy Inskip
Fuel Type: Euro 6 Diesel **Order No:** PO3054146
Customer: Millbrook **Date:** 05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
Cetane Number	EN ISO 5165		52.0	56.0	53.4
Cetane Index	EN ISO 4264		46.0	-	54.5
Density @ 15°C	EN ISO 12185	kg/L	0.8330	0.8370	0.8332
Cloud Point	EN ISO 23015	°C	-	-10	-13
Carbon Residue (10% Dis. Res)	EN ISO 10370	% m/m	-	0.20	0.01
Flash Point	EN ISO 2719	°C	55.0	-	64.0
Lubricity, corrected wear scar diameter (wsd 1.4) @ 60°C	EN ISO 12156-1	µm	-	400	165
Sulfur	EN ISO 20846	mg/kg	-	10.0	5.0
Strong Acid Number	ISO 6618	mgKOH/g	-	0.10	0
Viscosity at 40°C	EN ISO 3104	mm²/s	2.300	3.300	2.711
Water Content	EN ISO 12937	mg/kg	-	200	170
FAME Content	EN 14078	% v/v	6.0	7.0	6.5
Mono Aromatics Content	EN 12916 mod	% m/m	Report		21.5
Di Aromatics Content	EN 12916 mod	% m/m	Report		3.3
Tri+ Aromatics Content	EN 12916 mod	% m/m	Report		0.2
Polycyclic Aromatics Content	EN 12916 mod	% m/m	2.0	4.0	3.5
Total Aromatics	EN 12916 mod	% m/m	Report		25.0
Oxidation Stability	EN 15751	h	20.0	-	>20.0
Ash Content	EN ISO 6245	% m/m	-	0.010	<0.010
Copper Corrosion (3h at 50°C)	EN ISO 2160	Rating	1	-	1A
Total Contamination	EN 12662	mg/kg	-	24	15
Carbon	ASTM D3343 mod	% m/m	Report		85.96
Hydrogen	ASTM D3343 mod	% m/m	Report		13.33
Oxygen	EN 14078	% m/m	Report		0.70
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		45.62
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		42.79

Test Report

Certificate of Analysis

Fuel Blend No: CAF-G14/580
Fuel Type: Euro 6 Diesel
Customer: Millbrook
Contact: Andy Inskip
Order No: PO3054146
Date: 05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Distillation (Evaporated)					
E250	EN ISO 3405	% v/v	Report		33.4
E350	EN ISO 3405	% v/v	Report		96.0
IBP	EN ISO 3405	ºC	Report		171.9
10% Volume Evaporated	EN ISO 3405	ºC	Report		209.6
20% Volume Evaporated	EN ISO 3405	ºC	Report		227.8
30% Volume Evaporated	EN ISO 3405	ºC	Report		244.5
40% Volume Evaporated	EN ISO 3405	ºC	Report		260.0
50% Volume Evaporated	EN ISO 3405	ºC	245.0	-	274.7
60% Volume Evaporated	EN ISO 3405	ºC	Report		289.4
70% Volume Evaporated	EN ISO 3405	ºC	Report		303.7
80% Volume Evaporated	EN ISO 3405	ºC	Report		318.5
90% Volume Evaporated	EN ISO 3405	ºC	Report		334.6
95% Volume Evaporated	EN ISO 3405	ºC	345.0	360.0	346.5
FBP	EN ISO 3405	ºC	-	370.0	355.9
Loss	EN ISO 3405	% v/v	Report		0.0
Residue	EN ISO 3405	% v/v	Report		1.4

Sample Received Condition: Good (No Seal)
Date Sample Received: 22/10/2014

Notes:

Date:	05/03/2015
Authorised by: C L Goodfellow *Operations Director*	[signature]

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Website: www.corytonfuels.co.uk

Test Report

Diesel – B10

Certificate of Analysis

Fuel Blend No:	CAF-G15/313	**Contact:**	Andy Shepherd
Fuel Type:	B10 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Appearance	Visual		Report		C&B
Cetane Number	EN ISO 5165		Report		52.3
Cetane Index	EN ISO 4264		Report		50.7
Density @ 15°C	EN ISO 12185	kg/L	Report		0.8414
CFPP	EN 116	ºC	Report		-22
Flash Point	EN ISO 2719	ºC	Report		62.0
Lubricity, corrected wear scar diameter (wsd 1.4) @ 60ºC	EN ISO 12156-1	µm	Report		163
Sulfur	EN ISO 20846	mg/kg	Report		9.2
Viscosity at 40ºC	EN ISO 3104	mm^2/s	Report		2.667
Water Content	EN ISO 12937	mg/kg	Report		140
FAME Content	EN 14078	% m/m	Report		9.7
Mono Aromatics Content	IP 391 mod	% m/m	Report		24.9
Di Aromatics Content	IP 391 mod	% m/m	Report		4.0
Tri+ Aromatics Content	IP 391 mod	% m/m	Report		0.4
Polycyclic Aromatics Content	IP 391 mod	% m/m	Report		4.4
Total Aromatics	IP 391 mod	% m/m	Report		29.3
Oxidation Stability (16h)	EN ISO 12205	g/m^3	Report		<1
Ash Content	EN ISO 6245	% m/m	Report		<0.001
Carbon Residue (10% Dis. Res)	EN ISO 10370	% m/m	Report		0.06
Copper Corrosion (3h at 50ºC)	EN ISO 2160	Rating	Report		1A
Total Contamination	EN 12662	mg/kg	Report		7
Carbon	ASTM D3343 mod	% m/m	Report		85.92
Hydrogen	ASTM D3343	% m/m	Report		13.03
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		45.24
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		42.48

Test Report

MILLBROOK

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-G15/313	**Contact:**	Andy Shepherd
Fuel Type:	B10 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Distillation (Evaporated)					
E250	EN ISO 3405	% v/v	Report		36.6
E350	EN ISO 3405	% v/v	Report		95.4
IBP	EN ISO 3405	°C	Report		166.0
10% Volume Evaporated	EN ISO 3405	°C	Report		196.1
20% Volume Evaporated	EN ISO 3405	°C	Report		215.2
30% Volume Evaporated	EN ISO 3405	°C	Report		235.0
40% Volume Evaporated	EN ISO 3405	°C	Report		257.5
50% Volume Evaporated	EN ISO 3405	°C	Report		278.8
60% Volume Evaporated	EN ISO 3405	°C	Report		297.8
70% Volume Evaporated	EN ISO 3405	°C	Report		313.5
80% Volume Evaporated	EN ISO 3405	°C	Report		326.4
90% Volume Evaporated	EN ISO 3405	°C	Report		338.6
95% Volume Evaporated	EN ISO 3405	°C	Report		349.0
FBP	EN ISO 3405	°C	Report		357.6
Residue	EN ISO 3405	% v/v	Report		1.2

Sample Received Condition: Good (No Seal)
Date Sample Received: 26/05/2015

Notes:

Date:	08/06/2015
Authorised by: M Rodriguez *Blend Formulator*	

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Diesel – B30

Certificate of Analysis

Fuel Blend No:	CAF-G15/314	**Contact:**	Andy Shepherd
Fuel Type:	B30 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
Cetane Number	EN ISO 5165		Report		51.7
Cetane Index	EN ISO 4264		Report		51.2
Density @ 15°C	EN ISO 12185	kg/L	Report		0.8505
CFPP	EN 116	ºC	Report		-23
Flash Point	EN ISO 2719	ºC	Report		66.0
Lubricity, corrected wear scar diameter (wsd 1.4) @ 60ºC	EN ISO 12156-1	µm	Report		314
Sulfur	EN ISO 20846	mg/kg	Report		8.0
Viscosity at 40ºC	EN ISO 3104	mm^2/s	Report		2.986
Water Content	EN ISO 12937	mg/kg	Report		190
FAME Content	EN 14078	% m/m	Report		29.5
Mono Aromatics Content	IP 391 mod	% m/m	Report		19.3
Di Aromatics Content	IP 391 mod	% m/m	Report		3.0
Tri+ Aromatics Content	IP 391 mod	% m/m	Report		0.3
Polycyclic Aromatics Content	IP 391 mod	% m/m	Report		3.3
Total Aromatics	IP 391 mod	% m/m	Report		22.6
Oxidation Stability (16h)	EN ISO 12205	g/m^3	Report		5
Ash Content	EN ISO 6245	% m/m	Report		0.002
Carbon Residue (10% Dis. Res)	EN ISO 10370	% m/m	Report		0.11
Copper Corrosion (3h at 50ºC)	EN ISO 2160	Rating	Report		1A
Total Contamination	EN 12662	mg/kg	Report		12
Carbon	ASTM D3343 mod	% m/m	Report		84.34
Hydrogen	ASTM D3343	% m/m	Report		12.48
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		44.02
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		41.38

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Test Report

MILLBROOK

CORYTON
advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-G15/314	**Contact:**	Andy Shepherd
Fuel Type:	B30 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Distillation (Evaporated)					
E250	EN ISO 3405	% v/v	Report		26.7
E350	EN ISO 3405	% v/v	Report		95.2
IBP	EN ISO 3405	°C	Report		171.2
10% Volume Evaporated	EN ISO 3405	°C	Report		202.7
20% Volume Evaporated	EN ISO 3405	°C	Report		229.6
30% Volume Evaporated	EN ISO 3405	°C	Report		259.3
40% Volume Evaporated	EN ISO 3405	°C	Report		286.6
50% Volume Evaporated	EN ISO 3405	°C	Report		306.3
60% Volume Evaporated	EN ISO 3405	°C	Report		319.6
70% Volume Evaporated	EN ISO 3405	°C	Report		328.2
80% Volume Evaporated	EN ISO 3405	°C	Report		334.5
90% Volume Evaporated	EN ISO 3405	°C	Report		340.8
95% Volume Evaporated	EN ISO 3405	°C	Report		349.2
FBP	EN ISO 3405	°C	Report		355.2
Residue	EN ISO 3405	% v/v	Report		0.9

Sample Received Condition:	Good (No Seal)
Date Sample Received:	26/05/2015

Notes:

Date:	08/06/2015
Authorised by: M Rodriguez *Blend Formulator*	

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Appendix D. Description of test cycles

Preconditioning cycle - NEDC (New European Drive Cycle)

Phases of the New European Drive Cycle (NEDC) were used for vehicle preconditioning prior to each test. The NEDC consists of two phases; Urban (ECE) and Extra-Urban (EUDC) and is performed on a chassis dynamometer.
The preconditioning cycles were made up as follows:

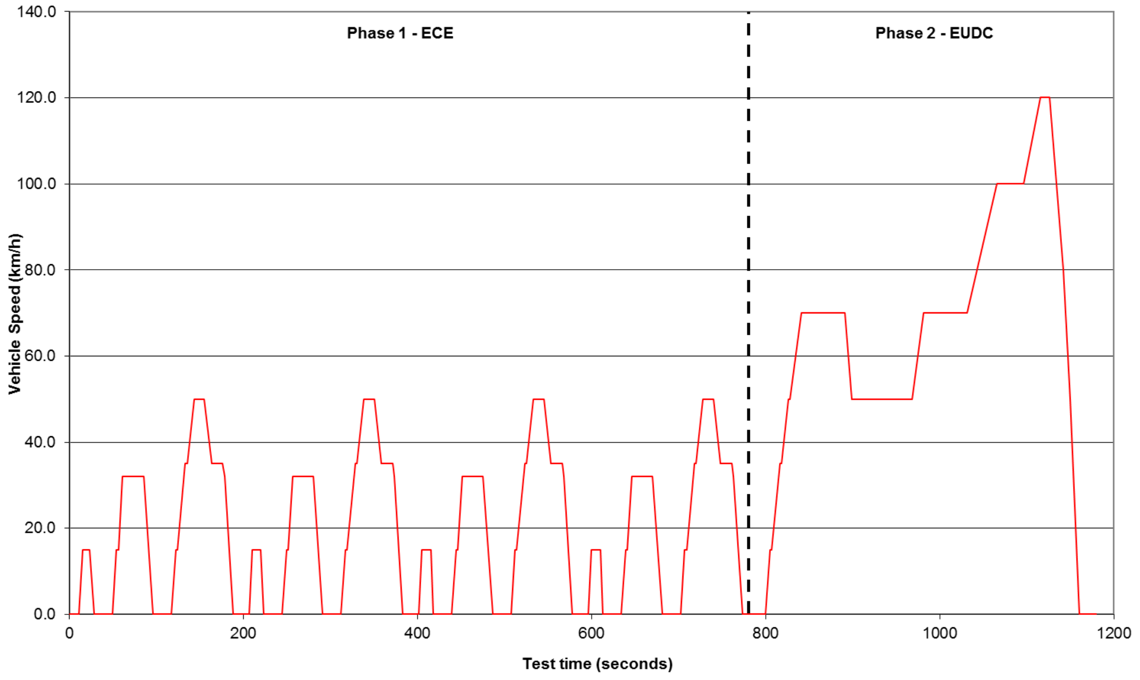
- Diesel vehicle; 3 x EUDC
- Gasoline vehicle; 1 x ECE, 2 x EUDC

Urban Cycle

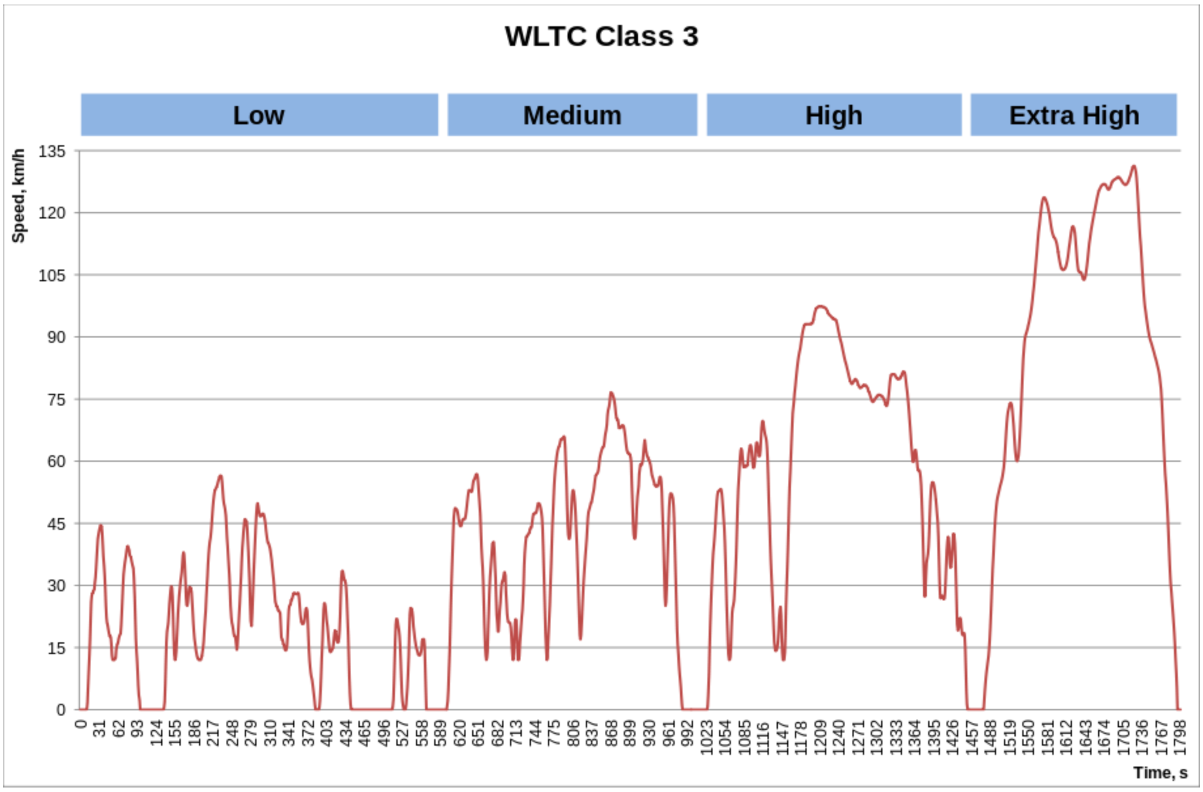
The Urban test cycle is carried out in a laboratory at an ambient temperature of 20° to 30°C on a rolling road from a cold start i.e. the engine has not run for several hours. The cycle consists of a series of accelerations, steady speeds, decelerations and idling. Maximum speed is 31 mph (50 km/h), average speed 12 mph (19 km/h) and the distance covered is 2.5 miles (4 km). The cycle is shown as Phase 1 in the diagram below.

Extra-Urban Cycle

This cycle is conducted immediately following the Urban cycle and consists of roughly half-steady speed driving and the remainder accelerations, decelerations and some idling. Maximum speed is 75 mph (120 km/h), average speed is 39 mph (63 km/h) and the distance covered is 4.3 miles (7 km). The cycle is shown as Phase 2 in the diagram below.



The graph below shows the WLTP drive cycle used in this project during which time the vehicle emissions were sampled.



The table below describes the makeup of the WLTC cycle.

WLTC Class 3 test cycle					
	Low	Medium	High	Extra High	Total
Duration, s	589	433	455	323	1800
Stop duration, s	156	48	31	7	242
Distance, m	3095	4756	7158	8254	23262
% of stops	26.5%	11.1%	6.8%	2.2%	13.4%
Maximum speed, km/h	56.5	76.6	97.4	131.3	
Average speed without stops, km/h	25.7	44.5	60.8	94.0	53.8
Average speed with stops, km/h	18.9	39.5	56.6	92.0	46.5
Minimum acceleration, m/s^2	-1.5	-1.5	-1.5	-1.2	
Maximum acceleration, m/s^2	1.5	1.6	1.6	1.0	

Appendix E. Carbon Balance Method

The fuel consumption of a hydrocarbon fuel can be calculated by measuring the carbon compounds present in the engine exhaust.

Fuel consumption is a measure of the amount of fuel used by an engine or a vehicle when operated for a specified time or over a specified distance.

The fuel consumption can be reported as an integrated result for a vehicle operated over a specified drive cycle or as instantaneous values at one second intervals. When the vehicle is operated over a drive cycle the results are usually reported as litres per 100 kilometres for EC tests and miles per US gallons for US Federal tests.

Fundamentals

1 Fuel consists primarily of carbon. The percentage mass of carbon contained in a fuel is given by the carbon mass fraction (sometimes called carbon weight fraction).

2 During combustion, the majority of the carbon in the fuel reacts with air to form carbon dioxide and carbon monoxide.

3 The mass flow rate of carbon entering the engine is identical to the mass flow rate of carbon leaving the engine.

4 A small proportion of the fuel passes through the engine and is present in the exhaust as un-burnt hydrocarbons.

The carbon balance equations used was:

$$FC_{Gasoline} = \frac{0.1}{D \cdot CWF} \cdot [(CWF \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

In these formulae:

FC = the fuel consumption in litre per 100 km
D = the density of the test fuel
CWF = the Carbon Weight Fraction of the test fuel
HC = the measured emission of hydrocarbons in g/km
CO = the measured emission of carbon monoxide in g/km
CO_2 = the measured emission of carbon dioxide in g/km

Test Report

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Impact of higher levels of bio components in transport fuels in the context of the Direction 98/70/EC of the European Parliament and of the Council of 13 October 1998, relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC

Final Report

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A report submitted to:
European Commission
Directorate-General for Climate Action
Unit C.2: Transport and Ozone
Brussels, B-1049

Ref: 340201/2014/692408/SER/CLIMA.C.2 under Framework Contract No CLIMA.C.2/FRA/2012/0013 LOT 1

A report submitted by ICF Consulting Limited

Date: 27 October 2015

Job Number: 088594

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Document Control

Document Title	Impact of higher levels of bio components in transport fuels in the context of the Direction 98/70/EC of the European Parliament and of the Council of 13 October 1998, relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC
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Date	27 October 2015

Contents

Executive summary

The overall objective of this study is to undertake an economic and environmental analysis of the impact of increasing the limits of the bio-content of petrol and diesel imposed by the FQD, and beyond 2020.[1] In particular, for specific biofuel blends identified in the study, the assessment considers both their positive and negative impacts associated with:

- Biofuels policies, market capacity, distribution of fuels, availability and origin of bio-content;
- Vehicle technology, in particular engine efficiency, tail pipe emissions, biofuel compatibility and fuel use in existing and future vehicle fleets and possible evolution of automotive technology;
- Air quality;
- Greenhouse gas emissions;
- Effect on the refinery sector; and
- Any impact on the current market shares of the fuel mix (diesel vs. petrol) and possible induced changes in Europe.

The findings of this work will provide input to the Commission when considering implications of increasing the bio-content level in transport fuels.[2]

The following presents a summary of the key findings from the study.

Biofuel policies and market capacity

Biofuel consumption is almost fully policy driven, with large variations between Member States

At the EU level, the main drivers are the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). The RED sets a binding 10% target (energy content) for renewable energy in transport in 2020; the FQD sets a reduction target for the GHG intensity of fuels of 6%, in 2020. The FQD also defines blending limits for FAME and ethanol (Chapter 1, Section 1.3.2.2), limiting the share of FAME in diesel to 7 vol% (6.4% energy content) and the share of ethanol in petrol to 10 vol% (6.8% energy content).[3] Both directives define sustainability criteria that biofuels have to meet to count towards both targets, the RED furthermore regulates that biofuels from waste and residues count double towards the 10% target. Recently, the Indirect Land Use Change (ILUC) Directive (Chapter 1, Section 1.3.2.3) has been adopted by the Council at second reading and is likely to enter into force in late 2015. Under this Directive there will be a cap on the contribution that biofuels from food crops and some energy crops can make to targets in the RED at 7%[4] of transport energy. Member States will also be required to set a target for advanced biofuels with a reference value of 0.5%. Furthermore, the multiplication factors for electricity from renewable sources are increased, from 1 to 2.5 for the energy consumed in electrified rail transport, and from 2.5 to 5 for renewable electricity use in road transport.

At the Member State level, by 2014, almost all, with the exception of Latvia, Cyprus and Estonia, had implemented biofuel obligations (quotas) for fuel suppliers (Chapter 1, Section 1.3.3.1). However, the level of these obligations varies significantly between countries, from an average target of less than 3% in Croatia and Greece, to 7% or higher in France, Poland and Slovenia. The majority of Member

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[1] Taking also into account certain recent policy developments such as the 2030 framework for climate and energy policies including COM(2014) 15 final

[2] The objective of the study in not an impact assessment or exploration of concrete alternative policy options but an assessment of the implications of (hypothetical) changes to the blending limits in the current fuel specification

[3] These limits are termed B7 and E10 respectively, with the letter referring to either biodiesel or ethanol and the number referring to the vol% limits.

[4] In the remainder of this document, all biofuel shares will be expressed in terms of energy content, unless explicitly indicated (vol%, to indicate a share in volume)

States are relying on blending or GHG reduction obligations to increase supply and demand of biofuels to meet their 2020 targets. This has reduced the need to also provide financial incentives. As such, only approximately half of EU Member States have implemented tax incentives (Chapter 1, Section 1.3.3.2), which differ based on the blend type (e.g., six Member States offer incentives for blends within the blending limit; while others focus on high blends), and incentive level.

There is still a lot of potential to further increase biofuel sales within the current blend limits defined by the FQD (B7, E10)

The FQD blending limits have not been an issue in many Member States yet, as most biofuel obligations are still below these limits (Chapter 1, Section 1.4.3.1). The average share of biodiesel in diesel in 2013 was 5.2%, which is still well below the blend limit B7, which equates to 6.4% FAME in energy content. However, this average encompasses Member States, such Austria, Bulgaria, Denmark, France, Poland and Portugal, who already consume more biodiesel than B7, as well as several Member States that can still add two or more percent of FAME to their diesel within the limit. Consequently, biodiesel sales can be increased within the current blending limits. For ethanol, shares are still relatively limited in almost all Member States. Currently, most Member States only have E5 petrol grades on their market; the average ethanol content in the EU is 3.4%, compared to the 6.8% limit of E10. There is still a lot of potential to further increase ethanol sales within the current blending limits, if all Member States would introduce E10. However, only three Member States (Finland, France and Germany) have introduced it so far. To increase blending levels to FQD limits or introduce a new higher blend such as E10, Member States will be required to provide additional incentives or to increase the obligations (Chapter 1, Section 1.3.4.1).

Policy uncertainties result in a lack of clarity about how demand for biofuels will develop throughout the EU until 2030.

The Indirect Land Use Change (ILUC) Directive, which enters into force in the second half of 2015 will have implications for future Member State biofuel policies and biofuel demand (Chapter 1, Section 1.6.1). The ILUC provisions will encourage the biofuel sector to move from biofuels from food crops to biofuels from waste, residues, ligno-cellulosic biomass, algae, etc. This shift towards double-counting biofuels,[5] as well as the increased contribution of electricity from renewable sources towards the target, could result in lower biofuel consumption than that expected in Member State National Renewable Energy Action Plans (NREAPs).

However, the extent of these two effects is uncertain, as the ILUC Directive leaves room for Member States to continue to support food-based biofuels (it only restricts their counting towards the RED target), and the cap does not apply to the FQD. Furthermore, Member States may set a national target for advanced biofuels lower than the 0.5%,[6] provided this decision is well-founded.

Beyond 2020, there is even more uncertainty as the EU's 2030 energy and climate package does not yet provide details about renewable energy in transport policies for 2030, although the Commission's proposal (COM (2014) 15 final)[7] does state that first generation biofuels should have a limited role in decarbonising the transport sector. In the recent Energy Union Package, it was announced that the Commission will propose a new Renewable Energy Package in 2016-2017, which will include a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU renewable energy target is met cost-effectively.

From the EU Energy Roadmap 2050 (COM(2011) 885/2) and the EU White Paper 'Roadmap to a Single European Transport Area' (COM(2011) 144), it can be concluded that, when these documents were prepared in 2011, an increase of biofuels use had been expected to contribute to longer term EU and Member State climate goals.

[5] Advanced biofuels and other waste biofuels are double counted towards the 10% target for renewable energy in transport in 2020 (a feature which already applied in the RED).

[6] A sub-target for advanced biofuels with a reference value of 0.5% has been introduced in the ILUC Directive.

[7] A policy framework for climate and energy in the period from 2020 to 2030; COM (2014) 15 final.

Fuel distribution impacts

The introduction of higher blends will require 'protection grades', but this will have cost implications for fuel distributors

When new blends or fuel grades such as E20 or B10 are to be introduced on the fuel market, they cannot just replace the current E5/E10 or B7, as a large share of the current vehicle fleet is not compatible with these new fuels. The current blends need to remain available throughout the EU as 'protection grades' for many years, until the non-compatible vehicles are phased out of the market (Chapter 1, Section 1.4.4).

The stakeholders in the fuel market (i.e., fuel suppliers, distributors and owners of retail stations) will then have the following options:

a. introduce the new blend by replacing an existing fuel grade that they offer;

b. invest in expanding the existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics, and add the new blend to their existing portfolio; or

c. not introduce the new blend, i.e. maintain their current fuel grade portfolio, and wait until market demand for the new blend is sufficient to warrant replacing one of their existing fuel grades

The cost and benefits of these three options, and therefore the optimal choice for a specific stakeholder, may depend on the specific situation of the filling station: the number of grades they sell and their market shares, whether or not they have the (physical and financial) possibilities to expand their infrastructure (e.g., invest in new (subsurface) fuel tanks, pumps, fuel piping, etc.). Since fuel markets in different Member States can have various ownership structures, ranging from Germany, Greece, Italy which are dominated by a limited number of major companies, to Poland and the UK where independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales, consideration is required for potential market distortion effects (Chapter 1, Section 1.4.4.1). For example, if one retailer has the opportunity to add a new blend with limited cost, a smaller competitor, with one fuel grade and insufficient means to invest, will likely lose market share to the larger competitor.

Higher biofuel blends may cause a number of technical issues that need to be resolved before roll-out, to ensure fuel quality and prevent technical issues in the fuel supply chain.

Higher ethanol blends can cause issues in tank systems through the supply chain from depot to petrol station (Chapter 1, Section 1.4.5.2). Costs to resolve these issues increase with increasing shares of ethanol.

Aging of higher FAME blends may lead to fuel quality control issues throughout the fuel chain, such as filter plugging, corrosion, durability problems and deposit formation (Chapter 1, Section 1.4.5.2). The aging rate is strongly dependent on storage conditions, and so could be compounded by a low uptake by the market, for example if a higher FAME blend is introduced at service stations with low throughput, or if there are not sufficient compatible vehicles available. Research in this area has been limited to date, so further research is required to understand and possibly resolve these issues before roll-out.

Information provision and strategic price setting will be important to encourage customers to buy higher biofuel blends.

Consumer acceptance and willingness to buy is crucial to successfully introducing a new biofuel blend or fuel grade at filling stations successfully (Chapter 1, Section 1.4.6.1). The different experiences with introducing E10 in Finland, France and Germany illustrate that consumer acceptance is important: in Germany, low consumer acceptance proved to be a significant barrier, resulting in much lower market shares, while Finland and France were the opposite as extensive effort was made to list E10 compatible vehicles, clearly label pumps and actively inform consumers using promotional literature.

The higher price of biofuels results in a higher price of fuels that contain higher biofuel shares ('high blends'), but this does not have to be a barrier to the sales of high blends (Chapter 1, Section 1.4.6.3).

Effective biofuel policies such as a biofuel obligation or tax incentives can provide sufficient incentives for fuel suppliers to sell these fuels despite the higher cost.

Biofuel availability and origin

Even with a 7% cap on first generation biofuels (ILUC Directive) in 2030, the maximum potential of the current blending limits (B7/E10) could still be achieved by these biofuels only.

In 2013, only 43% of the EU's biodiesel production capacity was actually used, along with 44% of biopetrol capacity (mainly ethanol) (Chapter 1, Section 1.6.2.2). More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, while 44% of the biopetrol production capacity located in France, Germany and the UK. Current European biodiesel production capacity is already sufficient to meet the 2020 demand, as predicted by the NREAPs. EU Biopetrol capacity can only meet 80% of the supply that Member States expect for 2020; however, since Member States are likely to use imports to fill the gap, the current capacity can be considered sufficient to meet the (remaining) demand (Chapter 1, Section 1.6.2.2).

Due to the current uncertainties regarding EU and Member State policies after 2020, projecting the demand for biofuels in 2030, at this point in time, is highly uncertain. However, based on EU-forecasts for road transport energy demand in 2030, it is estimated that if the current FAME and ethanol blend levels (B7 and E10) still apply in 2030, they would allow blending of 11.8 million tonnes (Mton) FAME and 7.0 million tonnes of oil equivalent (Mtoe) ethanol. The ILUC Directive places a 7% cap on the contribution that first generation biofuels[8] can make to RED targets; however, this would still equate to about 20.3 Mtoe of biofuels. Consequently, the maximum potential of the current blending limits (B7/E10) could still be achieved, without exceeding the ILUC cap. (Chapter 1, Section 1.6.3.2).

Current EU biopetrol production is first generation; advanced[9] biopetrol generation capacity still very limited. Current biodiesel production capacity can be used to produce FAME from plant oils and from waste and residues, but not for advanced biodiesel production.

Without policies for 2030, such as a cap on biofuels from food crops and a target for advanced biofuels, first generation will continue to dominate and there is continued uncertainty about whether more advanced routes will reach large-scale, commercial application in the future, and by when they could be expected. In the EU, the developments of advanced biofuel processes are supported by EU-level R&D funding (e.g., Horizon 2020 and the NER 300 programmes, the European Biofuels Technology Platform (EBTP)), but the R&D route from smaller scale to large scale application can take many years and even decades (Chapter 1, Section 1.6.3).

Biofuels are more costly than fossil fuels, and will remain more costly at least until 2025/2030 and possibly even longer.

The cost of biofuels that consumers have to pay, the retail prices, typically consist of cost of the biofuels itself (incl. cost of feedstock, oil price, production and distribution), taxes and excise duties. Import tariffs can also impact the cost of biofuels. It is estimated that the cost of rapeseed FAME is approximately 65% higher than that of conventional diesel. Similar ratios were found for the cost of ethanol from EU wheat or sugar beet, compared to petrol. In practice, prices of biofuels and fossil fuels vary significantly over time, but it is predicted by that biofuels will remain more costly at least until 2025/2030 (Chapter 1, Section 1.6.5). Advanced biofuels are more expensive than conventional biofuels, and this is expected to remain the case in the future.

[8] First generation biofuels refer to the fuels that have been derived from food crops.

[9] Advanced biofuels are those produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams.

Development of possible biofuel scenarios to 2030

Four hypothetical scenarios were developed to describe the potential development of biofuel demand to 2030. These scenarios form the basis of the analysis into air quality, carbon emissions, refinery and fuel supply impacts

There is still significant uncertainty about biofuel policy development to 2030, both at the EU and Member State level. The development of biofuel demand is therefore difficult to predict. However, based on findings from the analysis, four hypothetical scenarios have been developed (Chapter 1, Section 1.7.3):

- The Base Case scenario assumes that the energy content of biodiesel (FAME/HVO) and ethanol in 2013 (i.e., 5.2% and 3.4%, respectively), will not change through 2030.
- Scenario A assumes a full use of the biofuel blend limits of FAME and ethanol in the EU by 2020, and assumes there is no need for Member States to resort to higher blends; i.e., the blending limits remain constant at B7 and E10 through 2030.
- Scenario B assumes further growth of FAME and ethanol demand in the EU beyond 2020, and accommodates that with an introduction of B10 and E20 from 2020 onwards. B7 and E10 would remain available throughout the EU as protection grades, at least until 2030.
- Scenario C assumes an even stronger growth of FAME and ethanol demand in the longer term (2025-2030) than scenario B. Limitations due to biofuel availability also apply in this scenario, but these are assumed to be resolved after 2025. It assumes that B10 and E25 are introduced from 2020 onwards, B7 and E10 would remain available throughout the EU as protection grades, at least until 2030. In addition, a standard for B30 will be introduced, to be used in captive fleets only.

These scenarios form the basis for the analysis conducted into the potential impacts of higher biofuels on air quality, carbon emissions, the refinery sector, and fuel supply.

Vehicle technology

Increased use of higher biofuel blends would not impede future engine technology and some blends may be helpful in enhancing technology performance.

With the aim of improving fuel economy, petrol engine technology is expected to progress along two pathways in the future: 1) increased turbocharger boost with engine downsizing; and 2) use of very high compression ratios (Chapter 2, Section 2.3.1). Both engine trends will continue to value higher octane fuels, which could provide engine efficiency benefits, and ethanol's high latent heat of vaporisation, which could contribute to lower combustion temperatures and, therefore, potentially reduce NOx emissions.

Light and heavy duty diesel engine technology is expected to progress along a path of increased turbocharge boost, coupled with further engine downsizing (Chapter 2, Section 2.4.1). However, fundamental changes in diesel combustion technology are not expected in the 2030 timeframe. As such, current diesel fuel properties will be suitable for future diesel engines.

Regardless of the approach to improve petrol and diesel engine technology in the future, there will be no change in the impact of biofuel blends relative to their impact on current engines.

By 2020, the increased use of high ethanol blends is possible in petrol vehicles, with some technical issues.

Most post-2003 vehicles are E10 tolerant (i.e., they have no efficiency advantage from the higher octane value of ethanol, but they will not have safety or performance issues with this fuel. However, they cannot use higher blend levels (e.g., E20), and warranties may not include higher blends). However, for pre-2003 vehicles, which will likely comprise between 1.3 to 6.8% of the 2020 EU light duty fleet, fuel leaks or fuel system corrosion could occur (Chapter 2, Section 2.3.3.4). This could be addressed by upgrading fuel system gaskets and elastomers for costs of <200 Euros, but there may be a small number of vehicles requiring hardware changes. There are no public data on affected models and the EU would need to work with auto-manufacturers to identify affected vehicles, related upgrade costs and affected populations in 2020.

Manufacturers suggest that most post-2011 vehicles are E20 tolerant; however, precise numbers of non-E20 tolerant vehicles still in the market by 2020 are not available.[10] An E20 tolerant vehicle will not receive the efficiency benefit of the higher octane rating, without engine optimisation. It is assumed that the costs of optimisation will be small for naturally aspirated engines and under Euro 50 for turbocharged engines, if the changes are incorporated in the design stage.[11] This approach will affect future manufacturer product plans as engines will need to be modified. A lead time of 4 to 5 years will be required for manufacturers to design such engines (Chapter 2, Section 2.3.3.4).

Although B7 presents no technical issues, B10 and B30 FAME diesel blends are more problematic. Concerns also exist about the use of FAME blends with plug-in vehicles.

B7 (i.e., 7 vol%) is the current level of the FAME blend limit and is the default requirement for vehicle technology; as such, all EU diesel vehicles can run on B7. The introduction of B10 could lead vehicles with duty cycles having short trip lengths and many cold starts daily to experience significant oil dilution issues. This issue could be addressed by improved monitoring of engine oil and more frequent oil change intervals (i.e., reduced from current levels of 25,000 to 30,000 km to less than 20,000 km). In addition, the use of B10 during winter months may need to be prohibited (Chapter 2, Section 2.4.2).

Oil dilution and cold storage problems are heightened when using B30 (Chapter 2, Section 3.2). As such, vehicle manufacturers suggest that it may not be suitable to be placed in the market, but only to be used in “captive” fleets, where measures can be implemented, such as an oil dilution monitoring programme, and careful oversight of fuel quality. It is unclear if any hardware changes to the fuel system are needed for modern (post-2010) vehicles to use B30.

Concerns exist about the oxidation stability of FAME when used in plug-in vehicles where the tank fuel can be used over several months if the vehicle is operated primarily in electric mode. However, further research into this issue is required as plug-in diesels have entered the market only in 2014.

Irrespective of the hypothetical scenarios explored in this study, it is considered that the introduction of new, higher biofuel blends require fully compatible vehicles, which will be developed and sold once the technical specifications of these blends are confirmed.

The introduction of vehicles fully compatible for higher blends first requires agreement on fuel specifications (in the CEN), which are then included in the FQD and type approval regulation. Vehicle manufacturers can then develop and optimise vehicles for this new fuel standard, and introduce these on the market. The market penetration rate of these fully compatible vehicles determines the potential (maximal) growth of sales of these higher blends, and therefore provides a boundary condition to the consumption of these biofuels. Once the first fully compatible vehicles enter the market, it will take more than 20 years before the entire vehicle fleet will be compatible with the new blends.

Vehicle emissions

Biofuel blends (E10, E20, B7, B10 and B30) will have mostly positive emission benefits.

Based on a review of literature, ethanol blends will result in emission reductions ranging from 5-20% of regulated pollutants (carbon monoxide (CO); particulate matter (PM), hydrocarbons (HC)) and air toxics (benzene) when compared to current engines using E0 fuel (Chapter 2, Section 2.3.3.1 and Section 2.5.1). However, emissions for nitrogen oxides (NOx) could be slightly higher (~1%), as well as aldehyde emissions, especially in vehicles that are not optimised for the higher blends.

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[10] Since it is likely that there will be a significant proportion of the vehicle fleet that is not E20 tolerant during the 2020 to 2030 timeframe, a protection grade (e.g., E10) will be required. The rate of fleet renewal determines how long the protection grade has to be available. However, it is possible that even after 15 years, 15% of the vehicle fleet will still be incompatible with E20 (Chapter 1, Section 1.5.3).

[11] For non-E20 tolerant vehicles, optimisation costs will be significantly more; consequently, an E10 protection grade will be required.

Similarly, the use of B7, B10 or B30 will reduce emissions of HC, CO, PM and particulate number (PN), but literature indicates that NOx emissions will increase by a few percentage points (Chapter 2, Section 2.4.3.2 and Section 2.5.2).

Vehicle emissions testing indicates that pollutant emissions from E10, E20, B7, B10 and B30 are significantly lower than Euro 6 exhaust emission limits for passenger cars.

A limited vehicle emissions testing programme was conducted on single Euro VI compliant petrol and diesel vehicles, to the World Harmonized Light Vehicles Test Cycle (WLTC). Both vehicles were not optimised to the biofuel blends tested. For E10 and E20, total hydrocarbon (THC), PM and PN were 80% lower than Euro 6 emissions limits, while non-methane hydrocarbon (NMHC) was over 70% lower (Chapter 2, Section 2.3.3.1). CO and NOx vary between 50-70% and 18-46%, respectively, below Euro 6 emission limits.

For all biodiesel blends (B7, B10 and B30), CO, PM and PN were approximately >80%, >75% and >95% lower, respectively, than the Euro 6 exhaust emission limits (Chapter 2, Section 2.4.3). However, NOx emissions were over 7 times greater than Euro 6 limits, due to issues associated with the test cycle. Euro 6b limits are based on the New European Driving Cycle (NEDC), while the study tests were conducted using the Worldwide harmonized Light duty driving Test Cycle (WLTC). The test results are directionally similar to results from other studies which have compared NOx emissions from NEDC against other test cycles, such as WLTC and Real Driving Emissions (RDE). Overall, although the vehicle tests represent a small sample size, the results for NOx indicate a broader issue that warrants further investigation.

Air quality impacts

The introduction of higher biofuel blends will not detrimentally impact air pollution from the refinery sector

Modelling of refinery sector emissions was conducted for each of the four hypothetical biofuel scenarios (i.e., Base Case, and Scenarios A, B, and C). Refinery emissions of air pollutants (SOx, NOx, NMVOC, CO and PM) are expected to decline by 30-55% from 2010/2013 levels reported by the European Environment Agency (Chapter 3, Section 3.3.2). These declines are directly linked to reduced refinery throughput, and associated lower fuel consumption in the Base Case and higher biofuel scenarios (Chapter 1, Section 1.7.3), even though biorefinery production will likely offset some of the air pollution reduction due to refinery throughput reduction. The refinery sector accounts for only a small fraction of pollutant emissions when compared to vehicle tailpipe emissions.

Compared to current biofuel blending levels, the use of higher biofuel blends will not negatively impact air pollution from vehicle tailpipe emissions.

Modelling results indicate that regardless of the blending ratio (E10, E20, E25, B7, B10 or B30), vehicle tailpipe emissions compared to a Base Case using current biofuel blending levels, do not negatively impact air pollution (Chapter 3, Section 3.4.2). Pollutant emissions of THC, NMHC, CO, and PM will decline with higher blends. In 2030, light duty vehicles (LDV) emissions of these pollutants across each biofuel scenario (A, B and C) were on average 3%, 3%, 6% and 8%, respectively, lower than the Base Case. For NOx, emissions were on average 1% higher than the Base Case in 2030. CO_2 emissions for Scenarios A, B and C were the same as the Base Case in 2020, and 0.2% lower in 2030. For heavy duty vehicles (HDV), the trends were similar, although no declines in CO_2 were noted through 2030.

Moving to higher ethanol blends does not mean increases in the ethanol waiver (Annex III of the Fuel Quality Directive (FQD); 2009/30/EC), rather the required waiver (in kPa) gradually declines out to and beyond 30 volume % ethanol

Annex III of the Fuel Quality Directive (FQD; 2009/30/EC) sets out allowed vapour pressure (VP) waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. For a given base petrol, the blend vapour pressure (VP) peaks at an ethanol concentration of around 5% and then steadily declines as its concentration increases, initially sharply to about 10% concentration and then more slowly (Chapter 3, Section 3.5.6). Consequently, raising ethanol content from 0 to 5%

has a marked upward impact on blend VP, but increasing concentrations further actually lowers blend VP; e.g., based on calculations, from 68 kPa at 5% to 67.8 kPa at 10% and 66.8 kPa at 30%. Thus, going to higher ethanol concentrations beyond 5% does not cause increased pressure on petrol blend VP; rather the effect is to gradually reduce the vapour pressure waiver effect.

Higher ethanol blends will not result in adverse evaporative emissions impacts in petrol

An assessment of literature indicates that there would be no appreciable adverse evaporative emissions impacts from raising ethanol concentration in petrol (Chapter 3, Section 3.5.2). Studies indicate that diurnal, refuelling and hot-soak emissions were unaffected by higher ethanol content in petrol. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but not within the E10 to E25 range. Any reduction in VP from blends above E5 was noted to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

Greenhouse gas emissions impacts

Higher biofuel blending scenarios yield GHG benefits compared to the Base Case scenario, regardless of assumptions related to the emission factors for biofuels and ILUC emissions

The greenhouse gas (GHG) impact analysis of three hypothetical scenarios for higher bio blends suggests that these can yield benefits compared to the base case scenario. The estimated benefits are dependent on a) reducing the carbon intensity of biofuels over time as a result of improvements made in the supply chain of biofuels, b) expanded use of waste-based feedstocks, particularly for FAME and HVO production and c) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030, including for ethanol, biodiesel, and renewable diesel (Chapter 4, Section 4.4). Assuming a reduction in the carbon intensity emission factors of biofuels over time and excluding indirect land use change (ILUC) GHG emissions, the analysis (Chapter 4, Section 4.5) yields an estimated reduction in the range of 7.1 to 9.4% for the three higher blend limits and use scenarios in 2030. However, if no reductions in the carbon intensity of biofuels are assumed over time, and the emission factors as set out in current legislation are used, including default carbon intensity values for biofuels (included in FQD Annex IV) and indirect land use change factors (in the ILUC Directive), the analysis yields GHG emission reductions between 0.8 to 1.5% compared to the base case scenario.

Refining and fuel supply impacts

The fuel supply outlook in the Base Case incorporates further dieselisation[12], which will increase the strain on EU refining by lowering refinery throughputs and utilisations

The Base Case projection assumes EU petrol demand (including any biofuel content) dropping by 25% and 44% in 2020 and 2030, respectively, from 2011 levels (around 87,000 ktoe/yr (2 million bbl/d)). In contrast, EU diesel demand (including any biofuel content) is assumed to rise by 7% and 8% in 2020 and 2030, respectively, from the average demand levels seen between 2007 and 2013 (i.e., 205,000 ktoe/yr (4.2 million bbl/d)) (Chapter 5, Section 5.4.1).

In many refineries, the yield ratio of petrol to diesel is close to 1:1. In contrast, the Base Case scenario predicts an EU diesel to petrol demand ratio of 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis), which further exacerbates the yield and economic strain on European refineries through 2030 (Chapter 5, Section 5.4.1). In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. The continuing dieselisation trend (petrol demand decline with diesel demand increase) embodied in the Base Case scenario, and the associated increased strain on European refinery yields contributes to reduced refinery throughputs in the 2020 and 2030 Base Case model results. European refining throughputs decline to around 10 million bbl/d in 2030 compared to 11.9 million bbl/d in 2012, while at the same time necessitating higher petrol exports in order to enable diesel production. As a result, the Base Case scenario

[12] A continued decline in the ratio of petrol to diesel demand

projection is for petrol exports to be around 60% higher in 2020 and 2030 than they were in 2013, and for diesel/gasoil imports to double versus 2013 by 2020 and then triple by 2030.

Increases in biofuel demand will have a greater impact on refineries than the projected reduction in road fuel demand

Higher biofuel demand (as described by the three hypothetical scenarios) will have a greater impact on refineries than the projected reduction in road fuel demand in the Base Case. Specifically, by 2020, the EU mineral road fuels production could fall by 104,000 ktoe/yr (4.4%) from its 2014 level due to the Base Case fuel supply outlook, and by an additional 124,000 ktoe/yr (5.5%) due to higher biofuel demand (Chapter 5, Section 5.6.4). By 2030, mineral road fuels production could fall by 203,000 ktoe/yr (8.6 per cent) from its 2014 level due to Base Case assumptions, and, due to increasing biofuel demand, could fall by an additional:

- 209,000 ktoe/yr (9.7 per cent) in Scenario A;
- 240,000 ktoe/yr(11.1 per cent) in Scenario B; and
- 293,000 ktoe/yr (13.5 per cent) in Scenario C.

Higher biofuel supply and demand in the EU will have adverse impacts on the EU and Non-EU refining sectors in terms of throughputs

EU biopetrol and/or biodiesel supply was assumed to increase as needed in higher biofuel scenarios in order to prevent significant increases in EU biofuels imports (Chapter 5, Section 5.4.1). This has resulted in EU biofuel supply increases being entirely biodiesel in 2020 for all Scenarios (i.e., 0.2 mb/d) and predominantly biodiesel in the 2030 (i.e., as high as 0.5 million bbl/d under 2030 Scenario C).

Because the European industry operates with a petrol/diesel imbalance which is projected to worsen under the Base Case scenario, a primary impact of higher biofuel demand is to reduce diesel/gasoil imports into the EU such that the bulk of the refinery impacts are projected to be felt in regions outside the EU. Higher biofuel supply and use in the EU has adverse impacts on the EU and Non-EU refining sectors in terms of throughputs and margins. Implied further closures in 2030 due to the higher biofuel demand in Scenario A could be over 0.4 million bbl/d globally of which 0.08 million bbl/d occur in the EU. In comparison, for Scenario C, over 0.6 million bbl/d could be closed globally of which 0.2 million bbl/d could occur in the EU. However, the split of impacts between EU and Non-EU refining regions is dependent on Base Case assumptions (Chapter 5, Section 5.4.2.2). For example, if the 2030 Base Case outlook comprises higher demand for petrol in the EU, then a greater proportion of the total refinery throughput reductions and implied closures due to higher biofuels would occur in the EU.

The impact on refining margins in the EU, compared to the Base Case, will be small

In 2020, a reduction in margins on the order of 2-7% is estimated, while in 2030 a change of +2% to -4% is predicted for the higher biofuel scenarios compared to the Base Case (Chapter 5, Section 5.4.2, Section 5.6.3). For example, for gross margins, which vary between refineries, the absolute impact is a reduction of 7 $¢/bbl in 2020 for all Scenarios (compared to a base case margin of 3.93 US$/bbl) and 11 $¢/bbl in Scenario A, 13 $¢/bbl in Scenario B and 16 $¢/bbl in 2030 for Scenario C (compared to a base case margin of 3.83 US$/bbl) (Chapter 5, Section 5.6.3)

The underlying causes for the reduction in margins (Chapter 5, Section 5.4.1), include the projected continuing overall demand decline in Europe, (most notably for petrol), under the Base Case scenario,[13] and the relative margins on petrol oriented refineries dropping significantly between 2020 and 2030. This is because of a projected global slowing in petrol demand growth by 2030 in which the projected EU reduction plays an important role.

[13] The analysis assumes that EU refinery utilisations will drop from the 80% range in 2020 to approximately 70% in 2030 – with clear implications for further Base Case scenario closures by 2030. These closures were left implied in the results although clearly a 70% level is unsustainable; therefore the Base Case scenario implies significant closures before considering the added effects of higher biofuels. If the analysis had assumed further closures in the 2030 cases then the expected margins would be somewhat higher.

Consumer prices will increase as the biofuel energy share rises

The increase in consumer prices may be 2.3 €¢/l in 2020 (2 per cent) and, in 2030:

- 4.8 €¢/l (4 per cent) in Scenario A;
- 5.0 €¢/l (4.1 per cent) in Scenario B; and
- 5.8 €¢/l (4.8 per cent) in Scenario C.

Consumer prices are comprised of mineral road fuel wholesale prices, biofuel wholesale prices and the EU average current fuel duty and Value Added Tax. Mineral road fuel wholesale prices are 55.2 €¢/l for an 85 $/bbl crude oil price and biopetrol and biodiesel wholesale prices, which are weighted by their respective share in total biofuels, could be 91.9 €¢/l in 2020, rising to 97.8 €¢/l in 2030. Including taxes, the average price at the pump is 121.5 €¢/l in 2020 and 121.1 €¢/l in 2030. The difference in biofuel and mineral road fuel prices drives the consumer price increase as the biofuel share increases from the baseline, as laid out above. (Chapter 5, Section 5.6.2).

Higher crude oil prices would narrow the differential between mineral road fuel and biofuel prices and would make smaller the increase in consumer prices. At 124 $/bbl crude price, consumer prices increase by 1.0 €¢/l in 2020 across all scenarios and, in 2030, by 2.0 €¢/l in Scenario A; by 1.8 €¢/l in Scenario B and 1.9 €¢/l in Scenario C.

Study objectives

The overall objective of this study is to undertake an economic and environmental analysis of the impact of increasing the limits of the bio-content of petrol and diesel imposed by the FQD, and beyond 2020.[14] In particular, for specific biofuel blends identified in the study, the assessment considers both their positive and negative impacts associated with:

- Air quality and the resultant impact on human health;
- Market capacity, availability and origin of bio-content;
- Automotive technology, in particular engine efficiency, tail pipe emissions, biofuel compatibility and fuel use in existing and future vehicle fleets and possible evolution of automotive technology;
- Effect of an increase of the bio content in fuel on its overall carbon footprint (Life Cycle Assessment);
- Effect on the refinery sector and distribution of fuels;
- Competiveness of specific sectors or Member State fuel industry; and
- Any impact on the current market shares of the fuel mix (diesel vs. petrol) and possible induced changes in Europe.

The findings of this work will input to the Commission when considering implications of increasing the bio-content level in transport fuels.[15]

Overview of report

This is the Final Report of the study which presents the findings of in the following Chapters:

Chapter 1: Markets – current state and future trends

Chapter 2: Implications for automotive technology

Chapter 3: Effects on air quality and implications for vapour pressure

Chapter 4: Impacts on greenhouse gas (GHG) emissions

Chapter 5: Impacts on refining and fuel supply

This report has been developed by ICF, CE Delft, EnSys Energy and Vivid Economics. The work has involved close co-operation with DG CLIMA throughout the study and has included an industry stakeholder workshop in September 2015.

[14] Taking also into account certain recent policy developments such as the 2030 framework for climate and energy policies including COM(2014) 15 final

[15] The objective of the study in not an impact assessment or exploration of concrete alternative policy options but an assessment of the implications of (hypothetical) changes to the blending limits in the current fuel specification

1 Markets – current state and future trends

Abbreviations/acronyms

Advanced biofuels	
B7	Diesel containing up to 7% v/v
BOB	blendstock for oxygenate blending
BTL	biomass to liquid
CEN	European Committee for Standardization
E10	Ethanol blend containing up to 10% v/v
EC	European Commission
EN228	current standard including the fuel specification of petrol
EN590	current standard including the fuel specification of diesel
EU28	all 28 Member States of the European Union
FAME	fatty acid methyl esther
FQD	Fuel Quality Directive
Fungible biofuels	biofuels with fuel characteristics so close to fossil fuels that no blending limits should be taken into account
GHG	greenhouse gas emissions
HVO	hydrotreated vegetable oil
ILUC	indirect land use change
RED	Renewable Energy Directive

Country codes

EU28	EU-28
AT	Austria
BE	Belgium
BG	Bulgaria
CY	Cyprus
CZ	Czech Republic
DE	Germany
DK	Denmark

EE	Estonia
EL	Greece
ES	Spain
FI	Finland
FR	France
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
MT	Malta
NL	Netherlands
PL	Poland
PT	Portugal
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovak Republic
UK	United Kingdom

1.1 Summary

Chapter 1 of the report provides an overview of the current biofuel market in the EU: the key policies, current status of consumption and production, biofuel blends and feedstock for the biofuels. Based on the current status and expected policy developments, the potential developments until 2030 are discussed.

Integrating these findings with the results from Chapter 2 of this report, three hypothetical scenarios are derived for the development of biofuels for the period to 2030. These will be used as a basis for the assessment of potential impacts of higher biofuel blend walls, in the remainder of this report.

1.1.1 Policy incentives and uncertainties

Biofuel consumption in Member States is almost fully policy driven. At the EU level, the main drivers are the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). The RED sets a binding 10% target (energy content) for renewable energy in transport in 2020; the FQD sets a reduction target for the GHG intensity of fuels of 6%, in 2020. The FQD also defines blending limits for FAME and ethanol, limiting the share of FAME in diesel to 7 vol% (6.4% energy content) and the share of ethanol in petrol to 10 vol% (6.8% energy content). Both directives also define sustainability criteria that biofuels have to meet to count towards both targets and the RED furthermore regulates that biofuels from waste and residues count double towards the 10% target. As required by the RED, Member States submitted National Renewable Energy Action Plans (NREAPs) to the Commission, which outlined indicative trajectories towards the 2020 targets, as well as an outlook of the expected biofuel volumes and types in 2020. In 2012 the European Commission proposed a Directive amending the RED and FQD to address the issue of indirect land use change (ILUC). The Directive has now been adopted by the Council at second reading and is likely to enter into force in late 2015. Under this Directive there will be a cap on the contribution that biofuels from food crops and some energy crops can make to targets in the RED at 7% of transport energy. Member States will also be required to set a target for advanced biofuels with a reference value of 0.5%[16]. Furthermore, the multiplication factors for electricity from renewable sources are increased, from 1 to 2.5 for the energy consumed in electrified rail transport, and from 2.5 to 5 for renewable electricity use in road transport.

By 2014, almost all Member States, with the exception of Latvia, Cyprus and Estonia, had implemented biofuel obligations (quotas) for fuel suppliers. However, the level of these obligations varies significantly between countries, from an average target of less than 3% in Croatia and Greece, to 7% or higher in France, Poland and Slovenia (in 2014). In addition, tax incentives for biofuels are provided in approximately half of EU Member States.

The FQD blending limits have not been an issue in many Member States, as most biofuel obligations are still below these limits. However, various options to go beyond the B7 and E10 limits have been implemented: E10 has been introduced in three Member States (Finland, France and Germany), B8 has been allowed in France (although it is not yet being sold), fungible (drop-in) biofuels such as HVO, whose properties are very similar to fossil diesel, are blended and incentives for E85 are in place in some Member States (at least in France and Finland).

In this study, it is assumed that the EU policies provide the drivers and boundary conditions for the future growth of biofuels in the EU. The potential impact of developments in the sustainability criteria on biofuel supply and demand has been taken into account, however, other than GHG implications (Chapter 4), environmental and social effects of increasing biofuel volumes have not been assessed in detail in this study.

[16] In this text, all biofuel shares are expressed in terms of energy content, unless otherwise specified as vol% (volume content)

1.1.2 Current status of the market

In 2013, 13.6 Mtoe biofuel was consumed in the EU, which represented a share of 4.6% of the EU's petrol and diesel consumption (in energy content). 79% of this was biodiesel, mostly FAME, while 20% was biopetrol. Biofuel shares varied significantly between Member States: where Estonia had a share of only 0.4% in road transport fuel sales, Sweden achieved a 9% share with both a blending obligation and tax incentives in place.[17]

The 2013 EU-average share of biopetrol in petrol was 3.4%, which leads to the conclusion that there is still a lot of potential to further increase ethanol sales within the current blending limits: if all Member States were to introduce E10 and the ethanol content would then be increased to the maximum level allowed, i.e. to 6.8% (energy content, representing 10 vol%), the EU-wide ethanol share can increase by at least 2.9% (equivalent to over 1,600 ktoe of ethanol) without having to resort to higher blend[18]. This can be achieved either by providing specific incentives for E10 and ethanol consumption, or by gradually increasing the obligations and thus encouraging the fuel suppliers to introduce and actively market E10.

Even though all Member States but two (Estonia and Latvia, 2013 data) have switched to B7 as the standard diesel grade, FAME sales can be increased within the current blending limits by at least 1.2% (equivalent to over 3,000 ktoe of FAME): the 2013 EU-average share of biodiesel in diesel was 5.2%, whereas the share allowed by B7 is 6.4%[19]. Note that B7 diesel may contain between 0 and 7 vol% FAME, so having B7 on the market does not automatically imply that 7 vol% of FAME is added.

In line with the consumption of biofuel in the EU, the production of biofuel has increased sharply since 2004. The production capacity installed in the EU is significantly higher than production itself. In 2013, only 43% of the EU's biodiesel production capacity was actually used, 44% of biopetrol capacity (ethanol, mainly). More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, 44% of the production capacity of biopetrol is located in France, Germany and the UK. The 2013 biodiesel production capacity is already sufficient to meet the 2020 demand as set out in the NREAPs. The European biopetrol capacity is not yet sufficient to supply the bioethanol that the Member States expect for 2020, but this gap may be filled with ethanol imports from outside the EU. In 2012, about 15% of the EU's biofuel consumption was produced from wastes and residues (most recent data), the rest was mainly produced from rapeseed and other oils, and sugar beet and grains.

Almost all Member States, with the exception of Cyprus, Hungary, Latvia, Malta and Slovakia, are likely to need higher blends for FAME, a large share of double counting biofuels or some other solutions (HVO, FAME in non-road modes) if they are to achieve the biodiesel shares given in their NREAPs in 2020. Results for petrol are quite different: many Member States do not expect to use the full blending potential of E10 in 2020. Portugal and Slovenia only use a quarter and one third of the E10 blending potential, respectively. These differences are not due to technical reasons but rather due to differences in Member State policy strategies and ambitions. However, the NREAPs were drafted prior to the ILUC decision, and the impact of the new legislation on the Member States plans and policies is not yet known.

[17] Note that the more recent biofuel consumption data are for 2013, and the blending obligations data mentioned above are for 2014. Furthermore, blending obligations may also include double counting of biofuels from waste and residues, where these are only counted once in the actual consumption data.

[18] The actual room to increase ethanol sales will in fact be higher than 2.9%, since ethanol is also sold as ETBE and in E85 blends. However, as data of the EU-wide sales of ETBE and E85 are not available, this effect cannot be quantified.

[19] The actual room to increase FAME sales will be higher than the 1.2% given here, since the biodiesel sales data also include HVO (to which the B7 limit does not apply) and some of the FAME is sold as high blends (B10, B30) in captive fleets. As more specific data of the sales of biodiesel are not available, these effects cannot be quantified.

1.1.3 The potential impacts of introducing higher biofuel blends

The introduction of higher blends such as E20 or B10 requires so-called ‘protection grades’ remaining available, E10 or B7, as only part of the vehicle fleet will be compatible with the new blends (see Chapter 2, Section 2.3.3.4 for an in-depth discussion on vehicle compatibility). All stakeholders in the fuel market, i.e. fuel suppliers, distributors and owners of retail stations will then have to introduce the new blend either by replacing an existing fuel grade that they offer or by adding the new blend to their existing portfolio; where the latter option would require more significantly investments in expansion of existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics.

Fuel markets in different Member States can have various ownership structures, with some (e.g., Germany, Greece, and Italy) largely dominated by a limited number of major companies, and others (e.g., Poland, UK) much more fragmented. In the latter, independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales. This has implications for the introduction of a new blend, since a successful roll-out requires the active involvement of many different stakeholders. In both cases, introducing a new blend may lead to negative economic impacts on the smaller retailers, as they will have fewer resources to invest. These effects have, however, not yet been quantified or assessed.

Introducing a higher biofuel blend may cause a number of technical issues in fuel distribution and at service stations that need to be resolved to ensure fuel quality and prevent technical issues in the fuel supply chain. For higher FAME blends, these are mainly related to quality control and aging. For higher ethanol blends, technical issues may occur due to corrosion. Costs to resolve these issues increase with increasing shares of ethanol. A number of non-technical issues and barriers were also identified, for example consumer acceptance and willingness to buy the higher blends is an important prerequisite to a successful introduction.

Most petrol vehicles manufactured after 2003 are E10 tolerant, i.e. they can drive on E10 without technical or safety issues, but do not receive any fuel efficiency benefit. However, between 1.3 to 6.8% of the 2020 EU light duty fleet may not be compatible to E10, and thus could be susceptible to fuel leaks or fuel system corrosion. This would have to be addressed by retrofitting, or government incentives (scrappage schemes). From 2011 onwards, a majority of cars made in the EU are E20 tolerant; and all diesel vehicles can run on B7. These vehicles have, however, not been specifically designed for blends higher than the current blending limits B7 and E10, and warranties may not include higher blends. The introduction of new, higher biofuel blends is therefore considered to require vehicles specifically designed and optimised for these higher blends, i.e. be fully compatible with these blends. These can be developed and sold once the technical specifications of these blends are decided on.

The introduction of vehicles fully compatible with higher blends first requires agreement on fuel specifications (in the CEN), and then inclusion in the FQD and type approval regulation. Vehicle manufacturers can then develop and optimise vehicles for this new fuel standard, and introduce these on the market. The process for developing a new CEN standard and then for vehicle manufacturers to optimise vehicles for this new fuel standard is estimated to take about 4 years. Once the first fully compatible vehicles enter the market, it will take more than 20 years before the entire vehicle fleet will be fully compatible with the new blends. This time needed for fleet renewal will determine the need to maintain protection grade fuels for non-compatible vehicles.

Vehicle manufacturers and fuel suppliers recommend that some biofuel blends, notably FAME blends above B10, can best be used in captive fleets only, as they require closer quality monitoring of both fuels and vehicles. There is little data on EU-wide fuel sales in captive fleets, and so a rough estimate (used in the scenario development in this study) would be 25%.

1.1.4 Development of biofuel demand to 2030

There is still significant uncertainty about biofuel policy development to 2030, both at the EU and Member State level. The development of biofuel demand is therefore difficult to project.

The recent adoption of the ILUC Directive[20] (Directive 2015/1513) and potential future developments of the sustainability criteria for biofuels could be a strong driver for advanced biofuels (produced from woody and ligno-cellulosic wastes and residues and other non-food feedstock), if Member States set sub-targets for these fuels in the coming years. The production technologies of these biofuels are, however, either still in the R&D phase or are only just starting commercial scale production, and current production capacity for advanced biofuels is very limited. As new production technologies are necessary to unlock the potential of ligno-cellulosic waste, residues and other types of low-ILUC biomass for sustainable transport fuel production, technology developments are crucial to the future growth of sustainable biofuels.

Therefore, despite the current uncertainties, recent outlooks in the literature of EU biofuel demand give a relatively consistent picture of developments to 2030: first generation biofuel production is expected to consolidate at best, while it will take time before significant increases of advanced biofuels can be expected. Cost forecasts in the literature vary, but biofuels are reported to be more costly than fossil fuels (in €/GJ), and expected to remain more costly at least until 2025/2030. Outlooks that analysed the potential implications of the FQD blend limits for FAME and ethanol all recognised these limits as a barrier to meeting the 2020 targets, and to further increases of biofuel sales.

Based on these findings, four hypothetical scenarios are developed that have a number of assumptions in common, but result in very different growth paths for biofuels until 2030:

- The **Base case scenario** assumes that the energy content of biodiesel (FAME/HVO) and ethanol in 2013 (i.e., 5.2% and 3.4%, respectively), will not change through 2030.
- **Scenario A** assumes full use of the blend limits in the EU from 2020 onwards, for both FAME (B7) and ethanol (E10). It furthermore assumes that there is no need for Member States to resort to higher blends: the blending limits remain at **B7** and **E10**.
- **Scenario B** assumes further growth of FAME and ethanol demand in the EU beyond 2020, and accommodates that with an introduction of **B10** and **E20** from 2020 onwards. B7 and E10 will remain available throughout the EU as protection grades, at least until 2030. The new standards will be introduced in the FQD before 2020, and vehicle manufacturers will be required to ensure that all diesel and petrol new vehicles that are sold from 2020 onwards are fully compatible with B10 and E20 respectively.
- **Scenario C** assumes an even stronger growth of FAME and ethanol demand in the longer term (2025-2030) than scenario B. Limitations due to biofuel availability also apply in this scenario, but these are assumed to be resolved after 2025. It assumes that **B10** and **E25** are introduced from 2020 onwards, B7 and E10 will remain available throughout the EU as protection grades, at least until 2030. In addition, a standard for **B30** will be introduced, to be used in captive fleets only.

These scenarios form the basis for the analysis conducted into the potential impacts of higher biofuels on air quality, carbon emissions and the refinery sector, which are described in Chapter 3, 4 and 5.

1.2 Introduction

This assessment presents a picture of current and future trends in biofuel blends used for road transport through 2020 and 2030, based on fuel production and biomass availability, fuel distribution and infrastructure, and vehicle compatibility. Additionally, it assesses the current and possible future availability of related biofuel sources, given the origins of bio-content (type of biofuel, geographic origin, and type of feedstock), if there were to be an increase of demand.

[20] ILUC = Indirect Land Use Change. The Directive can be found at http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1445417906699&uri=CELEX:32015L1513

All data and information for this analysis has been obtained from literature reviews, nine open-structured interviews with stakeholders, and a number of written responses to a questionnaire. A list of the organisations and people interviewed can be found in Annex 1.

Chapter 1 is structured as follows:

- Section 1.3 provides an overview of the current EU and Member State policies aimed at increasing the share of biofuels in the transport mix. The current progress towards the 2020 renewable energy target for transport is discussed, and the status of Member State policies for higher biofuel blend is described.
- Section 1.4 provides an overview of current biofuel consumption throughout the EU and fuel distribution. Estimates are provided on the potential for further biofuel growth within the current blending limits and potential technical and non-technical fuel distribution issues that may occur when higher blends are introduced are identified.
- Section 1.5 assesses the issue of market penetration of vehicles compatible with higher blends, illustrating the barriers that vehicle compatibility can form to biofuel growth.
- Section 1.6 describes the current biofuel production in the EU, imports and exports, and assesses potential future developments. Estimates are provided for the future biomass availability and biofuel cost.
- Section 1.7 integrates the main findings of the previous Sections and Chapter 2, and assesses potential biofuel consumption developments until 2030, given the current status, policies and policy outlooks. Based on the key findings, three different scenarios are developed for 2030, each based on different assumptions and choices regarding biofuel policies and ambitions, biofuel blending limits and technology development for advanced biofuels.

Conclusions and recommendations are provided at the end of each Section, with the exception of Section 1.7: this chapter concludes with the scenarios.

1.3 Policy incentives

1.3.1 Introduction

The EU has implemented a number of directives that are key to both the current and future developments of biofuel demand and supply in the EU. These drive biofuel consumption, as well as the type of biofuels used and their environmental impacts: the share of biofuels in the transport mix is unlikely to increase, and advanced biofuels and other biofuels with higher environmental benefits will not be developed further without effective policies and incentives. This is mainly due to the higher cost of biofuels compared to their fossil counterparts, and the higher cost of advanced biofuels compared to conventional biofuels (which will both be quantified in Section 1.6.5). This makes the biofuel sector, the consumption of biofuels and biofuel R&D almost completely policy-driven.

This Section first discusses the current and future European policy framework (in Section 1.3.2), where the main drivers for biofuels used in the EU are given, together with a number of enabling policies.

This is followed by an overview of the implementation at the national level in Section 1.3.3, including an analysis of the main similarities and differences between Member States. Section 1.3.4 then focuses in on the current status and experiences with higher blends in various Member States. The chapter ends with a number of conclusions and recommendations.

In this report, this EU regulatory framework was taken as the key driver for biofuel demand and supply, which also sets sustainability criteria that act as boundary condition for the developments. The framework is dynamic over time and therefore uncertain, but is not assessed in itself here.

1.3.2 European policies linked to the consumption of biofuels

The binding targets of both the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD) for 2020 are currently the main driver for biofuels in the EU, as they will mainly be met by an increase in biofuel consumption. Both Directives are described below. The currently ongoing policy developments on the sustainability requirements and the recent decision on an Indirect Land Use Change (ILUC) Directive are described in Section 1.3.2.3, followed by an overview of related policies.

1.3.2.1 Renewable Energy Directive (RED)

The RED (EC, 2009a) covers all types of energy in the EU, as it sets an overall binding target of renewable energy use for the EU (20% in 2020) and individual targets for the various Member States. It also regulates quite a number of issues concerning renewable energy in the various sectors (electricity, heating and cooling, and transport). Articles 3(4) and 17–21 are relevant for the transport sector. According to Article 3(4), each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of the final consumption of energy in transport in that Member State.

Only biofuels that meet the sustainability criteria for biofuels and bioliquids as laid down in Article 17 of the RED are allowed to count towards the 10% target. The sustainability criteria set minimum standards, like a minimum reduction target for GHG emissions and the exclusion of environmentally vulnerable areas for biofuel production. These criteria address direct effects caused by biomass cultivation and biofuel production. Indirect effects are not covered in these criteria – see 1.3.2.2 below. The same sustainability criteria are laid down in the Fuel Quality Directive.

Article 21(2) of the RED defines that 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.

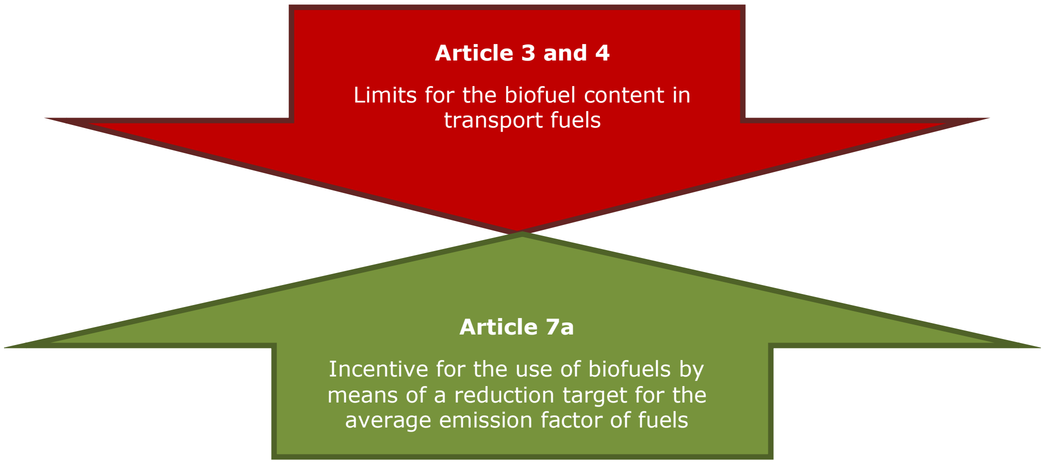
Furthermore, the electricity from renewable energy sources consumed by electric road vehicles shall be considered to be 2.5 times the energy content of the input of electricity from renewable energy sources (RED Article 3(4)), to account for the higher energy efficiency of electric vehicles compared to vehicles with an internal combustion engine.

1.3.2.2 The Fuel Quality Directive (FQD)

The FQD (EC, 2009a) has a double role in relation to the consumption of biofuels in the transport sector. On the one hand, the FQD provides an incentive for the use of biofuels in the transport sector by setting a target for the reduction of the average emission factor of fuels, however, on the other hand, the Directive limits the use of biofuels by setting limits for the biofuel content of fuels in the fuel quality specifications as prescribed by Articles 3 and 4.

In a way this may seem contradictory, but standardised fuel specifications also help to reach harmonisation across and among EU Member States. Both the limits in the fuel specifications as well as the reduction target of Article 7a are described in more detail in the next paragraphs.

Figure 1.1 Double-role of the FQD



Article 7a: the 6% reduction target for the average emissions factor of fuels

The FQD (EC, 2009b) requires fuels suppliers to gradually reduce the average life cycle GHG emissions of the transport fuels that they sell in the EU (Article 7a (2)). The targets were set in the Directive, but the methodology to calculate the contribution of various fuels and GHG mitigation measures towards the target has so far only been defined for biofuels, where the same methodology is used as defined in the RED.

Member States shall require suppliers to reduce life cycle greenhouse gas emissions per unit of energy from fuel and energy supplied by up to 10% by December 31st, 2020, compared with the fuel baseline. 6% of this reduction is mandatory and the remaining 4% can be met by, for example, the use of carbon capture and storage and credits purchased through the Clean Development Mechanism of the Kyoto Protocol, for reductions in the fuel supply sector. ‘Suppliers’ are, in general, the entities responsible for passing fuel or energy through an excise duty point.

The scope of the Directive is the fuels used by road vehicles, non-road mobile machinery (including inland waterway vessels when not at sea), agricultural and forestry tractors, and recreational craft when not at sea. The calculation methodology to determine the life cycle GHG emissions of biofuels is the same as the one used in the RED (and thus does not include ILUC emissions, see below).

Article 3 and 4: Fuel specifications

In addition to the relatively recent CO_2-target of the FQD, the Fuel Quality Directive has also laid down fuel specifications. These fuel specifications, for a range of fuels, aim to harmonise the technical specifications of the fuels brought on the European market. This harmonisation benefits the fuel industry and car manufacturers, because the fuel industry know what type of fuels to produce and can supply these to consumers throughout the EU, and car manufacturers and OEMs can use these specifications to optimise the performance of engines and cars and meet the emission standards.

With respect to fuels containing bio-components, the Fuel Quality Directive includes fuel specifications for petrol and diesel in Annex 1 and Annex 2, including a maximum content of ethanol in petrol (10 % v/v) and FAME in diesel (7% v/v).[21] What this means in terms of energy %, the unit in which the 10% target for renewable energy in transport is defined in the RED, is shown in the table below.

[21] See Annex 3 for background on the biofuels

Table 1.1 Maximum content of ethanol and FAME, as defined in the FQD, in term of volume and energy %

	volume %	energy %
Ethanol	10	6.8
FAME	7	6.4

Article 3 further indicates that Member States shall require suppliers to ensure the placing on the market of petrol with a maximum oxygen content of 2.7 % and a maximum ethanol content of 5 vol% until 2013, and they may require the placing on the market of such petrol for a longer period if they consider it necessary. Furthermore, they shall ensure the provision of appropriate information to consumers concerning the biofuel content of petrol and, in particular, on the appropriate use of different blends of petrol.

Article 4, however, does allow Member States to permit the placing on the market of diesel with a fatty acid methyl ester (FAME) content greater than 7 %, notwithstanding the requirements of FQD Annex II (without specifying a maximum level). There is no similar derogation for ethanol.

The FQD does not explicitly set maximum blending limits for drop-in biofuels such as pure diesel-like hydrocarbons made from biomass using the Fischer-Tropsch process (BTL, Biomass to Liquid) or hydro-treated vegetable oil (HVO). However, as the scope of the FQD is defined as petrol, diesel and gas oil containing at least 70% by weight of petroleum oils and of oils obtained from bituminous minerals, their share must remain below 30% by weight.

In addition, the FQD also requires the provision of appropriate information to consumers concerning the biofuel content of fuels and the appropriate use of biofuel blends.

1.3.2.3 Addressing ILUC

Before the adoption of the RED and FQD, researchers and NGOs had expressed their concerns regarding indirect emissions as a result of indirect land use change (ILUC) in various publications. Under the RED, the Commission had committed to investigate the subject and, if appropriate, to develop a proposal on how to deal with these indirect effects that may negate some or all of the GHG savings of individual biofuels (EC, 2012). In October 2012, the Commission published a proposal to amend the RED (EC, 2012) and the FQD. This proposal was then considered by the European Parliament and Council. The Directive has now been adopted by the Council at second reading and is likely to enter into force in late 2015.

Member States will then have two years to implement this new Directive in their national policies. The most relevant parts of the text adopted by Parliament are presented in Table 1.2.

Table 1.2 Key points of the text adopted by the Council and Parliament in the 2nd reading on ILUC[22]

Cap on land based biofuels in the Renewable Energy Directive	A cap has been introduced on the contribution that certain biofuels can make to targets in the Renewable Energy Directive. Biofuels and bioliquids produced from cereal and other starch-rich crops, sugars and oil crops and from some other crops grown as main crops primarily for energy purposes on agricultural land can contribute no more than 7% to targets in the RED. Member States may decide on setting a lower limit in their national implementation of the RED. They may also choose to apply this cap to the Fuel Quality Directive target.
Support for advanced biofuels and definition of advanced biofuels	Advanced biofuels are fuels produced from a defined list of feedstocks and feedstock categories, including cellulosic energy crops, algae, and cellulosic wastes and residues. A sub-target for advanced biofuels with a reference value of 0.5% has been introduced. Advanced biofuels and other waste biofuels (e.g. those made from used cooking oil) are double counted towards the 10% target for renewable energy in transport in 2020 (a feature which already applied in the RED). Member States are to report on their progress towards their national sub-target in 2020, to assess the effectiveness of the measures introduced by the Directive.
ILUC emissions	Fuel suppliers and the European Commission are to report on emissions deriving from ILUC, but they are not included in the sustainability criteria for the biofuels or the GHG calculation methodology of the RED and FQD. If appropriate, the Commission shall submit legislative proposals by 31 December 2017 for introducing adjusted estimated indirect land-use change emissions factors into the appropriate sustainability criteria of Directive 2009/28/EC
The use and value of ILUC factors	Provisional estimated ILUC emission factors are provided, distinguishing between three categories of feedstock: cereals and other starch-rich crops, sugars, and oil crops. These can be revised in later years to take account of technical and scientific progress.
Low ILUC conventional biofuels	The Commission shall report, by 31 December 2017, on the possibility of setting out criteria for the identification and certification of low indirect land-use change-risk biofuels and bioliquids. This could be, for example, biofuels from schemes that achieve productivity increases beyond business-as-usual.
Post-2020 support for sustainable biofuels	If appropriate, the Commission shall submit legislative proposals by 31 December 2017 for promoting sustainable biofuels after 2020 in a technology-neutral manner, in the context of the Horizon 2030 framework for climate and energy policies
Changes in the methodology to calculate the contribution from other	The electricity from renewable energy sources consumed by electrified rail transport shall be considered to be 2.5 times the energy content of the input of electricity from renewable energy sources when accounting towards targets in the RED. The electricity from renewable energy sources consumed by electric road vehicles shall be considered to be five times the energy content of the input

[22] Source: http://www.europarl.europa.eu/oeil/popups/summary.do?id=1387307&t=e&l=en and http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P8-TA-2015-0100#BKMD-6; both consulted on 10 July 2015.

renewable energy sources	of electricity from renewable energy sources when accounting towards targets in the RED. In the RED, these multiplication factors were 1 and 2.5, respectively.

In particular, the cap on land-based biofuels and the indicative sub-target for advanced biofuels could significantly influence feedstock use for biofuel production. However, as these only apply to the RED and not to the FQD nor to Member State support schemes, the actual impact is as yet unclear. The increase of the multiplication factors for renewable electricity in the RED effectively increases the contribution of this energy source towards the RED target, and thus reduces the need for biofuels to meet this target.

The impacts of these potential ILUC-measures are further discussed in Section 1.5 on biofuel production and biomass availability in relation to the sustainability of biofuels.

1.3.2.4 Relevant CEN-standards

Article 8 (1) of the Fuel Quality Directive obliges Member States to monitor compliance with the requirements of Articles 3 and 4, in respect of petrol and diesel fuels, on the basis of the analytical methods referred to in European standards EN 228 and EN 590 respectively. Both standards have been set by CEN's Technical Committee 'Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin' (TC19) (Working Group 24)(EC, 2009).

CEN TC19 develops European standards which standardize the methods of sampling, analysis and testing, terminology and specifications and classifications for petroleum related products, including petrol, diesel and biofuels (see standards.cen.eu). As such, it aims to ensure consistent quality of automotive fuels and biofuel blends, compatibility with car engines and fuel pump labelling (Constenoble, 2014).

B10 and B20/B30

Several activities have taken place within the CEN to further develop standards for higher levels of biocomponents in transport fuels. In relation to diesel, the 2015 Work Programme of CEN states that the organisation anticipates the adoption of new European standards including requirements and test methods in relation to B10 (EN16374:2014) and B20/B30 (EN16709:2014). Note that the current draft of B20/B30 standard explicitly states that it is intended for blends of more than 15 vol% up to 30 vol% of FAME in diesel fuel to be used in captive fleet application for designated vehicles, and both drafts state that these fuels are not suitable for all vehicles. Both standards are in their last phase of development.

Nowadays B20 and B30 are both blends that are already available, albeit limited to a number of Member States (such as Denmark, Spain, Italy, France, Poland and Czech Republic). Because these blends do not meet all the standards of regular diesel and they require close monitoring of fuel quality and engine oil dilution by FAME, they have been limited to application in 'captive fleets', like bus fleets (sources: interviews with automakers and the draft standard EN16709:2014). During the development of the draft standard EN16709:2014 this definition of 'captive fleets' has been a major point of discussion. Until this standard, captive fleets have been defined at the local level, resulting in numerous definitions, which have hindered harmonisation. At the end of 2014, the European Commission and the CEN working group reached an agreement on the definition of captive fleets, which facilitates the testing of new alternative fuel blends. At the same time, this requires improvements in labelling of these blends at the pump. The vote on the final text of this standard is foreseen for May 2015 (source: interview with NEN[23]).

Deciding on a final standard for B10 is a more complex process than deciding on a B20 or B30 standard, since B10 is not intended to be limited to captive fleets, but will be sold at

[23] NEN is the Netherlands Standardization Institute, which supports the standardization process in The Netherlands. Information from https://www.nen.nl/NEN-Shop/Vakgebieden/Energie-Distributie/Nieuwsberichten-Energie-Distributie/EC-en-CEN-bereiken-voorlopig-akkoord-over-wagenparken-en-biobrandstofmarkering.htm and personal communication with Ortwin Costenoble, NEN

public filling stations for the general fleet. This results in a number of additional requirements for the B10 standards: for example, because close monitoring of B10 impacts is not possible for non-captive fleets, there is a greater need to solve potential cold flow problems related to the application of FAME in winter circumstances (the requirements for 'cold properties' can be stipulated nationally, and may differ in winter and summer, and between countries, see AGQM, 2013). CEN concludes that further research on these technical problems and how these could be avoided is of great importance; a final vote on B10 can only be expected when there is sufficient trust in the solutions for these technical issues (source: interview with NEN) .

Ethanol

For ethanol a standard has been set, which prescribes the requirements for ethanol as a blend component for petrol in blends up to 85% ethanol (EN15376:2014). Several studies have been performed on the feasibility of the large-scale introduction of either E20 or E25. Further developments have, however, been limited to studies investigating the next steps required by different stakeholders to eventually introduce these blends on the market.

1.3.2.5 Energy and Climate package (2030)

The RED and FQD are both policies aimed at realising the overall targets of the Energy and Climate package for 2020, often referred to as 20-20-20 framework, because it requires a 20% reduction in EU GHG emissions compared to 1990 levels, a share of 20% renewable energy in EU energy consumption and a 20% improvement in EU energy efficiency.

In January 2014 the European Commission published as proposal for the new policy framework for energy and climate in 2030 (EC, 2014a), and on 23 October 2014 the EU leaders agreed on the so-called Energy and Climate package (European Council, 2014), which proposes:

- At least a 40% reduction of domestic GHG emission reduction compared to 1990 by 2030. To achieve this, the sectors covered by the EU emissions trading system (EU ETS) would have to reduce their emissions by 43% compared to 2005; emissions from sectors outside the EU ETS (including transport) would need to be cut by 30% below the 2005 level.
- At least 27% for renewable energy by 2030.
- Increasing energy efficiency by at least 27% by 2030.
- Reform of the EU emissions trading system.

At time of writing, it is still unsure if there will be a specific (or indicative) renewable energy source in transport target for 2030. Based on the Council decision, there will be no national binding renewable energy targets, only EU-wide targets.

In the recent Energy Union Package (COM(2015)80 final) a number of relevant actions were announced, namely that the Commission will propose a new Renewable Energy Package in 2016-2017, which will include a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU target is met cost-effectively. (EC, 2015)

1.3.2.6 Clean Power for Transport Directive

The Clean Power for Transport Directive of 22 October 2014 identifies biofuels, together with hydrogen, natural gas and LPG as one of the principle alternative fuels having a potential for the long-term substitution of oil. Biofuels are seen as an alternative for all modes of transport. However, according to the EC, the lack of a harmonised alternative fuels infrastructure could harm the uptake of alternative fuels in EU mobility. An important focus point of this Directive is the information provided to the vehicle users at refuelling stations, including information on the availability of fuels and compatibility of vehicles. Therefore Article 7 obliges Member States to ensure that all relevant information is available in motor vehicle manuals, at refuelling and recharging points, on motor vehicles itself and in motor vehicle dealer shops. This requirement applies to all motor vehicles (and manuals) brought on the market after 18 November 2016. (EC, 2014)

1.3.2.7 Guidelines on state aid

On June 28 2014 the European Commission has published the Communication 'Guidelines on State aid for environmental protection and energy 2014-2020'. These guidelines are applicable from 1 July 2014 until 2020 and contain several provisions related to state aid for biofuels, such as:

- The European Commission recognizes the current overcapacity in the food-based biofuel market and therefore does no longer see investment aid from government institutions in new and existing capacity to be justified. Investment aid should therefore only be allowed in case of conversion into advanced biofuel plants.
- Operation aid to food-based biofuels can no longer be granted after 2020. Operation aid until 2020 should only be granted to plants in operation before 31 December 2013.
- Biofuels that fall under a blending obligation and receive state aid as well will not result in an increased level of environmental protection and therefore should not receive any state aid. Member States are only allowed to grant state aid in case they can demonstrate the aid is meant for sustainable biofuels that are too expensive to come on the market without financial support.
- New and existing aid schemes for food-based biofuel should be limited to 2020.

Despite these limitations for financial support for biofuels, Member States will still be allowed to provide non-financial incentivises for food-based biofuel consumption after 2020. For examples, by the continuation of the current blending obligations. (EC, 2014)

1.3.3 National implementation

The RED sets a binding target for the share of renewable energy in transport in 2020, the FQD sets a reduction target for the GHG intensity of transport fuels in 2020, and both define sustainability criteria for the biofuels that count towards these targets. Neither of them, however, prescribe the policy measures that Member States should implement to comply with these Directives. Member States have therefore implemented both Directives in different ways, resulting in a range of different policy measures that all aim to increase the shares of biofuels on their market, in order to assure the realisation (or, in some cases, overachievement) of these targets by 2020.

The next paragraphs describe the various instruments and the differences between Member States, where we distinguish between quota and obligations (Section 1.3.3.1) and financial instruments (Section 1.3.3.2).

1.3.3.1 Quotas and obligations

Most of the EU28 Member States have decided to oblige fuel suppliers to put a share of total fuel sales as biofuels on the market. These quotas will help to ensure the increase of the consumption of biofuel volumes required to meet the 10% target in 2020 of the RED, as well as the 6% reduction target for the GHG intensity of transport fuels of the FQD.

In Table 1.3 an overview of the mandates per Member States is provided. Almost all Member States (25 to be specific), with the exception of Latvia, Cyprus and Estonia, had binding targets in place for the consumption of biofuels in 2014. All targets are presented in energy content in this table to facilitate comparison, although 11 countries have actually set volumetric targets. 12 countries also had subtargets in place for diesel and petrol. On average, lower subtargets are in place for petrol compared to diesel. The targets mentioned do include double-counting of biofuels from waste and residues (in line with Art. 21(2) of the RED), so the actual share in the fuel volume can be lower.

Table 1.3 Overview blending quota per Member State in 2014, in energy content

Member State	Overall Target	Target for petrol	Target for diesel		Overall target	Target for petrol	Target for diesel
France	7.57%	7.00%	7.70%	Bulgaria (v)	4.94%	3.34%	5.53%
Poland	7.10%			Hungary	4.90%	4.90%	4.90%
Slovenia	7.00%			Romania (v)	4.79%	3.00%	5.53%
Sweden (v)	6.41%	3.20%	8.78%	Luxembourg	4.75%		
Germany	6.25%	2.80%	4.40%	Czech Republic (v)	4.57%	2.73%	5.53%
Finland	6.00%			Slovakia (v)	4.50%	2.73%	6.27%
Lithuania (v)	5.80%	3.34%	6.45%	Italy	4.50%		
Austria	5.75%	3.40%	6.30%	Malta	4.50%		
Denmark	5.57%			Spain	4.10%	3.90%	4.10%
Portugal	5.50%			United Kingdom (v)	3.90%		
Netherlands	5.50%	3.50%	3.50%	Greece (v)	2.64%		
Belgium (v)	5.09%	2.66%	5.53%	Croatia (v)	2.06%		
Ireland (v)	4.94%			Mean target	5.15%	3.58%	5.81%

Source: Biofuel Barometer, 2014

(v) = obligations originally set in % v/v

France, Poland, Slovenia and Sweden have the highest targets, which could present problems in meeting within the current blending limits set by the FQD (see Section 1.3.2.2).

However, a number of options are available to address this issue:

- the share of double counting biofuels can be increased to meet the blending obligations without increasing the actual volumes of biofuels (in line with Article 21(2) of the RED, see Section 1.3.2.1);
- drop-in diesel fuels such as HVO can be used to further increase biofuel shares in diesel beyond the 7 % v/v limit for FAME;
- higher blends can be used in captive fleets (for example B20, B30) or on public filling stations if indicated clearly (for example E85, to be used in flex fuel vehicles)[24];
- Member States may permit the placing on the market of diesel with a fatty acid methyl ester (FAME) content greater than 7 % v/v, in line with Article 4 of the FQD (Section 1.3.2.2).

These options are all used to some extent by various Member States, as will be illustrated when looking at specific efforts to introduce high blends in a number of MS, in Section 1.3.4.

[24] Higher blends might also be used in non-road modes such as diesel rail transport. However, as these fuels are outside the scope of the FQD, these are not included in this assessment

The mandates typically increase over time, but so far most countries have only defined the targets until 2014 or 2015. To what extent the blending limits will pose an issue for more Member States to meet their 2020 targets will become clear in the next years.

The effectiveness of the mandates depend on the penalties that are imposed on fuel suppliers that do not meet the targets. These may vary between Member States. In Germany the fine is €19/GJ, which is estimated to be roughly two times the fulfilment cost (this factor varies depending on fluctuations in the market prices for biofuels and fossil fuels). Until now the quota has been fulfilled and the amount of penalties were minimal. (Interview: German BMU)

The following presents examples of how some Member States have addressed their obligations:

Germany: from tax reductions via blending obligations to a GHG reduction quota

In Germany, the first biofuel policies in place were tax incentives for biofuels. However, as biofuel volumes increased, the decreasing tax proceeds (2 billion euro a year at the highest point) were becoming a major concern. This was one of the reasons for the government to shift to quota and gradually reduce tax reductions or exemptions. At the time of writing, there are still a few tax exemptions for biomethane and BTL and cellulosic bioethanol, but all will expire by the end of 2015. From that date only the GHG quota will be in place.

Since 1.1.2015, another policy shift has occurred: the German government decided to shift from a blending quota system to a GHG reduction quota from 2015 onwards. Fuel suppliers are now not obliged to achieve a certain minimum level of biofuels but rather a minimum level of GHG savings, compared to conventional fossil petrol and diesel. The GHG savings to be achieved are 3.5% GHG in 2015 and 2016, 4% from 2017 onwards and 7% GHG from 2020[25].

To allow for optimization in terms of costs the German parliament decided to have only one target in place rather than separate targets for the share of renewable energy (aimed at the RED target) and for the GHG intensity target of the FQD (see Sections 1.3.2.1 and 1.3.2.2). The introduction has been widely discussed in public in the last year, but the political and legislative decision to shift from an energy quota to a GHG quota in 2015 was already taken in 2009.

With the GHG reduction quota in place, a direct incentive for the use of biofuels with a high GHG reduction potential is provided. However, the result is that the biofuel volumes are more difficult to predict: the higher the GHG savings of the biofuels sold, the lower the actual volume of biofuels sold will be. To avoid overlapping measures, the double counting of biofuels from waste and residues was discontinued. It is too early to assess the impacts of this shift, and estimates on the impacts on the biofuel volumes that will be sold in the coming years vary. Mineral oil companies expect an increase, whereas the biodiesel sector was concerned that it would specifically and negatively impact biodiesel volumes (source of this statement and the following: interview with German authorities). Small fuel suppliers were also found to fear higher prices. Even though there were different opinions on the level of the quota, stakeholders agreed on the principle of a shift from energy to GHG reduction quota. Based on initial feedback from the market a small increase in the amounts is expected this year, but so far little or no change in market share of the feedstocks is observed. A feedstock-based evaluation of the data for the quota year 2015 is expected not before mid-2016.

Spain: Lowering the targets because of energy prices concerns

On 22 February 2013 Spain decided to reduce the blending obligation from 6.5% to 4.1% in order to lower the energy prices in the country to improve Spanish market conditions. The subtarget for diesel was reduced from 7% to 4.1% and the subtarget for petrol from 4.1% to

[25] http://www.bmub.bund.de/themen/luft-laerm-verkehr/luftreinhaltung/luft-luftreinhaltung-download/artikel/zwoelftes-gesetz-zur-aenderung-des-bundes-immissionsschutzgesetzes/?tx_ttnews%5BbackPid%5D=704

3.9%. This resulted in an immediate drop of 57% in biodiesel consumption and 10.5% in biopetrol consumption (EurObserv'ER, 2014).

Italy: Subtarget for advanced biofuels

In anticipation of a decision to be taken on ILUC, Italy adopted a subtarget for advanced biofuels of 0.6% of all petrol and diesel as of 2018 in October 2014. This will increase up to 1% in 2022. Italy is the first Member State to introduce a subtarget for advanced biofuels. In 2013, the first Italian plant for advanced biofuel production was commissioned and three more plants will start operations in 2015. (European Parliament, 2015; Ministro Dello Sviluppo Economico, 2014)

At time of writing, the authors were not aware of other Member States that have or planned to introduce any subtargets for advanced biofuels, but it is likely that more will follow, in line with the ILUC Directive. It is therefore recommended to monitor the developments.

1.3.3.2 Financial instruments (tax exemptions and subsidies)

In addition to the blending obligations, specific type of biofuels can be granted a tax exemption or reduction. National customs authorities are in most cases responsible for implementing tax legislation related to biofuels. The following taxes can be differentiated in such a way that these provide an incentive for biofuel consumption:

- vehicle registration tax;
- circulation taxes;
- fuel taxes;
- CO_2 tax;
- Road charging.

The European Commission regularly publishes an overview of taxes (EC, 2015b). On an annual basis UPEI publishes an overview of actual financial incentives, based on information provided by their members. The most recent publication (UPEI 2014) provides this overview for the year 2014, although not all Member States are included in this report. Information from other sources (e.g. EC, 2015b) has been added to the (UPEI 2014) data to complete the list (Table 1.4).

Table 1.4 Overview of financial incentives for biofuels

	Biodiesel	Biopetrol
Austria	NI	A reduction of 33 EUR/ 1000l litres in excise duties is applicable for petrol with a minimum biofuel content of 46 l and sulphur content <=10 mg/kg (EC, 2015b)
Belgium	No more tax incentives since 1.6.2014. New government proposal to the EU: from 1.1.2015, to introduce a tax incentive of €17.2/m3 of end product if 7% tendered FAME, UCO or TME is blended. 45% of the market is liberalised (therefore only 55% of the needed volume for detaxation will be tendered). There is still no approval from the EU.	No more tax incentives since 1.6.2014. New government proposal to the EU: from 1.1.2015, to introduce a tax incentive of €15.3/m3 of end product if 5% or €30.6 if 10% tendered bio ethanol is blended. 35% of the market is liberalised (therefore only 65% of the needed volume for detaxation will be tendered). There is still no approval from the EU.
Bulgaria	NI	NI
Cyprus	NI	NI

	Biodiesel	Biopetrol
Czech Republic	No tax incentives for mandatory blended products, for blend >31% FAME has an advantage of 31% of basic excise duty. 100% FAME has 100% tax incentive (excise duty = 0) Diesel blend comprising of not less than 30 % of rapeseed oil methyl ester of volume: reduced rate as of 7665 CZK/1000 litres until 30 June 2015 (EC, 2015b).	No tax incentive for obligatory blending, E85: no tax on ethanol share, full tax on petrol share. On the low percentage blends of biofuels no excise duty exemption is granted. In the case of bioethanol comprising of not less than 70 % and not more than 85 % of the denatured ethyl alcohol, reimbursement of excise duty is granted at the level of the ethyl alcohol proportion in the mineral oil. High percentage blends with ethyl alcohol produced from biomass and 2nd generation biofuels are exempted from excise duty within pilot projects for technological development if intended for use as propellant (EC, 2015b).
Germany	From 2013: 2.14 ct/l/ no tax advantage on blend	E85: 100% for ethanol part No tax advantage on blend
Denmark	NI	NI
Estonia	None	None
Greece	Biodiesel is taxed like motor gas oil : 330 € per 1000 lt	NI
Spain	No tax incentive since 1 January 2013. New advantages could be considered for labelled blends.	
Finland	Biofuels have lower excise duty rates (EC, 2015b)	Biofuels have lower excise duty rates (EC, 2015b)
France	2013: 8 €/hl 2014: 4.5 €/hl 2015: 3 €/hl	2013: 14€/hl 2014: 8.25€/hl 2015: 7 €/hl
Croatia	No tax incentives. Pure biodiesel, B100 has 100% tax incentive (excise duty = 0)	NI.
Hungary	No tax advantage on bio part	No tax advantage on bio part. E85 is freely available in Hungary, there is tax advantage, but the tax of E85 has been increased year by year.
Ireland	No tax incentives	No tax incentives Substitute fuels, including biofuel, used as auto-fuel in substitute for petrol are taxed at the petrol rate. (EC, 2015b)
Italy	No tax incentives	No tax incentives
Lithuania	NI	-when the percentage of biological origin substances is not less than 30 percentage, the excise duty rate is reduced by the percentage in proportion to the percentage of additives of biological origin in the product; - when the percentage of biological origin substances is less than 30 percentage, the excise duty rate is reduced by the percentage in proportion to the percentage of additives of biological origin in the product and only for the part that exceeds

	Biodiesel	Biopetrol
		the compulsory blending of additives of biological origin (EC, 2015b).
Luxembourg	NI	NI
Latvia	No tax incentive up to 30% RME content. RME content 30-99%: tax incentive approximately 30% from original excise. 100% bio – 100% tax incentive	No tax incentive up to 70% bioethanol content. Bioethanol content 70-85% - tax incentive approximately 70% from original excise.
Malta	NI	NI
Netherlands	No tax incentives	No tax incentives
Poland	No tax incentives	No tax incentives
Portugal	NI	NI
Romania	The energy products used as motor fuel are exempted from the payment of excise duties when they are produced in totality from biomass (EC, 2015b)	The energy products used as motor fuel are exempted from the payment of excise duties when they are produced in totality from biomass (EC, 2015b)
Sweden	Energy tax reduction of 84% for FAME low blending, full exemption for high blending and HVO. Full exemption of CO2 tax treatment (EC, 2014e) Fame for low-level blending and HVO receive the energy tax reduction and the CO2 tax exemption only up to 5% (FAME) of 15% (HVO) of total declared fuel amounts. If the share is higher than these thresholds, the share of above the threshold is taxed fully	Energy tax reduction of 89% for biotethanol low blending, full exemption for high blending. Full exemption of CO2 tax treatment (EC, 2014e). Bioethanol for low-level blending receives the energy tax reduction and the CO2 tax exemption only up to 5% of total declared fuel amounts. If the bioethanol share is higher than this threshold, the share of bioethanol above the 5% threshold is taxed fully
Slovenia	Transport fuels in their pure form are exempt from excise duty. Blends of biofuels with fossil fuels may qualify for a refund of excuse duty paid or for an exemption from excise duty commensurate with the proportion of biofuel added, up to a maximum of 5%.	Transport fuel in their pure form are exempt from excise duty. Blends of biofuels with fossil fuels may qualify for a refund of excise study paid or for an exemption from excise duty commensurate with the proportion of biofuel added, up to a maximum of 5%.
Slovak Republic	Up to 5 vol-% for Biodiesel blending is without tax, more than that you have to pay the tax. The excise duty reduction for biofuels is granted only to companies that operate as tax warehouses.	Reduction in excise duty of 36 euro/ 1000 litres for petrol with a minimum biofuel content of 4.5% or more (EC, 2015b).
United Kingdom	20p/litre duty derogation on UCOME expired 31.3.2012	NI

NI: No information on tax incentives for biofuels found.

From Table 1.4 above the following conclusions can be drawn:

- There is a large variation in tax incentive for biofuels throughout the EU. Of the countries where data on tax incentives for biofuels were found, 50% has no tax incentives for biofuels. The remaining countries have many different incentives in place (described in the following bullets).
- As noted in Section 1.3.3.1, 25 of the EU's 28 Member States rely on blending or GHG reduction obligations to increase supply and demand of biofuels, and meet their RED transport target for 2020. This reduces the need to also provide financial incentives to meet the target, and only six EU Member States were found to provide financial incentives for biofuels that are sold in low blends (i.e. up to the FQD blending limits)
  - Slovenia and the Slovak Republic give excise duty reductions for low blends only up to a certain lever of biofuel content. Above this level normal rates apply.
  - Sweden provides an energy tax reduction and CO_2 tax exemption for low-level biofuel blending up to a certain level.
  - Finland also has tax incentives for biofuels as they can profit from lower CO_2 taxation
  - France has biofuel tax incentives which reduce over time
  - Lithuania only provides tax incentives for bioethanol volumes that exceed the blending obligations.
- Member States were found to have specific tax incentives in place for higher blends, namely
  - Germany and Hungary have incentives for E85 (in Hungary, these reduce over time)
  - Croatia provides an excise duty exemption for B100 only
  - Latvia has financial incentives for higher blends (30-100 vol% FAME, 70-85 vol% ethanol).
  - Lithuania provides an excise duty reduction for ethanol blends higher than 30%
  - Romania and Slovenia have excise duty exemptions for all pure biofuels
  - Sweden provides exemptions for high blending and HVO
  - the Czech Republic has no tax incentives for mandatory blended products, but there are incentives for FAME blends higher than 31vol% (with 100% FAME exempt from excise duties), for ethanol blends between 70 and 85 vol% and for 2nd generation biofuels from pilot projects.

1.3.3.3 Realisation of the targets in 2020

In Table 1.5 the development of the shares of renewable energy in transport (RES-T) are presented per Member State.

These data include all forms of renewable energy in transport (besides biofuels mainly renewable electricity in rail transport), in line with the calculation provisions of Article 3(4) of the RED (Source: Eurostat). Actual biofuel shares are therefore lower than these, and will be given in Section 1.4.2.2.

Most Member States have shown a steep increase in the share of renewable energy in transport in the period 2004 to 2010. The average share of RES-T then dropped in 2011, by 1.4% on average but much more in some counties such as the Czech Republic, Spain, Finland, France and Portugal. This can be mainly explained by the time required for the implementation of the biofuel sustainability schemes required by the RED (from 2011 onwards, Eurostat only included biofuels of countries that fully complied with the RED's sustainability criteria in Article 17 and 18 (source: Eurostat)), and partly also by developments of biofuel cost over the years (EEA, 2015)(EurObserv'ER Biofuels Barometers of recent years). Since 2011, however, implementation of the relevant RED provisions has progressed, and the shares have remained stable or increased in all countries.

The table clearly shows the variation in renewable energy shares throughout the EU. Sweden has by far the largest share in 2013, with 16.7%, clearly aiming for a much more ambitious level of biofuels in 2020 than needed for the RED and FQD targets. Austria, Germany, Finland and Poland have also reached RES-T shares of 6% or higher in 2013, and are well on their way to the 10% target in 2020. On the other side of the spectrum, a number of countries, namely Estonia, Spain and Portugal, reported shares of less than 1%. These different shares per Member State are typically the effect of the large variations in policies and blending obligations described in the previous two paragraphs, driven by very different ambitions and policy strategies in the various countries.

Note that when comparing the blending obligations that were shown in Table 1.3 with the results in Table 1.5, these data are not always consistent. This is due to a number of factors, most notably the fact that Member State policies change over time (Table 1.3 shows the obligations in 2014), the effect of financial incentives (Table 1.4) and other types of renewable energy in transport such as renewable electricity use in rail and road transport: these contribute to the share of RES-T in the table below, but are not included in biofuel quota.[26]

Table 1.5 Share of energy from renewable sources in transport (RES-T)

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
EU-28	1.0%	1.4%	2.1%	2.8%	3.5%	4.3%	4.8%	3.4%	5.1%	5.4%
Austria	2.5%	2.8%	5.5%	6.3%	7.5%	9.1%	8.7%	7.7%	7.8%	7.5%
Belgium	0.2%	0.2%	0.2%	1.3%	1.3%	3.4%	4.2%	4.0%	4.4%	4.3%
Bulgaria	0.4%	0.3%	0.6%	0.4%	0.5%	0.5%	1.0%	0.4%	0.3%	5.6%
Cyprus	0.0%	0.0%	0.0%	0.0%	1.9%	2.0%	2.0%	0.0%	0.0%	1.1%
Czech Republic	1.1%	0.5%	0.8%	1.0%	2.3%	3.7%	4.6%	0.7%	5.6%	5.7%
Germany	1.9%	3.7%	6.4%	7.4%	6.0%	5.5%	6.0%	5.9%	6.9%	6.3%
Denmark	0.2%	0.2%	0.3%	0.3%	0.3%	0.4%	0.9%	3.3%	5.5%	5.7%
Estonia	0.1%	0.2%	0.1%	0.1%	0.1%	0.2%	0.2%	0.2%	0.3%	0.2%
Greece	0.0%	0.0%	0.7%	1.2%	1.0%	1.1%	1.9%	0.7%	1.0%	1.1%
Spain	0.8%	1.0%	0.7%	1.2%	1.9%	3.5%	4.7%	0.4%	0.4%	0.4%
Finland	0.5%	0.4%	0.4%	0.4%	2.4%	4.0%	3.8%	0.4%	0.4%	9.9%
France	1.1%	1.7%	2.0%	3.6%	5.8%	6.2%	6.1%	0.5%	7.1%	7.2%
Croatia	0.4%	0.4%	0.4%	0.5%	0.6%	0.7%	0.5%	0.4%	0.4%	2.1%
Hungary	0.4%	0.4%	0.6%	1.0%	4.0%	4.2%	4.7%	5.0%	4.6%	5.3%
Ireland	0.0%	0.0%	0.1%	0.5%	1.3%	1.9%	2.4%	3.9%	4.1%	5.0%
Italy	1.0%	0.8%	0.9%	0.8%	2.3%	3.7%	4.6%	4.7%	5.8%	5.0%
Lithuania	0.3%	0.5%	1.7%	3.7%	4.2%	4.3%	3.6%	3.7%	4.8%	4.6%
Luxembourg	0.1%	0.1%	0.1%	2.1%	2.1%	2.1%	2.0%	2.1%	2.2%	3.9%*
Latvia	1.1%	1.3%	1.2%	0.9%	0.9%	1.1%	3.3%	3.2%	3.1%	3.1%
Malta	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	1.8%	3.1%	3.3%
Netherlands	0.2%	0.2%	0.5%	2.9%	2.7%	4.3%	3.1%	4.6%	5.0%	5.0%
Poland	0.7%	1.0%	1.2%	1.2%	3.6%	5.1%	6.3%	6.5%	6.1%	6.0%

[26] Higher blends might also be used in non-road modes such as diesel rail transport. However, as these fuels are outside the scope of the FQD, these are not included in this assessment

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Portugal	0.2%	0.2%	1.3%	2.2%	2.3%	3.6%	5.3%	0.4%	0.4%	0.7%
Romania	0.9%	1.0%	0.8%	1.8%	2.7%	3.5%	3.2%	2.1%	4.0%	4.6%
Sweden	3.8%	3.9%	4.7%	5.7%	6.3%	6.9%	7.2%	9.5%	12.9 %	16.7 %
Slovenia	0.4%	0.3%	0.6%	1.1%	1.5%	2.0%	2.8%	2.1%	2.9%	3.4%
Slovak Republic	0.6%	1.1%	2.9%	3.5%	3.9%	4.9%	4.8%	5.0%	4.8%	5.3%
United Kingdom	0.2%	0.3%	0.6%	1.0%	2.1%	2.7%	3.1%	2.7%	3.7%	4.4%

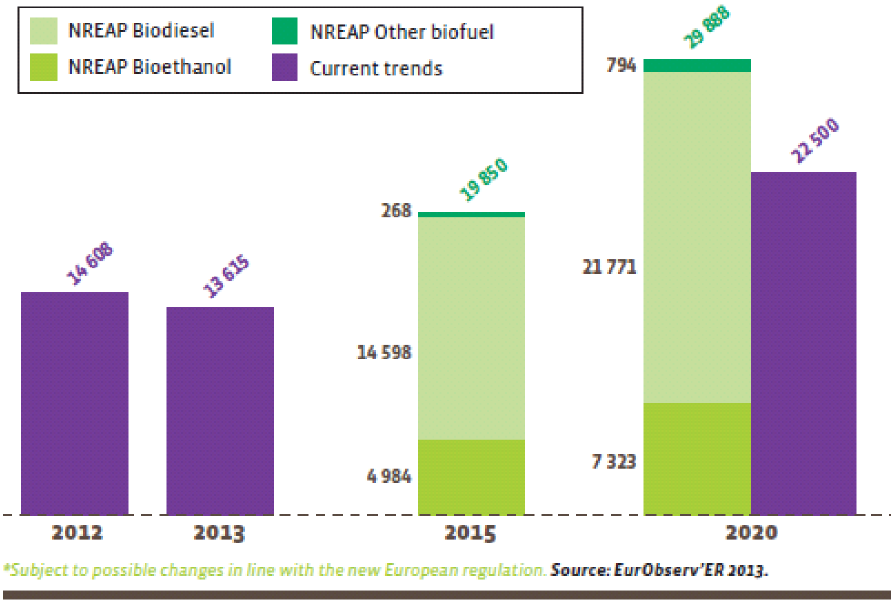
Source: Eurostat, 2015

Progress towards the 6% GHG reduction target of the FQD cannot be assessed in a similar way, as the GHG intensity data of the Member States or fuel suppliers are not yet monitored and reported on at EU level. Furthermore, the calculation methodology to determine the GHG intensity of fossil fuels, electricity, natural gas and various other types of fuels used in road transport has only recently been decided on (Council Directive 2015/652) and the GHG intensity reporting obligation that is included in Article 7a of the FQD was put on hold during the decision making process.

When looking at the question whether the renewable energy target for transport of the RED will be met in 2020, as a first step these trends can be compared with the indicative trajectories that the Member States provided to the Commission in their National Renewable Energy Action Plans (NREAPs)[27]. In the NREAPs the Member States have estimated the biofuel volumes they require for meeting the 10% target of the RED, for 2015 and 2020. From this comparison, EurObserv'ER (2014) concludes that on an EU level, the current biofuel consumption trend is insufficient to meet the 2020 biofuel volumes as predicted in the NREAPs, and to meet the RED target in 2020. Their graph of the currently realised biofuel volumes against the NREAPs quantities and EurObserv'ER's projection for 2020 is depicted in Figure 1.2. They expect that only 75% of the biofuel volumes planned for in the NREAPs will be realised in 2020.

[27] The NREAPs and links to related databases and forecasts can be found at ec.europa.eu/energy/en/topics/renewable-energy/national-action-plans;

Figure 1.2 Comparison of the current biofuel consumption for transport trend against the NREAP



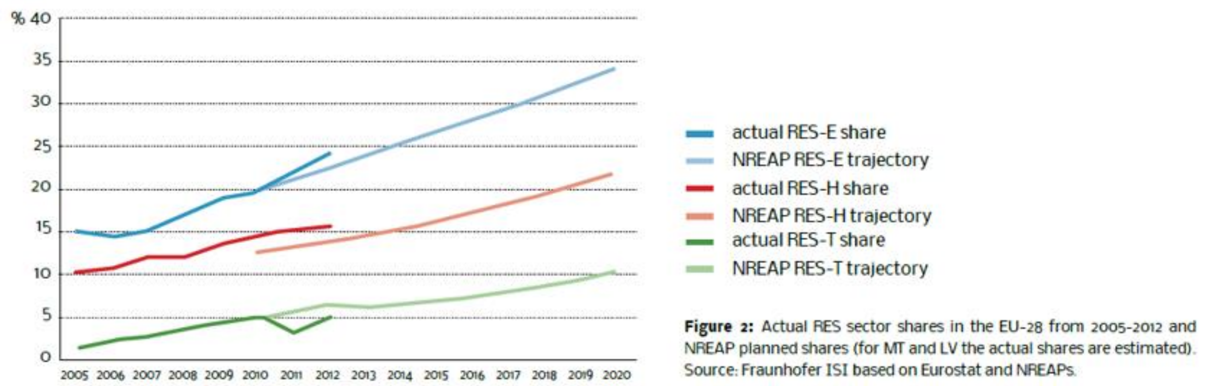
Source: National Renewable Energy Action Plan roadmaps (ktoe) (EurObserv'ER, 2014)

Note that this projection is relatively uncertain, as EurObserv'ER indicates that it is subject to the new European legislation on ILUC (as noted in the footnote of the graph), which may have a significant impact on the share of double counting biofuels in the total. The projection does take into account the draft ILUC directive that was subject to agreement with the Energy Council at the time of the analysis, and thus assumed the incorporation of a cap of 7% on conventional biofuels as well as 0.5 % of advanced biofuels (all in energy content).

The conclusion that progress is currently too low to meet the 2020 RED target is also confirmed by the EU Tracking Roadmap 2014 (Eufores, 2014): according to this roadmap, renewable energy in transport (RES-T) has seen less progress than the heating and cooling sector (RES-H/C) and electricity production (RES-E). In 2012, only 8 Member States have shown progress in line with their NREAP 2011 target, while the other 20 Member States lagged behind. Both the projected trajectory according to the NREAPs and the actual developments in RES-T shares are depicted in Figure 1.3.

Figure 1.3 Comparison of the current trends with trajectories presented in the NREAPs (National Renewable Energy Action Plan)

RES SECTOR SHARE IN FINAL SECTORAL ENERGY CONSUMPTION



Source: Eufores, 2014

Similar conclusions were drawn in a study that approached this issue more from a vehicle fleet and fuel demand perspective, and also taking into account the potential impact of the ILUC proposal: (JEC, 2014) assessed different fuel demand scenarios in the period until 2020, taking the ILUC proposal and amendments (status end 2013) into account. JEC finds that none of these will lead to achieving the RED and FQD targets. Their fuel demand scenarios were based on different regulatory sets of provision (including, for example, higher biofuel blend grades) and a range of other assumptions related to the vehicle fleet (more on this study in Section 1.7.2).

The Commission's recent Renewable Energy Progress Report, COM(2015)293, also finds that progress in the past five years (until 2013) towards the 10% transport target of the RED has been slow. Achieving 10% renewable energy target for transport by 2020 is therefore considered to be challenging, but still feasible, and progress achieved in some Member States testify to this.

Note that none of the above assessments take into account the increase of the multiplication factors for electricity from renewable sources in rail and road transport, as was included in the final ILUC decision. As this will increase the contribution of this energy source towards the RED target, it will reduce the need for biofuels to meet this target. This effect will depend on the Member States' implementation of the ILUC Directive, but the potential impacts can be illustrated by the following calculations, based on the expected consumption of renewable electricity in rail and road in 2020, as presented in the NREAPs:

- In the NREAPs, the 2020 EU-wide contribution of electricity from renewable sources towards the RED target is 0.7% for rail, and 0.5% for road transport. These percentages take the current RED multiplication factors into account, of 1 for electricity use in rail, and 2.5 for road.

- As the ILUC Directive increases these multiplication factors to 2.5 for rail and 5 for road, the EU-wide contribution of electricity from renewable sources towards the RED target increases to 1.6% and 1.0%, respectively.

- The contribution of other renewable energy sources, mainly biofuels, towards the 10% transport target of the RED could thus reduce by a total of 1.5 percentage point, compared to the situation without the ILUC Directive and the NREAPs.

- These effects differ between Member States, where some countries have higher shares of electric rail and road transport and thus higher impacts of this measure (notably Austria and Sweden), and others have much lower shares (including Estonia, Lithuania, Cyprus and Poland).

As mentioned above, the actual impacts of these multiplication factors on overall biofuel consumption in 2020 will depend on the Member States' implementation of the ILUC Directive.

Further discussion on expected developments and forecasts beyond 2020 is included in Section 6 of this chapter.

1.3.3.4 Introduction of higher levels of biocomponents in Member States

According to the NREAPs and RED progress reports most Member States have not reported any specific actions on marketing of biofuels nor expressed the need for mid or high blends in their strategies to realise the RED and FQD targets. Nevertheless, a number of countries have implemented policy measures aimed to facilitate marketing of the increasing biofuel volumes, notably by

- actively introducing E10,
- allowing B8 to be introduced,
- acknowledging the potential benefits of fungible (drop-in) biofuels such as HVO
- providing fiscal benefits to higher blends such as E85 or B30 (as described in Section 1.3.3.2) or subsidies for E85 compatible vehicles

In the following, the policy measures that have been implemented so far to promote these options are described in more detail.

1.3.4 Member State policies for high blends

This Section is based on literature, interviews with biofuel suppliers, petroleum companies and vehicle manufacturers, complemented by interviews with relevant national authorities for three Member States: Germany, Finland and France (see Annex 1). These three Member States were chosen as case studies as they have relatively ambitious biofuel policies, they have introduced E10 on their market and have relatively high shares of biofuels (6.3%, 9.9% and 7.2%, respectively, in 2013, see Table 1.5). Since not all Member States have been thoroughly assessed, this overview only provides a snapshot of specific policy actions. However, as higher blends are typically only actively pursued in countries with higher biofuel shares and ambitious targets, the policies and actions described can be seen as key and illustrative examples of the current EU developments in this area.

1.3.4.1 Member States with experience with E10

In Germany, Finland and France. E10 has been introduced in recent years. In all three countries bringing E10 onto the market is not obligatory, fuel suppliers may choose whether to offer E5 or E10 to their consumers. However, the blending obligations and related penalties are set at such a level that fuel suppliers find it necessary to increase the market share of E10, to enable them to sell the biofuel volumes required by the obligation.

Nevertheless, the strategy and policy measures taken varied between the countries, as well as the resulting effects: E10 was successfully introduced in France and Finland, but encountered significant resistance in Germany, resulting in limited market shares in that country. The actions taken can be divided into information provision and incentives and obligations.

Information provision and involvement of stakeholders

Since not all vehicles in the fleet can drive on E10, clear and accurate information provision to the vehicle owners is considered key to the successful introduction of E10. Additionally, apart from this technical issues, consumers also need to have confidence in the E10, both from a technical but also from an environmental point of view, otherwise they are likely to continue to buy the E5. The importance of these issues is clearly demonstrated when comparing the three countries analysed here.

In **France**, E10 was successfully introduced in April 2009. The government, together with car manufacturers, prepared for this introduction by compiling a list of E10 compatible vehicles, pumps were clearly labelled and the ethanol industry actively informed consumers using promotional literature (e.g., flyers). There was no specific opposition to E10 by stakeholders such as French NGOs.

Germany introduced E10 in December 2010, with a very different outcome. Before this introduction meetings with stakeholders, including car manufacturers, petroleum industry, etc. were held and concerted actions regarding user information and communication etc. were agreed upon. Despite these efforts, however, the introduction of E10 in Germany was hindered by low consumer acceptance. Reasons for this have been the strong opposition of NGOs due to concerns about the sustainability of the biofuels, and confusion caused by changing lists with compatible vehicles. The main lessons the national authorities have drawn from this are to improve the provision of information on the compatibility of vehicles, ensuring it is clear and correct, and to better explain the motivation behind the introduction of E10 to the general public and NGOs.

In **Finland** a special internet page on vehicle compatibility was set up to inform consumers as well: http://www.e10bensiini.fi/en. This website provides background information on the E10 fuel and contains a list of E10 compatible motors.

Tax incentives and blending obligations

As will be shown in Section 1.6.5, ethanol is more expensive than the petrol it replaces, and policies measures such as blending obligations and/or tax incentives are key to increase the biofuel volumes on the market. When these measures are effective and sufficiently ambitious, they automatically create a need for the fuel suppliers to move to higher blending levels such as E10: E10 allows them to add up to 6.8% of bioethanol to their petrol (on energy basis) instead of the 3.3% of E5.

In Germany, from the introduction of E10 in 2010 until the end of 2014, E10 was fully driven by the energy quota: fuel suppliers were required to put a minimum percentage of biofuels on the market, 6.25% by energy content in 2014. The associated fine for not meeting this quota, €19/GJ, was estimated to be roughly two times the fulfilment cost (although this factor varied depending on fluctuations in the market prices for biofuels and fossil fuels). The quota has been fulfilled in these years, and the amount of penalties were minimal. Since the beginning of 2015, the energy quota was replaced by a GHG reduction quota (see Section 1.3.3.1), with a penalty for not meeting the target of 0.47€/kg CO_2.

It is too early to assess the effect of this shift on the biofuel volumes and types, and therefore on the market share of ethanol and the need for E10 to meet these goals.

In **France**, the suppliers need the E10 sales to meet the blending obligation and prevent penalties, and make the E10 2 to 3 eurocents cheaper than E5, to encourage consumers with E10-compatible vehicles to buy the fuel. Tax exemptions, put in place to incentivise ethanol sales, are currently decreasing and will stop at the end of this year, but this is not expected to impact the growth of E10 sales, since the obligation de facto requires the fuel suppliers to sell E10.

In France, the fuel suppliers would like to see the tax exemption increased by a few €ct to make E10 more attractive. During the interview with the French ministry, it was explained that this is difficult to arrange due to the overlap between E5 and E10: E5 covers 0-5% ethanol and E10 covers 0-10%, thus creating overlap between the two blends. If there are tax differences between E5 and E10, it would de facto encourage E5 to be brought on the market as E10. This makes any tax advantage for E10 legally difficult to implement. During the interview, it was suggested that a modification of the Fuel Quality Directive, to ensure that E5 contains 0-5% ethanol and E10 5-10% (or even smaller ranges), would thus help from a government policy perspective: it would allow E10 to receive a higher tax incentive than E5.

E10 is broadly accepted (and sold) in **Finland**, because E10 is cheaper due to tax benefits (source: interview with government, E10 benefits from lower taxes on energy and CO_2). 70% of the vehicles are compatible to run on E10, and 60% actually run on E10, because car drivers prefer the cheaper option. According to the government official that was interviewed, there are even indications that consumers mix E85 with E10 to derive higher blends, because the fuels sales of E85 are about twice as much as would be expected from the market share of E85-compatible Flex Fuels Vehicles (E85 benefits from lower CO_2 taxes as well)[28].

The introduction of E10

Before the introduction of E10 in **Germany**, many refuelling stations offered three blends of petrol and two blends of diesel. With respect to petrol they offered E5 RON95, a RON91 fuel and a premium E5 RON98. In many cases the RON91 petrol has been replaced by the E10 RON95 (there is no E10 RON98 on the market), as this was seen to be the optimal solution considering refuelling station logistics and market share (economical) impacts. The result is that the national fuel sales statistics now show a very low share of RON91 (0.01%), and German refineries stopped providing it. The government official interviewed considered it

[28] This comment has not been substantiated further, it is recommended to further assess this issue to better understand the mechanisms that occur in the market.

possible that refuelling stations who still offer RON91 might in fact be selling E5 RON95 under the name of RON91, which is allowed legally due to higher quality of E5 RON95.

In **France**, before the introduction of E10, normally two grades of petrol were offered at service stations: a premium grade and E5 RON95. After the introduction of E10 most premium grades were replaced by E10.

1.3.4.2 Policy measures in other countries, in anticipation of the introduction of E10

There is no data on which Member States have started preparations for the introduction of E10, for example by adapting national legislation that allows oil companies to bring E10 on the market. In any case, this hasn't resulted in significant market shares of E10 in the Member States, besides Finland, France and Germany. For example, in the UK the national legislation allowed oil companies to supply petrol containing up to 10% ethanol since March 2013, in line with the EU standard for petrol (EN228), but until now no E10 has been brought on the market. The UK government decided in November 2013 to amend the Motor Fuel Regulations in order to guarantee the availability of E5 for another three years. Larger retailers selling more than three million litres or more must offer E10 unleaded and E5 super-unleaded until January 2017. Due to limited pump capacities smaller independent retailers have to choose what to offer (Department for Transport, 2013). This is in line with Article 3(3) of the FQD which obliges Member States to 'require suppliers to ensure the placing on the market of petrol with a maximum oxygen content of 2.7 % and a maximum ethanol content of 5 % until 2013 and may require the placing on the market of such petrol for a longer period if they consider it necessary. They shall ensure the provision of appropriate information to consumers concerning the biofuel content of petrol and, in particular, on the appropriate use of different blends of petrol.'

With respect to the latter, information provision to consumers, Poland has taken action on the labelling of E10 by drafting regulations for labelling requirements at the pump in February 2015. The marking methodology as laid down in these requirements should help consumers to distinguish the several blends. Information to be provided will include detailed information on the composition of E10. (ENDS Europe, 2015)

1.3.4.3 B8 in France

France faces problems with realising the blending obligation, because of its relatively ambitious targets: (7.7% energy content, of which 7% single counting and 0.7% double-counting). These levels exceed the maximum blending limits of both E10 (6.8% ethanol energy content) and B7 (6.4% FAME energy content), and other marketing options such as HVO or biofuel use in non-road transport are deemed to be insufficient to fill the gap. For this reason, France allows B8 on the national market since the start of 2015, making use of the provision in Article 4 of the FQD that allows Member States to permit the placing on the market of diesel with a FAME content greater than 7 % (see Section 1.3.2.2).

Until today almost no B8 have been brought on the market due to the discussion on the interpretation of this provision in the FQD, The European Commission, DG CLIMA communicated in a non-paper that Member States cannot go beyond B7 and anything above B7 requires a protection grade[29], but non-papers do not have a legal status. This has raised concerns about the practical implementation as well as a potential distortion of the market, as French service stations consist for 60% of supermarkets, which only have the infrastructure and facilities to sell 1 blend of diesel. They would have to choose which blend they will sell, and cannot offer both a protection grade and B8. The remaining (40%) service stations are linked to oil companies and could offer 2 grades premium/regular; they could introduce a higher diesel blend in a similar way as E10.

Because of the ongoing discussion the further introduction of B8 is currently on hold. Despite this interpretation issue, this case shows that certain Member States might encounter

[29] European Commission, Non-paper on the scope of the Fuel Quality Directive, Ref. ARES(2014)1760981 – 28/05/2014

problems with the current blending limits earlier than others due to the characteristics of their national fuel markets and the height of the blending obligations.

1.3.4.4 Fungible biofuels

Both France and Finland see fungible biofuels as part of the solution, but the higher prices of fungible fuels are seen as a barrier. Especially in Finland, where the individual target for renewable energy in transport was set twice as high as the 10% target of the RED, HVO has always been one of the key elements of its biofuel strategy, together with the introduction of E10 and E85. This is likely to be due to the large domestic production capacity of HVO (Neste Oil).

Currently, there is only one type of fungible biofuel on the market, HVO, produced by Neste Oil. Quantitative cost data for HVO are not available in public literature, and it is not traded publically as it is only produced by one company, but the fuel suppliers that were interviewed all confirmed that FAME is the cheaper biodiesel option, because the production process is inherently less complex than for HVO. When fuel suppliers decide on an optimal biofuel strategy in a certain country, they compare the different options, including HVO, to meet the blending obligations. Fungible fuels may be the optimal solution in some cases when comparing with the cost of introducing higher blends of FAME or ethanol. However, some fuel suppliers expressed their concerns that HVO is only provided by one producer, resulting in a lack of a competitive market for this product. Specific data on this cost comparison are confidential, and likely to depend on the specific situation and Member State policy. One fuel supplier indicated that they are actively pursuing the development of another type of fungible biofuel, but this is still in the R&D phase and a decision to invest in a larger scale plan will not be made before 2018.

1.3.4.5 Other blends

In **France** E85 has been stimulated with subsidies for E85 compatible vehicles; consequently, fuel tax on E85 is the lowest as allowed by the European legislation. Although 500 fuel stations are currently offering E85 in France, the market share of E85 vehicles is quite low. According to the interviews with government officials, this is mainly due to the car manufacturers not focussing on selling E85 vehicles, which may be interpreted as a sign of low consumer interest. It was further mentioned by government official that whereas in Sweden, retrofitting a petrol car with a flex fuel kit is legally allowed, this is not the case in France. This was also perceived to be a barrier to the uptake of E85 in France.

During a meeting with Renault, they stated that although the petrol options in **France** are labelled as E5 and E10, they are actually a mix of ethanol and ETBE (ethyl tertiary-butyl ether) derived from bio-ethanol so the oxygen content of the blend matches that of E5 and E10 respectively. For example, the E10 in France is 7% ethanol + 7% (approximately) ETBE so that the resulting blend has an oxygen content of 3.5% by weight. The use of ETBE in France is driven by the capacity of the largest local refiner TOTAL to manufacture ETBE. TOTAL also distributes its products in other countries in the EU. According to VW, in **Germany** there is some ETBE use but most E5 and E10 are ethanol blends.

In **Finland** E85 is completely produced from domestically produced waste, according to the government officials that were interviewed. Although the target for 2020 is estimated to be mainly realised by the use of E10 and fungible biofuels (HVO), E85 will play a role in the strategy to be completely carbon neutral in 2050. Therefore, from 2030 onwards, all new built vehicles should be able to drive carbon neutral. Finland is moving forward to achieve both this 2030 and the longer term target, for example by legally allowing retrofit of vehicle to achieve E85 compatibility

1.3.5 Conclusions

Biofuel consumption in Member States is being almost fully policy driven. At the EU level, the main drivers are the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) (EC, 2009a and EC, 2009b). The RED sets a binding 10% target (energy content) for renewable energy in transport in 2020, the FQD a reduction target for the GHG intensity of fuels of 6%, in 2020. Both directives also define sustainability criteria that the biofuels have to meet to count towards the targets, the RED furthermore regulates that biofuels from waste and residues are counted double towards the 10% target. Member States are free to decide on the policy measures to achieve these targets, within the boundaries provided by the EU regulations. The development of standards for high blend fuels is ongoing within CEN.

Recently, it has been decided to address the issue of indirect land use change effects by implementing a number of changes to both the RED and FQD, the main measures are that biofuels and bioliquids produced from cereal and other starch-rich crops, sugars and oil crops and from some energy crops can contribute no more than 7% to targets in the RED, and the introduction of a sub-target for advanced biofuels with a reference value of 0.5% in the RED. The effect of this new legislation is, however, as yet unclear.

The FQD also defines blending limits for FAME and ethanol, limiting the share of FAME in diesel to 7 vol% (6.4% energy content) and the share of ethanol in petrol to 10 vol% (6.8% energy content). Member States are, however, permitted to allow the placing on the market of diesel with a FAME content greater than 7%, under certain conditions.

The EU's energy and climate policy framework for 2030 does not provide binding targets for renewable energy in transport. The post-2020 renewable energy policy as well as the future policy on sustainable biomass and biofuels is yet to be shaped.

By 2014, almost all Member States, with the exception of Latvia, Cyprus and Estonia, had implemented biofuel obligations (quota) for fuel suppliers. However, the level of these obligations vary significantly between countries, from an average target less than 3% in Croatia and Greece, to 7% or higher in France, Poland and Slovenia. Member States have clearly not foreseen the same growth paths towards 2020. In addition, tax incentives for biofuels are provided in approximately half of the EU Member States, including one of the countries without obligation, Latvia (there is no information on tax incentives for Cyprus, and no incentive in Estonia). Nine Member States have specific tax incentives in place for higher blends: Germany, Hungary, Croatia, Latvia, Lithuania, Romania, Slovenia, Sweden and the Czech Republic. These incentives do differ, however, as they target different blends or provide different levels of incentives.

When assessing the progress of the various Member States towards the 10% target of the RED for 2020, current trends are found to be insufficient to meet the target on an EU level. However, achieving the target by 2020 remains feasible, as concluded in the Commission's recent Renewable Energy Progress Report (COM(2015)293). There is a significant variation in renewable energy shares throughout the EU (2013 data). Sweden has by far the largest share in 2013, with 16.7%, clearly aiming for a much more ambitious level of renewable energy in 2020 than needed for the RED target. Other Member States, notably Austria, Germany, Finland and Poland, are well on track to meet the target. On the other side of the spectrum, a number of countries, namely Estonia, Spain and Portugal, reported shares less than 1%. These different rates of progress are typically the result of large variations in blending obligations and financial incentives. Progress towards the 6% GHG reduction target of the FQD cannot be assessed in a similar way, as the GHG intensity data of the Member States or fuel suppliers are not yet monitored and reported on at EU level.

Blending limits have not been an issue in many Member States yet, as most biofuel obligations are still below these limits. Various options to go beyond the B7 and E10 limits have been implemented, mostly, but not limited to the Member States with high blending obligations and biofuel shares: Until now, E10 has been introduced in three Member States: Finland, France and Germany, where the rest of the EU has E5 or only pure petrol on the market (see the overview in the next chapter). Experiences with the introduction of E10 vary between these three countries, these are described in Section 1.3.4.1. B8 has been allowed in France (although it is not yet being sold yet), fungible (drop-in) biofuels such as HVO are being blended in the EU (but market shares are limited due to higher cost) and incentives for E85 are in place in some Member States (at least in France and Finland).

1.3.5.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations for improvement of the biofuel policy framework can be derived:

- Closely monitor and assess Member State policies and progress in the coming years, to ensure that the 2020 targets are met. A number of Member States with currently very low biofuel shares (Estonia, Spain and Portugal in particular, but see Table 1.5 for more information about the other countries) need to follow very ambitious growth paths in the coming years.
- The impacts of the ILUC decision on Member State policies and progress towards the targets should be assessed, to ensure that policies are adequately modified and the 2020 target is met with these new conditions. To facilitate this, it is recommended to revise the policy plans and indicative trajectories that the Member States submitted in their National Renewable Energy Action Plans, to align them with this new regulation. Potential issues that may arise due to the ILUC decision, for example related to potential insufficient supply of advanced biofuels or biofuels from waste and residues, will be further analysed in Section 1.6.
- Progress towards the FQD target for the GHG intensity of transport fuels should be monitored at the EU level, similar to the monitoring and reporting for the RED. The methodological basis for this monitoring was recently decided on, and laid down in Council Directive (2015) 652 (which is to be transposed by Member States by April 2017)
- Member States should be encouraged to assess what fuel blends they expect to need to meet the 2020 targets. As a start, it is recommended that all Member States prepare for the introduction of E10, as this allows an increase of the level of biofuels in petrol with relatively little effort (see Section 1.4.3 for a further assessment). This is likely to be necessary to supply the biofuel volumes to the market that are required to meet the 10% targets.
- Member States should furthermore develop plans for post-2020 policies for biofuels, and for the expected contribution of biofuels in their country towards the 2030 EU-wide target of 27% renewable energy. This will allow stakeholders to anticipate and prepare for future developments and demand.
- The FQD sets maximum contents of biofuels and, for instance allows E5 as a petrol with 0-5 vol% ethanol and E10 to contain 0-10 vol% ethanol. Avoiding such overlap in specifications by setting minimum level too could facilitate implementation of (financial) incentives for biofuel.

1.4 Biofuel consumption and distribution

1.4.1 Introduction

This Section discusses the impact of new biofuel blends on fuel distribution practices. Stakeholders involved in the fuel distribution chain mainly include refineries, oil companies, fuel suppliers and filling stations owners. The structure of this Section is as follows:

- Current market shares and fuel sales of petrol and diesel are given in Section 1.4.2.
- The potential biofuel levels that could be achieved with the B7 and E10 blending limits are assessed in Section 1.4.4.
- The structure of the fuel distribution market is discussed in Section 1.4.4.
- Technical opportunities and barriers are identified in Section 1.4.5.
- Non-technical opportunities and barriers are described in Section 1.4.6
- Conclusions and recommendations that can be drawn from these Sections can be found in Section 1.4.7

1.4.2 Current fuel sales

1.4.2.1 Market shares of petrol and diesel in transport

The current diesel and petrol fuel sales are presented in Table 1.6 (EU-level average) and Figure 1.6 (data per Member State). The diesel-to-petrol ratio varies significantly between Member States, as can be seen in Figure 1.6.

Refineries only have limited flexibility in the ratio of petrol and diesel they can produce, and the current EU fuel output does not meet EU fuel demand: 10% of diesel demand needs to imported, 40% of EU petrol production is exported[30]. From an economic point of view, oil companies would like to limit the level of diesel imports and the level of petrol exports. This deficit of diesel and surplus of petrol is the result of the fact that heavy duty vehicles must run on diesel to achieve the desired (technical) performance, in combination with Member State fuel taxation regimes that favour diesel over petrol (this is the case in all EU Member States, with the exception of the UK which has equal excise duties for diesel and petrol, status 2013[31]).

The demand for biofuels will impact these figures:

- increasing the share of biodiesel will may reduce the need for the import of diesel,
- replacing petrol by biopetrol could potentially increase export levels.

The net effect will depend on the balance between these two types of biofuel.

Oil companies and fuel suppliers will take this effect into account when deciding on the fuels they will supply as it effects the economics of these decisions. The potential impact of increased biofuel demand on refineries will be evaluated in Part 3 and 5 of this study.

Table 1.6 Share of diesel and petrol versus the share of biodiesel and biopetrol in the EU in 2014

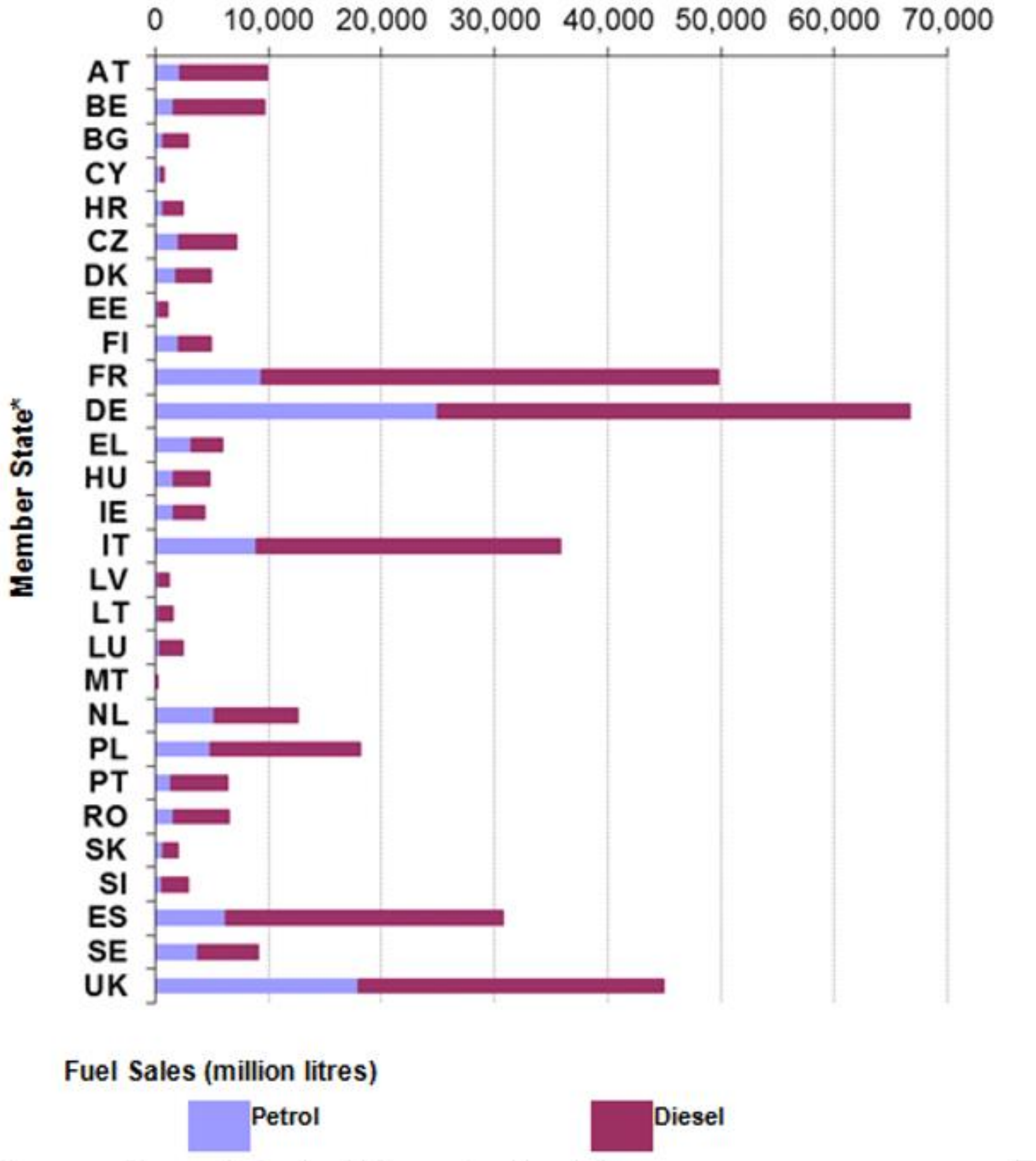
Diesel	70%	Biodiesel	80%
Petrol	30%	Biopetrol	20%

Source: Eurostat, 2015

[30] http://www.epure.org/media-centre/opinion-editorial/ethanol-best-choice-achieve-higher-ghg-savings#_ftn3 based on FuelsEurope/Eurostat/Biofuels Barometer

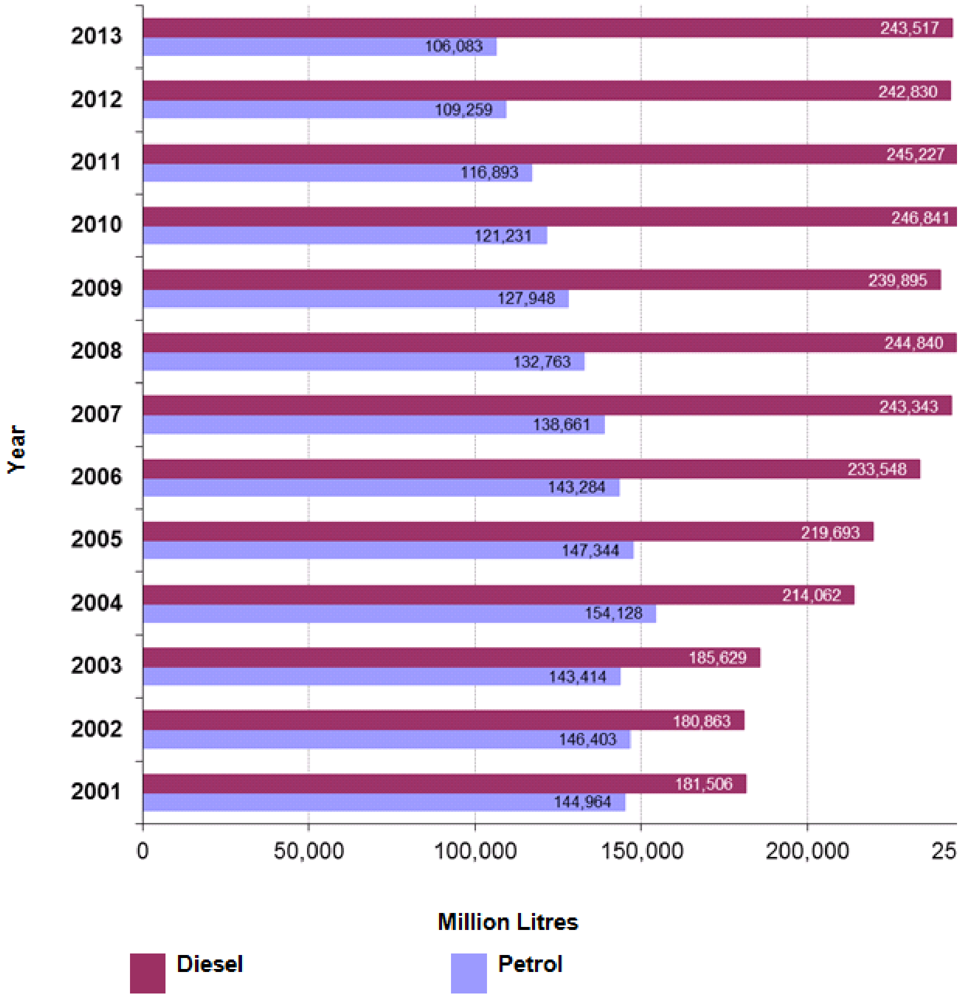
[31] See http://www.eea.europa.eu/data-and-maps/daviz/road-fuel-excise-duties#tab-chart_1

Figure 1.4 National fuel sales by fuel type across the EU (million litres)



The shift to diesel is still ongoing in the EU, as can be seen in the data of Figure 1.5. This trend is expected to continue in the coming years: in 2020 diesel volumes on the European market are predicted to be four times as high as petrol sales (Ricardo-AEA, to be published).

Figure 1.5 Temporal trends in EU fuel sales (Ricardo AEA, to be published)

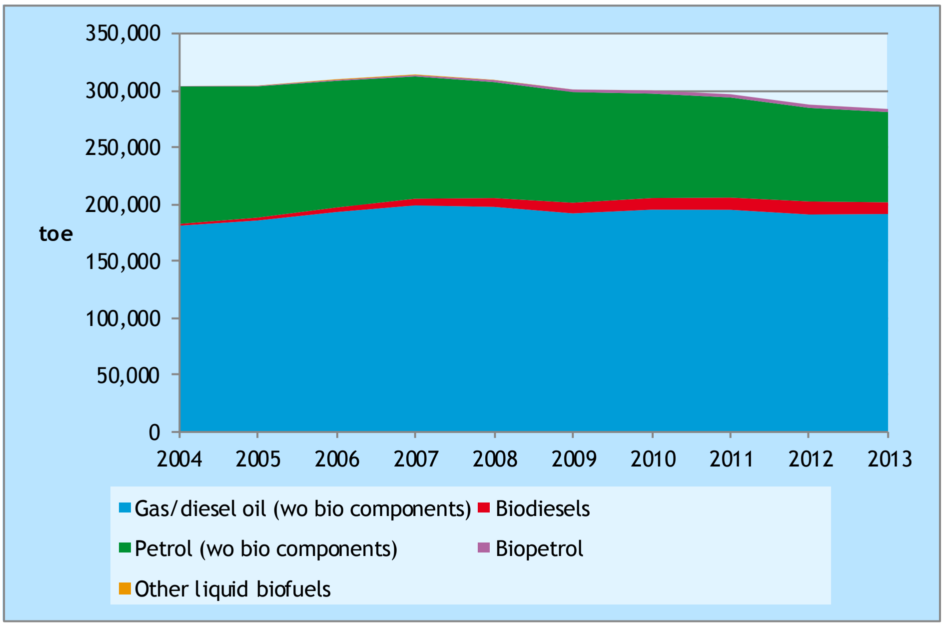


* Excludes France in 2003 - 2005, as no submissions were provided. Excludes Luxembourg in 2007 to 2009 and Malta in 2006 and 2009 as no reports were provided. In addition, the EU expanded in 2004, 2007 from 15 to 27 Member States and in 2013 to 28 Member States.

1.4.2.2 *Biofuel consumption and developments over the years*

In 2013, 4.6% of the EU's transport fuels was biofuels (in terms of energy content, rather than volume), which amounts to 13.6 Mtoe (source: Eurostat data). 79% of this was biodiesel, mostly FAME, 20% was biopetrol, the remainder mostly biogas fuel (Eurobserver, 2014). Putting these data into perspective, the total development of transport energy consumption in the EU is shown in Figure 1.6. The share of biofuels has clearly increased since 2004, but the large majority of transport fuels are still diesel and petrol.

Figure 1.6 Final Energy Consumption – Transport

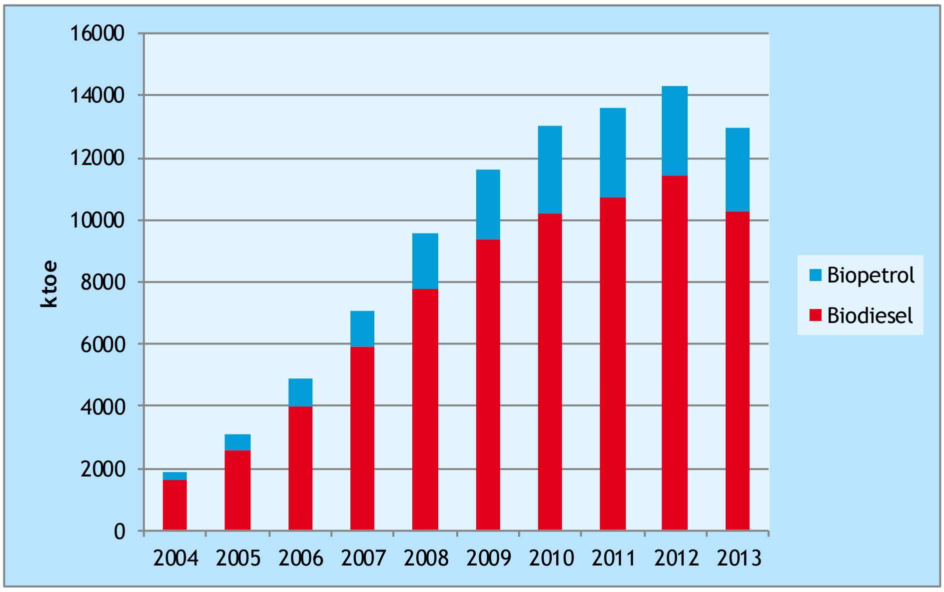


Source: Eurostat, 2015

Looking into the trends of biofuel consumption in more detail (Figure 1.7) it can be seen that after a steep growth of biofuel demand in the EU between 2004 and 2009, the growth curve has levelled off, and demand even dropped between 2012 and 2013. This is mainly explained by the introduction of the sustainability criteria (these Eurostat data only take into account biofuels that comply with the criteria), policy changes (e.g. lowering of the target in Spain, see Section 1.3.3.1) and an increasing use of double counting biofuels (from waste and residues, see Section 1.6.2.1) to meet the biofuel obligations.

The relatively large share of biodiesel in the biofuel mix is mainly due to economic reasons (source: interviews with fuel suppliers). As mentioned in Section 1.3.3.1, some Member States have set minimum levels of biopetrol in their overall biofuel obligations to specifically ensure that the market also demands petrol-replacements, and a diverse mix of biofuels is developed. The biodiesel consumed in the EU is mainly FAME, with HVO having a market share of about 7 to 8 percent (source: Neste Oil).

Figure 1.7 Development of biofuel consumption in EU-28 between 2004-2013



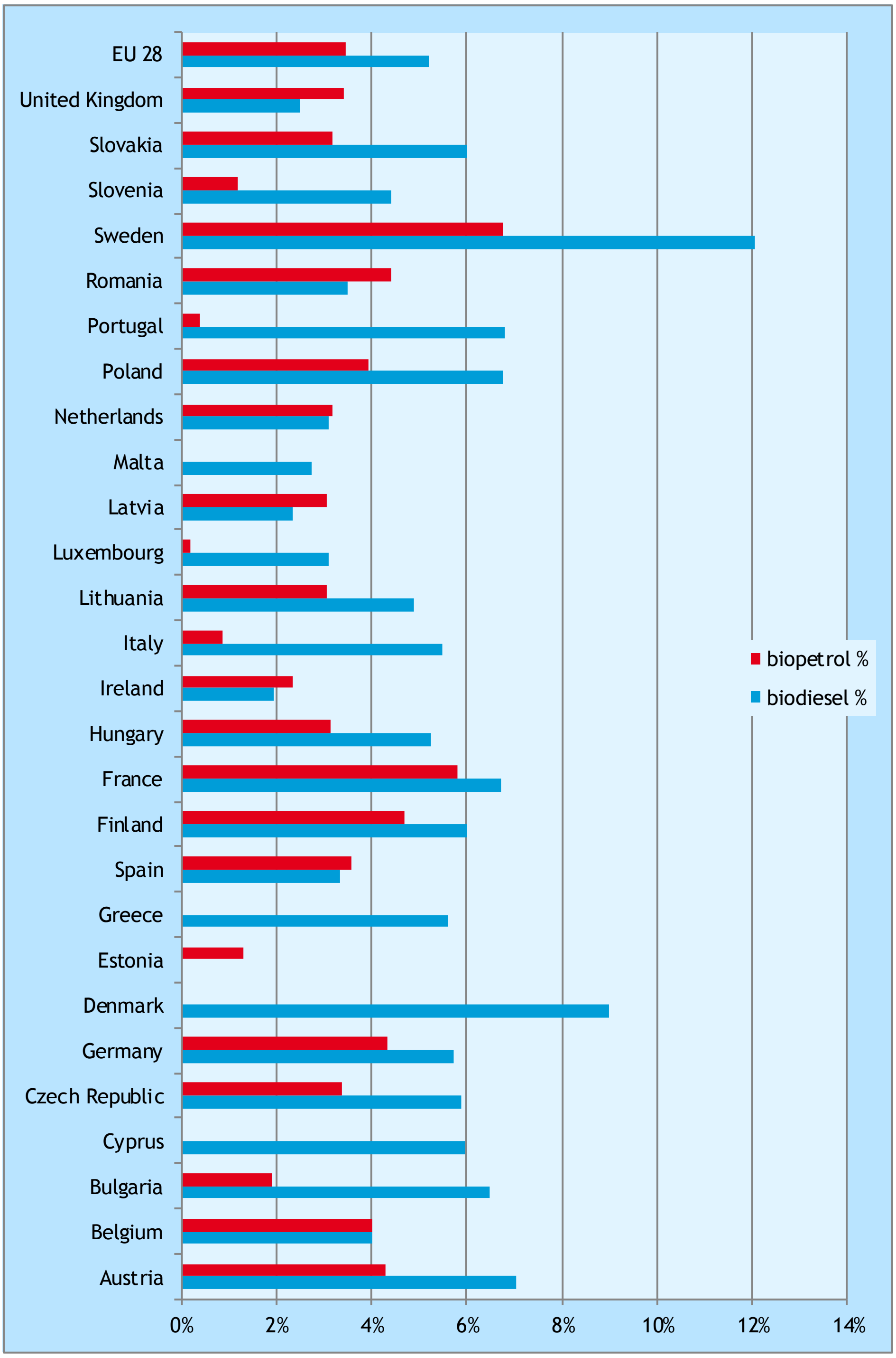
Source: Eurostat, 2015 (double counting not taken into account)

With a 4.6% average share of biofuels in total EU transport fuel sales (based on energy content), the variations between Member States are quite significant, as can be seen in Figure 1.8. Sweden clearly has the highest share, more than 16% in 2013, and another fifteen Member States have achieved market shares above 4%, in 2013. Nevertheless, there were still quite a few countries with shares below 1%: Bulgaria, Estonia, Greece, Spain, Cyprus, Malta, Portugal and Finland.

In the EU as a whole, and in most Member States, biodiesel has a higher share in diesel than biopetrol has in petrol, as shown in Figure 1.8 – the only exceptions are the UK, Romania, the Netherlands, Latvia, Ireland, Spain and Estonia. Belgium has equal (4.0%) biofuel shares in both petrol and diesel.[32]

[32] Details about the share of FAME and HVO in the biodiesel consumption data are not reported by Eurostat. National consumption data of HVO are confidential, but NesteOil, the main producer, reports that HVO was sold to 17 of the 28 Member States (source: NesteOil).

Figure 1.8 Shares of biodiesel and biopetrol in total diesel and petrol sales, respectively, in 2013



Source: Eurostat, 2015

Comparing these data with the current blending limits of B7 and E10:

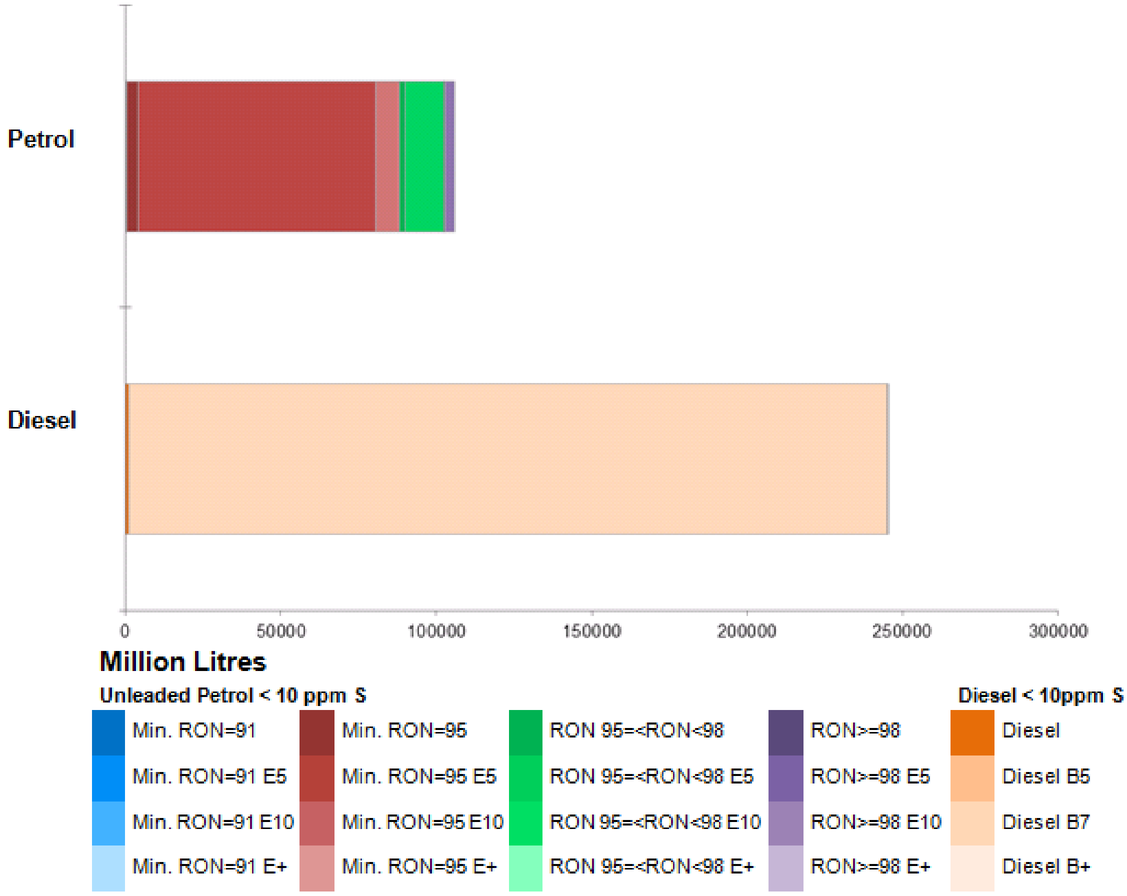
- six Member States achieved a higher share of biodiesel sales than 7 vol%, i.e. 6.4 % energy content: Austria, Bulgaria, Denmark, France, Poland, Portugal and Sweden. This can be achieved with sales of FAME in higher blends in captive fleets (B20, B30 or B100), or by adding HVO.
- no Member State exceeded the E10 level, i.e. 6.8% energy content, although Sweden just reached this level.

Only Sweden had an overall biofuel share above the 7% energy content that was set as limit for biofuels from food-based crops to count towards the RED target in the recent ILUC decision. Note that this does not mean that they overshoot the 7% cap, as part of Sweden's biofuels are produced from waste and residues (exact data are on this share are, however, not available as Eurostat currently does not differentiate between food-based and other types of biofuels) and Sweden already exceeds the 10% target – the cap only applies to the biofuels that count towards the target.

1.4.2.3 Petrol and diesel blends in the Member States

Looking at the type of blends used to achieve these shares, the annual Fuel Quality Monitoring reports of Member States can be of help. Based on the reports submitted over 2013, the shares of the different blends on the European market are depicted in Figure 1.9 (EC, 2015c).

Figure 1.9 EU Fuel Sales volumes by fuel type



Source: EC, 2015c

Note: E+ are petrol types with ethanol levels higher than E10, B+ includes all diesel with FAME levels higher than B7

The petrol fuels sold on the European market mainly have been sold as RON95 fuels and, to a lesser extent, as RON 98. The majority of the fuels was labelled as E5. The overall shares of E10 and E85 (indicated as E+ in the figure) are negligible in the overall sales, although may be significant in some Member States (see below).

Diesel has been almost entirely (99%) been sold as B7.

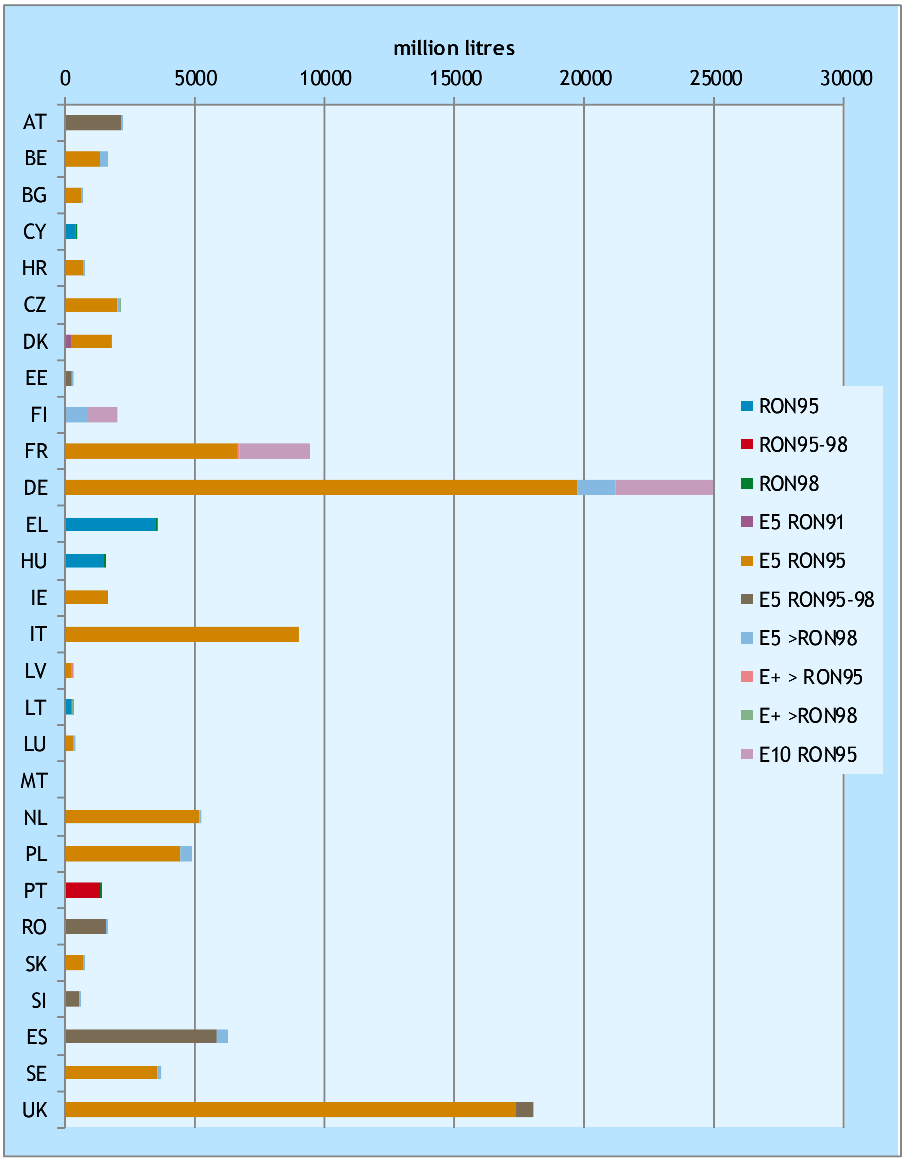
The variation in petrol grades between Member States is quite significant, as illustrated in the figures below[33]: absolute sales of different grades of petrol are shown in Figure 1.10, the same data are expressed as shares of total fuel sales (i.e. volume %) in Figure 1.11.

[33] These figures are based on (Ricardo-AEA, 2015), a report for the European Commission which is confidential but contains more detailed data than (EC, 2015c). Permission was granted to use these data in this report.

A somewhat different cross Section of the data is shown in Figure 1.12 and Figure 1.13, where the different RON-grades are combined, and the figures only distinguish between E0, E5, E10 and E+.

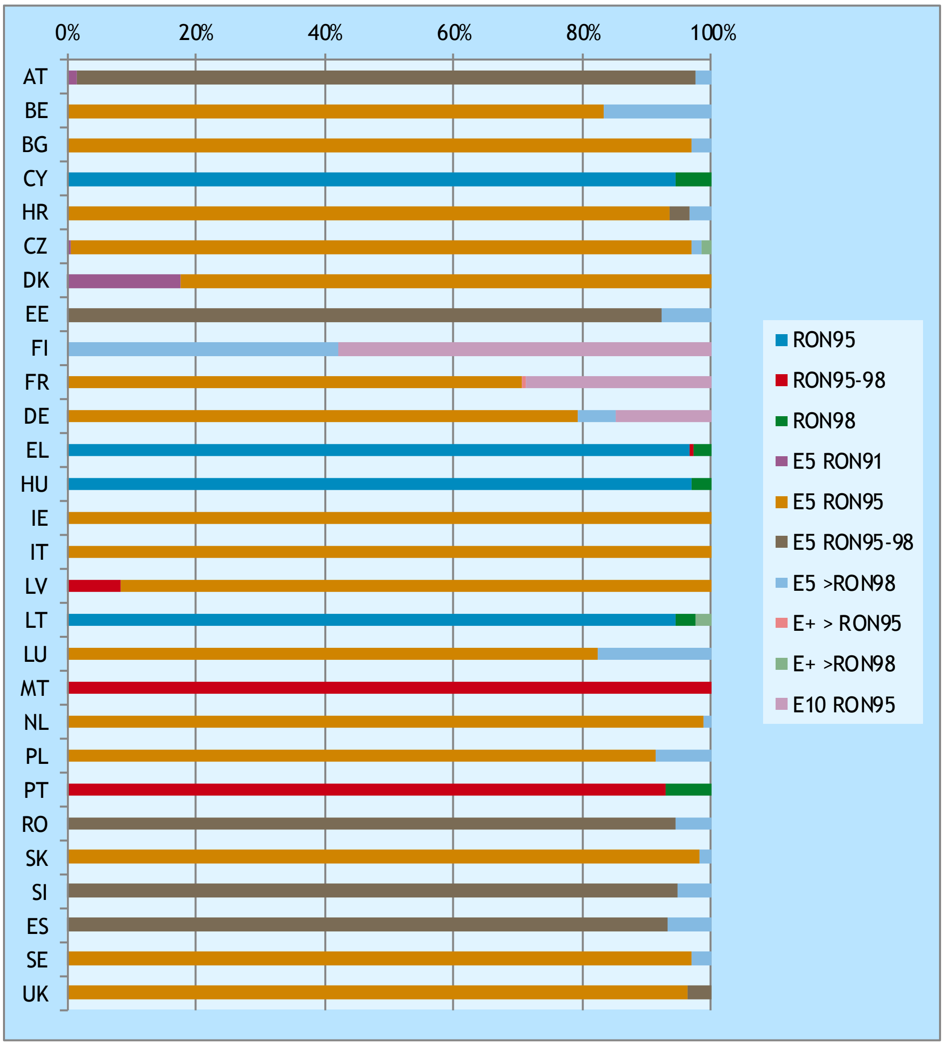
The figures show that E5, and in particular E5 RON 95, is the main petrol grade sold in most Member States. However, some countries, namely Cyprus, Greece, Hungary, Lithuania, Malta and Portugal have almost no E5 in their fuel mix, only pure petrol, according to Ricardo-AEA, 2015. As discussed in the previous chapter, E10 is only available in Germany, France and Finland. The market share of E10 is highest in Finland, almost 60% of the total petrol market, whereas France has about 30% market share of E10, and Germany about 15%. E+, i.e. ethanol blends higher that 10 vol%, has been sold in France, Czech Republic, Lithuania and Latvia. However, these data are somewhat uncertain, as (Ricardo-AEA, 2015) states that Member States reporting of fuels with high bioethanol/ FAME blends (e.g. E85) is inconsistent, as this type of fuel is not covered by the Fuel Quality Monitoring Directive.

Figure 1.10 Fuel sales of ethanol blends per Member State in 2013, in million litres



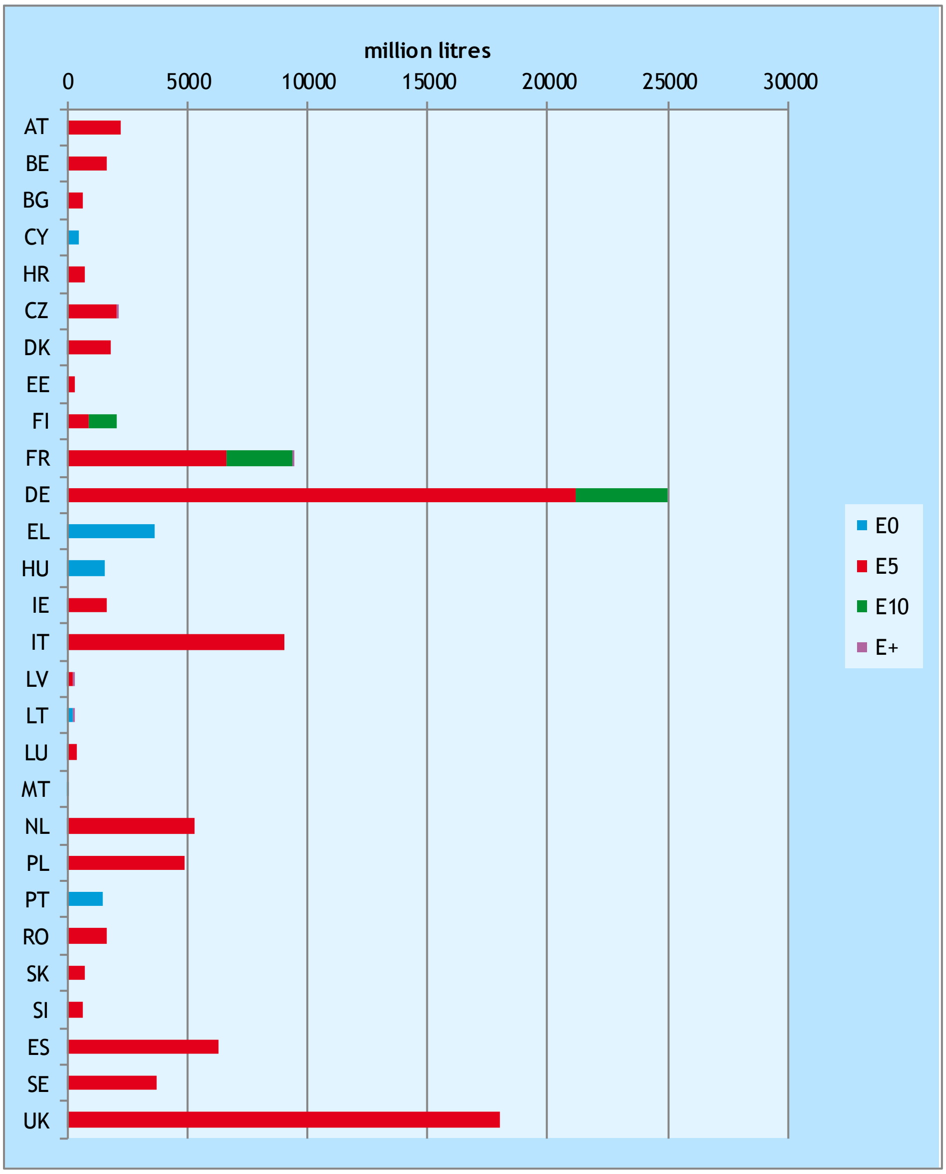
Source: Ricardo-AEA, 2015

Figure 1.11 Fuel sales of ethanol blends per Member State in 2013, in volume %



Source: Ricardo-AEA, 2015

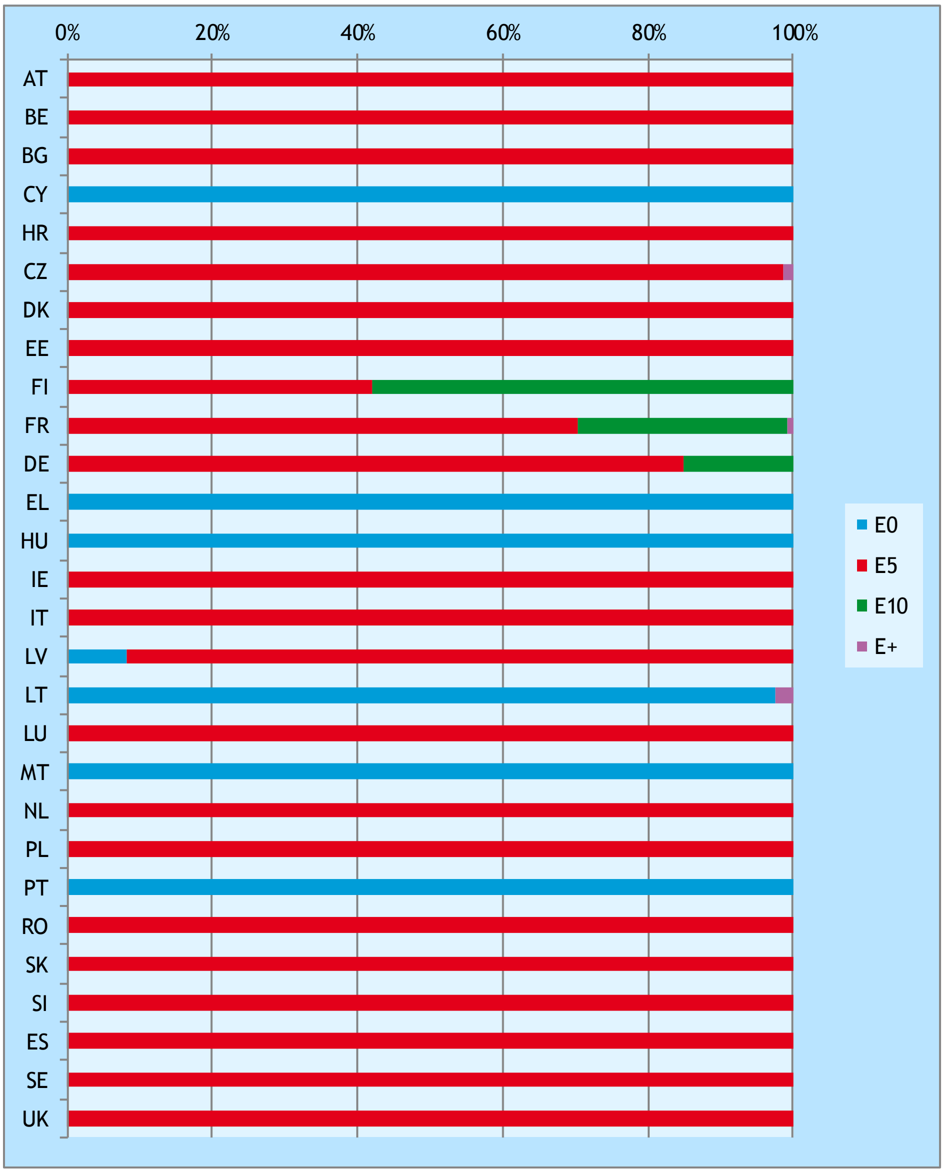
Figure 1.12 Fuel sales of ethanol blends per Member State (aggregated) in 2013, in million litres



Source: Ricardo-AEA, 2015

Note: E+ are petrol types with ethanol levels higher than E10

Figure 1.13 Fuel sales of ethanol blends per Member State (aggregated) in 2013, in volume %

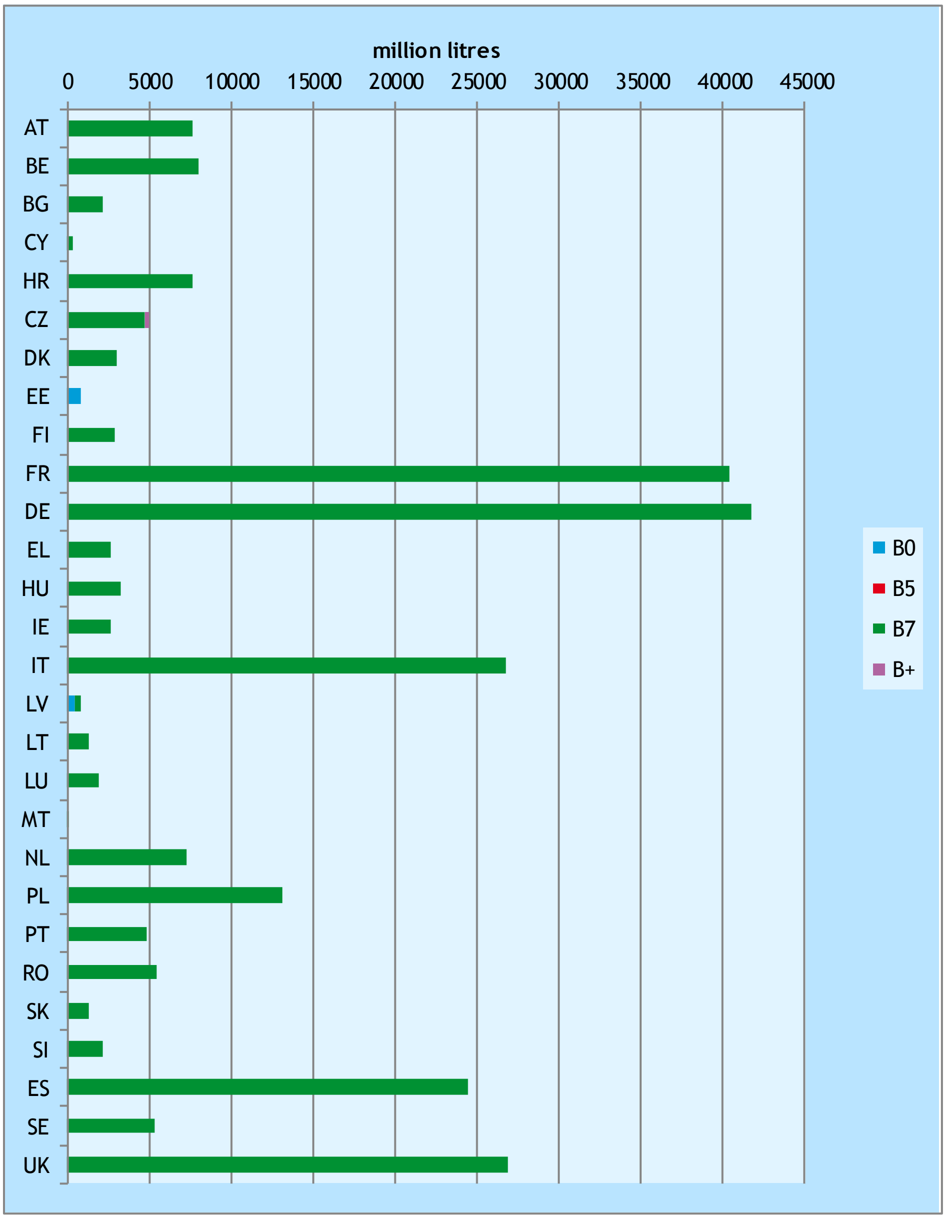


Source: Ricardo-AEA, 2015

Note: E+ are petrol types with ethanol levels higher than E10

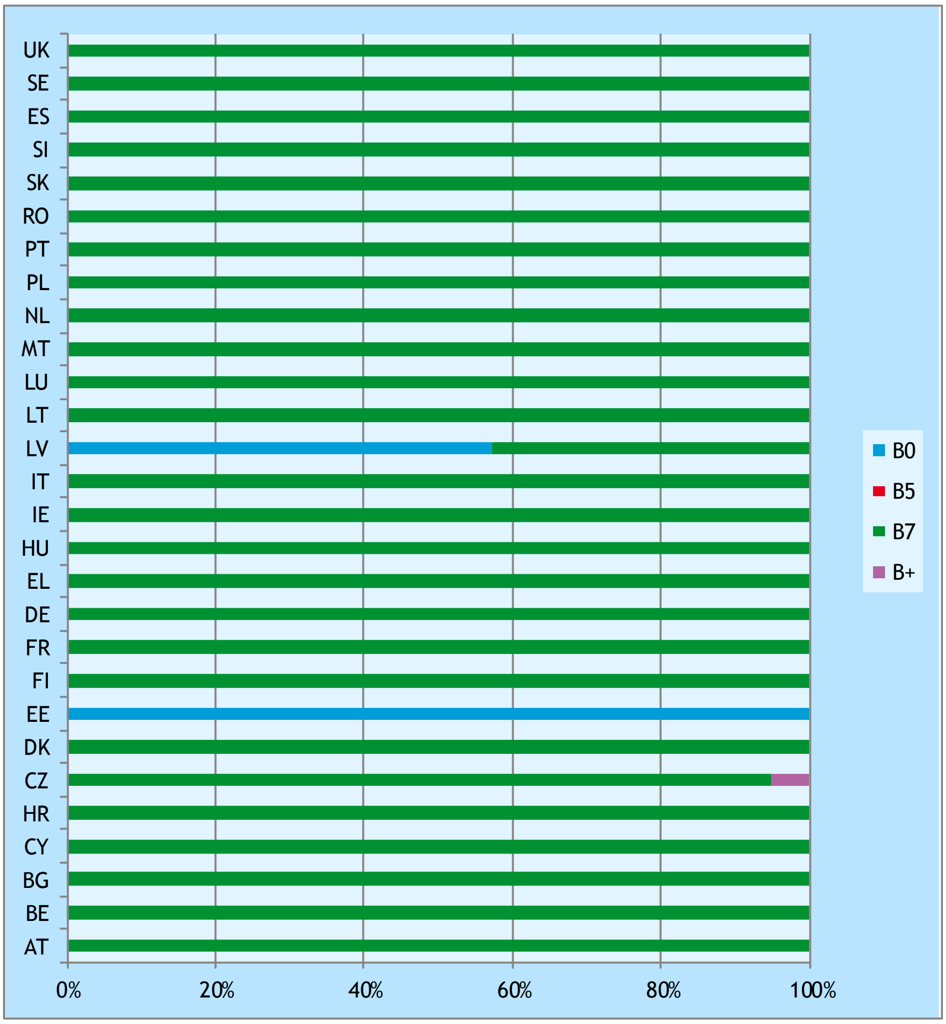
Looking at the diesel blends in the EU, shown in Figure 1.14 (absolute sales) and Figure 1.15 (in vol%), it can be concluded that the majority of Member States only have B7 on their market. The only exceptions are Estonia and Latvia: in the first, only pure diesel is available, in the second, pure diesel still has a market share of almost 60%. Diesels with FAME levels higher than B7 (B+) are only reported in the Czech Republic. These are used in dedicated vehicles or captive fleets, typically as B20, B30 or B100. However, as mentioned above, Member State reporting of these high blend fuels may not be consistent as this type of fuel is not covered by the Fuel Quality Monitoring Directive (Ricardo-AEA, 2015).

Figure 1.14 Fuel sales of diesel blends per Member State in 2013, in million litres



Source: Ricardo-AEA, 2015. B+ are diesel types with FAME levels higher than B7

Figure 1.15 Fuel sales of diesel blends per Member State in 2013, in volume % of total diesel sales



Source: Ricardo-AEA, 2015

Note that these data are sales of different petrol and diesel grades, which do not as such indicate whether Member States have allowed the blends specified in the FQD on their national markets. So the fact that E10 has only a substantial market share in a few Member States does not imply E10 has not been allowed in national legislation.

Also, they do not say anything about the actual biofuel volumes sold: as explained before, the names of the biofuel blends only indicate the maximum volume% that is allowed in that type of petrol and diesel, as specified in the FQD. For example, B7 may contain a FAME vol% between 0 and 7.

There are only limited and relatively uncertain data available on trends regarding biofuel blends in the EU, as Member States are only required to report on biofuel content from 2011 onwards, and the report on 2011 still had a number of inconsistencies (e.g. the Netherlands reported only E0 and B0 on its market, whereas Eurostat data show that biopetrol had a share of 3 energy% in overall petrol consumption, and biodiesel has a 2.5 energy% share of overall diesel consumption). Since then, however, reporting has improved, as (Ricardo-AEA, 2015) concludes.

1.4.3 Potential of B7/ E5 and E10

As the majority of Member States do not yet make use of the full potential of the current blending limits B7 and E10, several stakeholders mentioned that a more widespread use of B7 and E10 would be a logical next step in increasing biofuel volumes. The maximum marketing potential of these blending limits have not been reached yet, and this would be a relatively simple route to increase biofuel sales without vehicle adaptations and with limited impact on fuel distribution. The only implications would be introducing E10 on all national markets, for example by putting the necessary incentives in place and implement information campaigns for consumers, as was discussed and illustrated by the experiences in Finland, France and Germany in Section 1.3.4.1. As was shown in Section 1.3.2.2, in terms of energy content, B7 would allow up to 6.4% FAME, E10 up to 6.8% of ethanol.

As will be demonstrated in the following, there is still a lot of potential to further increase ethanol sales, if more, and eventually all, Member States would introduce E10, either by providing specific incentives for E10 or by gradually increasing the obligations and thus encouraging the fuel suppliers to introduce and actively market E10. Similarly, FAME sales can be further increased within the current blending limits if all Member States would move to B7, and at the same time increase their biofuel obligations so that fuel suppliers indeed blend FAME in their diesel to the maximum level allowed.

1.4.3.1 The current situation

This is demonstrated in the following tables, where the 2013 fuel sales data are analysed for all EU Member States. Table 1.7 compares the current biodiesel consumption to the maximum level within the limits, B7 (which equates to 6.4% FAME, in energy content). As was shown in the previous Section, several countries, namely Austria, Bulgaria, Denmark, France, Poland and Portugal, already consume more biodiesel than the B7 level would allow, where Sweden sells almost twice as much as the blending limit allows. These are also the countries with relatively high blending obligations, in some cases supported by tax incentives for biofuels – see the Member State policy overview in Section 1.3.3. These higher shares can be achieved with higher FAME blends in captive fleets, non-road modes and/or by blending HVO.

In the other Member States the share of FAME can still increase quite significantly within the current blending limits: a total of 12 Member States can still add two or more percent of FAME to their diesel within the limits.

Note that Estonia is the only country that did not sell any biodiesel in 2013, which is confirmed by Fuel Quality Monitoring data shown in the previous Section (100% pure diesel in Estonia). The other country that still had a significant market share of pure diesel (almost 60%), Latvia, achieved a 3% share of biodiesel in 2013.

Table 1.7 Maximum current blending potential (ktoe) in diesel for the individual Member States

	Total diesel consumption	biodiesel consumption (2013)	2013 biodiesel share (energy %)	Additional blending potential (to B7)
AT	6,003	423	7.0%	-0.7%
BE	7,007	281	4.0%	2.4%
BG	1,483	96	6.5%	-0.1%
CY	252	15	5.9%	0.4%
CZ	3,808	224	5.9%	0.5%
DE	33,075	1,893	5.7%	0.7%
DK	2,517	227	9.0%	-2.6%
EE	484	0	0.0%	6.4%
EL	2,164	121	5.6%	0.8%

	Total diesel consumption	biodiesel consumption (2013)	2013 biodiesel share (energy %)	Additional blending potential (to B7)
ES	21,335	716	3.4%	3.0%
FI	2,576	155	6.0%	0.4%
FR	34,285	2,299	6.7%	-0.3%
HU	2,009	106	5.3%	1.1%
IE	2,282	45	2.0%	4.4%
IT	21,435	1,176	5.5%	0.9%
LT	1,052	51	4.9%	1.5%
LU	1,772	55	3.1%	3.3%
LV	642	15	2.4%	4.0%
MT	109	3	2.8%	3.6%
NL	6,304	194	3.1%	3.3%
PL	8,930	603	6.8%	-0.4%
PT	3,751	255	6.8%	-0.4%
RO	3,468	122	3.5%	2.9%
SE	3,746	451	12.0%	-5.6%
SI	1,266	56	4.4%	2.0%
SK	1,353	81	6.0%	0.4%
UK	23,772	599	2.5%	3.9%
EU total	**196,884**	**10.261**	**5.2%**	**1.2%**

Source: Eurostat fuels consumption in transport data, 2013

The 2013 data for petrol are shown in Table 1.8. Here, the 2013 petrol consumption data are compared with the biopetrol consumption, illustrating that biopetrol shares are still relatively limited in almost all Member States. As most Member States only have E5 petrol grades on their market (equal to 3.3% energy), it is not surprising that many countries have biopetrol shares lower than 3.3%.

However, there are still quite a number of countries with biopetrol shares between 3.3 and 5 energy%, namely Austria, Belgium, Czech Republic, Germany, Spain, Finland, Poland, Romania and the UK. In Germany and Finland, this can be explained by the market shares of E10, in the other countries we can assume that E85 also has a market share (either in captive fleets or on public filling stations, for flex fuel vehicles). Note that many of these countries had tax incentives for higher blends of biopetrol, as shown in Section 1.3.3.2.

Only France and Sweden had shares higher than 5 % (energy content, which equals about 7.6 vol%). For France, this can be explained by the relatively high market share of E10 (almost 60%, see Section 1.4.2.3). As Sweden only reported E5 petrol grades, it can be assumed that the remaining bioetprol is due to sales of E85. However, as explained in Section 1.4.2.3 the current Fuel Quality Monitoring requirements do not require reporting of high biofuel blends, and reliable data on consumption of these blends are currently not available.

Table 1.8 Maximum current blending potential (ktoe) in petrol for the individual Member States

	Petrol consumption	biopetrol consumption (2013)	2013 biopetrol share (energy %)	Additional blending potential (to E10)
AT	1,561	67	4.3%	2.3%
BE	1,193	48	4.0%	2.6%
BG	442	8	1.9%	4.7%
CY	369	0	0.0%	6.6%
CZ	1,574	54	3.4%	3.2%
DE	17,591	765	4.3%	2.3%
DK	1,336	0	0.0%	6.6%
EE	241	3	1.3%	5.3%
EL	2,834	0	0.0%	6.6%
ES	4,666	167	3.6%	3.0%
FI	1,401	66	4.7%	1.9%
FR	6,739	392	5.8%	0.8%
HU	1,193	38	3.1%	3.5%
IE	1,186	28	2.3%	4.3%
IT	8,399	74	0.9%	5.7%
LT	210	6	3.1%	3.6%
LU	327	1	0.2%	6.4%
LV	210	6	3.0%	3.6%
MT	75	0	0.0%	6.6%
NL	3,956	125	3.2%	3.4%
PL	3,660	144	3.9%	2.7%
PT	1,148	5	0.4%	6.2%
RO	1,268	56	4.4%	2.2%
SE	2,662	180	6.8%	-0.1%
SI	485	6	1.2%	5.4%
SK	563	18	3.2%	3.4%
UK	13,450	459	3.4%	3.2%
EU total	**78,736**	**2,715**	**3.4%**	**2.9%**

Source: Eurostat fuels consumption in transport data, 2013

1.4.3.2 Expectations for 2020

In (CE Delft, 2013), the potential of the current blending limits were compared to the biofuel volumes that the Member States expected to use in 2020, according to their NREAPs. This allowed to assess to what extent the 2020 renewable energy in transport target could be met with the current blending limits, and to determine whether higher blends or other measures would be needed (without taking into account the recent ILUC decision).

The EU-wide result is shown in Table 1.9, together with the blending potential of non-road modes (not part of this assessment) and a volume of HVO that was considered to be the maximum achievable potential for 2020 (limited by production capacities). This table shows that overall EU sales of both biodiesel and biopetrol can still increase significantly within the current blending limits: biodiesel sales, currently at 10.7 Mtoe (2013), can increase to 17 Mtoe, of which 15 Mtoe FAME, and biopetrol can increase from the current 2.7 Mtoe to 7 Mtoe.

However, the table also shows that B7 is insufficient to accommodate the Member State's plans regarding biodiesel volumes in 2020. 5 Mtoe of FAME will have to be brought on the market through higher blends, higher shares of HVO or much larger volumes of double counting biodiesel than anticipated in the NREAPs – in the NREAPs, Member States expected that 7% of their biodiesel would be double counting in 2020.

The gap is smaller for biopetrol: if all Member States make full use of E10 in 2020, 1 Mtoe of biopetrol would have to be sold through higher blends, more use of double counting ethanol or other biopetrol options. In the NREAPs, MS expect 9% of the biopetrol in 2020 to be double counting.

As mentioned before, the biofuel plans outlined by the Member States in the NREAPs do not yet take the ILUC decision into account. This decision may be expected, for example, to result in an increase of the share of double counting biofuels, which will reduce the actual biofuel volumes that need to be consumed to meet the 10% target in 2020. This is likely to reduce the gap, i.e. reduce the biofuel volumes that remain after the blending limits have been used to the maximum. The increase in multiplication factors in the RED for renewable electricity used in road and rail may further enhance this effect, and also results in a reduction of biofuel consumption that is required for the 10% RED target. As new plans have not yet been submitted, this analysis is still based on the most recently submitted NREAPs.

Table 1.9 Maximum blending potential (Mtoe) in diesel and petrol, and gap with the NREAPs in 2020

Type of biofuel	Application	Biofuel blending potential (Mtoe)	Actual sales in 2013 (Mtoe, Eurostat)	Mtoe expected in 2020, according to NREAPs	Gap with NREAPs
Biodiesel	FAME B7 in road	13	**10.7**	**22**	**5**
	FAME B7 in non-road	2			
	HVO	2			
	Total	**17**			
Biopetrol	E10 in road	7	**2.7**	**7**	**1**
	E10 in non-road	0			
	Total	**7**			
Total		**22**		**29**	**8**

Source: CE Delft, 2013 and Eurostat, 2013

Note: Non-road includes mobile machinery.

There are large differences between Member States, however, due to different diesel-to-petrol ratios and different biofuel strategies. This can be seen in the tables below, where the detailed data for the various Member States are shown (from CE Delft, 2013)[34]. It should be noted that these data are relatively uncertain, as the blending potential was estimated using PRIMES fuel demand forecasts for 2020 (reference scenario 2012) which are relatively uncertain on a Member State level (CE Delft, 2013).

The results for diesel, shown in Table 1.10, show that almost all Member States, with the exception of Cyprus, Hungary, Latvia, Malta and Slovakia, are likely to need higher blends, a large share of double counting biofuels or some other solutions (HVO, FAME in non-road modes) it they are to achieve the biodiesel shares given in their NREAPs, in 2020. Assuming these forecasts are correct, there are eleven Member States that can only blend less than 60% of their expected biodiesel volumes in 2020 as FAME in road transport, with the current blending limits: Belgium, Bulgaria, the Czech Republic, Germany, Estonia, Finland, Ireland, Lithuania, Poland, Slovenia and the UK. They all need to resort to other solutions to bring more than 40% of their expected biodiesel volumes onto the market.

Table 1.10 Maximum blending potential (ktoe) in diesel in 2020, compared the NREAPs expectations, for the individual Member States

	B7: FAME blending potential in 2020 (ktoe)		Biodiesel demand in NREAPs (ktoe)	Gap with NREAPs (ktoe)	Gap (in % of biodiesel demand in NREAPs)
AT	313		411	98	24%
BE	385		697	313	45%
BG	117		220	103	47%

[34] Note that non-road modes and HVO are not included in this table.

	B7: FAME blending potential in 2020 (ktoe)		Biodiesel demand in NREAPs (ktoe)	Gap with NREAPs (ktoe)	Gap (in % of biodiesel demand in NREAPs)
CY	24		24	-2	-8%
CZ	291		494	203	41%
DE	1,997		4,443	2,446	55%
DK	141		167	26	16%
EE	29		50	21	42%
EL	150		203	53	26%
ES	1,894		3,100	1,206	39%
FI	136		430	294	68%
FR	1,911		2,849	939	33%
HU	208		203	-7	-3%
IE	172		342	170	50%
IT	1,381		1,880	499	27%
LT	62		131	69	53%
LU	131		193	62	32%
LV	50		29	-21	-72%
MT	10		7	-2	-29%
NL	418		552	134	24%
PL	721		1,452	728	50%
PT	299		449	153	34%
RO	244		325	84	26%
SE	246		251	7	3%
SI	100		174	74	43%
SK	112		110	-2	-2%
UK	1,297		2,463	1,166	47%

Source: CE Delft, 2013

NB. Positive numbers: blending potential lower than expected demand; negative numbers: blending potential higher than expected demand

The results for petrol, i.e. the E10 blending potential, shown in Table 1.11, is quite different. Comparing the petrol demand forecast with the NREAP biofuel volumes, many Member States do not expect to use the blending potential that E10 offers, in 2020. Portugal and Slovenia only use a quarter and one third of the E10 blending potential, respectively. These countries can significantly increase overall biofuel demand within the current blending limits by increasing the share of ethanol demand up to the E10 level.

Table 1.11 Maximum blending potential (ktoe) in petrol in 2020, compared the NREAPs expectations, for the individual Member States

	E10: Bioethanol blending potential in 2020		Biopetrol demand in NREAPs	Gap with NREAPs	Gap (in % of biopetrol demand in NREAPs)
AT	127		79	-45	-57%
BE	103		91	-12	-13%
BG	43		60	17	28%
CY	21		14	-7	-50%
CZ	162		129	-33	-26%
DE	1163		857	-308	-36%
DK	105		93	-12	-13%
EE	17		38	21	55%
EL	253		413	160	39%
ES	490		399	-88	-22%
FI	105		129	24	19%
FR	640		650	10	2%
HU	122		303	184	61%
IE	119		139	19	14%
IT	970		600	-368	-61%
LT	31		36	5	14%
LU	26		24	-2	-8%
LV	24		19	-7	-37%
MT	2		5	2	40%
NL	201		282	81	29%
PL	356		451	96	21%
PT	107		26	-81	-312%
RO	129		162	33	20%
SE	232		466	234	50%
SI	50		19	-31	-163%
SK	48		74	26	35%
UK	1039		1744	702	40%

Source: CE Delft, 2013 and Eurostat, 2013

NB. Positive numbers: blending potential lower than expected demand; negative numbers: blending potential higher than expected demand

1.4.4 Fuel distribution impacts of introducing a new blend

When new blends or fuel grades such as E20 or B10 are to be introduced on the fuel market, they cannot just replace the current E5/E10 or B7, as a large share of the current vehicle fleet is not compatible with these new fuels. The current blends need to remain available throughout the EU as protection grades for many years, until the non-compatible vehicles are phased out of the market. The following Section will zoom in on the implication of additional blends to fuel distribution, from refineries to the retail stations and end consumers. The issue of compatibility vehicles and their market penetration is discussed further in the next chapter.

If a new blend is introduced, all stakeholders in the fuel market, i.e. fuel suppliers, distributors and owners of retail stations will be faced with the choice of whether they will offer the new blend to their customers. They have three basic options:

a. introduce the new blend by replacing an existing fuel grade that they offer;
b. invest in expanding the existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics and add the new blend to their existing portfolio;
c. not introduce the new blend, i.e. maintain their current fuel grade portfolio, and wait until market demand for the new blend is sufficient to warrant replacing one of their existing fuel grades.

The latter option assumes that they are not obliged to offer the new blend.

The cost and benefits of these three options, and therefore the optimal choice for a specific stakeholder, depends on the specific situation: on the local fuel market, the characteristics of the distribution and retail stations (for example the number of grades they are equipped to sell) and the cost and practical feasibility of expanding the infrastructure. The ownership of the infrastructure and retail stations is also a relevant factor: larger companies typically have more resources and opportunities for investments than smaller companies or retailers that sell with low margins.

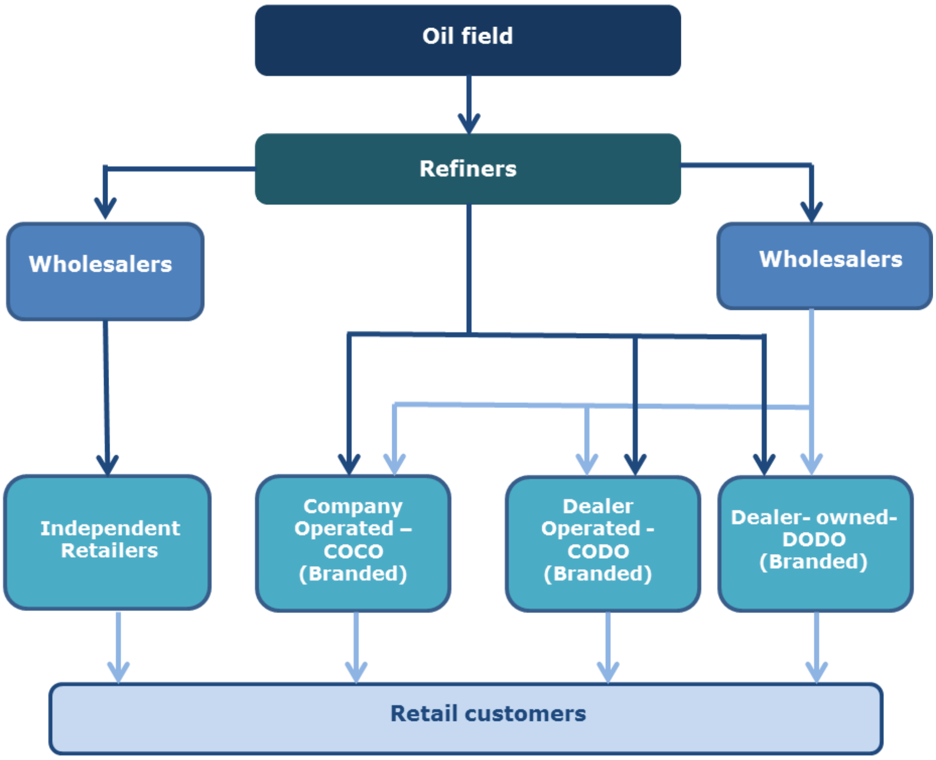
As cost and benefits will vary between suppliers and even per fuel retail station, introducing a new blend may cause market distortion effects: if one retailer has the opportunity to add the new blend to its portfolio with limited cost, and a competitor does not and has to choose which blend to offer (for example, a small service station with just one fuel grade and insufficient means to invest), the latter is likely to lose market share to the first. As will be demonstrated in the next Section, there are a number of countries where this issue is particularly relevant.

To create insight in the effects that introducing a higher blend may have on the fuel distribution sector, the following paragraphs provide an overview and qualitative assessment of the impacts that may occur. First, the structure of the fuel market is addressed, followed by an overview of the technical opportunities and barriers of introducing a new blend on the market. This analysis is qualitative only, however, as data on cost and economic impacts of the various options are unavailable in public literature. As far as we are aware, the potential financial impacts of higher blends on fuel distribution and the relevant stakeholders have not been quantified or analysed in detail yet in the public literature. The introduction of E10 in France, Finland and Germany (described in Section 1.3.4.1) provides some information on the mechanisms that occur in the market when an additional petrol grade is introduced, but a (quantitative) assessment of the impacts has not yet been carried out.

1.4.4.1 Structure of the fuel market

Fuel markets in different Member States can have various ownership structures, depending on national circumstances and regulations. This is illustrated in Figure 1.16 where the potential routes from the oil fields to retail customers are depicted for fossil fuels. (OECD, 2013) In some countries, supermarkets are also an important point of retail for fuels (see below).

Figure 1.16 Road fuel supply chain



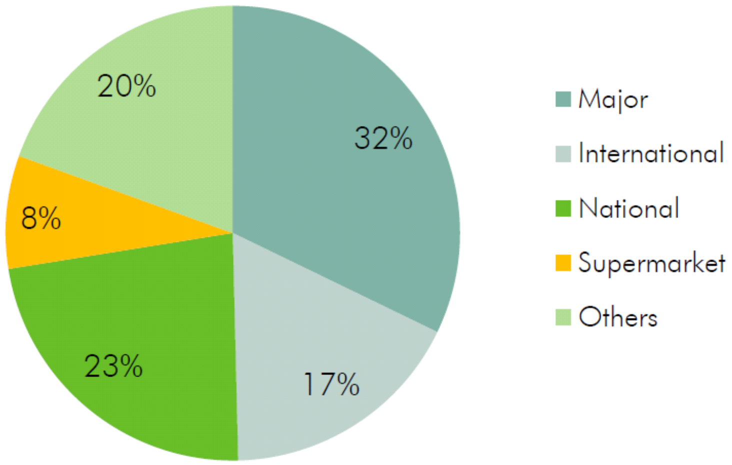
Source: OECD, 2013 (adapted from Deck and Wilson (2004)

Biofuels can be added to these fossil fuels at various stages in the supply chain: they can be added at the refinery site itself, before the fuel is transported to distribution sites, or at the point of fuelling the tanker, when it is filled up to supply the filling stations.

As shown in the figure above, there are four different type of retailers:

- **Vertically integrated oil companies operating at all levels of the fuel chain (company owned – company operated (COCO)):** Prices at the pump are determined by refiners.
- **Dealers operating under an oil company (company owned – dealer operated = CODO):** Dealers operating under an oil company carry the commercial risk and are responsible for their own prices. However, these businesses can be strongly influenced by contractual arrangements between the oil companies and the dealer.
- **Independent fuel suppliers – dealer owned –dealer operated (DODO):** Independent fuel suppliers own and operate their service stations. Although they are often supplied by oil companies, these fuel suppliers are less affected by contractual agreements and they can determine their own prices.
- **Supermarkets:** supermarkets are not depicted in the figure above, but are a category on its own, and have a significant market share in some countries. The retail of road fuel is typically not part of the core business of supermarkets, but these service stations are mostly located near shopping centres and can be considered to be a means to attract customers. These service stations typically buy very high volumes of fuel at lower wholesale price and also sell it at a very low gross margin.

Figure 1.17 Market share per fuel retailers type[35]



Source: Verdict Retail 2012

Table 1.12 shows how the ownership structure varies for a number of Member States in the EU (source: (OECD, 2013), unless stated otherwise). Note that not all MS are included in this table as not all have been assessed in these studies, so this table rather provides an illustration of the variation throughout the EU, rather than a comprehensive EU-wide overview.

In Germany, Greece, Italy and, to a lesser extent, Austria, Bulgaria, Portugal, Romania, Spain and Sweden, the fuels market is largely dominated by a limited number of major companies – in these countries, they hold market shares of more than 60%. The fuel markets in Latvia, Lithuania, Poland and the UK are much more fragmented. In these countries, independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales.

Table 1.12 Description of fuel market for 13 Member States

Austria	Of the 1545 petrol stations (end 2011), 60 %, were so called major-branded. The majors' market shares are – also relating to sales – comparatively high but decreasing over the last years (in 2003 they had a common market share of 85 % of annual fuel sales, in 2008 it declined to 77 %, the five biggest firms having 76 %).
Bulgaria	The sole distributor for the fuel quantities produced in the one refinery in Bulgaria is “Lukoil Bulgaria”, accounting for approx. 60 % of the petrol and 70 % of the diesel supply in Bulgaria. “Lukoil Bulgaria” was a pricing leader on both wholesale and retail markets (2009-2011). Significant market share at the retail level of vertically integrated wholesalers. Except for the branded petrol stations the retail market was composed of a large number of insignificant market players (around 3200 independent petrol stations in Bulgaria).
Germany	Five leading companies (vertically integrated along the value chain), together hold a dominant position on the retail market.
Greece	There are approximately 6.500 petrol filling station that cover the demand for oil products. The majority of them are company owned-dealer operated (CODOs) or dealer owned dealer operated (DODOs).. Nearly 400 are unbranded / independent.
Italy	The Italian fuel retail market (studied in 2010-2012) is still dominated by the seven vertically integrated oil companies, controlling 22000 fuel stations. There are around 2000 independent retailers and 82 retailing stations owned by supermarkets. The number of independent retailers, however, has significantly

[35] From http://www.cbre.eu/portal/pls/portal/res_rep.show_report?report_id=3217

	increased in the last few years (in 2005 they were estimated to be around 1100).
Latvia	Latvia's fuel retail market (2011) is predominantly operated by small independent retailers, which own 32.5% of service stations. The top three players, account for 62% of total fuel volume sales in Latvia (Data monitor group 2013)
Lithuania	There are approximately 880 service station in Lithuania (January 1, 2012). The Top Five players by fuel volume share accounted for only 35.0% of the Lithuanian service station network, indicating a fragmented (Data monitor group 2013).
Poland	Orlen (former state monopoly in the wholesale and retailing of petroleum products) is by far the largest retailer of road fuels, controlling about 25% of all petrol stations in Poland (around 1750 stations) through ownership, franchising or similar contracts. Orlen-controlled. Its largest 4 competitors (Vertically integrated oil companies) have a share of 5-7% in the national retail market. Only 2-3% of stations are operated by supermarket chains. Of the remaining 3000 stations, which constitute about 45% of the national market, the vast majority are owned and operated independently or within small regional chains
Portugal	The top four fuel retailers in Portugal account for 70.6% of the national service station network, with Galp, the largest player, accounting for 29.7% of all sites (Data monitor group 2013). The aggregate market share of super/hypermarkets in the retail market for diesel and petrol-95 has reached around 25%.(OECD, 2013)
Romania	In 2011, the top five fuel retailers in Romania accounted for 63.9% of all service stations (1,944 sites).
Spain	In Spain there are about 9,000 petrol stations, most of which (83%) are owned by wholesale operators through exclusive distribution agreements. Three operators with refining capacity in Spain jointly own 70-73% retail market share. Petrol stations hypermarkets and supermarkets only have 3% of market share,
Sweden	The Top Five retailers in Sweden accounted for 71.3% of all service stations (2,786) in 2011 (Data monitor group 2013).
United Kingdom	Supermarkets have share of road fuel sold in the UK of 39 per cent in 2012. This share is increasing (OECD 2013). The station are owned for 55% by oil companies, 19% by main retailers, 16% by supermarkets and 10% by unbranded and other retailers (Energy institute 2014)..

Source: OECD, 2013

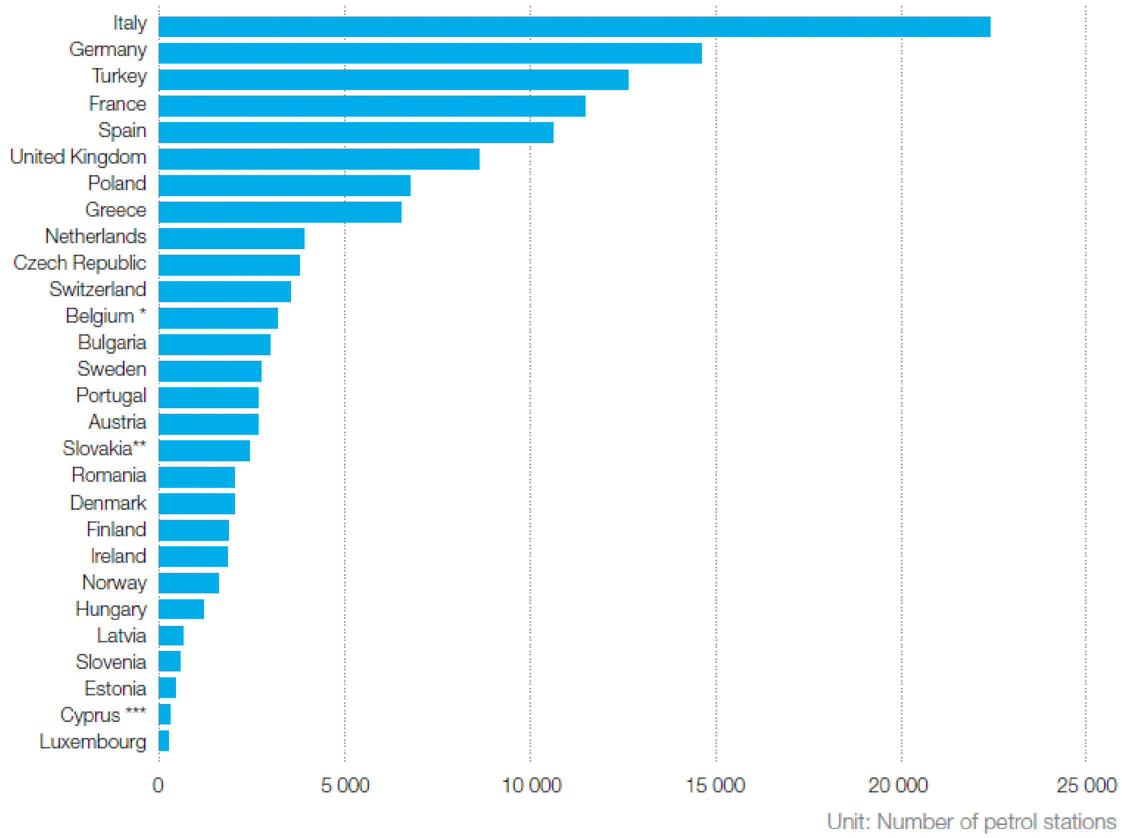
In the countries with a limited number of dominant companies in the market (e.g. Germany, Greece and Italy in Table 1.12), it is to be expected that these companies will be in a key position to decide on whether or not a new fuel grade is rolled out on a large scale. If they do so, the smaller retailers either need to follow and also offer the new grade, or rather keep the current portfolio of fuel grades, thus risking to lose market share to those competitors that do offer the new grade. This may have two implications: first, a limited number of stakeholders control the fuel market and are therefore key to the successful introduction of a new fuel grade, and second, introducing a new blend can lead to negative economic impacts on the smaller retailers.

In the countries with a more fragmented and diverse fuel market (such as Latvia, Lithuania, Poland and the UK), a successful roll-out of a new blend requires the active involvement of many different stakeholders (i.e. retailers). As these stakeholders are likely to have more limited resources than the major oil companies, they may still be faced with potential negative economic impacts: in all countries listed in this table, major oil companies have at least some market share, and thus can decide to introduce the new grade. This may then lead to the same type of market distortion described above, although the impacts are likely to be smaller than in the countries with a limited number of dominant market players.

In view of the potential impacts of new blends on the market structure and the current lack of (quantitative) insight into these effects, it is recommended to further assess these impacts before considering policy options. This assessment could start with an analysis of impacts of the introduction of E10 in Finland, France and Germany on the market structure and the various stakeholders, in order to identify whether any market distortion effects occurred and to assess whether the market structure poses barriers to the successful introduction of a new blend.

To illustrate how many petrol stations would be involved in the roll-out of a new blend in each Member State, Figure 1.18 provides data from the National Oil Industry Association on the number of petrol stations throughout Europe: there are about 130,000 petrol stations within the EU, almost half of these are located in Italy, Germany, France and Spain. There are no data on the number of fuel pumps or fuel grades that these petrol stations can offer.

Figure 1.18 Number of petrol stations in Europe in 2013



* Source: FAPETRO (department of the Federal Public Services Belgium)
** Source: Statistical Office of the Slovak Republic
*** Source: Petrol Owner's Association
Note: Data for Bulgaria and Slovakia refer to 2012

Source: Fuel Europe, based on data from the National Oil Industry Associations

1.4.5 Technical issues and barriers to introducing higher biofuel blends

Despite fuel standards and quality control, biofuels have somewhat different technical characteristics than fossil fuels. Higher blends can thus cause a number of technical issues in fuel distribution, which will be described in the following Sections.

1.4.5.1 Refinery/distribution level

BOB (blendstock for oxygenate blending)

Nowadays oil companies usually use two base blendstocks (BOB = blendstock for oxygenate blending): one for E5 and E10 RON95 and one for RON98 (Davison Consultants ltd, 2013). The introduction of new blend levels is expected to directly impact the number and type of base blendstocks, so called BOB, because higher ethanol blends require other BOBs (with lower vapour pressure, modified distillation characteristics and reduced octane) to still meet the fuel specifications, as laid down in EN228. Addition of ethanol to petrol also offers a significant octane boost, more than hydrocarbon streams, Davison (2013) concludes that the octane gain from an additional 10% ethanol is about 3 points RON. This can be beneficial to the fuel economy of vehicles if the engine is optimised for this higher octane level, as discussed in Chapter 2.

Therefore, from a logistics perspective an increase in BOBs in the EU would increase cost and require investments, for example in additional storage tanks[36]. A solution would be to define a new specification other than EN228 to be able to have only one BOB in place for all fuel blends, (Davison Consultants ltd, 2013) concludes. They suggest to develop a table for vapour pressure waiver for different levels of ethanol (e.g. 15-20 vol% or 20-25 vol%), similar to the waiver that is currently included in EN228, for ethanol levels from 0 to 10%. Different petrol specifications could have implications for the engines (drivability) and vehicle emissions, as these are sensitive to the fuel characteristics. (Davison Consultants ltd, 2013) recommends that further study of these issues is required.

1.4.5.2 Service station level

Practical issues when introducing a new fuel grade

As shown in Section 1.4.4.1, there are currently about 130,000 petrol stations within the EU, but detailed data on the fuel grades that they provide or the number of fuel tanks or pumps they have available are not available. From the interviews with fuel suppliers it can, however, be concluded that some of these may offer up to 3 to 4 grades of petrol and up to two grades of diesel, which typically include:

- 95 RON E5
- 95 RON E10
- 98 RON E5 premium
- 100 + RON super premium
- Standard and premium diesel grade

For many smaller refuelling stations, however, this number will be limited to 1 or 2 grades of petrol, and 1 grade of diesel.

If a new grade is introduced, for example E10 or, in the future, E20, part of the vehicle fleet will switch to that new blend, but part may continue to buy the older grades, for example E5 – typically either because their vehicle is not compatible with the new grade, or because of a cost differential. As explained earlier, the smaller service stations may then have to choose which blend they will sell, as they are limited in the number of fuel grades they can sell. They may then loose customers that want to buy any of the other blends.

Alternatively, they may consider to make the investments required to offer more fuel grades. This typically involves investments in new (subsurface) fuel tanks and the necessary infrastructure to fill these tanks and sell the fuels (pumps, fuel piping, etc.), and requires a suitable location as well as permits from the relevant authorities. Although (S. Searle, 2014) report that the cost to retrofit an existing dispenser to use a higher ethanol blend, such as E25 is between US$1000-US$4000, there is still insufficient data on the potential costs to introduce a new blend at a filling station, of which new storage is the largest cost element.

[36] These costs have not yet been quantified.

These data are typically confidential, and will differ between service stations, so the cost of the various options cannot be quantified at the moment.

Because the options to add a new fuels grade are limited and may require significant investments, it is likely that refuelling stations will first try introduce new blends by replacing other already existing blends. This could be observed in the Member States where E10 has become available, as was described in Section 1.3.4.1:

- in Germany, before E10 was introduced many petrol stations offered E5 RON95, a RON91 fuel and a premium E5 RON98. In many cases, the E10 RON95 has replaced the RON91 petrol (source: interview with German authorities).
- in France, the premium petrol grade (typically RON98) was typically replaced by E10 RON95 (source: interview with French authorities), which is now sold next to E5 RON95 (see the fuels sales data in Section 1.4.2.3, Figure 1.11).

When moving towards new biofuel blends that cannot be used by the whole vehicle fleet, it is thus important to think about what will be the protection grade, and what will be the best options for fuel suppliers and service stations to offer. For example, two potential longer term options to move beyond the current E10 limit for petrol would be to:

- replace E5 with E10 as the base (protection) fuel (i.e. discontinue the sales of E5), and offer E20 or E25 as a new fuel
- replace E10 with a E20/25 100+Ron fuel, and retain a E5 or hydrocarbon 98+ premium fuel as protection grade.

These options both have the advantage that the whole fleet can be supplied with two different grades of petrol, but have different implications regarding potential biofuel sales, pricing, perhaps regarding number of BOB required (depending on specifications), etc.

The need for protection grades in currently existing infrastructure raises the question how long protection grades should be offered. This depends of course on the renewal rate of the vehicle fleet (to be discussed in Section 1.5 below), but also on the more subjective choice regarding at what share of incompatible vehicles it is justified to stop offering the protection grade. The time period may be reduced if it is possible to retrofit older cars to make them compatible or at least tolerant to the new fuel, or if an additive can be added to the fuel to achieve the same result. However, as the average lifetime of passenger cars is more than 15 years, and a significant share of the new cars currently sold is expected to have lifetime (much) longer than this, it is clear that complete renewal of a fleet takes more than two decades.

Impacts on equipment / material compatibility

Besides logistical modifications and physical space required for additional storage tanks and equipment, higher levels of biocomponents may also require modifications to equipment due to material compatibility issues. This is especially an issue for higher ethanol blends: the higher the blend, the more measures need to be taken to prevent corrosion.

According to (Davison Consultants ltd, 2013), oil companies state that technical issues arise beyond E15. For some oil companies, blend levels above E15 cause issues in their tank systems through the supply chain from depot to petrol station, which increases cost. Costs may further increase due to additional infrastructure needs. Beyond E18 there may be a need to change metalwork in terminals due to corrosion, although this depends on the nature of the tank coating as well as water content of the fuel. Beyond E23 (or E25) potential for galvanic corrosion is introduced. The oil companies thus conclude that if ethanol blends are to increase, it appears to be that E20 strikes the right balance against increased infrastructure costs (Davison Consultants, 2013).

Quality control and aging

The quality of diesel fuel containing FAME in the storage tanks at service stations and indeed also in vehicles, for example during long term parking, decreases over time, as aging occurs during storage and use. This is mainly linked to the oxidation stability of FAME, which is much worse compared to conventional fuels, the higher boiling point of FAME and cold weather characteristics. When considering large scale introduction of higher blends of FAME, it is important to understand both these issues and the risks to the fuelling infrastructure and vehicles that this may cause, so that the necessary measures can be taken to resolve these issues and reduce the risks.

This was analysed in a joint industry study (Lacey et.al, 2010), in which the change in fuel quality was measured that occurred in B10 fuels, during warm climate storage conditions during a period of 27 weeks, in vehicles that were only occasionally operated. The study concluded that aging may result in formation of insoluble materials and acids, which may create materials compatibility issues, filter plugging, corrosion, durability problems and deposit formation. Lacey further found that the aging rate was strongly dependent on storage conditions, with large variations between vehicle types (particularly rapid changes in stability occurred in passenger vehicles compared to light-duty vans), and with rates of aging decreasing over time. However, the causes for these variations could not be identified, and the impacts of this aging on the vehicles was not measured. (Lacey et.al., 2010) therefore recommends that these issues be further studied.

Aging and resulting quality issues are compounded by a low uptake by the market, for example if a higher FAME blend is introduced at service stations with low throughput, fuel suppliers (members of Fuels Europe) observed during an interview. For conventional fuels, aging is not a big problem, because both the stability of the fuels and the consumption rate are high enough. However, higher biofuel blends might stay in tanks for longer period of times, if there aren't sufficient compatible vehicles on the road or when consumers do not choose these specific blends, for example because of higher costs.

Fuel suppliers deliver fuels that comply with high quality standards as defined in the FQD and by CEN, but can no longer control the quality once the fuels are stored in the storage tanks at service stations or in the vehicles. Especially in relation to the ramp-up period of new biofuel blends in the market, when service stations start to offer the product but sales are still limited, this point is an issue of concern to the fuel suppliers. A possible option suggested by fuel suppliers would be to introduce a best before date for biofuel blends (source: interview with Fuels Europe).

It can thus be concluded that aging of higher FAME blends may lead to quality control issues throughout the fuel chain that need to be understood and possibly resolved before roll-out of these blends as they may result in technical problems both in the fuel chain and in the vehicles. Research on these issues so far has been limited, it is thus recommended to further study the potential issues and solutions.

1.4.6 Non-technological barriers to introduction of a new blend

From the available literature and the interviews with stakeholders, several non-technological barriers to the introduction of higher blends were identified. These mainly relate to consumers and marketing, to potential impacts on the competitiveness of fuel suppliers (ranging from oil companies to retail stations) and refineries and potential impacts on harmonisation of the fuel market in the EU.

1.4.6.1 Information provision and consumer acceptance

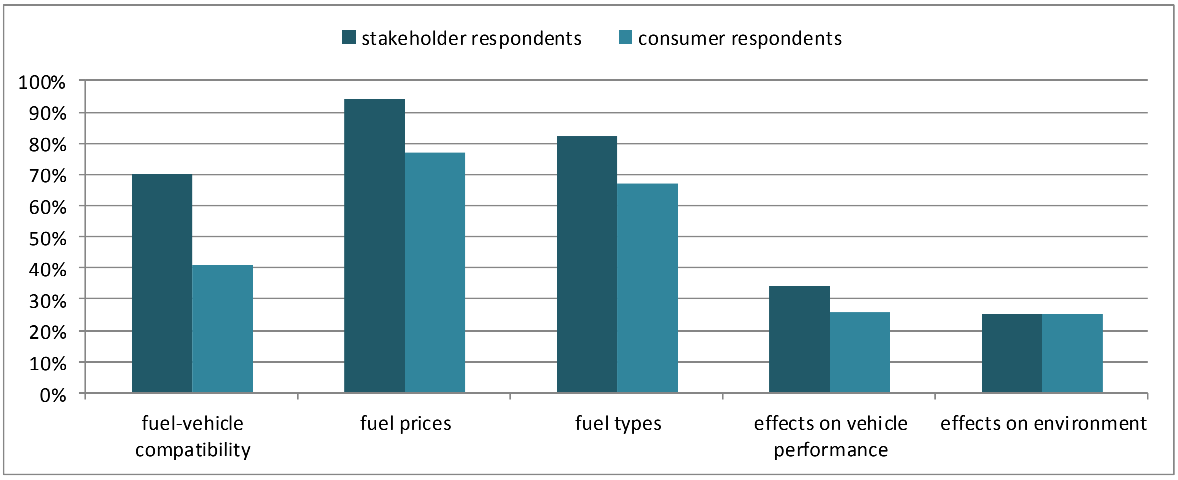
Consumer acceptance and willingness to buy is crucial to successfully introducing a new biofuel blend or fuel grade at filling stations. As long as the old fuels are still for sale – which has to be the case when higher biofuel blends are introduced since not all vehicles are compatible with these higher blends - consumers that can buy the new fuel have a choice with which fuel they will fill up their vehicle. They therefore need to be convinced to fill their cars with the new fuel. Prices are important (discussed below), but also other considerations are at play.

Both the oil industry (interviews with Fuels Europe and UPEI) as well as governments (Germany, Finland and France) stressed the importance of consumer acceptance: the oil industry depend for their market shares on consumer acceptance, governments depend on consumer acceptance to meet their targets. Wrong or incomplete information and lack of understanding of the reasons for the introduction of higher level of biocomponents can harm consumer trust. Civic Consulting (Civic Consulting, 2014) has performed an extensive study including both a consumer and stakeholder survey on several aspects, such as:

- understanding of information on fuel-vehicle compatibility
- ability to compare prices (energy content differences)
- attitude towards sustainability of biofuels

The survey outcomes showed a mismatch between the perception of stakeholders (competition authorities, other public authorities, consumer organisation and auto clubs and industry organisations) and the perception of consumers on how easy information can be found. Especially, the easiness to find information on fuel-vehicle compatibility have been assessed differently by the two groups: 70% of the stakeholders find information on compatibility easy to find against 41% of the consumers. Somewhat smaller gaps are found for information on fuel prices, fuel types and effects on vehicle performance. Except from the equal opinion on the accessibility of information on the effects of fuels on the environment, stakeholders overestimate the easiness to find information compared to that experienced by consumers.

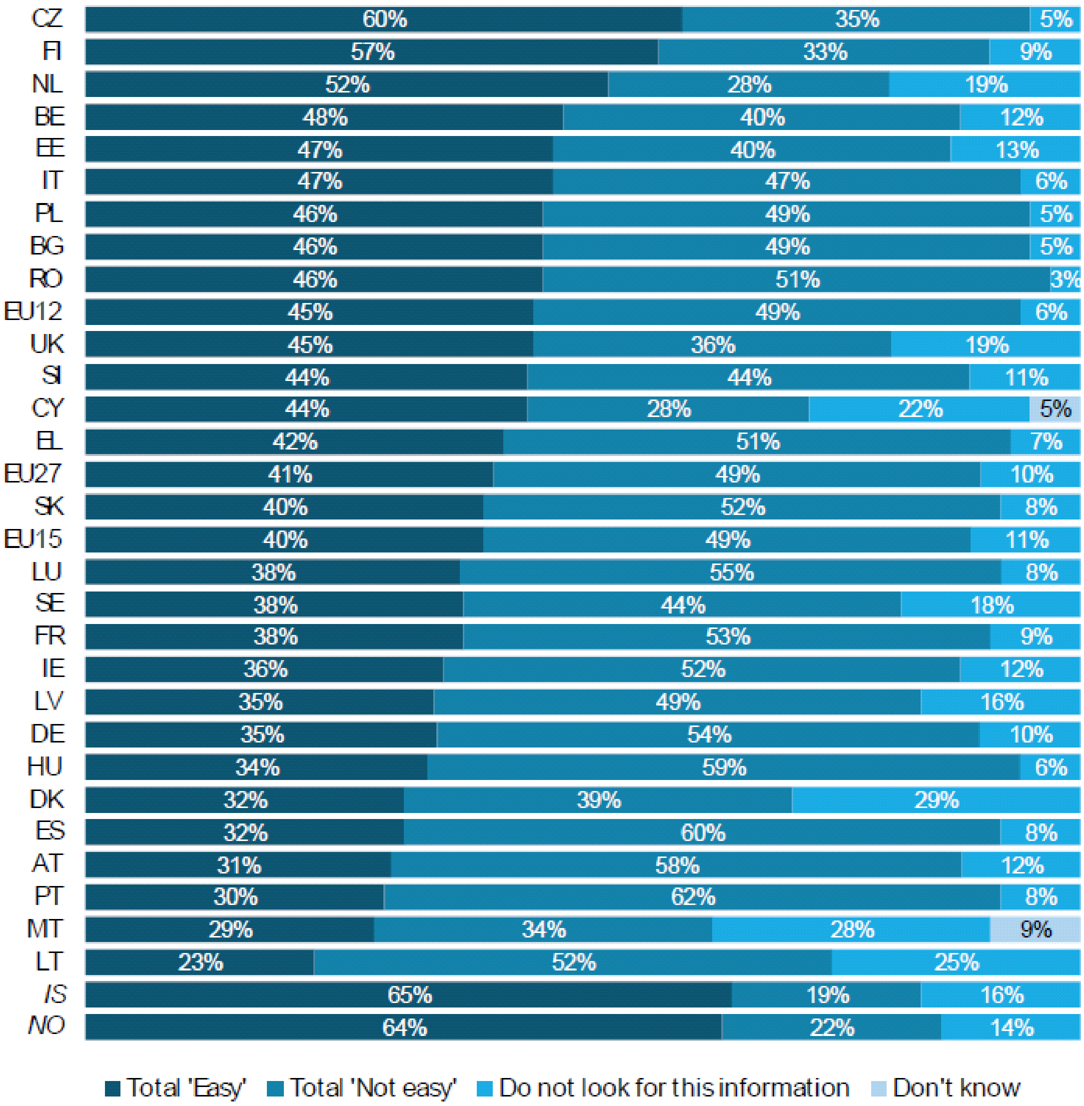
Figure 1.19 Disparities between consumers and stakeholder opinion on easiness to find information on fuel related aspects



Source: Civil Consulting, 2014

In Figure 1.20 the perception of consumers on the ease of finding information on fuel-vehicle compatibility per Member State is depicted and shows that only in a few countries more than 50% of the consumers find it easy to find this information. In all other countries, the majority of the consumers faces problems in their search for information or have simply not yet looked for the information.

Figure 1.20 Ease of finding clear information about fuel-vehicle compatibility analysis by country (based on consumer survey, N=25797 for EU27)



Source: Civil Consulting, 2014

According to some of the fuel suppliers that were interviewed, the timing of introduction of new blends and specifications is crucial to a successful market strategy, and all aspects of the fuel chain should be taken into account. For example, biofuel blends should only be introduced on the market when a significant share of vehicles is compatible, consumers have been informed and additional information is easily accessible.

What the minimum market share of compatible vehicles needs to be before a new fuel can be rolled out on EU or Member State level is currently unknown. This is likely to depend on the local and national market structure and will even vary between service stations and fuel suppliers, as the cost and benefits of introducing a blend varies between retail stations (as explained in Section 1.4.4). There is no relevant past experience that can be used here as empirical evidence, apart from the recent introduction of E10 in Finland, France and Germany. This took place at a time where most of the vehicles could drive on E10, about 70 % of the petrol cars (source of this estimate: interview with Finish government official). None of the stakeholders interviewed (government officials, fuel suppliers or vehicle manufacturers) suggested that vehicle compatibility was too low at that time. Whether this is also the minimum (or optimal) level is, however, unknown.

The different experiences with introducing E10 in Finland, France and Germany, as described in Section 1.3.4.1, do illustrate that the importance of consumer acceptance: in

Germany, low consumer acceptance proved to be a significant barrier to the introduction of E10, resulting in much lower market shares of E10 in the total fuel sales than in Finland and France (see Section 1.4.2.3), where this was not issue.

1.4.6.2 Opportunity for differentiation of products

Fuel suppliers can improve their market position by a differentiation of their products. That is why many fuel suppliers offer premium fuels such as 98RON at their refuelling stations.

As explained in Section 1.4.4, when a new biofuel blend is introduced, fuel suppliers have the option to substitute premium fuels by the new blend. This has been observed in France, where refuelling stations were seen to replace their premium grade with E10 (source: interview with French authorities, see also Section 1.3.4.1).

However, this reduces the opportunities for branding and market differentiation and thus negatively influences the competitiveness of fuel suppliers (source: interviews with fuel suppliers). The extent of this impact is, however, not known (i.e. it has not been analysed in the public literature, this data is confidential to the fuel suppliers and services stations).

1.4.6.3 Price barriers

As consumers are not obliged to buy a higher biofuel blend, they will need some form of an incentive to buy to higher blend. Higher ethanol blends may provide fuel efficiency benefits (see Chapter 2) but otherwise, consumers will base their choice mainly on price (perhaps in combination with some other incentive such as a saving scheme).

However, the costs of biofuels are higher than of their fossil counterparts, as will be shown in Section 1.6.5. Therefore, higher biofuel blends are more expensive than fuels with lower shares of biofuels.

Nevertheless, in the countries where E10 has been available on the market (Finland, France and Germany), E10 is typically 2 or 3 Eurocents cheaper to consumers[37] (source: interviews with the government authorities and car manufacturers). In Finland, this is due to a lower CO_2 tax on the fuel (biopetrol is exempt from this tax), but in France and Germany, there are no tax benefits for E10 compared to E5. In these countries, the lower price of E10 is driven by the biofuel obligations: fuel suppliers have to meet the obligations, and therefore need to encourage consumers to buy the higher blend[38]. The price differentials between fuels is then not only driven by actual cost of the fuels, but also by the biofuel obligation.[39]

Tax reductions or strategic price setting can therefore be a very efficient means to encourage customers to buy a specific blend. However, if there are no tax reductions, the evidence suggests that fuel suppliers will only change their fuel prices in favour of the high blends if they must sell them: a biofuels or GHG obligation that cannot be met by low blends only is likely to be a prerequisite for fuel suppliers to promote the more costly higher blends. This is due to the competitive market in which they operate: any cost increase or price reduction may affect their margins. However, as long as a biofuels (or GHG reduction) obligation is equal for all fuel suppliers, the impact on their profit margins can be limited by passing on any additional cost of biofuels to the customers. All competitors are then faced with the same requirements, and therefore with (roughly) the same compliance cost.

In reality, some market distortion may still occur, especially for those fuel suppliers and retail stations that compete with suppliers that do not have to meet the obligations. This may occur close to national borders, when the policies in neighbouring countries are less ambitious. Fuel suppliers on that side of the border then add lower shares of biofuels, resulting in lower

[37] Note that part of this price differential will be offset by the higher fuel consumption (in terms of litre per kilometre), because ethanol has lower energy content than petrol.

[38] This is further driven by the legal provisions in the obligations of France and Germany that fuel suppliers receive a fine from the government if they do not meet their blending obligations.

[39] The real cost of E10 without any subsidy or tax benefit is unknown. The 2-3 cent lower cost of E10 is based on anecdotal evidence from interviews, and could not be further substantiated.

overall fuel cost and a competitive advantage to fuel suppliers in the country with more ambitious policies.

This border effect has been observed in the past, as demonstrated in a recent study in the Netherlands on the effect of increasing the excise duty in 1.1.2014 (Ministry of Finance, 2014). The Dutch excise duty on petrol was increased by 0.013 €/litre (about 1.7%), and by 0.038 €/litre (8.6%) for diesel[40]. This measure result in a stronger reduction of fuel sales in the region within 10 kilometre from the Dutch border: petrol sales decreased by about 11% in the first quarter of 2014 compared to Q1 of 2013, whereas average petrol sales in the Netherlands decrease by 4%. Beyond 10 kilometres, the effect was found to be negligible (Ministry of Finance, 2014). A similar effect, although somewhat smaller, could be observed for diesel.

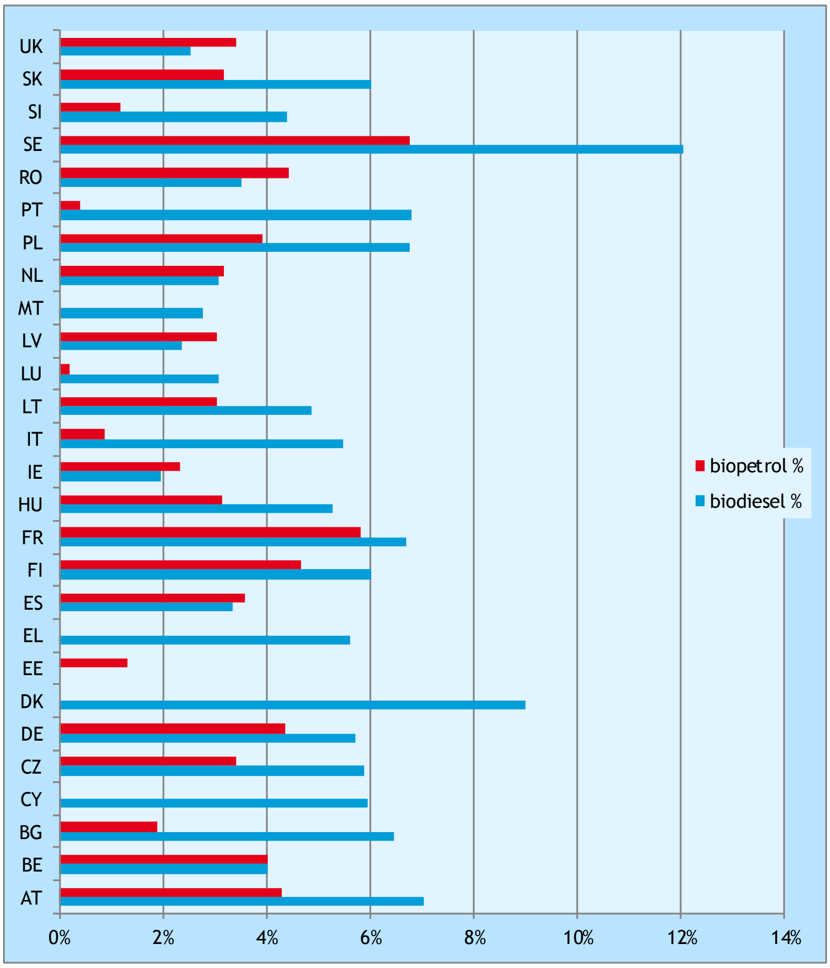
In conclusion, there is a cost differential between higher blends and the standard fuels, due to the higher cost of biofuels. However, this does not need to be a barrier to the successful introduction of a higher blend, if an effective biofuel policy is in place, such as a blending obligation: offering these higher blends at lower prices than the standard grade can be a very effective means for fuel suppliers to increase the sales of higher blends and thus meet the obligation. Lower tax levels for higher blends can have the same result, as well as a biofuel (or GHG) obligation that is set high enough for fuel suppliers to sell the higher blends. The competitive impacts can be expected to be limited, if all fuel suppliers need to meet the same obligation, but suppliers close to national borders may be impacted if the neighbouring countries have a less ambitious policy in place.

1.4.6.4 Different blends in different Member States

Several oil refineries mentioned during the interviews that the currently limited level of harmonisation of national policy in the RED and FQD results in a market barrier that increases cost. The RED and FQD both set out binding requirements regarding the share of renewable energy in transport and the CO2-intensity of fuels in 2020 (see Section 1.3.2), but Member States are free to choose the policy measures with which they want to achieve these targets. This has resulted in a broad range of biofuel policies, as shown in Section 1.3.3, and an equally broad range of biofuel shares throughout the EU, as was demonstrated in the Section 1.3.3.3 and further detailed in Figure 1.21. In 2013, biodiesel shares varied between 0% in Estonia and 12% in Sweden, biopetrol shares varied between 0% in Cyprus, Denmark, Greece and Malta to 6.8% in Sweden.

[40] The excise duty in 2014 in the Netherlands was higher than in both Germany and Belgium: for petrol the differential was 0.104 and 0.145 €/litre respectively, for diesel this was 0.008 and 0.05 €/litre respectively.

Figure 1.21 Shares of biodiesel and biopetrol in the EU Member States



Source: Eurostat, 2013

The data on fuel grades available in the various Member States, in Section 1.4.2.3, further illustrates the diversity of the fuel market in the EU, especially for petrol (there are 10 petrol grades and only 3 diesel grades on the EU market).

Due to these differences between Member States, oil refineries and fuel suppliers that supply various national markets typically have to offer multiple blends (up to 7 in some cases, as mentioned by fuel suppliers during the interviews). Introducing more blends on the market will further increase the number of fuel grades and blends that they need supply, thus further increasing operational costs for refineries and suppliers. Note that there is no technical limitation to the number of fuel grades that can be supplied, although refineries and fuel suppliers may have to invest in additional infrastructure, depending on the existing situation, and the specific characteristics of the new grade. The extent of the cost and efforts to the refineries to add more blends to their portfolio will be assessed in Task 3 and 5 of this study.

1.4.7 Conclusions

Diesel currently has a market share of 70% in overall road transport fuel sales in the EU, and this share is increasing over time, a share of around 80% is expected for 2020. As refineries cannot produce this petrol to diesel ratio, 10% of the EU's diesel is currently imported, and 40% of petrol production is exported. Increasing the share of biodiesel reduces the imbalance, while replacing petrol by biopetrol has the opposite effect. The impact of this effect on biofuel demand and supply is unknown, but oil companies and fuel suppliers will take this effect into account in their operational decisions.

In 2013, 13.6 Mtoe biofuels was consumed in the EU, which represented a share of 4.6% of the EU's petrol and diesel consumption (in energy content, most recent Eurostat data). 79% of this was biodiesel, mostly FAME, 20% was biopetrol. 2013 was the first year since 2004 that biofuel consumption reduced. The biofuel shares varied significantly between Member States: where Estonia had a share of only 0.4% in petrol and diesel sales (in energy content), Sweden achieved 9%.

In most Member States, E5 and B7 are the main fuel grades on offer. E10 has been introduced on the market in only a few countries (Finland, France and Germany). The market share of E10 is highest in Finland, almost 60% of the total petrol market, whereas France has about 30% market share of E10, and Germany about 15%. Some countries, namely Cyprus, Greece, Hungary, Lithuania, Malta and Portugal have almost no E5 in their fuel mix, only pure petrol (data from 2013)

There is still a lot of potential to further increase biopetrol sales within the current blending limits, if all Member States would introduce E10, either by providing specific incentives for E10 or by gradually increasing the obligations and thus encouraging the fuel suppliers to introduce and actively market E10. As most Member States only have E5 petrol grades on their market (equal to 3.3% energy), it is not surprising that many countries have biopetrol shares lower than 3.3%. However, there are also quite a number of countries with biopetrol shares between 3.3 and 5 energy%, namely Austria, Belgium, Czech Republic, Germany, Spain, Finland, Poland, Romania and the UK. Only France and Sweden had shares higher than 5 % (energy content, which equals about 7.6 vol%).

Biodiesel sales can also be further increased within the current blending limits. Firstly, the two Member States that have not yet switched completely to B7, Estonia and Latvia (2013 data), should do so. Secondly, biofuel obligations can be increased further so that fuel suppliers are encouraged to indeed blend FAME in their diesel to the maximum level allowed. Having B7 on the market does not mean that a share of 7 vol% FAME (6.4% energy content) is indeed achieved: a total of 12 Member States can still add two or more percent of FAME to their diesel within the limits. Some Member States seem to have reached the maximum level already: Austria, Bulgaria, Denmark, France, Poland and Portugal, consume more biodiesel than the B7 level, where Sweden sells almost twice as much as the blending limit (2013 data)[41]. In addition, even though actual HVO consumption data are unavailable, it can be derived from production capacity data that the maximum level of HVO in diesel can also be increased further within the current fuel specifications (the FQD limits the share of biocomponents in diesel to 30%)

The introduction of higher blends such as E20 or B10 requires so-called 'protection grades', as only part of the vehicle fleet will be compatible with the new blend. How long this protection grade should be kept on the market mainly depends on the renewal rate of the vehicle fleet, but may well be up to 20 years. All stakeholders in the fuel market, i.e. fuel suppliers, distributors and owners of retail stations will then have the following options:

a. introduce the new blend by replacing an existing fuel grade that they offer;
b. invest in expanding the existing infrastructure (such as pipelines, subsurface fuel tanks and pumps) and logistics, and add the new blend to their existing portfolio;
c. not introduce the new blend, i.e. maintain their current fuel grade portfolio, and wait until market demand for the new blend is sufficient to warrant replacing one of their existing fuel grades

The cost and benefits of these three options, and therefore the optimal choice for a specific stakeholder, may depend on the specific situation of the filling station: the number of grades they sell and their market shares, whether or not they have the (physical and financial) possibilities to expand their infrastructure, etc.

[41] Biodiesel levels above the B7 limit may be achieved with consumption of fungible biodiesel (HVO), higher FAME blends in captive fleets or use of FAME in non-road modes.

Fuel markets in different Member States can have various ownership structures. For example, in Germany, Greece, Italy and, to a lesser extent, Austria, Bulgaria, Portugal, Romania, Spain and Sweden, the fuels market is largely dominated by a limited number of major companies, whereas fuel markets in Latvia, Lithuania, Poland and the UK are much more fragmented. In these countries, independent retailers, small companies or supermarkets are responsible for about 40% to 75% of the fuel sales. This has implications for the introduction of a new blend (in a more fragmented fuel market, a successful roll-out of a new blend requires the active involvement of many different stakeholders). In both cases, introducing a new blend may lead to negative economic impacts on the smaller retailers, as they will have fewer resources to invest. These effects have, however, not yet been quantified or assessed.

Introducing a higher biofuel blend may cause a number of technical issues that need to be resolved to ensure fuel quality and prevent technical issues in the fuel supply chain. For higher FAME blends, these are mainly related to quality control and aging. For higher ethanol blends, technical issues may occur due to corrosion. Costs to resolve these issues increase with increasing shares of ethanol.

A number of non-technical issues and barriers were also identified. One of these is consumer acceptance and willingness to buy: this is crucial to successfully introducing a new biofuel blend since the lower, protection grade fuels, remains available. The higher price of biofuels results in a higher price of fuels that contain higher shares of biofuels, but this does not have to be a barrier to the sales of high blends. Effective biofuel policies such as a biofuel obligation or tax incentives can provide sufficient incentives for fuels suppliers to sell these fuels despite the higher cost.

1.4.7.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations can be derived if one would consider to increase the maximum content of biofuels in petrol and/or diesel and thereby introduce a new fuel grade:

- Member States should be encouraged to assess how the biofuels needed to meet the 2020 targets can be supplied to the market, taking into account the recent legislation including the ILUC decision. This assessment should include making full use of blending options within current limits, i.e. whether to prepare for the introduction of E10 and to make full use of the B7 blending potential are attractive options in the national context, as these are options that can be relatively easy to implement.
- Further analyse the implications of introducing a new blend on the fuel distribution and market structure, assess potential market distortion effects in the varying markets that exist in the EU. The introduction of E10 in Finland, France and Germany can serve as good case studies for this.
- Assess the potential options for phasing out the protection grades E5 and B7 or even E10 in the future in exchange for a higher blend, if such a higher blend is to be introduced. This assessment should explore questions such as: How many years should a protection grade remain available on the market? What social and economic impacts of phasing out a protection grade can be expected (as some vehicles in the fleet may still need the protection grade fuel at the time of phasing out)? What are the potential options to reduce the negative effects?
- Further assess the technical issues and barriers to introducing higher blends of FAME or ethanol. Specific areas of concerns are quality control and aging of higher FAME blends.
- When designing a new standard for higher ethanol blends, attention should be given to the blendstock for oxygenate blending (BOB). Higher bioethanol blends require different BOBs (with lower vapour pressure, modified distillation characteristics and reduced octane) to still meet the fuel specifications, increasing cost to refineries and distribution. It is therefore recommended to assess options to resolve this.

1.5 Market penetration of vehicles fully compatible with higher blends

1.5.1 Introduction

The future growth of higher biofuel blends such as B10, E20 or E25 is closely linked to the compatibility of the vehicle fleet to run on these blends. As will be seen in Section 1.6 on biofuels and biomass availability, vehicle compatibility is certainly not the only barrier to future biofuel growth, but it can play an important limitation which must be anticipated well in advance. This Section focusses on the potential market penetration of vehicles that are compatible to higher blends.

It should be noted that in this context, vehicle compatibility can mean different things:

- Vehicles can be **tolerant** to the higher blend, where they can drive on these blends without technical or safety issues. For example, most petrol vehicles manufactured after 2003 are E10 tolerant (see Chapter 2), and from 2011 onwards, a majority of cars made in the EU are E20 tolerant. However, the E10 and E20 tolerant cars will not have been optimised for the higher blends (and so will not receive any fuel efficiency benefit), but rather for the blending limits and FQD requirements at the time of sales of these vehicles. Also, vehicle warranties may not include use of the higher blends, as these may refer to the fuel standard at time of the sales.
- Vehicles can be **fully compatible** with the blend: there are not technical or safety issues, and the blend is included in the warranty of the vehicle. If necessary, the maintenance schemes are adapted to the blends (e.g. more frequent oil changes). Additionally, in the case of ethanol blends, hardware and/or software changes have been incorporated into the vehicle to achieve the fuel efficiency benefit of the biofuel blend. For example, in the case of E20 rated at 100+RON, this could result in fuel efficiency gains between 3% and 6.4% (Chapter 2, Section 2.3.3.3). There is no fuel efficiency gain expected from using higher levels of FAME in diesel.

The discussion in the following mainly refers to the latter category, fully compatible vehicles, where it is assumed that only vehicles explicitly sold as fully compatible with higher blends will consume these blends. Use of these blends in tolerant vehicles may be technically possible but might have legal (warranty) and other implications, and is not considered here in more detail. If this would be considered a potential viable option to further increase biofuel use beyond blending limits, it is recommended to further assess potential barriers and opportunities to this route, in close cooperation with the vehicle manufacturers.

Note that this chapter is only relevant for FAME and ethanol. Fungible biofuels such as HVO or BTL are already compatible with the current fleet; thus, the market penetration of compatible vehicles is not an issue for these fuels.

1.5.2 Market penetration of vehicles

As described in (CE Delft, 2013), the market introduction of vehicles fully compatible with higher biofuel blends typically requires the following steps:

- Deciding on fuel specifications for the new blend (within CEN)
- Car manufactures and OEMs to develop vehicles that are compatible with these fuels, i.e. meet the emissions regulations as well as lifetime requirements, and optimise the engine performance (i.e. fuel efficiency) for the new blend (as described in Chapter 2).
- Type approval of these vehicles
- Bringing these new cars to the market. Two different approaches are possible:
  - All new vehicles are fully compatible with the new blend, from a certain date onwards.
  - Part of the new vehicles are fully compatible with the higher blend, vehicle manufacturers continue to also offer vehicles fully compatible with other blends.

  An example of the first approach is E10: all new vehicles are currently fully compatible with E10. This is the preferred way forward if a higher blend will be rolled out to public

filling stations and it is foreseen that this will become the new protection grade fuel in the future.
Examples of the second approach is E85 (some new vehicles are flex fuel and compatible with E85, but not all) and B30, which is intended for use in captive fleets only.

- Consumers then need to buy these fully compatible vehicles. This does not require any action in the first approach, but specific marketing efforts may be required in case of the second approach.

The market penetration rate of the fully compatible vehicles then determines the potential growth of sales of these higher blends. It also determines how long the protection grade has to be available.

As is discussed in Chapter 2, Section 2.3.2, as of 2011, the majority of the petrol cars made in the EU are already E20 tolerant. This means that even if vehicles have been type approved and fully compatible for lower blends, no safety or technical issues will occur if the higher blend is used. However, tolerant vehicles will gain no efficiency advantage in using the higher blend and car warranties may in fact limit the actual use to current fuel specifications and blending limits, i.e. to E10.

To obtain the efficiency benefit of E20, vehicles that are fully compatible with this fuel will need to be developed. These vehicles will then also be tolerant to lower ethanol blends. This tolerance has the advantage that it prevents any technical issues even when the vehicle owners do not use the blend their vehicle was designed for. It also allows fuel suppliers to use the full range of ethanol blends that E10 and E20 fuel specifications allow, i.e. between zero and 10 or 20 vol% ethanol. The potential downside is the potential lower vehicle efficiency when different blends are used in practice (Chapter 2).

1.5.2.1 Timeline

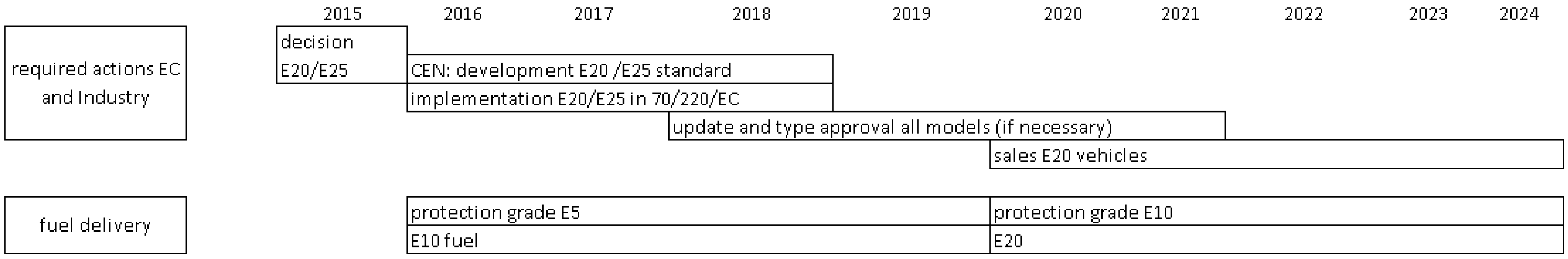
In (CE Delft, 2013), illustrative timelines were constructed for the implementation of vehicles specifically designed for a higher blend, following the steps described above. Figure 1.22 shows the result for the case of E20/E25, if vehicles and blends are to be introduced throughout the EU, based on a hypothetical decision to start the process in 2015.

- First, the CEN will develop a new standardisation, in close cooperation with stakeholders.
- This will have to be implementation in the relevant legislation (FQD and type approval). In the figure below, it is assumed that by the end of 2018, the new legislation is in place.
- Vehicle manufactures will start to adapt their vehicles and optimise them for the new standards once it becomes clear what the new standards will be (at the end of 2017, in the figure).
- Once models are type approved, they can be sold. This can be expected to start with some models, in the timeline below it is assumed that by 2020 all new vehicles will be required to be E20/E25 compatible.
- From that time onwards, E20/E25 can be rolled out to fuel stations, together with the necessary information provision and incentives to consumers. E10 will then become the new protection grade fuel, and E5 will be removed from the market.
- Depending on the incentives provided, the market share of E20 fuels can increase gradually over time, as the share of E20/E25-compatible vehicles in the total fleet increases.

A later decision on the standards, or any other delay in the decision making will, of course, result in a delay of these steps.

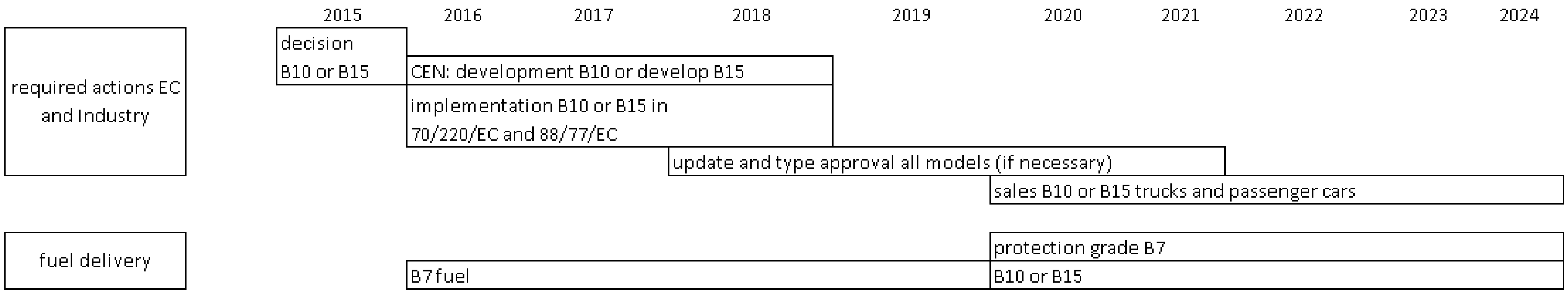
The process to arrive at a higher FAME standard can follow a similar, hypothetical timeline, see Figure 1.23.

Figure 1.22 Illustrative timeline for implementation of E20 or E25 for petrol based on a hypothetical decision in 2015



Source: CE Delft, 2013. Bringing biofuels on the market, Options to increase EU biofuels volumes beyond the current blending limit (years adjusted)

Figure 1.23 Illustrative timeline for implementation of B10 or B15 for diesel based on a hypothetical decision in 2015



Source: CE Delft, 2013. Bringing biofuels on the market, Options to increase EU biofuels volumes beyond the current blending limit (years adjusted)

1.5.2.2 Market penetration of fully compatible vehicles

Once the high-blend fully compatible vehicles become available on the market, their share in the total vehicle fleet will increase over time. This can be illustrated in the following – again hypothetical - example. The actual timing of the different steps in this timeline may, of course, be quite different, depending on the actual timing of the decision making process.

- Assuming that by the end of 2015, an EU-level decision is made that B10 and E20 will become the new high blends, and the process described in Figure 1.22 will be started.
- B10 and E20 compatible vehicles will be brought on the market by 2016, as some vehicle manufacturers have already developed these vehicles. They will not be type approved for B10 and E20 yet, but these vehicles will be compatible with the higher blends and their warranty will explicitly include driving on B10 diesel and E20 petrol, respectively.
- The share of B10 and E20-approved vehicles in the new vehicles sales will then increase between 2016 and 2020.
- From 2020 onwards, all new diesel vehicles (light and heavy duty) will be compatible with B10, all new petrol vehicles will be compatible with E20. This is in line with the finding in Chapter 2 that the lead time for manufacturers to design engines optimised for E20 would be 4 to 5 years.

Using the PRIMES reference scenario (2012) (also used in Section 1.4.3.2) as a basis to determine the EU vehicle fleet renewal data, the results indicate that in this hypothetical example,

- a market share of almost 25% of B10 and E20-optimised cars can be expected in the EU-wide vehicle fleet in 2020, and 19% B10 compatible trucks;
- these shares increase to more than 85% B10 and E20-optimised cars in 2030, and 78% B10-compatible trucks.

The remaining part of the fleet in 2030 will still need to drive on B7 or E10 (unless some form of retrofit is applied).

These results, of course, depend on fleet renewable rates, which is a function of vehicle sales and vehicle lifetimes: if vehicle renewable is slower and vehicle lifetimes are longer than assumed in this PRIMES reference scenario, the market share of compatible vehicles will be lower than calculated here[42]. It also depends on the ramp-up of the sales of B10- and E20-optimised vehicles: if it takes longer to develop these vehicles, market shares will also be lower in 2020 and 2030.

1.5.2.3 The potential role of captive fleets

High blends can be rolled out to public fuelling stations, but it can also be decided to only introduce them in captive fleets, which are vehicle fleets that refuel at dedicated filling stations[43]. More specifically, vehicle manufacturers and fuel suppliers recommend that some biofuel blends, notably FAME blends above B10 (e.g. B20, B30 or B100), should be used in captive fleets only, as they require closer quality monitoring of both fuels and vehicles (Chapter 2, Section 2.4.2).

These captive fleets are owned and operated by companies with their own fuel depot, for example large hauliers, bus or taxi companies or couriers with a fleet of delivery vans. Switching these to high blends has the advantage that they can be monitored closely, providing an opportunity to introduce higher blends without requiring large scale availability of high blends at public service stations.

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[42] Note that the assumptions in PRIMES reference scenario (2012) are not shown here as this concerns quite a lot of detailed data. These calculations should be seen as an illustrative example.

[43] Higher blends may also be applied in non-road modes with dedicated fuelling stations such as diesel trains, however, these are outside the scope of this assessment.

Unfortunately, as concluded in CE Delft, 2013, there are only very limited data on the fuel consumption of centrally-fuelled captive fleets in the EU and its Member States, and estimates in literature appear to be quite limited and show significant ranges. Based on these data (CE Delft, 2013), estimates that about 25% of diesel fuels sales would be through captive fleets, a figure that will also be used in the scenario development in this study (see Section 1.7.3).

1.5.3 Vehicle compatibility and biofuel demand

The compatibility of vehicles in the EU fleet will set a maximum boundary to the FAME and ethanol volumes that the fleet can absorb, i.e. to the maximum market potential of these biofuels from a vehicle point of view. As noted above, this may not be an issue if biofuel supply proves to be the main barrier (to be discussed in the next chapter) or Member States prefer to meet their climate and energy goals with measures other than biofuels. However, as it takes time to achieve market penetration of high blend fully compatible vehicles, it is important to start this process well in advance before the high blends need to be sold.

In the example above it takes about 15 years from the time of the decision to move forward with B10 and E20 until an 85% market share is achieved in the passenger car vehicle fleet, and even longer in the heavy duty fleet. By that time, the remaining share of the fleet are vehicles older than 10 years and fully compatible for use with B7 or E10 only. The maximum FAME and ethanol shares that the total vehicle fleet can then handle is

- 8.7% FAME (energy content) in diesel, which is about 23,476 ktoe FAME in the EU in 2030 (according to the PRIMES reference scenario (2012) used here)
- 13% ethanol (energy content) in petrol, this equals about 6,400 ktoe ethanol in the EU in 2030 (again based on the PRIMES reference scenario (2012)).

Whether or not this maximum share of biofuel consumption is achieved then depends on the availability of the biofuels and on the policy incentives provided – without policy incentives it is unlikely that fuel suppliers will bring the high blends on the market, and consumers would buy these blends rather than the protection grade fuel. This could be tax incentives for high blends (see Section 1.3.3.2 for examples), or biofuel obligations for fuels suppliers that are set at levels high enough to encourage fuels suppliers to sell these higher blends (as the recent experiences with E10 have illustrated (see Section 1.3.4.1).

1.5.4 Conclusions

In the EU, most petrol vehicles manufactured after 2003 are E10 tolerant, and from 2011 onwards, a majority of cars made in the EU are E20 tolerant; all diesel vehicles can run on B7. The term tolerant implies here that they will not have safety or relevant performance issues with these fuels. These vehicles are not fully compatible with blends higher than the current blending limits B7 and E10, and warranties may not include higher blends.

Irrespective of the hypothetical scenarios explored in this study, it is considered that the introduction of new, higher biofuel blends requires fully compatible vehicles, which will be developed and sold once the technical specifications of these blends are decided on. The introduction of vehicles fully compatible for higher blends first requires agreement on fuel specifications (in the CEN), which are then included in the FQD and type approval regulation. Vehicle manufacturers can then develop and optimise vehicles for this new fuel standard, and introduce these on the market. The market penetration rate of these fully compatible vehicles determines the potential (maximal) growth of sales of these higher blends, and therefore provides a boundary condition to the consumption of these biofuels. Once the first fully compatible vehicles enter the market, it will take more than 20 years before the entire vehicle fleet will be compatible with the new blends.

The rate of fleet renewal also determines how long the protection grade has to be available: the share of vehicles incompatible with the higher blend (or fully compatible for lower blends) will reduce gradually over time. In the example used in this chapter (Chapter 1, Section 1.5.2.2), 15 to 22% of the vehicle fleet will still be incompatible with the higher blend 15 years after a standard for B10 or E20 has been decided on.

Vehicle manufacturers and fuel suppliers recommend that some biofuel blends, notably FAME blends above B10 (e.g. B20, B30 or B100), can best be used in captive fleets only, as they require closer quality monitoring of both fuels and vehicles. There is, however, very little data on current EU-wide fuel sales in captive fleets, a rough estimate (to be used in the scenario development in Section 1.7.3) would be 25%.

Vehicle compatibility is only one part of future biofuel developments. Whether or not the maximum share of biofuel consumption is actually achieved then depends on the availability of the biofuels and on the policy incentives provided – without policy incentives it is unlikely that fuel suppliers will bring the high blends on the market, and consumers would buy these blends rather than the protection grade fuel.

1.5.4.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations can be derived:

- It is recommended to take the timelines for the market introduction of high blend compatible vehicles into account when drafting future (2020 and 2030) forecasts and plans for biofuel developments, to ensure that vehicle compatibility is properly taken into account.
- Fleet renewal rates are likely to vary between Member States, and may also vary over time, as both vehicle sales and the lifetime of vehicles may vary over time. It is therefore recommended to assess market penetration of compatible vehicles in more detail, and for individual Member States.
- Assess the extent of captive fleets in the EU, to determine what share of diesel is sold through private rather than public filling stations. This will enable a more reliable estimate of the volume of higher FAME blends that could be sold through these channels.

1.6 Biofuel and biomass availability

1.6.1 Introduction

This chapter assesses the future availability of biofuels from the perspective of the availability of both feedstock and production capacity. These can both be barriers to further growth of biofuel supply and demand, and therefore potentially important areas for policy makers to address, and to take into account when developing forecasts and scenarios for 2020, 2030 and beyond.

As explained in Section 1.3, the biofuel demand, the biofuel blends, the type of biofuels that will be brought on the market and the feedstocks used to produce these biofuels in the coming decades strongly depend on the EU and national policies in place. These determine both demand and supply, define the sustainability criteria that the biomass feedstock has to meet and the specifications of the fuels themselves.

Until 2020, these developments are mainly determined by the RED and FQD, where the RED sets a 10% binding target for the share of renewable energy in transport fuels in 2020 (with biofuels from waste and residues counted twice towards the target) and the FQD sets a 6% mandatory target for the reduction of the GHG intensity of transport fuels. In addition, both directives define the sustainability criteria that biofuels have to meet to be counted towards these targets. The Member States implemented these directives in recent years, and, as required by the RED, submitted National Renewable Energy Action Plans to the Commission providing, inter alia, indicative trajectories for the development of renewable energy in transport shares between 2010 and 2020, and outlining their plans and policies to meet the transport target in 2020.

However, as the ILUC Directive is likely to enter into force in the second half of 2015 (see Section 1.3.2.3), there will be implications for the future Member State biofuel policies and biofuel demand. As long as the revised Member State policies are unknown, it is difficult to predict the extent of these implications, but impacts can be expected due to

- a 7% cap on the contribution towards the RED target of biofuels and bioliquids produced from cereal and other starch-rich crops, sugars and oil crops and from some other crops grown as main crops primarily for energy purposes on agricultural land.
- the introduction of a sub-target for advanced biofuels in the RED, with a reference value of 0.5%.
- an increased contribution of electricity consumption from renewable source in rail and road transport, due to higher multiplication factors in the calculation methodology of the RED.

These provisions will require the biofuel sector to move from biofuels from food crops to biofuels from waste, residues, ligno-cellulosic biomass, algae, etc., which generally achieve higher GHG savings and also have fewer negative impacts on other environmental indicators such as on biodiversity (EC, 2012b). This shift towards double-counting biofuels, as well as the increased contribution of electricity from renewable sources towards the target, can furthermore result in lower biofuel consumption than expected in the NREAPs.

The extent of these two effects is currently, however, difficult to predict as the Directive leaves room for Member States to continue to support food-based biofuels (it only restricts their counting towards the RED target), and the cap does not apply to the FQD. Furthermore, Member States are allowed to set a national target for advanced biofuels lower than the 0.5%, provided this decision is well-founded (potential grounds are specified in the Directive).

Developments beyond 2020 are even more uncertain at this time as the design and decision making process for the post-2020 renewable energy policies is still ongoing. The EU's 2030 energy and climate package (EC, 2014a and European Council, 2014) does not yet provide details about renewable energy in transport policies beyond 2030, although the Commission's proposal (EC, 2014a) does state that first generation biofuels have a limited role in decarbonising the transport sector. In the recent Energy Union Package, it was announced that the Commission will propose a new Renewable Energy Package in 2016-2017, which will includes a new policy for sustainable biomass and biofuels as well as legislation to ensure that the 2030 EU target is met cost-effectively (EC, 2015).

From the EU Energy Roadmap 2050 (COM(2011) 885/2) and the EU White Paper 'Roadmap to a Single European Transport Area' (COM(2011) 144), it can be concluded that a further increase of biofuels use is to be expected, as it is necessary to meet the longer term EU and Member State climate goals. Nevertheless, a number of scenarios are possible to meet the longer term climate goals, both in terms of timeline (i.e. growth over time) and in the future biofuels and feedstock mix.

In view of these uncertainties, it is as yet unclear how demand for biofuels will develop throughout the EU until 2030, at what rate the level of advanced biofuels is likely to increase during that time period, and whether the level of biofuels from food commodities and energy crops will be reduced over time or not.

Even with the ILUC Directive in place, the EU-wide supply and demand for biofuels from food and energy crops can still grow by several percent in the EU without exceeding the RED cap: it restricts the contribution that biofuels from food and some energy crops can make towards targets in the RED to 7%, whereas the EU average biofuel share was 4.6% in 2013 (see the data provided in Section 1.4.2.2). The EU average share of biofuels from food crops was even lower, and likely less than 4% (based on the 2012 share of 15% biofuels from waste and residues, see Section 1.6.2.4, this share is not known for more recent years).

In the case that the EU's post-2020 renewable energy policy would continue to impose a cap on food-based biofuels to count towards renewable energy targets (or Member States would implement such a cap in national policies on their own accord), future growth of biofuel supply and demand can be expected to be dominated by biofuels produced from waste and residues and other types of feedstock (including some types of energy crops) that do not compete with crops grown on agricultural land. This would be in line with the Commission's statements on the limited role of first generation biofuels in decarbonizing the transport sector, in the 2030 energy and climate package (EC, 2014a).

As will be shown in the following, this would require a significant change to the biofuel production sector, currently to a large extent geared towards first generation biofuels. Second generation biofuel production capacity and feedstock availability are likely to remain important boundary conditions to the future supply of advanced biofuels, and removal of these barriers depends to a large extent on the success of research, development and investment efforts in this area. However, as post-2020 policies are not yet decided on, it is as yet unclear whether these developments will indeed take place.

The chapter will start with an overview of the key data on the biofuel sector in the EU: current biofuel production and biofuel production capacity in the EU, as well as export and import of biofuel data and feedstocks used are discussed in Section 1.6.2. The different biofuel production routes are presented in Section 1.6.3, where it will be shown that most second generation production routes are still in R&D phase, thus posing a barrier to fast growth of second generation biofuel supply. Availability of feedstock for these conversion routes is assessed in Section 1.6.4, followed by an overview of expected cost developments of biofuels, in Section 1.6.5.

1.6.2 Biofuel production, exports and imports

1.6.2.1 Biofuel production in the EU

In Figure 1.24 the EU28 primary production of the various types of biofuels is presented for the period 2004-2013. In line with the consumption of biofuels in the EU, the production of biofuels has increased sharply since the introduction of biofuel indicative targets under the Biofuel Directive of 2003. Production dropped in 2011, mainly due to increased biodiesel imports in that year, but increased again in recent years after anti-dumping legislation was implemented (see Section 1.6.2.3). EU biofuel production is almost completely first generation biofuels, to a large extent based on feedstock such as rapeseed oil, sugar beet, grains, etc., supplemented by biodiesel production from residual oils and fats from both food industry and consumers (see section 1.6.2.4 for a more detailed feedstock overview).

Similar to the EU's biofuel consumption pattern, biodiesel[44] has the largest share in production, about 80% of total biofuel production in 2013. Biodiesel production data include both FAME and HVO, but there are not separate statistics on these two types of fuel[45]. It is nevertheless reasonable to assume that FAME has (by far) the largest market share as the EU's production capacity of FAME is significantly higher than that of HVO (see next Section, 1.6.2.2), and cost of FAME are typically lower (as was discussed in Section 1.3.4.4). This was also confirmed in the interviews with both fuel suppliers and car manufacturers

Biopetrol[46] production is mainly bioethanol. This can then be blended directly with petrol, but it can also be first converted to bioETBE. There are, however, no data on which share of the bioopetrol volumes depicted here are bioETBE.

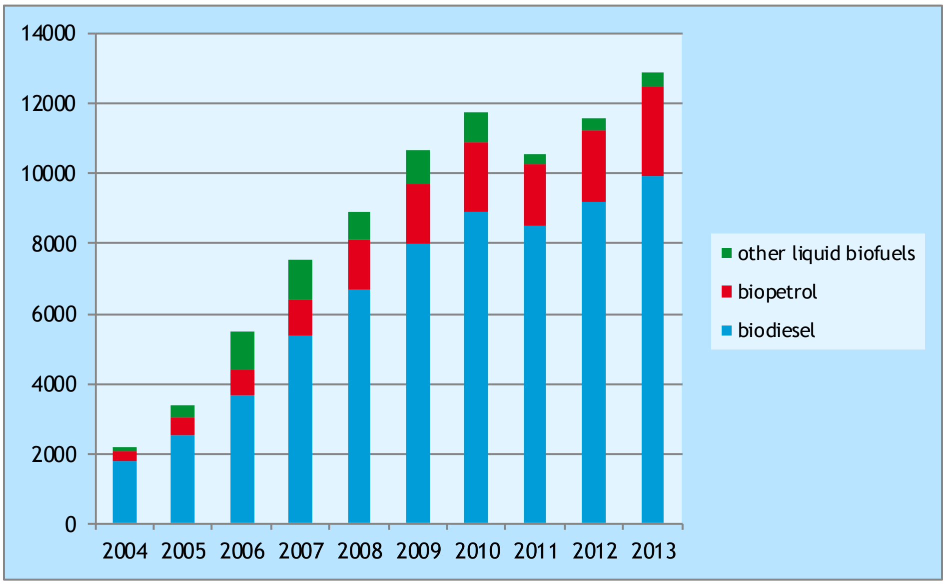
Note that 'other liquid biofuels' are not specified by Eurostat.

[44] Biodiesel data include FAME, HVO, and cold-pressed bio-oil

[45] Note that the production capacity data of HVO are not reported by Eurostat, but based on data provided by NesteOil, the main producer of HVO – see the next Section.

[46] Biogasoline data include bioethanol, bioETBE, biomethanol and bioMTBE

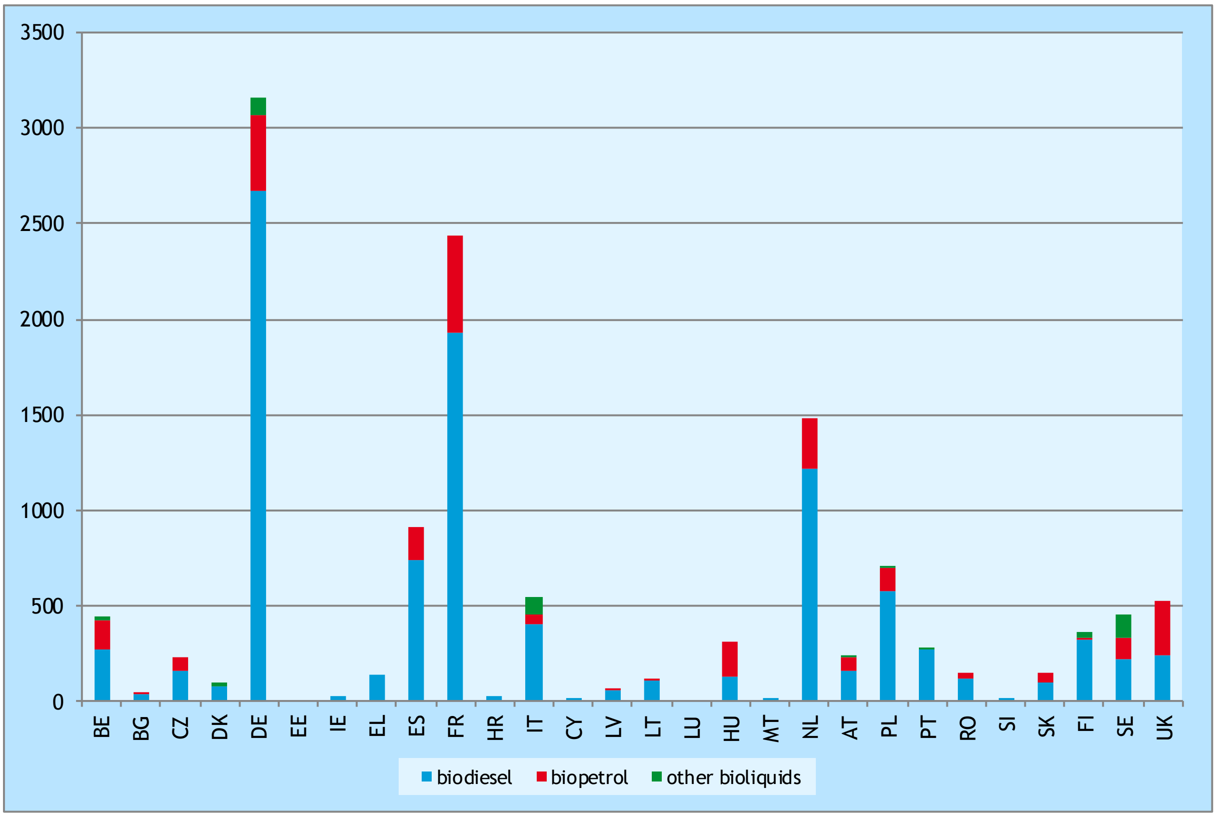
Figure 1.24 Primary production 2004-2013 in ktoe, EU28



Source: Eurostat, 2013

Figure 1.25 shows that Germany, France and the Netherlands have been mainly responsible for the EU's biofuel production in 2013 with Germany being the largest biofuel producing country.

Figure 1.25 Production of biofuels per Member State in 2013 in ktoe



Source: Eurostat, 2013

1.6.2.2 Capacity installed

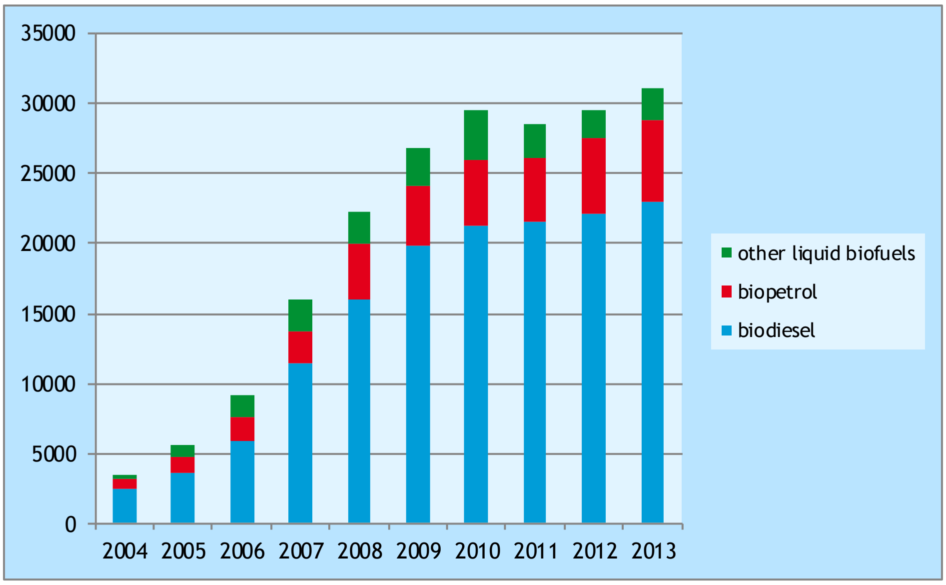
The production capacity installed in the EU is significantly higher than production itself, as shown for the various biofuels in Figure 1.26. In 2013, only 43% of the EU's biodiesel production capacity was actually used, 44% of biopetrol capacity and only 17% of capacity for other liquid biofuels[47]. In absolute terms, biodiesel had the most idle capacity available. In line with current EU biofuel production, this production capacity is almost completely for first generation biofuels (see section 1.6.2.4).

This situation of overcapacity has been in place since 2009/2010, resulting in relatively limited investments and roll-out of in new capacity since 2010. Investments in new capacity are still very limited due to the existing overcapacity, in combination with the uncertainties in future demand and sustainability criteria (and state aid guidelines that effectively limit state investment aid to conversion into advanced biofuel plans from 2014 until 2020, see Section 1.3.2.7). Stakeholders indicate that a clear outlook for biofuel demand until and beyond 2020 is required before investments will pick up again.

Production capacity per Member State is shown in Figure 1.27 (in ktoe total capacity) and Figure 1.28 (share per Member State). More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, 44% of the production capacity of biopetrol is located in France, Germany and the UK. The category 'other liquid biofuels' is left out of the latter graph (for clarity), but Germany accounts for 86% of capacity in this category. In 2013, only two Member States did not report any biofuel production capacity: Estonia and Luxemburg. Another 11 Member States, namely Bulgaria, Denmark, Ireland, Hungary, Cyprus, Latvia, Lithuania, Malta, Romania, Slovenia and Slovakia, each also accounted for less than 1% of production capacity.

The biodiesel production capacity is mainly FAME, but Neste Oil also has a number of HVO production plants in operation in the EU, in Finland (380 kton/annum) and Rotterdam (800 kton/annum)[48]. Together, this accounts for about 5% of the EU's biodiesel production capacity.

Figure 1.26 Biofuel production capacity 2004-2013 in ktoe, EU28

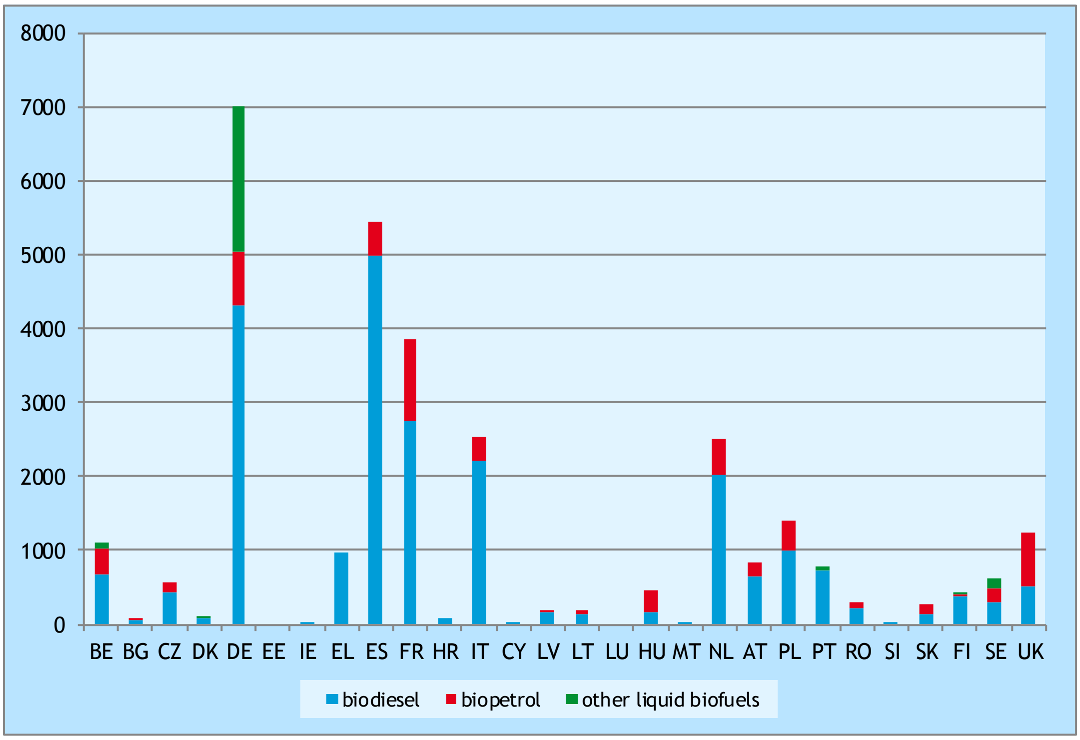


Source: Eurostat, 2013

[47] 'Other liquid biofuels' are not specified by Eurostat.

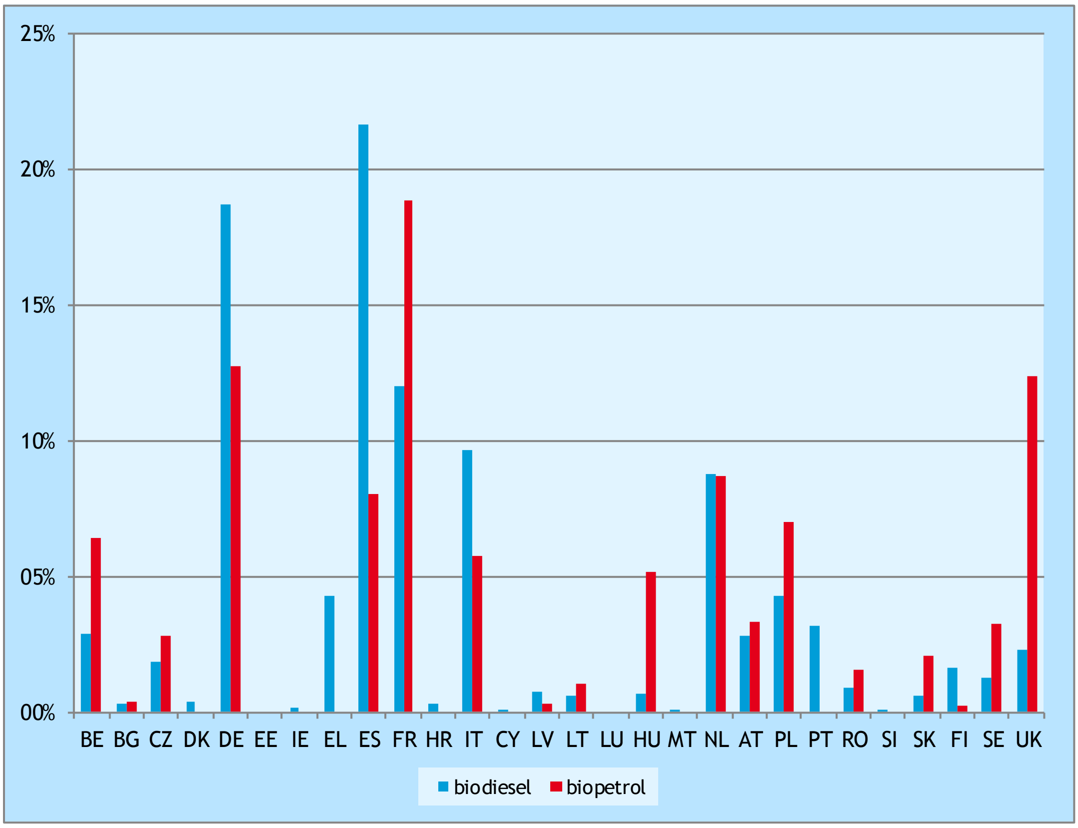
[48] Source: www.nesteoil.com

Figure 1.27 Biofuel production capacity per Member State in 2013 in ktoe



Source: Eurostat, 2013

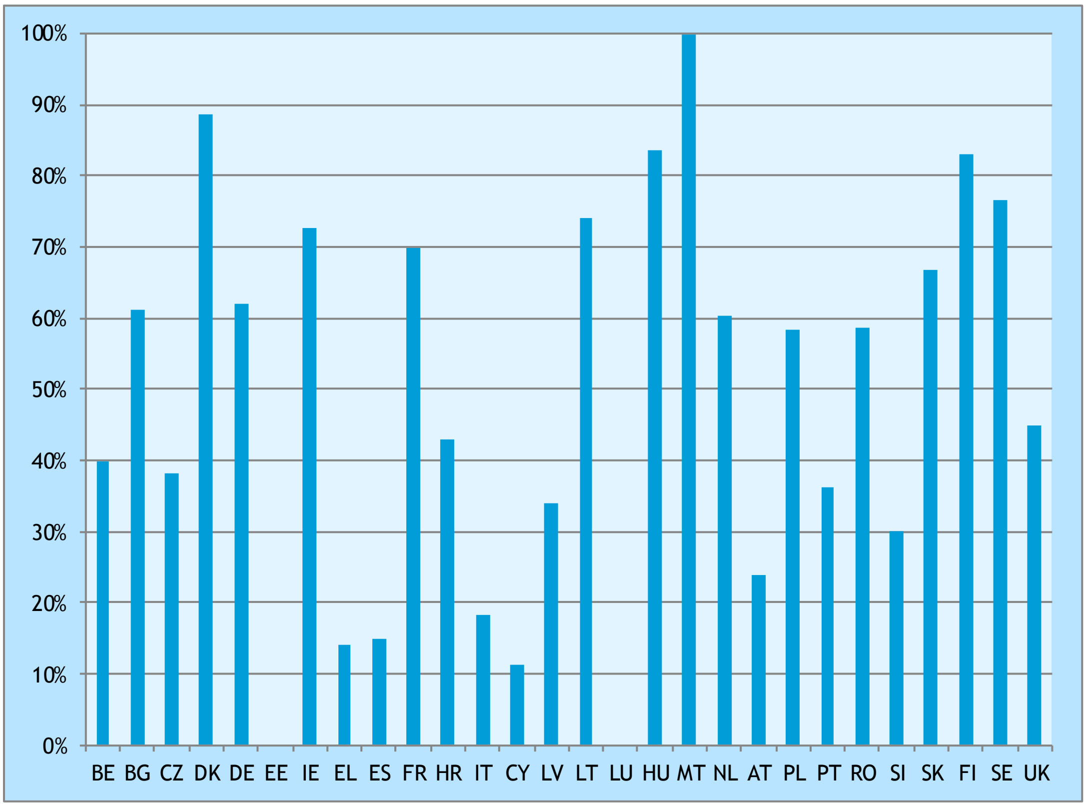
Figure 1.28 Share of biodiesel and biopetrol production capacity per Member State in 2013



Source: Eurostat, 2013

Zooming in on the use of biodiesel capacity in the EU, Figure 1.29 illustrates that in the ratio between production and capacity varies quite strongly between Member States. Biodiesel production capacity is used by more than 80% in Denmark, Hungary, Malta and Finland. However, in Europe's main biodiesel producing countries Spain, Germany and France, this ratio is only 15%, 62% and 70% respectively.

Figure 1.29 Ratio of actual production versus installed capacity for biodiesel in 2013



Source: Eurostat, 2013

There are several reasons for the underutilisation of production capacities, as Ecofys concluded in (Ecofys, 2012), based on their analysis of the data until 2010:

- The market seemed very attractive when decisions for construction were taken and construction started at many places concurrently. Once the plants came into production there was an overcapacity;
- Changing legislation especially in Germany, meant an immediate decrease in demand, especially for biodiesel;
- Increasing imports to the European Union, led to lower use of domestically produced European biofuels. Amongst others, low-cost imports of FAME from the USA and Argentina were driven by favourable blending subsidies (USA) and export policies (Argentina) in those countries;
- Increasing oil and feedstock prices increased the biofuel production cost but did not raise the competing pump prices for diesel and petrol at the same pace. The gap between biofuel production cost and value at the pump became too big to be bridged by the incentive schemes in place;
- The consumption increase has been lower than expected, partly related to sustainability concerns, and poor introduction of higher blends (E10 in Germany).

Is the current production capacity sufficient to meet 2020 biofuel demand?

When these capacity data are compared to the biofuel demand in 2020 according to the Member States' plans outlined in the National Renewable Energy Action Plans (NREAPs), it can be concluded that

- the 2013 biodiesel production capacity (22,983 ktoe) is already sufficient to meet the 2020 expected demand (21,646 ktoe) (ECN, 2011). MS expected to import 7,825 ktoe of this demand, i.e. 36%, which would not be necessary from a production capacity point of view.
- the European 2013 biopetrol capacity (5,779 ktoe) is not yet sufficient to supply the bioethanol/bioETBE that the Member States expect for 2020: 7,306 ktoe.(ECN, 2011). However, as MS are expected to import 3,216 ktoe of this volume from outside the EU, the current capacity can be considered sufficient to meet the (remaining) demand from EU-produced bioethanol/bioETBE: 4,091 ktoe.

The NREAPs do not provide separate trajectories of forecast for FAME and HVO, nor for bioethanol and bio-ETBE.

However, the plans outlined in the NREAPs did not yet take the ILUC Directive into account, and the upcoming changes in Member States plans and strategies that will be the result of its national implementation in the coming years. The increased multiplication factors for use of electricity from renewable sources in rail and road transport may reduce the projected biofuel consumption in the coming years. Furthermore, the sub-target for advanced biofuels that is introduced in the RED could be an effective driver to increase R&D and expand production capacity for advanced biofuels in the EU, provided that Member States decide to introduce these in national legislation. The Eurostat data do not distinguish between the different types of biofuels that are defined and addressed in the RED and FQD (e.g. biofuels from various food crops, biofuels from used cooking oil or animal fat, biofuels from feedstocks as defined in Annex IX Part A), but from the available data it can be concluded that advanced biofuel production capacity still has a very limited market share in total EU biofuel production capacity (see, for example, the EurObserv'ER Biofuels Barometers of recent years, Pelkmans, 2014, and section 1.6.3). As sub-target of 0.5% throughout the EU would require almost 1,300 ktoe advanced biofuel consumption, based on the 2020 petrol and diesel consumption forecast of the PRIMES reference scenario.

The possible implications of the policy developments, and in particular of a future shift from first to second generation biofuels, in the light of Europe's current biofuel production capacity, will be discussed further in Section 1.6.3 and Chapter 1.7.

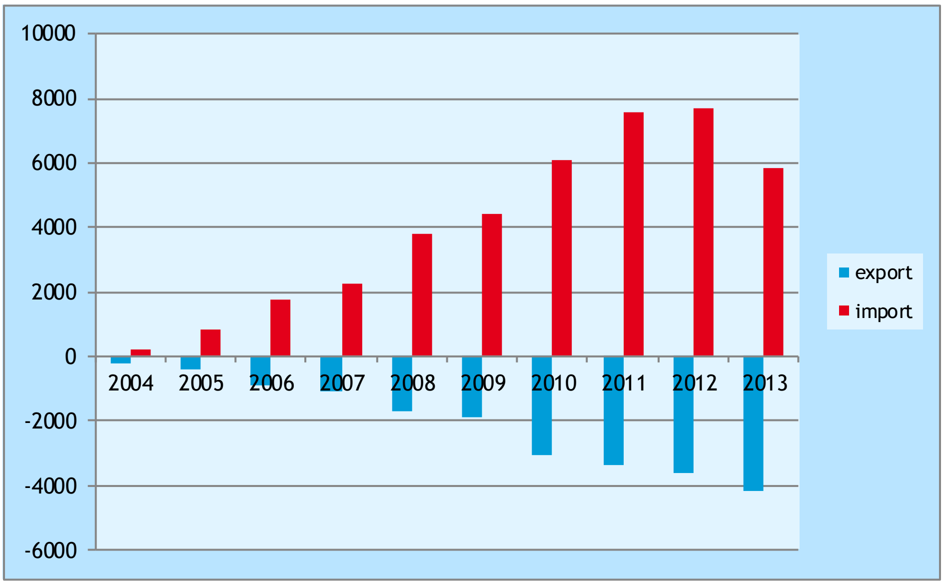
1.6.2.3 Export and import of biofuels from outside EU28

Despite the current overcapacity, the EU28 as a whole is a net importer of biofuels, as can be seen in Figure 1.30. Import increased steeply between 2006 and 2011, mainly due to increased demand in the EU and relatively low cost of biofuels outside the EU, but reduced by 20% again between 2012 and 2013, which can be at least partly attributed to anti-dumping barriers to imports from the USA, Argentina and Indonesia[49]. (Eurobserver, 2014) reports that since 2010, more than 90% of Europe's biodiesel import was sourced from the latter two countries.

Export continues to increase in recent years.

[49] Anti-dumping taxes were imposed on American bioethanol imports from February 2013 onwards (62.9 Euro per tonne, for a 5 year period), barriers for imports from Argentine (additional custom duties of 215-250 Euro per tonne) and Indonesian biodiesel (120-180 Euro per tonne) came into force on 28 November 2013 (Eurobserver, 2014)(for more background information, see also (Eurobserver, 2013))

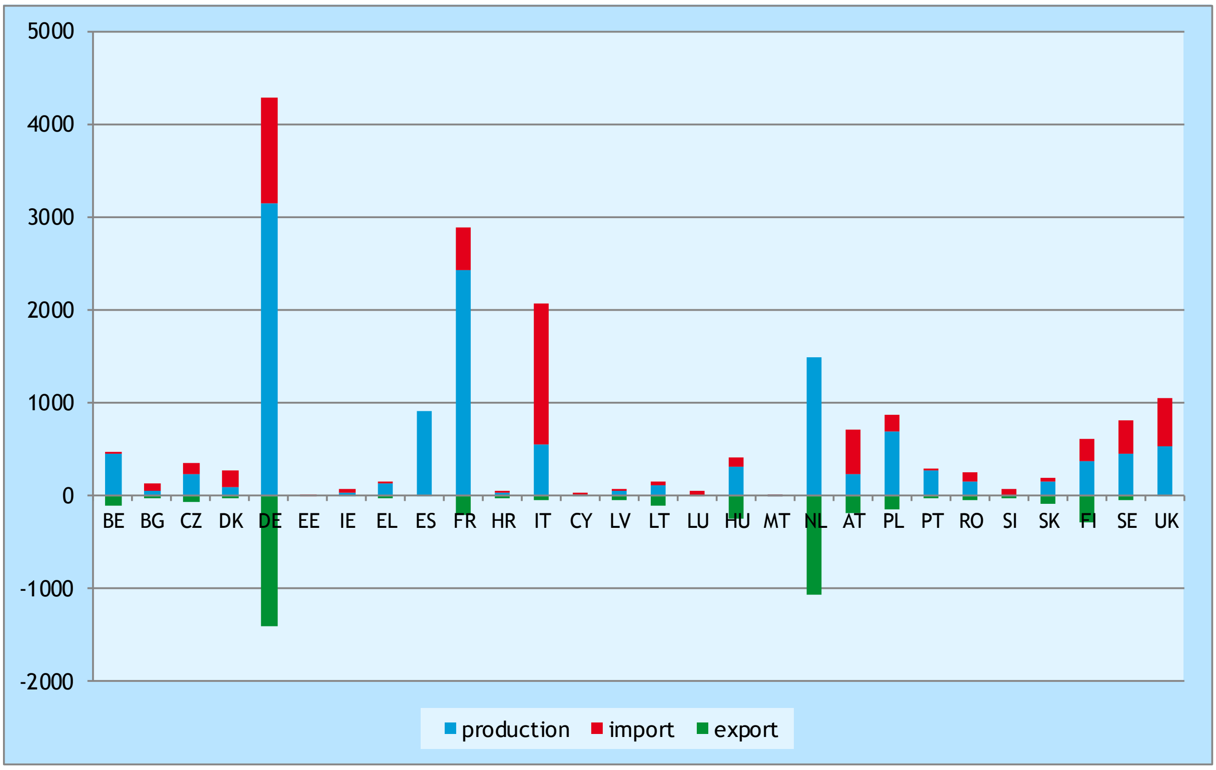
Figure 1.30 Export and import of biofuels in the EU28 in 2013 in ktoe



Source: Eurostat, 2013

Looking at the Member State data (Figure 1.31), it can be seen that Germany and the Netherlands are both large importers and exporters of biofuels, with France and Italy also importing significant volumes. These are countries with good (port) access for tankers.

Figure 1.31 Production, import and export of biofuels per Member States in 2013 in ktoe



Source: Eurostat, 2013

1.6.2.4 *Feedstocks used for biofuel production*

Biofuel production in the EU has up to recently been based predominantly on FAME and bio-ethanol production routes, almost exclusively using primary agrocommodities as feedstock:

- rapeseed oil (approximately 70%) and to a lesser extent soybean oil and residual oil for biodiesel.
- sugar beet, grains (mainly wheat and corn, some barley and rye) and surplus wine for ethanol.

An exception to this development is utilization of residual fats from both food industry and consumers for biodiesel production (see, for example, Pelkmans, 2014).

For a few years there have also been HVO production and glycerine (and natural gas) based methanol production facilities in The Netherlands and Scandinavia. HVO production has been based on a mixture of primary and secondary feedstocks. Globally, Neste Oil, the operator of the HVO facilities in Finland and The Netherlands, refined about 1.1 MMT of palm oil and other vegetable oils, and 1.3 MMT of waste and residues. The waste and residues consist of mainly palm fatty acid distillate (PFAD), and animal fats, UCO, and in smaller volumes, tall oil pitch, technical corn oil, and spent bleaching oil (source: interview with Neste Oil).

These are all mature biofuel production technologies. These biofuels are double counted towards the 10% RED target, but the biofuels produced from animal fats (categories 1 and 2 with Regulation (EC) No 1069/2009) and UCO do not count towards the sub-target for advanced biofuels of the RED as defined in the ILUC Directive.

EU-production of advanced biofuels produced from ligno-cellulosic biomass (included in Annex IX Part A of the ILUC Directive) has only started recently. In Crescentino, Italy, a first commercial 40 ktonnes/year ethanol plant processing wheat and rice straw and giant reed (grown locally) has been commissioned in 2013 (Eurobserver, 2014). Several other advanced ethanol plants are currently in the planning stage: in Italy, the US and China at commercial scale (up to about 80 ktonnes/year) and in Sweden and Spain at industrial pilot plant scale (see Eurobserver, 2014 for a more detailed overview).

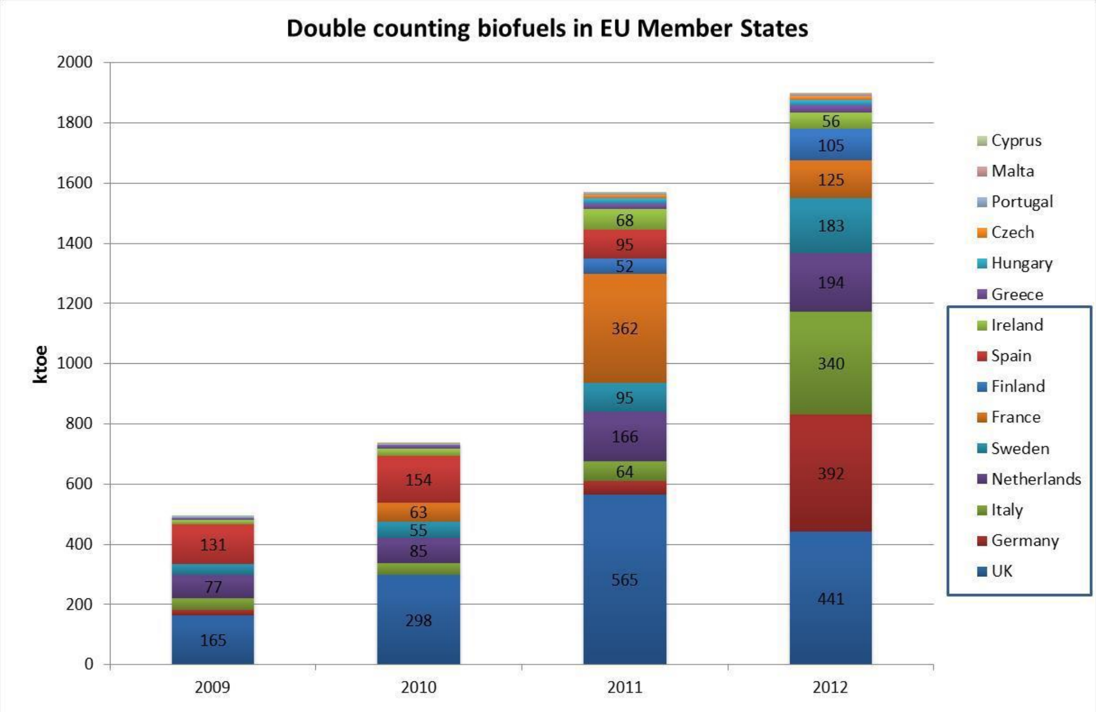
Based on the Member State's RED progress reports, Pelkmans (2014) made an overview of the consumption of double counting biofuels (i.e. biofuels from waste and residues) in the various Member States, as shown in Figure 1.32. In 2012, only four Member States, namely the Netherlands, Italy, Germany and the UK, were responsible for 70% of the biofuels from waste and residues consumed in the EU. More than 90% of these were produced from used cooking oils and animal fats (Pelkmans, 2014). Comparing these data with the overall biofuel consumption data in the EU (above), the share of biofuels from waste and residues is found to have increased from 1.4% in 2010 to almost 15% in 2012.

These are consumption data, production data are not available at this level of detail. Part of these biofuels are imported from outside the EU, as can be seen in the detailed UK and Netherlands biofuel reports (Department for Transport, 2014 and NEa, 2014), but these data are not yet available for the whole of the EU (and Eurostat production statistics currently does not distinguish between types of feedstock, or double and single counting biofuels). The national progress reports that the Member States submit biannually do provide data for the consumption of biofuels that comply with Article 21(2), i.e. production from waste and residues, as well as data of the share of imported biofuels. (Pelkman, 2014) used the most recent data for the analysis, which was consumption data for 2012.

Eurobserver, 2014 finds the implementation of the double counting incentive, Article 21(2) of the RED, in an increasing number of Member States to be the main reason for this strong growth, and expects this trend to continue in the coming years as investments in conversion capacity for biodiesel from used oils and waste fats and in ethanol from cellulosic biomass are ongoing. As these biofuels will not fall under the 7% cap in the RED for biofuels from food crops, as agreed in the ILUC Directive, this directive will further promote their demand in the longer term[50].

[50] The ILUC Directive will replace Article 21(2) by Article 3(4f), which will further specify the types of feedstock to be double counted and removes the obligation for Member States to implement double counting in national biofuel policy. The double counting towards the RED transport target remains.

Figure 1.32 Overview of double counting biofuels in the EU Member States



Source: Pelkmans, 2014

In addition to double counting and the ILUC-related cap in the RED, biofuel feedstock will also be influenced by the biofuel sustainability criteria of the RED and FQD. These require minimum GHG emission savings from biofuels, as defined in the ILUC Directive: currently 35% GHG emissions savings, increasing to 50% from 2018 for biofuels in operation before the ILUC Directive comes into force, and 60% for installations starting operation after the Directive comes into force (all values refer to direct emissions only, ILUC effects not included).

Based on life cycle assessments of GHG savings of various types of biofuels, both the 50% and 60% minimum GHG saving required in the future might create a preference for ethanol above biodiesel. For biodiesel, rapeseed oil is a mandatory main component (especially in winter, to meet the specific cold flow requirements, see, for example AGQM, 2013), but typical GHG savings for rapeseed oil based biodiesel amounts to only 45% (Annex V of the RED). However, studies indicate that in most Member States the 50% reduction target can be met (Hamelinck, 2013), as processes are adapted over time to meet the more stringent criteria.

If, however, ILUC related emissions were to be taken into account in the GHG balance in future sustainability criteria and/or in the FQD GHG intensity calculations, the result might be a strong reduction or even end of primary vegetable based biodiesel and HVO production and consumption in the EU, as these feedstock typically have relatively high indirect GHG emissions (see the provisional estimated ILUC emission in Annex V of the ILUC Directive: oil crops are allocated a mean value of 55 gCO_{2eq}/MJ, whereas cereals and sugars have a mean value of 12 and 13 gCO_{2eq}/MJ, respectively).

Future feedstock use is therefore dependant on a range of policy developments, most notably on the post-2020 development of the sustainability and ILUC policies, such as the minimum level of GHG savings in the biofuel sustainability criteria, the cap on biofuels from food and energy crops, and sub-targets for advanced biofuels.

1.6.3 Current and future biofuel conversion routes

Besides the current biofuel conversion routes, mainly resulting in FAME, bioethanol/bio-ETBE and HVO, a number of new biofuel production technologies are under development and might gain market shares in the future. In view of the sustainability and ILUC concerns and the EU's ambition to move away from first generation biofuels (as described in EC, 2014a), most R&D efforts are spent on further developing the routes that can use non-food and/or low-ILUC biomass as feedstock.

Efforts are also specifically put into research to develop new conversion routes that can produce fungible and versatile biofuels (such as drop-in biofuels that can also be converted into jet fuel), from non-food and/or low-ILUC feedstocks. These would resolve any issues with FQD blending limits, and would have the significant advantage over FAME and bioethanol that they can be used in the existing vehicle fleet and fuel distribution system, to any level that may be required in the future.

Annex 2 of this report contains an overview of both current and potential future conversion routes for biofuels, distinguishing between both diesel and petrol replacers.

The key characteristics of these routes are outlined in Table 1.13, which presents an overview of the currently applied and potentially upcoming biofuel production routes (sources: see Annex 2). In this overview a distinction is made between:

- The type of production process;
- The comparability with conventional automotive fuels (fungible/non-fungible)
- The applied types of feedstocks per production route and the expected level of indirect land use change (ILUC) per type of feedstock.
- The status of the production process: mature (conventional) and in R&D phase (advanced).

Production routes not included concern for example bio-butanol and DME. Bio-butanol production is still in development and low yields per unit of time and unit or reactor volume make it questionable whether this route will ever become economically sufficiently viable. Development of the DME route in Sweden has ceased. Nevertheless, it should be realised that as research efforts into different routes continue, new conversion technologies and fuels may appear in the future.

The main conclusion that can be drawn from this overview is that there are several conversion technologies available that can convert food crops into biofuels, but these are all associated with high or moderate risks of ILUC – the only exception is FAME and HVO production from used cooking oil, and HVO production from tall oil.

Production technologies to convert other feedstocks with low or no risk of ILUC (typically ligno-cellulosic,agricultural and forestry residues, such as wheat straw/corn stover/bagasse, wood based biomass, non-food crops such as grasses, miscanthus, algae, or industrial waste and residue streams), are being developed, but are not yet mature and commercially available in significant volumes. Of these, bioethanol production from ligno-cellulosic biomass is currently the most advanced: as mentioned earlier, the first European commercial 40 ktonnes/year ethanol plant processing wheat and rice straw and giant reed was commissioned in 2013, in Italy. Fuel suppliers and biofuel producers generally mentioned the lack of certainty in the EU policy making as the main obstacle for investments and commercialization of advanced biofuels in the EU.

Whether or not the more advanced routes will reach large-scale, commercial application in the future, and by when they can be expected, is currently difficult to predict. The R&D route from smaller scale to large scale application can take many years and even decades: Fischer Tropsch (BTL) biodiesel production, for example, has been under development of several decades but has not yet reached commercial scale production. It is also possible that some of these technologies will never reach maturity, if technical problems persist, if funding is insufficient or cost cannot be reduced to levels that are commercially attractive.

In the EU, the developments of advanced biofuel processes are supported by EU-level R&D funding. For example, the Commission supports innovative bioenergy projects through the both the Horizon 2020 and the NER 300 programme, and the European Biofuels Technology Platform (EBTP). These programmes include a number of advanced biodiesel and bioethanol projects – see http://www.biofuelstp.eu/funding.html for an overview of European R&D projects related to advanced biofuels production. In this context, it can also be noted that R&D into advanced biofuels is not limited to the EU, it is also actively pursued in, for example, the USA, Brazil and China (see, for example, Eurobserver, 2014). Once these R&D efforts are successful, they may also be applied in the EU.

Stakeholders from both the oil and the biofuel industry (including the EBTP) furthermore stress the potential importance of regulatory support such as a cap on biofuels from food crops and a target for advanced biofuels. They stress that concrete policies for 2030 can help to provide a positive market outlook for these biofuels, which is a prerequisite for the market to invest in R&D, demonstration and commercial-scale production units. The current incentive for biofuels from waste and residues, the double counting provision of the RED (Article 21(2)), has not yet resulted in innovation, as was concluded in the recent mid-term review of the RED (CE Delft, 2015), its positive effect is limited to incentivising the use of mature conversion processes only, i.e. FAME and HVO production from used oils and fats.

Table 1.13 Overview of applied and upcoming biofuel production routes

		Type of feedstock converted	Conversion technology	Type of feedstocks used	Fungibility	low ILUC / no ILUC/	conventional / advanced
Diesel (and kero) replacement	FAME						
	■ oil seeds, arable land	oils and fats, vegetable or animal	esterification of vegetable oils	rape seed, sun flower, soy, …	non-fungible	high	conventional
	■ oil seeds, plantation crops			oil palm, coconut	non-fungible	high	conventional
	■ UCO			UCO (used cooking oil)	non-fungible	no	conventional
	HVO						
	■ oil seeds, arable land		hydro-deoxygenation of vegetable oils	rape seed, sun flower, soy, …	(fungible)	high	conventional
	■ oil seeds, plantation crops			oil palm, coconut	(fungible)	high	conventional
	■ UCO			UCO (used cooking oil)	(fungible)	no	conventional
	■ tall oil			tall oil	(fungible)	no	conventional
	FT-diesel, wood	Ligno cellulosic	Gasification + catalytic CxHy formation from syngas	wood (thinnings)	fungible	no	advanced
Petrol replacement	Bio-ethanol						
	■ cereals	Sugars (and starches)	Starch hydrolysis, sugar fermentation, ethanol isolation	wheat, maize, …..	non-fungible	moderate	conventional
	■ starch crops			cassave	non-fungible	moderate	conventional
	■ sugar crops		sugar fermentation, ethanol isolation	sugar cane, sugar beet, sweet sorghum	non-fungible	moderate	conventional
	■ straw, giant reed, biochemical route	Ligno cellulosic		straw, giant reed	non-fungible	no - moderate	advanced
	■ wood, thermochemical route		Gasification + catalytic C2H5OH formation from syngas	wood (thinnings)	non-fungible	no	advanced
	Methanol	Ligno cellulosic	Gasification + catalytic CxHy formation from syngas	Glycerol	non-fungible	high	advanced

		Type of feedstock converted	Conversion technology	Type of feedstocks used	Fungibility	low ILUC / no ILUC/	conventional / advanced
Petrol /Kero / Diesel	Fischer Tropsch (BTL), Virent bioforming process, Hydropyrolysis	Ligno cellulosic	Catalyzed thermochemical routes	Wood, straw, lignocellulosic crops. For bioforming process: sugar and starch containing crops	fungible	no - moderate	advanced

1.6.3.2 How much first generation and advanced biofuel production capacity would be needed in 2030?

Due to the current uncertainties regarding EU and Member State policies after 2020, it is nearly impossible to predict the demand for biofuels in 2030 at this point in time.[51] Nevertheless, some illustrative calculations can be made, for a number of hypothetical assumptions. These can help to create insight in, for example, the advanced biofuels production capacities that would need to be developed in the coming decade for certain biofuel blend limits and caps on first generation biofuels. A more extensive exploration of future biofuel developments can be found in the next chapter, where three concrete (but also hypothetical) scenarios are developed for 2030.

To assess how much biofuel and therefore biomass demand there might be in 2030, first, road transport energy demand in 2030 has to be estimated. In the EU PRIMES reference scenario (2012), used for the analysis in the Transport White Paper of 2011, it is estimated that in 2030, EU road transport (blended) diesel demand is 185 Mtoe, and (blended) petrol demand amounts to 105 Mtoe. Using these data as a basis for the calculations, the following can be concluded.

- If the current FAME and ethanol blend levels (B7 and E10) still apply in 2030, they would allow blending of 11.8 kton FAME and 7.0 ktoe ethanol – see Table 1.14. More biofuels can be added if they are fungible (drop-in), for example HVO diesel or Fischer Tropsch (BTL) fuel.
- If the biofuel blend levels were raised to B10 and E20 throughout the EU, this would allow blending of almost 17 Mtoe FAME and 14 Mtoe bioethanol. Again, more biofuels can be added if they are fungible (drop-in). The overall blend limit for bio-components in standard diesel and petrol is currently 30 vol% (as defined in the FQD), although higher blends can be used in captive fleets.
- A 7% cap on first generation biofuels would amount to a maximum of 20.3 Mtoe of biofuels from food crops in 2030. The maximum potential of the current blending limits (B7/E10) could then be achieved by these biofuels only, without exceeding the cap.

Table 1.14 Maximum biofuel demand in 2030 in Mtoe, assuming the whole vehicle fleet runs on B7/E10 or B10/ E20, compared to current (2013) EU production levels

	total fuel demand	max. FAME and ethanol with B7 and E10 (current limits)	max. FAME and ethanol with B10 and E20	current production FAME and ethanol	current EU production capacity FAME and ethanol	max. volume from food feedstocks (in case of a 7% cap)
diesel	185	11.8	16.9	10.0	23.0	
petrol	105	7.0	13.9	2.5	5.8	
total	290	18.8	30.8	12.5	28.8	20.3

Source: CE Delft analysis, based on PRIMES reference scenario (2012) for fuel demand, and Eurostat data on production capacity

The table furthermore illustrates that

[51] Including because the ILUC Directive cap is applicable to the target in the RED - Member States may choose to provide incentives for biofuels as national policy without accounting this against the RED target.

- the current FAME production capacity in the EU would be sufficient to supply even B10 throughout the EU. This capacity can be used to produce FAME from plant oils as well as from a number of UCO and animal fats.
- Ethanol production capacity would have to be more than doubled to supply the volume needed for E20 throughout the EU, or imports would have to increase very significantly. For comparison: 2013 ethanol imports were about 1 Mtoe. As discussed before, current bioethanol production capacity is first generation only, production and consumption of advanced ethanol is still very limited, although Europe's first larger scale production plants for ethanol from ligno-cellulosic feedstocks (e.g., straw) are becoming operational.

Reasons for the underutilisation of production capacity in the past years were given in section 1.6.2.2, these do not indicate any particular barriers to increasing the utilisation of the EU's existing production capacity as EU biofuel demand increases. However, as the biofuel market is a global one, these opportunities, and in particular the share of imports of biofuels, will depend on the development of cost and demand, both within the EU and globally. Regarding advanced biofuels, the global market is still very much in its infancy, and further analysis on future investments in production capacity and advanced biofuel cost would be required to provide more insight in risks and opportunities for the European biofuel sector.

It is important to realise that the figures given above also depend on the development of energy efficiency and alternative renewable energy options in transport: an increase of electric vehicles and other types of renewable energy use (e.g. hydrogen, biomethane) may reduce the need for biofuels to meet any Member State targets or ambitions regarding GHG emissions and renewable energy use in transport. This effect is enhanced by the multiplication factors for electricity from renewable sources in the RED, but it is currently unknown whether these will be continued in post-2020 policy.

1.6.4 Biomass availability

Increasing the demand for biofuels in the EU requires an equal increase of suitable biomass supply, where suitable can be defined as

- it can be converted to a (high-quality automotive) biofuel;
- both the biomass and the resulting biofuel meet the sustainability criteria that apply in the future;
- the cost of the biofuel is reasonable, compared to other renewable energy in transport and GHG reduction options;
- security of supply is secured.

Assuming that the ILUC Directive and the EU's post-2020 energy and climate framework are successful in creating a shift in production and demand from first to second generation biofuel, in line with the ambitions expressed in (EC, 2014a), future growth of biofuel demand will have to come from low-ILUC feedstock such as cellulosic energy crops, algae, cellulosic wastes and residues.

The answer to the question what the potential supply of these sustainable feedstocks could be, at acceptable cost, is thus key to assess any future potential for biofuel growth.

As discussed in the previous Section, many of these feedstocks, in particular the cellulosic ones, require different conversion technologies than the ones used today. As these are either still in R&D phase or still at the beginning of large scale roll-out, it has to be seen which of these routes will reach full commercialisation and, therefore, which of these low-ILUC feedstocks can indeed be used for biofuel production in the future.

At the same time, the same feedstocks can also be used for other sectors and applications, such as for production of electricity, heat, chemicals or materials. Thus, it is not only about the potential volumes of suitable and sustainable feedstock, but also about future demand from other sectors.

Detailed estimates of potential availability and cost of biofuels from the non-food feedstock that does not fall under the cap are not yet available, and have not been assessed in the Impact Assessment of the proposal (SWD(2012) 343 final).

A quick scan of the available literature was performed to derive an estimate of the main feedstocks that are included in Annex IX of the ILUC Directive as well as of low-ILUC biomass, and their potential availability in the EU. This analysis can be found in A2.1, the main results are presented below. These findings provide an indication of the options available and their potential. However, it is recommended to assess these issues in more detail now that the ILUC Directive has been decided on. A full analysis should furthermore also look at options for imports, and at potential demand for these feedstocks from other sectors, as they can also be used, for example, for production of renewable electricity and heat and as feedstock for the chemical industry[52].

To illustrate the potential increase of biomass and waste from other sectors: the PRIMES reference scenario 2013 (EC, 2013) projects the following:

- the contribution of biomass to the EU's electricity generation will double in the coming decades, from 4% in 2010 to 6% in 2020/2030 and 8% in 2050.
- the share of biomass in steam supply will increase from 26% in 2010 to 35% in 2050, district heating is predicted to relying on biomass for 57% in 2050 (in comparison to 26% in 2010)

These shares, and therefore biomass demand, are even higher in the decarbonisation scenarios developed for the EU Energy Roadmap 2050 (EC, 2011b). In the various scenarios that were developed, total use of biomass in 2050 varied between about 186 Mtoe (reference scenario) and 320 Mtoe (High RES scenario), compared to the 86 Mtoe of biomass used in the EU in 2005. This includes biomass demand for all energy purposes, including transport, electricity and heat - the share of biofuels in these figures varies between 20% and 30%.. Note that these scenarios do not further specify the different types of biomass.

An overview of what the findings of A2.1 mean in terms of maximum potential of advanced biodiesel and biopetrol is provided in Table 1.15.

This table shows that there is a very significant potential of biomass from low-ILUC biomass or feedstocks that are included in Annex IX. Most of this is either cellulosic or woody biomass, which requires advanced conversion technologies to be converted into a high quality liquid biofuel, or cultivated, low-ILUC biomass (see A2.1 for further details). As discussed in the previous Section, the technology to use these cellulosic and woody feedstocks to produce bioethanol is currently the most advanced, but efforts are ongoing to develop a number of alternative conversion processes that could produce both petrol and diesel replacements from these feedstocks. Note that the potential availability of these types of feedstocks is one of the key drivers for these R&D efforts: if the share of sustainable biofuels in transport fuels is to be increased significantly in the future, both the fuels suppliers and the biofuel industry needs to be able to rely on routes with sufficient and reliable sustainable biomass supply (source: interviews with these stakeholders, and literature).

The results in Table 1.15 also show that there is still potential to increase production and consumption of biodiesel from UCO, animal fats and tall oil: current consumption is about 1.7 to 1.9 Mtoe (see Section 1.6.2.1), potential supply is estimated at 4.0 to 7.1 Mtoe - representing 2.2% to 3.8% of EU-wide diesel demand in 2020, as calculated in the PRIMES reference scenario (see previous paragraph)

There are two important issues to consider when interpreting these data:

- As noted in the remarks Section of the table and mentioned above, many of these feedstocks can also be used for other applications. The waste and residues can typically also be used for electricity and heat production, and as renewable feedstock for the

[52] Such an assessment is currently being carried out in a study commissioned by the European Commission, DG Energy, to be published.

chemical industry. The cultivated low-ILUC biofuels can also be used for food and feed. To derive a realistic estimate of potential availability for the biofuel sector thus requires a much more extensive and complex assessment of future availability and demand from all sectors involved.

- As mentioned before, the uncertainties regarding future success of the R&D efforts in the various advanced biofuel routes are still significant. Especially the advanced biodiesel processes still seem to be relatively far away from commercial application.

Table 1.15 Key results on potential availability of biofuels from non-food biomass within the EU (in Mtoe/yr)

		Mtoe/year			Economical and technical feasibility	Sustainability	Remarks
Diesel replacement	UCO	1	-	3.1	+	+	
	Animal fats/fats from slaughtered animals (C3 - C1)	2.5	-	3.1	+	-/0	competes with other uses
	Tall oil	0.5	-	0.9	+	-/0	competes with other uses, subsidy driven
	Total	**4**	**-**	7.1			
Petrol replacement	Additional sugar beet cultivation	45	-	32	?	+	
	Ethanol from cover crops	30	-	38.4	?	+	
	Straw	23	-	17.9	+	+	Sustainable potential, Actively developed by biofuel producers
	Prunings and other agri residues	5	-	3.84	?	depends on soil impacts	competes with power/heat generation
	Additional thinnings	18	-	12.8			
	Branch and top wood	10	-	7.05			
	Additional wood from landscape care	6	-	3.84			
	intensified mobilization of forest wood and residues	5	-	3.84			
	Wet residual grass	3	-	2.56	?	+	First small scale initiatives by research institutes
	Biodegradable consumer waste	2	-	1.92	+	+	Actively developed by biofuel producers
	Total	**147**	**-**	124			

1.6.5 Cost of biofuels

In the previous Sections of this Chapter, it was mentioned on several occasions (notably in Sections 1.3 & 1.4) that costs of biofuels are higher than the costs of the fossil fuels they replace. In the following, these costs will be quantified, and estimates for the future development of biofuel costs provided.

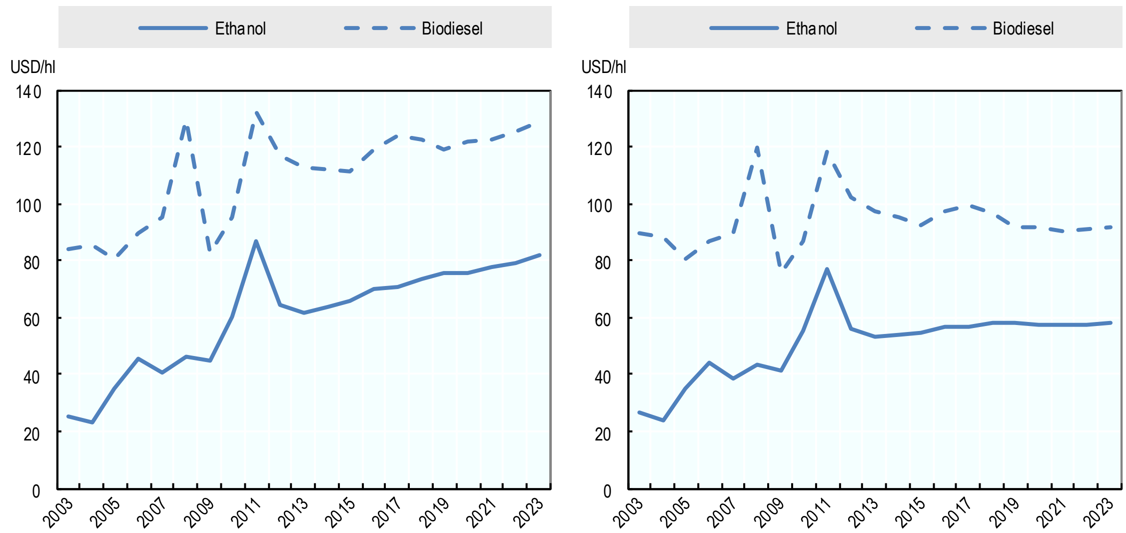
The ‘cost of biofuels’ that consumers have to pay, the retail prices, typically consist of cost of the biofuels itself (incl. production and distribution), taxes and excise duties. As was shown in Section 1.3.3.2, financial incentives such as excise duty reductions are applied throughout the EU to compensate for the higher cost of biofuels: of the countries where data on tax incentives for biofuels were found, 50% has tax incentives for biofuels in place, ranging from lower excise duty for low or (specific types of) high blends to exemption from CO_2 taxes for biofuels. Import tariffs can also impact the cost of biofuels. For example, there is a general import duty in place on ethanol. As was mentioned in Section 1.6.2.3, anti-dumping taxes are put in place on American bioethanol, as well on biodiesel from Argentine and Indonesia (Eurobserver, 2014). On the other hand, many of the exporting countries benefit from duty-free or reduced duty access to the EU market as a result of the General Scheme of Preferences[53] (GSP) or Tariff Reduced Quota (TRQ)[54], as part of trade agreements with the EU.

Actual data on biofuel cost are not as transparent as the cost of fossil fuels, as biofuels are typically sold to consumers in the EU as blends and not as pure biofuels. Their cost are thus hidden in overall fuel cost and not transparent to the general public, but some data sources exist. Cost of advanced biofuels are even more difficult to estimate, as these are usually confidential and there is no experience with large scale production plant yet (IEA, 2011).

An overview of recent (2013) cost of FAME biodiesel and bioethanol in the EU is provided in (EP, 2015), where is its estimated that the cost of rapeseed FAME is approximately 65% higher than that of conventional diesel, in terms of € per GJ. Similar ratios were found for the cost of ethanol from EU wheat or sugar beet, compared to petrol. However, in practice, both prices of various biofuels and fossil fuels vary significantly over time.

Recent global cost developments for biodiesel (FAME) and bioethanol, and expectations until 2023, as presented in OECD/FAO, 2014, are shown in Figure 1.33. These data are for the pure biofuels (i.e. for the biofuel part of a blend), and do not take into account any taxes such as import duties or excise duties. This figure shows that biofuel prices fluctuated significantly between 2007 and 2012, but have stabilised since then. OECD/FAO expects prices to remain almost constant in real terms until 2023 (right graph).

Figure 1.33 Biofuel prices expressed in nominal terms (left) and in real terms (right)



Source: OECD/FAO, 2014

The cost of biofuels is determined by the sum of the following cost items:

- feedstock cost, including cost of transport to the biofuel production plant and any pre-conditioning that is required (such as oil seed crushing)

[53] http://ec.europa.eu/trade/policy/countries-and-regions/development/generalised-scheme-of-preferences/index_en.htm

[54] http://ec.europa.eu/taxation_customs/common/databases/quota/index_en.htm

- cost of biofuel production
- cost of transport and storage of the biofuels to the point of retail
- profit of any co-products of the biofuel production, such as DDGS, glycerine, bagasse, lignin or waste heat
- Import tariffs.

In the current situation in the EU, biofuels are not economically competitive with conventional fuels (i.e. petrol and diesel). Brazilian sugarcane ethanol could be competitive without the import tariff, but not with the tariff in place. This is confirmed by the empirical evidence that biofuel uptake in the EU only occurs when obligations or effective financial incentives are in place, and by detailed IEA biofuel cost analyses (IEA, 2011)(IEA, 2013).

These IEA assessments undertook bottom-up cost calculations for a range of biofuels, and estimated the impact of technological development and future oil price. (IEA, 2011) and (IEA, 2013). The results for the cost of fuel production in the 'Current Technology Scenario' (IEA, 2013) are shown in Figure 1.34. Not all fuel pathways that were analysed are included in this graph: FAME, for example, is not included, but costs were found to be about 20% higher than the cost of corn ethanol. Costs of HVO were not assessed. A somewhat different approach was taken in IEA, 2011, where expected future biofuel cost developments were assessed using two different scenarios:

- a low-cost scenario in which a minimal impact of rising oil prices on biofuel production cost is assumed; and
- a high-cost scenario which assumes a greater impact of oil price on feedstock and production cost.

The results are given in Figure 1.35. In both scenarios, the oil price is assumed to be 120 USD/bbl in 2050, the analysis is furthermore based on estimates of the lowest costs that may be achieved in the future.

Both IEA reports note that cost predictions are relatively uncertain and actual cost of biofuels depend on the local conditions, but following key conclusions can be drawn from these studies (IEA, 2011)(IEA, 2013):

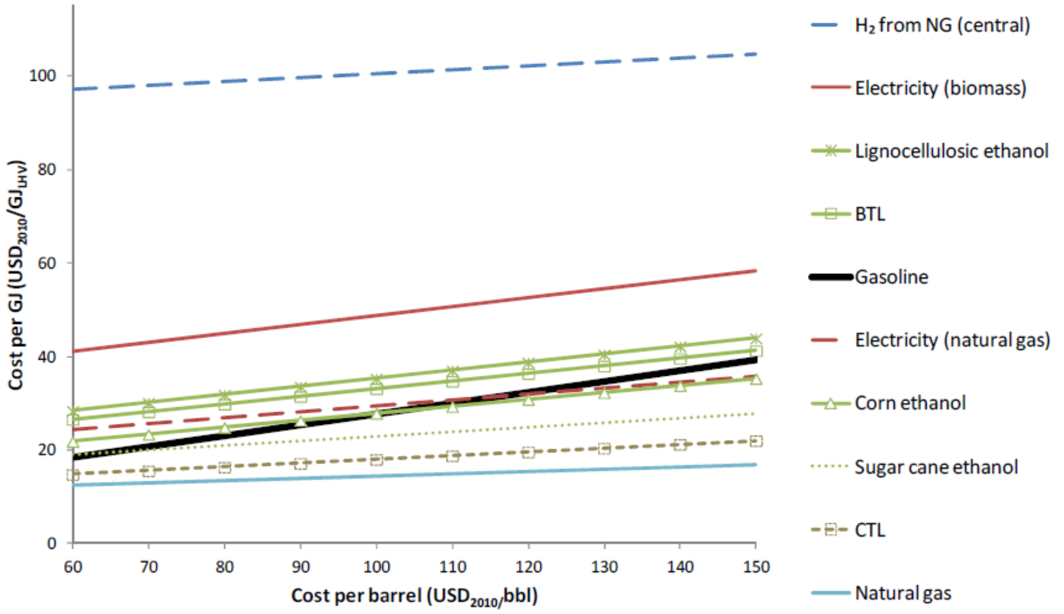
- In the Current Technology Scenario, sugar cane ethanol is competitive with conventional fuel at an oil price greater than 60 USD/bbl. However, corn ethanol can become competitive at oil prices above 110 USD/bbl, where FAME follows at about 130 USD/bbl according to (IEA, 2013). IEA, 2011 finds much higher prices for FAME (see Figure 1.35) than IEA, 2013, due to different assumptions used.[55] At the time of writing this report, crude oil spot prices (in 2010 USD), are approximately 50 USD/bbl, and World Bank projections indicate it could be 65 USD/bbl in 2020, and 83 USD/bbl in 2025.[56] This will have major implications for the competitiveness of biofuels with conventional fuels during the timeframe of this study.
- Advanced biofuels such as lignocellulosic ethanol and biomass-to-liquid (BTL) are more expensive than petrol and conventional biofuels, and this situation is not expected to change when technologies mature. It is expected that ligno-cellulosic bioethanol and BTL biodiesel would be competitive with fossil fuels at oil prices over USD 130/bbl.
- Oil price is a relevant parameter, not only for petroleum fuels but also for biofuels, as energy is used throughout the biofuel chain, from crop cultivation to final transport to the retail station. This is also the case for the advanced biofuels such as lignocellulosic ethanol and BTL. Increasing oil prices thus also cause biofuel prices to increase.

[55] Import tariffs not taken into account and comparing prices of pure ethanol with pure petrol

[56] World Bank commodity price forecasts (April, 2015); http://www.worldbank.org/content/dam/Worldbank/GEP/GEPcommodities/PriceForecast_20150422.pdf

- Feedstock prices play a major role in biofuel cost: for conventional biofuels today, the main cost factor is feedstock, which accounts for 45% to 70% of total production cost[57]. The situation is different for advanced biofuels: for advanced ethanol and BTL, the main cost factor is capital cost (35% to 50%), followed by feedstock (25% to 40%). This has the advantage of reduced feedstock cost volatility, the relatively high upfront investment cost can, however, create a barrier to investors.
- The benefits of co-products from the biofuel production process can be quite significant: DDGS, glycerine, bagasse, lignin or waste heat can reduce biofuel production costs by up to 20% depending on the fuel type and use of co-product.
- Biofuel cost significantly depend on the scale of the production plant and the technology complexity, and will eventually also depend on future learning rates and cumulative production.

Figure 1.34 Cost of fuel production versus oil price for select fuels in Current Technology Scenario

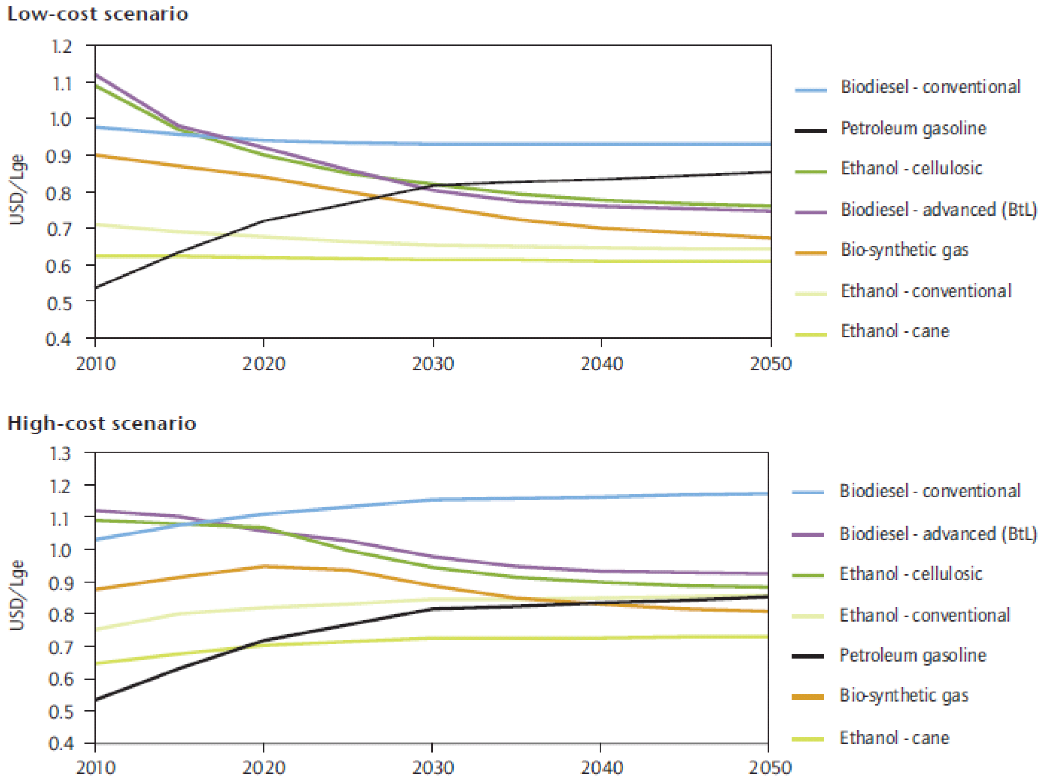


Note: BTL = biomass-to-liquids; CTL = coal-to-liquids; NG = natural gas; USD_{2010}/bbl = 2010 nominal USD per barrel of oil; USD_{2010}/GJ_{LHV} = 2010 nominal USD per gigajoule using lower heating value. Fuel production costs in this figure are extrapolated from their USD 60/bbl value using an arithmetical average of the two methods (Petroleum Intensity and Historic Trend) are discussed below (see Chapter "Results").
Source: unless otherwise stated, all material in figures and tables derive from IEA data and analysis.

Source: IEA, 2013

[57] (IEA-ETSPA/IRENA, 2013) even states that feedstock cost may be 80% to 90% of the final cost of palm biodiesel, corn ethanol and rapeseed diesel (differences are likely due to different assumptions, feedstock cost) .

Figure 1.35 Cost of different biofuels compared to petrol



Note: costs reflect global average retail price without taxation. Regional differences can occur depending on feedstock prices and other cost factors.

NB. Cost are given in USD per litre petrol equivalent (USD/lge), to account for differences in energy content.

Source: IEA 2011

The development of the cost differential between biofuels and fossil transport fuels is therefore relatively uncertain, and depending on technological development of the biofuel routes, feedstock price and, to a lesser extent, the oil price. In the low-cost scenario of (IEA, 2011) and the high oil price range of (IEA, 2013), conventional biofuels are found to become competitive over time, but this was not the case in the other scenarios. Furthermore, all scenarios find that advanced biofuels remain more costly than both fossil petrol and conventional, first generation biofuels (although cost predictions of FAME were found to vary significantly).

It can therefore be concluded that policy incentives for biofuels in general, and for advanced biofuels in particular, remain necessary in the time period until 2030, and that it is likely that the biofuel market will remain dependent on incentives also in the longer term. This also means that transport energy is likely to become more costly when the share of biofuels is increased, and even more so when increasing the share of advanced biofuels. (IEA, 2011) estimates for their biofuel roadmap that use of biofuels would increase global cost of transport energy by between 0.2% and 1.1 in 2030, where advanced biofuels account for the major share of these costs. This assumes an increasing share of biofuels in total global transport fuel demand, resulting in about 9% in 2030 (and, eventually, a 27% share in 2050).

1.6.6 Conclusions

In line with the consumption of biofuels in the EU, the production of biofuels has increased sharply since 2004. Production dropped in 2011, mainly due to increased biodiesel imports in that year, but increased again in recent years after anti-dumping legislation was implemented. Biodiesel has the largest share in production, about 80% of total biofuel production in 2013. Germany, France and the Netherlands have been mainly responsible for the EU's biofuel production in 2013 with Germany being the largest biofuel producing country.

The production capacity installed in the EU is significantly higher than production itself. In 2013, only 43% of the EU's biodiesel production capacity was actually used, 44% of biopetrol capacity (ethanol, mainly) and only 17% of capacity for other liquid biofuels. More than half of Europe's biodiesel production capacity is located in Spain, Germany and France, 44% of the production capacity of biopetrol is located in France, Germany and the UK. In 2013, only two Member States did not report any biofuel production capacity: Estonia and Luxemburg. Another 11 Member States, namely Bulgaria, Denmark, Ireland, Hungary, Cyprus, Latvia, Lithuania, Malta, Romania, Slovenia and Slovakia, each also accounted for less than 1% of production capacity. HVO production capacity is about 5% of the EU's total biodiesel production capacity.

The 2013 biodiesel production capacity (22,983 ktoe) is already sufficient to meet the 2020 demand (21,646 ktoe) as predicted in the NREAPs. The European biopetrol capacity (5,779 ktoe) is not yet sufficient to supply the bioethanol/bioETBE that the Member States expect for 2020: **7,306 ktoe.** However, as Member States expected to import 3,216 ktoe of this volume from outside the EU, the current capacity can be considered sufficient to meet the (remaining) demand. The NREAPs do not provide separate trajectories of forecasts for FAME and HVO, nor for bioethanol and bio-ETBE.

Current FAME production capacity in the EU would be sufficient to supply B10 throughout the EU. Ethanol production capacity would have to be more than doubled to supply the volume needed for E20, or imports would have to increase significantly. Current bioethanol production capacity is first generation, production and consumption of advanced ethanol is still very limited, although Europe's first larger scale production plants for ethanol from ligno-cellulosic feedstocks (e.g straw) are becoming operational. FAME production capacity can be used to produce FAME from plant oils and from waste and residues.

Despite the overcapacity, about 4 Mton of biofuel is exported and 6 Mton is imported (data for 2013). Especially imports can be seen to vary over time, depending on the availability of low-cost biofuels, on import taxes and anti-dumping measures. Export is increasing steadily over the years.

In 2012, about 15% of the EU's biofuel consumption was produced from waste and residues (most recent data), the rest was mainly produced form rapeseed and other oils, and sugar beets and grains. Future development of feedstock used is strongly dependant on policy developments: the minimum level of GHG savings in the biofuel sustainability criteria, the cap on biofuels from food crops and on incentives such as sub-targets in obligations for advanced biofuels. The ILUC Directive is a step towards a shift from food-crops to waste and residues, although the 7% cap in the RED still allows the consumption of biofuels from food crops to grow in the coming years.

Several technologies are available that can convert food crops into biofuels, but these are all associated with high or moderate risks of ILUC – the only exception is FAME and HVO production from used cooking oil, and HVO production from tall oil**.**

Production technologies to convert other feedstocks with low or no risk of ILUC (typically ligno-cellulosic, agricultural and forestry residues) are being developed, but are not yet mature and commercially available in significant volumes. Of these, bioethanol production from ligno-cellulosic biomass is currently the most advanced. Whether or not the more advanced routes will reach large-scale, commercial application in the future, and by when they can be expected, is difficult to predict. The R&D route from smaller scale to large scale application can take many years and even decades.

Biomass availability uncertainties are significant, but results show that there is very high potential in the EU for straw, thinnings and branch and top wood, as well as of low-ILUC feedstock production such as sugar beet cultivated on degraded land. The latter, however, only qualifies to count above the 7% cap in the RED under certain conditions, whereas the first requires advanced production technologies.

Biofuels are more costly than fossil fuels (in terms of €/GJ), and will remain more costly at least until 2025/2030 and perhaps also in the longer term, depending on technology development, cost of feedstock and oil price. Advanced biofuels are more expensive than conventional biofuels, and this is expected to remain the case in the future. Policy incentives for biofuels in general, and for advanced biofuels in particular, remain necessary in the time period until 2030, and that it is likely that the biofuel market will remain dependent on incentives also in the longer term.

1.6.6.1 Recommendations

Looking at the various findings in this chapter, a number of recommendations can be derived:

- Improve EU-wide monitoring of feedstock used for biofuels consumed in the EU. Distinguish between biofuels from food crops, biofuels from feedstock specified in Part B of Annex IX of the ILUC Directive, and biofuels from feedstock listed in Part A in statistical data gathering and reporting[58].
- Assess the implications of the ILUC Directive, and any future changes in sustainability criteria, on biofuels and biomass demand and cost. This can create insight into the development of the market, cost, and potential barriers to future growth of biofuels. In this context, further analysis of potential global market developments are also recommended, to provide more insight into the underutilisation of production capacity and other associated risks and opportunities for the European biofuel sector.
- Assess the potential of biofuels from the various types of non-food feedstocks in more detail. This analysis should look at availability in the EU but also look at options for imports. Also, assess potential demand for these feedstocks from other sectors, as they can also be used, for example, for production of renewable electricity and heat and as feedstock for the chemical industry, taking into account principles such as cascading of biomass. The status of conversion technologies should also be taken into account[59].
- Assess the options to provide more room for low-ILUC, cultivated (energy) crops in future biofuel policy. This may increase the potential future biofuel supply significantly.
- Continue to support R&D for advanced production technologies, and implement effective incentives for advanced biofuels in national policies.

1.7 Development of biofuel demand to 2030

1.7.1 Introduction

This chapter aims to provide an outlook of future biofuel demand in the EU, until 2030, based on the findings in the previous sections and in Chapter 2. This outlook can provide insight in the potential developments, and provide a basis for future policy development related to high blends, as it helps to identify the possible implications of current policies, the uncertainties that exist and the gaps in current knowledge.

Combining the findings of the previous chapters, a number of key conclusions can be drawn regarding the current status of biofuel demand and the outlook until 2030.

- In recent years, biofuel demand in the EU increased to an average share of 4.6% of road transport fuels in 2013 (energy content). The political debate regarding the ILUC proposal, which could potentially have significant impact on biofuel policies and demand,

[58] Note that Member State RED progress reports include data on the share of double-counting biofuels, but these do not distinguish between Part A and Part B feedstocks. Furthermore, these reports are only bi-annual, instead of annual as the Eurostat fuel statistics.

[59] Such an assessment is currently being carried out in a study commissioned by the European Commission, DG Energy, to be published.

created uncertainty in the market. This has resulted in limited investments in new production capacity in recent years.

- Now that this been decided, the outlook for the sector until 2020 will become clearer. Member States will implement the ILUC regulation in the coming years, which shall ensure that the contribution biofuels from food crops towards the RED target does not increase beyond 7%, and provide additional incentives for biofuels from waste and residues. However, Member States have some flexibility when implementing the RED-related policies of the ILUC Directive (e.g. they may choose to set a lower cap for biofuels from food crops and deviate from the reference value for the sub-target for advanced biofuels), and the cap does not apply to the FQD nor to national support policies. It may therefore not be before 2017, when the ILUC proposal has to be implemented in all Member States, that details regarding biofuel demand in 2020 will be known.
- From 2020 onwards, the EU will not set binding targets for renewable energy in transport use in Member States, only an EU-level overall RES target of 27% in 2030. This suggests that each Member States can decide on the role of transport energy in their overall RES policies. Details of the post-2020 renewable energy regulatory framework are still unknown (to be proposed by the Commission in 2016-2017), but in view of recent policy debates, the authors of this study would expect that this will include sustainability criteria for biofuels that will be a continuation or further strengthening of the current criteria including ILUC.
- In view of these uncertainties, both in the coming years and even more so between 2020 and 2030, the development of biofuel demand is difficult to predict.
- This is further complicated by the currently limited production capacity for advanced biofuels. The current policies, especially the double counting provision of the RED (Article 21(2)), have proven to be an effective incentive for biofuels from waste and residues that can be produced with well-developed, mature production processes. This has resulted in a strong increase of consumption of biodiesels (FAME and HVO) from used cooking oil and animal fats. Advanced biofuels, i.e. biofuels that can be produced from the feedstock listed in Part A of Annex IX of the ILUC Directive, are, however, still in R&D phase or are only just starting commercial scale production. As new production technologies are necessary to unlock the potential of ligno-cellulosic waste, residues and other types of low-ILUC biomass for sustainable transport fuel production, technology development is crucial to the future growth of sustainable biofuels. Commercial scale production of advanced bioethanol production has started only recently, advanced biodiesel production from ligno-cellulosic biomass has not (yet) progressed this far.
- The ILUC decision can be a certain driver for these types of biofuels in the longer term, depending on the level of the cap (for food-based biofuels) and sub-target (for advanced biofuels) after 2020 and 2030 Member State policies and ambitions.
- The data on biofuel policies and actual biofuel consumption show a significant variation in ambition throughout the EU: average biofuel shares in 2013 varied between 0.4% in Estonia and 9.8% in Sweden. As all Member States will have to meet the 10% target in 2020, this range will become smaller in the coming years, but without binding renewable energy in transport targets after 2020, differences between Member State's ambitions and energy policy strategies are likely to remain also after 2020.
- Apart from biomass and biofuel availability, the FAME and ethanol blend limits can become a significant barrier to further growth of consumption of these fuels: the current limits only allow blending of up to 6.4% energy content of FAME (B7) and up to 6.8% energy content of ethanol.
- Most Member States still have biofuel shares well below these FAME and ethanol blending limits. In France, B8 was allowed on the national market in order to meet the biofuel obligation of 7.7% energy content, in line with a specific provision of the FQD.

- 25 of the 28 Member States have not yet introduced E10 on their market, E10 has so far only gained market shares in Finland, France and Germany. In the rest of the EU, E5, which includes up to 3.3% (energy content) bioethanol, is still sufficient to meet the targets and obligations. Once blending obligations increase in the coming years, as the 10% target of 2020 becomes closer, it can be expected that the number of Member States with E10 will increase, as this is a relatively straightforward and well regulated way to increase ethanol sales from 3.3% to 6.8%, based on energy content.
- A number of other Member States make use of higher blends, by promoting E85 (for example in France, Finland, Sweden) or B20 or B30 in captive fleets (for example in Spain, Italy, France and Poland). Fungible biofuels such as HVO, not affected by these limits, currently have a market share less than 5% of the EU's biodiesel consumption.

Despite the uncertainties, the following aims to provide some insight in to potential developments through 2030. First, based on a literature analysis, an overview of findings from a number of recent analyses and assessments is presented. This assesses the implication of a cap on biofuels from land-based feedstock, and also takes into account blending limits and vehicle compatibility issues. Then, in Section 1.7.3, three scenarios are derived for the period until 2030. These are based on the findings in Chapters 1 and 2 of this report, and will be used as input for the remaining tasks of this project.

1.7.2 Expectations until 2030: literature analysis

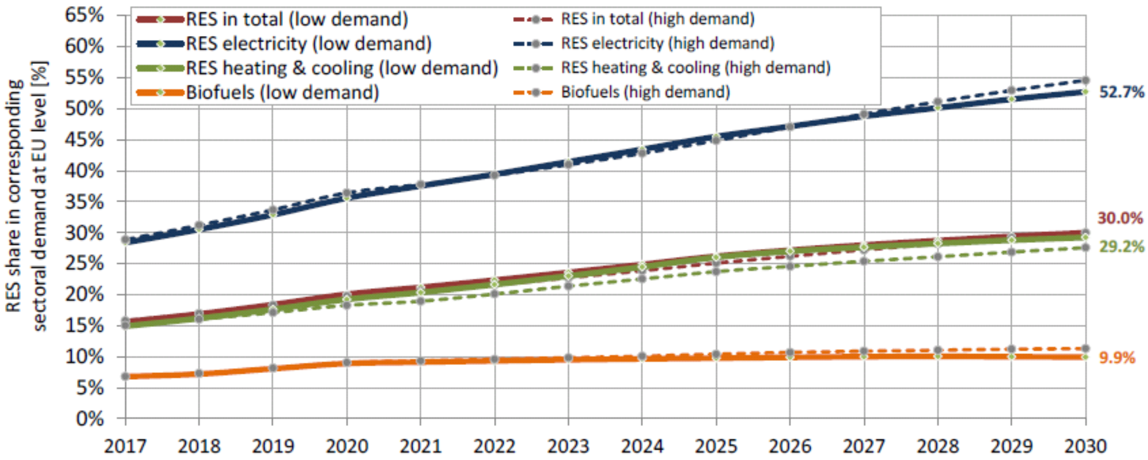
As discussed earlier, a cap on biofuels from food crops will have quite significant impacts on the feedstock that can be used for future (growth of) biofuel production. A number of forecast and outlooks have been published in recent years to assess this impact.

These studies either specifically looked at the European situation and the potential effects of current or expected policies (Resch et al, 2014)(JEC, 2014)(E4Tech,2013), or assessed the global developments, focussing on impacts on agriculture and forestry (OECD/FAO, 2014)(IEA, 2015). Not all of these studies provide outlooks until 2030 and all had different assumptions on policy developments, but most studies incorporate a shift from first generation biofuels (from food crops) to advanced biofuels (from waste and residues, ligno-cellulosic biomass etc). Without going into the details of each of these studies, for these we refer to the original literature, the key assumptions and main results are provided below.

Note that as part of this literature analysis, the European Commission's Impact Assessments of the ILUC proposal (EC, 2012b) and of the proposal for a 2030 climate and energy policy package (EC, 2014a) have also been analysed. However, these are only high level assessments, and potential impacts on, for example, biofuel and feedstock demand, vehicle compatibility or costs are not assessed, so they have not been included in the following.

Resch et al., 2014 carried out a brief assessment of the potential impact of 2030 RES targets for Europe on renewable energy use in the different sectors. Various targets were assessed, with the 30% target the closest to the agreed target of 27%. They do not specify the sustainability criteria that they assumed for biofuels, but it can be derived from their conclusion that a cap on food-based biofuels is assumed. They conclude from their modelling results that this 30% RES target would result in stagnation of biofuel consumption between 2020 and 2030, and result in a shift from first to second generation biofuels. They find that biofuel demand is somewhat dependent on developments in other sectors: in case the implementation of energy efficiency measures in the heating and cooling sector turns out to be unsuccessful (high energy demand scenario) a slightly higher renewable energy in transport contribution is foreseen to compensate for these failing measures (Resch et al., 2014). Their forecast for biofuel demand is depicted in Figure 1.36, they expect a share of about 10% in transport energy demand in 2030.

Figure 1.36 Future renewable energy sources (RES) pathways up to 2030 at EU level, pursuing a 30% target, in total and per energy sector depending on the future gross final energy demand



Source: Resch et al, 2014

JEC, 2014 only looked at developments until 2020, and focussed on the transport sector. This study included a much more detailed assessment of some of the barriers to future biofuel development that were also identified in the previous chapters: blend limits, vehicle compatibility and advanced biofuel production capacity. The study took into account the 2013 ILUC proposal by the Commission, as well as the outcome of EP and Council discussions, status end of 2013. It does include, therefore, a 7% cap on first generation biofuels in 2020, and voluntary Member State sub-targets for advanced biofuels. JEC, 2014 assessed different fuel demand scenarios in the period until 2020, based on different regulatory sets of provision (including the introduction of two higher biofuel blend grades: E20, and B10 in captive HD fleets) and a range of other assumptions related to the vehicle fleet. Costs and investments were not assessed. The main conclusions from that study are the following:

- None of the scenarios, tested against the legislative concepts discussed at the time, would achieve the RED and FQD targets
- The introduction of an accounting cap on conventional biofuels towards achieving the RED target will diminish the potential impact of higher biofuel blends. It will also affect the use of drop-in fuels from such sources to blend beyond the current (diesel) grade.
- Switching to low-ILUC risk feedstocks has the potential to have a major impact on achieving the FQD and RED targets but is expected to be limited by feedstock availability.

In line with the findings of this study, the study stresses that both the supply of advanced biofuels and vehicle compatibility are barriers to increasing biofuel demand under the new ILUC regulation.

In the **Autofuel roadmap** developed by E4Tech (E4tech, 2013), the energy share of biofuels in road transport is foreseen to be between 5.8 and 6.3% in 2020 and 10.6-11.8% by 2030, as shown in Table 1.16. Their forecast for the growth of the share of biofuels is also quite conservative, in line with the reports above and for the same reasons: it takes into account the time needed for the shift to advance biofuels as well as limitations due to blending limits and vehicle compatibility. Regarding high blends, it assumes that the FAME limit of B7 is not increased (because of the engineering challenge associated with making engines that use biodiesel blends higher than B7 compatible with Euro-VI air quality requirements, and due to the expected tightness in the sustainable vegetable oils market). The ethanol limit in petrol is increased, however, by introducing E20 in 2025, and E10 is assumed to be rolled-out across the EU by 2020. These findings are based on policies in place in 2013, i.e. the GHG thresholds outlined in the RED, the ILUC proposal and decision were not taken into account Costs were not assessed. (E4Tech, 2013)

Table 1.16 Energy share of biofuels in transport in 2020 and 2030

	2020	2030
Road transport	5.8-6.3%	10.6%-11.8%
All transport (incl. non-road transport)	6.7%-7%	12-15%
Biofuels from waste and residues		diesel: 9-21% petrol: 16-21%

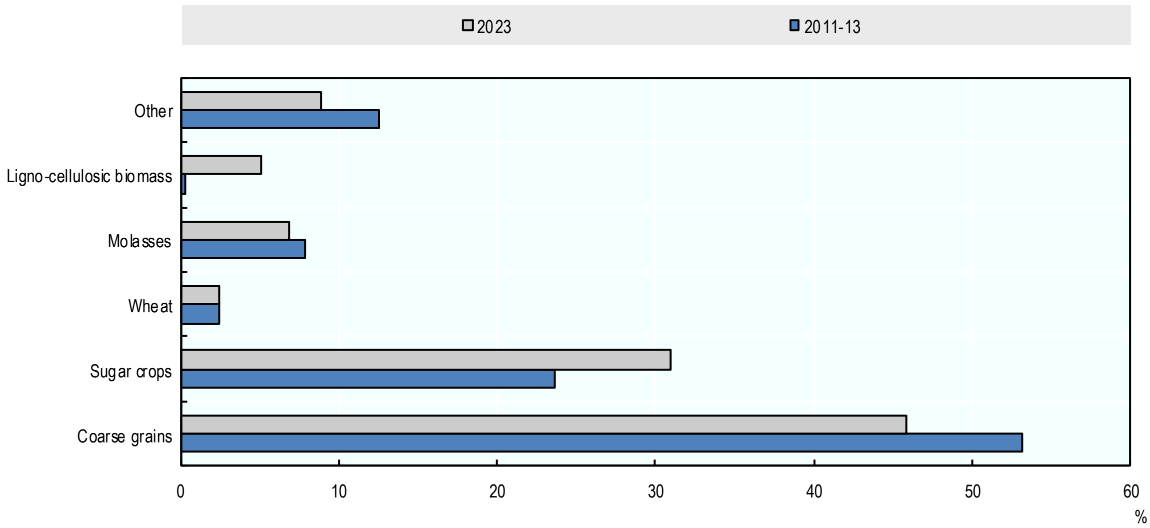
Source: E4Tech, 2013

The OECD/FAO and EC regularly publish reports and detailed outlooks for agricultural markets and forestry, which also address production and consumption of biofuels in the EU. These outlooks are limited to the period until 2023 or 2024, and give a diverse picture:

The **2014 – 2023 OECD FAO Agricultural Outlook** (OECD/FAO, 2014) predicts a steady and significant increase of 50% in domestic production, imports and consumption up to 2020, after which all three remain at the 2020 levels. This Outlook takes into account global policy developments regarding biofuel supply, demand and global trade. It does not take into account the ILUC proposal and decision but rather assumes that the current biofuel policies in the Member States are continued.

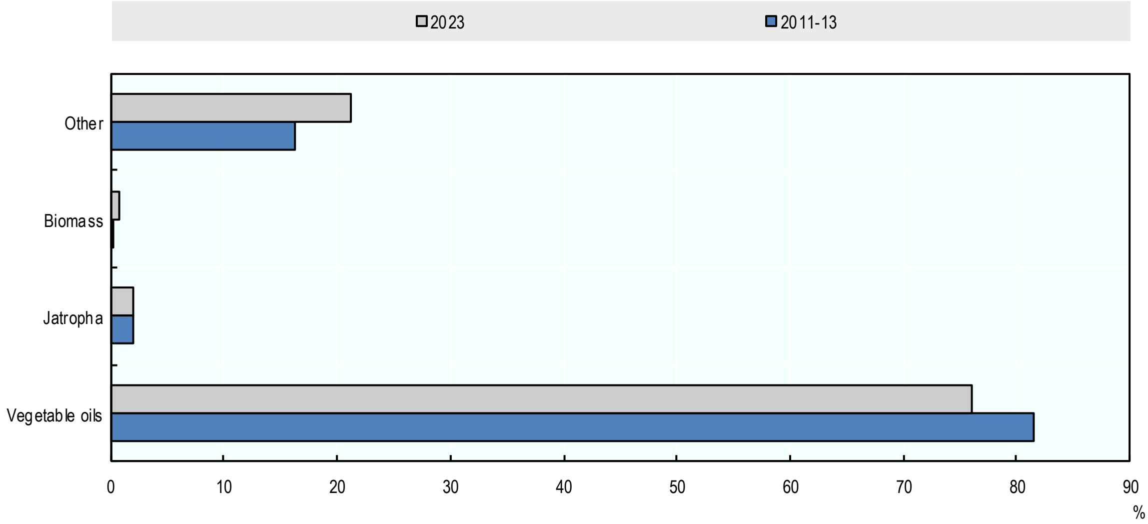
- Biodiesel demand will increase until 2020, and remain at a constant level in beyond 2020. Production of second generation bioethanol will remain very limited. Imports will be necessary to meet the RED target.
- Second generation biodiesel production is not assumed to take off during the outlook period 2014-2023. Ligno-cellulosic biomass based ethanol is expected to grow towards the end of the projection period, it is projected to account for 5% of the world ethanol production. The OECD/FAO expect global feedstock use for biofuel production to develop as shown in the figures below. The Outlook does not provide specific data for feedstocks for EU biofuel production.

Figure 1.37 Share of feedstocks used for bioethanol production



Source: OECD/FAO, 2014

Figure 1.38 Share of feedstocks used for biodiesel production



Source: OECD/FAO, 2014

The **Prospects for EU agricultural markets and income 2014-2024** (EC, 2014f) also forecasts developments in the biofuel market. It assumes that progress towards the 10% RED target is progressing, but that by 2020, biofuels only have a share of 7% of liquid transport fuels – due to the slow increases of biofuel demand in recent years and absence of strong policy incentives. The main conclusions for the developments until 2024 are the following

- Production of biodiesel will grow slightly, but growth is only related to increased utilization of waste oils. Utilization of primary vegetable oils will remain at current level;
- 1st generation bio-ethanol production in the EU will increase slightly with 10% - 20% and will be based increasingly on cereals while utilization of sugar beets (and molasses) will decline.
- There will hardly be any 2nd generation biodiesel (i.e. biodiesel from ligno-cellullosic and woody feedstock) and only limited volumes of 2nd generation bio-ethanol on the market in 2024.
- Imports of bio-ethanol are expected to double from 0.5 to 1.0 Mtoe, while imports of biodiesel are expected to decline from 1.0 Mtoe to 0.5 Mtoe.
- Total share in transportation fuels will amount to approximately 7% (energy content) in 2018 and will next remain constant up to 2024. By 2020, food-based biofuels will have a share of 5%. Contribution of biodiesel from waste oils will amount to 2.9 Mtoe and a share of 1.1% (counting as 2.2%).

Despite their differences, the outlooks give a relatively consistent picture of a future with consolidation of the first generation biofuel production at best, while any incentives for advanced biofuel demand take time to result in significant increases of these biofuels on the market. Overall biofuel shares are likely to remain limited to 10-12% (energy content) in 2030. Outlooks that analysed the potential implications of the FQD blend limits for FAME and ethanol all recognised these as a barrier to meeting the 2020 target, and to further increases of biofuel sales. Whether these developments are sufficient to meet the longer term 2050 target of 60% GHG reduction in transport (EC, 2011) is unknown, and requires further analysis.

In any case, 2030 biofuel demand will strongly depend on the 2030 climate and energy policies, the sustainability criteria and ILUC policies, but it will also be affected by global biofuel policies, agricultural demand, technology developments and oil price. So far, no comprehensive study has been carried out to predict biofuel demand and supply in the EU until 2030 in any detail. It is recommended to assess these issues further now that the ILUC proposal has been decided on. This can provide valuable input to 2030 policies development, both on EU and on Member State level.

1.7.3 Three scenarios for the time period until 2030

To do the uncertainties justice, four scenarios for the period until 2030 are developed. These aim to ‘cover the playing field’: they are not meant to predict the future, but explore what might be possible, given the current technical constraints, opportunities and ambitions, and policy developments. All four are considered to be feasible, albeit three of the four require significant policy efforts and investments, starting in the coming years.

These scenarios will be used as a basis for the analysis of Tasks 2, 4 and 5 of this project.

The Base case scenario assumes that the energy content of biodiesel (FAME/HVO) and biopetrol in 2013 (i.e., 5.2% and 3.4%, respectively), will not change through 2030.

The remaining scenarios have a number of assumptions and methodological issues in common, all based on the findings in this report:

- They all take the current blending limits and current situation regarding vehicle fleet and biofuel market as a starting point, as well as the RED and FQD targets for 2020 and the recent ILUC decision. As the 2030 energy and climate package does not specify the share of biofuels in 2030, this is varied in the scenarios.
- They all assume that the cap on biofuels from food crops in the EU’s renewable energy policy will either remain at the 7% level after 2020, or will be lowered over time. It is furthermore assumed that Member States will also adopt this cap for biofuels policy measures that go beyond any EU targets, i.e. the share of food-based biofuels in the EU will not exceed 7% of road transport fuels. Growth beyond this cap will then have to come from biofuels from waste and residues or energy crops, as included in Annex IX of the ILUC Directive. A further increase of biofuel demand will thus be limited by the availability of the feedstocks listed in Part B of this Annex, and by production capacity for the advanced biofuels that are produced from feedstocks listed in Part A (see the analysis in Section 1.6).
- To meet the RED target in 2020, all Member States have switched to B7 and E10 as the main road transport fuels, and fuel suppliers make full use of these limits.
- By 2020, it is assumed that the whole vehicle fleet throughout the EU can drive on B7 and E10, and lower blends can be removed from the market. There will still be a small share of older petrol vehicles that have to drive on E5 (See Chapter 2), but this is assumed to be resolved by either government incentives (scrappage schemes), retrofit or by a limited number of filling stations, typically located in regions where there are relatively high shares of these vehicles. Compared to overall fuel consumption, these volumes will be negligible.
- In all three scenarios, B7 and E10 will be protection grade fuels between 2020 and 2030. These remain available in all Member States as part of the vehicle fleet are not compatible with higher blends.
- The potential share of fungible (drop-in) biofuels will be limited by production capacities and cost.
- The scenarios assume that EU-wide transport energy demand develops in line with the forecast of PRIMES reference scenario (2012). This forecast estimates that in 2030, EU road transport (blended) diesel demand is 185 Mtoe, and (blended) petrol demand amounts to 105 Mtoe.

The key parameters that are varied in these scenarios are:

- The blending limits for diesel and petrol
- Assumptions regarding vehicle compatibility for higher blends
- Introduction of higher blends in the Member States

- The actual share of biofuels in diesel and petrol (distinguishing between FAME, ethanol and fungible (drop-in) fuels)

In the next paragraphs, the key assumptions and rationale of the three scenarios will be described (Section 1.7.3.1), followed by an assessment of the biofuel consumption that is to be expected in each of these scenarios, in 2020 and 2030 (Section 1.7.3.2): how much biofuels will be consumed in each scenario, and are these volumes feasible in the light of the findings of Section 1.6, i.e. given the biofuel production capacities and the expected shift from food-based to advanced biofuels? Section 1.7.4 then addresses what would be necessary to achieve the scenarios.

1.7.3.1 The key assumptions of the scenarios

An overview of what assumptions were used for these parameters in each of the three scenarios is provided in Table 1.17.

The rationale behind these assumptions, and the key characteristics of these scenarios are described in the following. Note that these scenarios are designed based on the key findings and conclusions of the assessments of Chapter 1 and 2. They are not the result of a quantitative modelling exercise of biofuel developments of a detailed assessment of cost.

The **Base Case Scenario** assumes that current (2013) energy content of biodiesel (FAME/HVO) and ethanol is 5.2% and 3.4%, respectively. The Base case scenario reflects the assumption that due to policy uncertainty there is no change in the biofuel levels (i.e., % energy content) from current 2013 levels. Consequently, 2020 and 2030 will also have biodiesel (FAME/HVO) and ethanol consumption at 5.2% and 3.4%, energy content, respectively.

Scenario A: the FQD blending limits remain at **B7** and **E10** and MS will ensure an actual supply up to these limits. This implies introduction of E10 in all Member States, and increasing actual blend levels up to the maximum allowed by these limits. The scenario would include the result of the ILUC decision and a certain further shift from first generation to advanced biofuels after 2020, while the ILUC directive de facto limits the range of feedstocks and production processes that will be used for biofuels that are consumed in the EU.

This scenario is generally in line with the outlooks for post-2020 biofuel developments provided in Section 1.7.2. It is also in line with the outlook for the availability of advanced biofuels that followed from Section 1.4 - limited production capacity, the need for further R&D and uncertainties regarding biomass availability are all barriers to the growth of advanced biofuel production and consumption in the EU, with the current slow uptake of E10 throughout the EU (indicating little need for higher blends at the moment) and the relatively limited biofuel share in many EU Member States (see Section 1.3.3 for details).

As this scenario assumes that the levels of FAME and ethanol will be the maximum allowed by the blending limits, in all Member States, between 2020 and 2030, their shares will then remain constant in this time period, at 6.4% and 6.8% respectively, based on energy content. These could be all from food crops if the 7% cap is held constant, but it seems reasonable to assume that the Member States policies will promote production from waste and residues (e.g. by continuing the double counting after 2020 and/or by setting sub-targets for advanced biofuels) which will result in an increasing share of biofuels from waste and residues in these volumes.

In this scenario, the share of fungible fuels (HVO and possibly new options that are currently under development) is expected to increase gradually over time: as the blending limits are not raised, fungible fuels will be an attractive option for Member States that wish to have ambitious biofuel targets to meet their post-2020 targets. The rate of increase will be limited, for the same reasons that were mentioned above. In is assumed that fungible biofuels will only be diesel replacers (as is HVO), and their share in total diesel sales will increase from 5% in 2020 to 10% in 2030.

This scenario would imply that a decision about blending limits is postponed to a time when the key barriers to biofuel growth are removed and there is more certainty about the future biofuel demand and supply.

Scenario B assumes further growth of FAME and ethanol demand in the EU beyond 2020, and accommodates that with an introduction of **B10** and **E20** from 2020 onwards. B7 and E10 will remain available throughout the EU as protection grades, at least until 2030.[60] The new standards will be introduced in the FQD before 2020, and vehicle manufacturers will be required to ensure that all diesel and petrol new vehicles that are sold from 2020 onwards are fully compatible to B10 and E20 respectively. They should also be tolerant to B7 and E10. Member States and fuel suppliers will be free to bring these higher blends on the market. As Member States ambitions are likely to vary after 2020 (as they do now, see Section 1.3.3) it is likely that the introduction of higher blends will also vary between Member States.

The need to retain a protection grade E5 fuel beyond 2020 has been stressed by some fuel system suppliers. The presence of E5 fuel however, will limit the transition to E10 and partially defeat the intent of this scenario. One option is for EU governments to offer a free upgrade of the fuel system to make the vehicles E10 tolerant, or pay for accelerated scrappage of the affected vehicles if the cost of the upgrade of an old vehicle exceeds its value. For example if the vehicle population of the seriously affected vehicles is about 100,000 vehicles (corresponding to the remaining 2000 to 2005 model year vehicles that Bosch suggests has serious issues) in 2020, than payments can be made to those select vehicles to have their owners scrap them.

This scenario acknowledges that blending limits can be a barrier to the further growth of biofuels, and aims to remove this barrier in such a way that takes into account preferences expressed by fuel suppliers (see Section 1.4.4) and conclusions drawn from Chapter 2. As discussed earlier in Section 1.4, on the one hand, introducing the higher blends will incur additional fuel distribution and infrastructure cost, and may result in market distortions; quality issues and aging of B10 require further analysis (and possibly measures to resolve), and, depending on the fuel standard, E20 may require adaptation to refineries and fuel distribution. On the other hand, E20 allows for fuel efficiency gains of vehicles (see Chapter 2, Section 2.3.3.3), and any technical issues related to the fuel supply chain can be resolved at relatively limited cost. B10 and E20 are deemed technically feasible, both by the fuel suppliers and the vehicle manufacturers. Furthermore, introducing higher blends in EU and Member State regulation enables Member States to increase their biofuel obligations and targets, whilst leaving it up to the fuel suppliers whether they want to achieve these targets with FAME, ethanol or fungible biofuels.

The assumed continuation of the 7% cap on biofuels from food crops and limited availability of advanced biofuels also limits biofuel growth in this scenario, but to a lesser extent: this scenario assumes a faster development of advanced biofuel production capacity than in scenario A.

This scenario assumes that the actual levels of FAME in B10 will gradually increase from 7 vol% in 2020 to 10 vol% in 2030, which equals 6.4% to 9.1% energy content. This is likely to be a mix of FAME from food crops and from used cooking oil and animal fat mainly. The actual levels of ethanol in E20 will increase from 10 vol% to 20 vol% between 2020 and 2030, i.e. from 6.8% to 13.2% based on energy content. This will be a mix of ethanol from food crops and from ligno-cellolusic feedstock, where it is assumed that the share of the latter will increase over time as R&D is progressing and production capacities for advanced bioethanol increase. The protection grade fuels are assumed to contain the maximum levels of FAME and ethanol that are allowed, in the timeframe 2020 and 2030.

In this scenario, the share of fungible fuels (HVO and possibly new options that are currently under development) is expected to increase gradually over time, albeit at a somewhat slower

[60] As discussed in Section 2.3.3.3, it is assumed that a protection grade E5 fuel beyond 2020 will not be provided as it will limit the transition to E10 and partially defeat the intent of this scenario. However, by not offering an E5 protection grade, it is assumed that there will be either government incentives (scrappage schemes), or retrofit.

rate than in scenario A as there is less need for these type of biofuels in road transport fuels. The share of fungible diesel is assumed to increase from 5% in 2020 to 8% in 2030. No fungible biopetrol is expected in this scenario, as the development of advanced ethanol is already progressing, and the blending limit of E20 is assumed to be sufficient to accommodate demand growth between 2020 and 2030.

Scenario C assumes an even stronger growth of FAME and ethanol demand in the longer term (2025-2030) than scenario B. Limitations due to biofuel availability also apply in this scenario, but these are assumed to be resolved after 2025. It assumes that **B10** and **E25** are introduced from 2020 onwards, B7 and E10 will remain available throughout the EU as protection grades, at least until 2030.[61] In addition, a standard for **B30** will be introduced, to be used in captive fleets only. Based on the discussion above in Section 1.5.2.3, it is assumed that captive fleets are responsible for about 25% of the EU's diesel sales.

As in scenario B, the new standards would be introduced in the FQD before 2020, and vehicle manufacturers would be required to ensure that all diesel and petrol new vehicles that are sold from 2020 onwards are compatible with B10 and E25 respectively. They should also be tolerant to B7 and E10. Member States and fuel suppliers will be free to bring these higher blends on the market. As Member States ambitions are likely to vary after 2020, it is to be expected that the introduction of higher blends will also vary between Member States.

Compared to scenario B, this scenario allows for a more rapid growth of FAME and ethanol shares in Member States. However, cost for fuel suppliers will be higher than in scenario B, as more severe investments are required to resolve technical issues (see Section 1.4.5). Furthermore, the production capacity of advanced biofuels is expected to be a limiting factor to biofuel growth,

Regarding actual biofuel consumption, this scenario assumes that the actual levels of FAME in B10 diesel sold at public filling stations (i.e. to non-captive fleets) will gradually increase from 7 vol% in 2020 to 10 vol% in 2030, which equals 6.4% to 9.1% energy content. The share of FAME in B30 diesel sold to captive fleets will increase even more rapidly, from 7 vol% in 2020 to 30 vol% in 2030 (27.4 % energy content). With a 25% market share of B30 and the remaining diesel B10, this results in an average share of FAME of 11.0%.

The actual levels of ethanol in E25 will increase from 10 vol% to 25 vol% between 2020 and 2030, i.e. from 6.8% to 16.5% based on energy content. This will be a mix of ethanol from food crops and from ligno-cellolusic feedstock, where it is assumed that the share of the latter will increase over time as R&D is progressing and production capacities for advanced bioethanol are increasing.

As in scenario A and B, the protection grade fuels B7 and E10 are assumed to contain the maximum levels of FAME and ethanol that are allowed, in the timeframe 2020 and 2030.

In this scenario, the share of fungible fuels (HVO and possibly new options that are currently under development) is expected to increase gradually over time, at a rate comparable to than in scenario B: the share of fungible fuels is assumed to increase from 5% in 2020 to 8% in 2030. As in scenarios A and B, no fungible biopetrol is expected in this scenario, as the development of advanced ethanol is already progressing, and the blending limit of E25 is assumed to be sufficient to accommodate demand growth between 2020 and 2030.

[61] Although there maybe vehicles that are not E10 compatible, it is assumed that these will be addressed by either government incentives (scrappage schemes), or retrofit, and not an E5 protection grade.

Table 1.17 Overview of the three scenarios developed for this project

	Scenario: Base Case	Scenario A: B7 and E10	Scenario B: increase limits to B10 and E20	Scenario C: increase limits to B10 and E25, B30 for captive fleets
Blending limit for diesel	B7	B7 remains in place until 2030	The limit will be raised to B10 from 2020 onwards. B7 has to remain on the market as protection grade.	The limit will be raised to B10 from 2020 onwards. B7 has to remain on the market as protection grade.
Blending limit for petrol	E10	E10 remains in place until 2030.	The limit will be raised to E20 from 2020 onwards. E10 has to remain on the market as protection grade.	The limit will be raised to E25 from 2020 onwards. E10 has to remain on the market as protection grade.
Blending limit for captive fleets	None	none	none	A B30 standard will be introduced from 2020 onwards, to be used in captive fleets only
Diesel vehicle compatibility	No change	whole fleet is B7 compatible from 2020 onwards	Whole fleet is B7 compatible from 2020 onwards. From 2016 onwards, B10 compatible vehicles will come on the market. The share of B10 compatible vehicles in the new vehicle sales will then increase gradually from 0% in 2015 to 100% in 2020	Whole fleet is B7 compatible from 2020 onwards. From 2016 onwards, B10 and B30 compatible vehicles will come on the market. The share of B10 compatible vehicles in the new vehicle sales for non-captive fleets will increase gradually from 0% in 2015 to 100% in 2020. The share of B30 compatible vehicles in the new vehicle sales for captive fleets will increase gradually from 0% in 2015 to 100% in 2020. From 2020 onwards, all new diesel vehicles will be either B10 or B30 compatible
Petrol vehicle compatibility	No change	whole fleet is E10 compatible from 2020 onwards	Whole fleet is E10 compatible from 2020 onwards. From 2016 onwards, E20 compatible vehicles will come on the market. The share of E20 compatible vehicles in the new vehicle sales will then increase gradually from 0% in 2015 to 100% in 2020	Whole fleet is E10 compatible from 2020 onwards. From 2016 onwards, E25 compatible vehicles will come on the market. The share of E25 compatible vehicles in the new vehicle sales will then increase gradually from 0% in 2015 to 100% in 2020

	Scenario: Base Case	Scenario A: B7 and E10	Scenario B: increase limits to B10 and E20	Scenario C: increase limits to B10 and E25, B30 for captive fleets
Introduction of the higher blends in the Member States	none	E10 will become the standard petrol grade in all Member States	Member States will start introducing B10 and E20 from 2020 onwards. The number of countries with B10 and E20 will gradually increase of time, until all Member States have these blends on their market in 2030.	Member States will start introducing B10 and E25 from 2020 onwards, the same holds for B30 in captive fleets. The number of countries with B10, B30 and E25 will gradually increase of time, until all Member States have these blends on their market in 2030.
Share of FAME in diesel	4.9% (energy content) from 2013 onwards	7 vol% from 2020 onwards (6.4 % energy content)	B10: 7 vol% in 2020 (6.4 % energy content), gradually increasing to 10 vol% in 2030 (9.1% energy) B7: protection grade, with 7 vol% throughout 2020-2030	All grades: 7 vol% in 2020 (6.4 % energy content). B10: In non-captive fleets, gradually increasing to 10 vol% in 2030 (9.1% energy). B30: In captive fleets, gradually increasing to 30 vol% in 2030 (27.4 % energy content)
Share of ethanol in petrol	3.4% (energy content) from 2013 onwards	10 vol% from 2020 onwards (6.8 % energy content)	E20: 10 vol% in 2020 (6.8 % energy content), gradually increasing to 20 vol% in 2030 (13.2% energy) E10: protection grade, with 10 vol% throughout 2020-2030	E25: 10 vol% in 2020 (6.8 % energy content), gradually increasing to 25 vol% in 2030 (16.5% energy) E10: protection grade, with 10 vol% throughout 2020-2030
Share of fungible biofuels	0.26% (energy content) from 2013 onwards	Increase gradually, from 5% of all diesel sales in 2020 to 10% in 2030 (energy content). Fungible biofuels in diesel only.	Increase gradually, from 5% of all diesel sales in 2020 to 8% in 2030 (energy content). Fungible biofuels in diesel only.	Increase gradually, from 5% of all diesel sales in 2020 to 8% in 2030 (energy content). Fungible biofuels in diesel only.

1.7.3.2 Biofuel consumption in the scenarios

The resulting EU-wide biofuel demand in these scenarios, for each type of biofuel, is given in Table 1.18. For scenarios A, B and C, the biofuel consumption at the starting point of 2020 is the same, as the market introduction of higher blends does not start until 2020. Scenarios A, B and C assume that B7 and E10 are fully used throughout the EU, and biofuel levels have increased to the maximum allowed by 2020, because of the RED and FQD targets in 2020.

Biofuel consumption in 2030 does, however, differ between scenarios A, B and C.

- **Scenario A** results in a small increase of FAME consumption between 2020 and 2030 and ethanol consumption reduced by about 25% (due to a predicted reduction of petrol demand in the EU). However, consumption of fungible fuels more than double between 2020 and 2030: in this scenario, demand for these biofuels increases due to the relatively low blending limits.

- **Scenario B** assumes that FAME and ethanol demand grows significantly between 2020 and 2030, which is enabled by the higher blending limits (B10 and E20) and the increasing share of compatible vehicles in the vehicle fleet. Fungible fuels still play an important role in the EU biofuel mix, but consumption increases at a somewhat lower rate than in scenario A as FAME and ethanol consumption can also grow.
- **Scenario C** is even more ambitious: biofuel demand increases even more than in scenario B. The higher blending limit for ethanol allows EU-wide ethanol consumption to increase to 16.4%, the introduction of B30 in captive fleets allows FAME consumption to increase to 11.0%, energy content.

For comparison, the 2013 actual consumption data that were shown in Section 1.4.2.2 are included in the table[62].

Clearly, consumption of all types of biofuels would be expected to increase significantly in scenarios B and C, compared to the current levels. These scenarios would also result in biofuel shares higher than the (assumed) 7% cap on food-based biofuels in 2030, they would therefore require significant volumes of biofuels from non-food feedstock as well. Comparing these data with the findings in Chapter 1.6, it can be concluded that these volumes would be feasible, if

- the 7% cap remains in place, and
- bioethanol and fungible biofuels are produced mainly from non-food feedstock in 2030.

As discussed in Section 1.6.3, the latter still requires significant R&D efforts, as well as (eventually) significant investments in production capacity for these advanced biofuels. As efforts are ongoing and technologies seem to be progressing well, expansion of the production capacities to the levels required in scenarios B and C can be considered technically feasible, but nevertheless uncertain. In any case, effective policies, both on EU and Member State level, would be a prerequisite to achieving the ambitious growth paths needed for these scenarios.

A potential barrier to meeting scenario B and, to an even larger extent, scenario C, is the limited potential for FAME production from non-food feedstock. The 7% cap allows about 18,500 ktoe of first-generation biofuels to be consumed. As the maximum EU potential of FAME from used cooking oil and animal fats was estimated to be only 3,500 to 6,200 ktoe, a large share of the FAME would have to be produced from food crops. FAME production would then use a relatively large share of the first-generation biofuels allowed under the cap.

Table 1.18 Biofuel volumes sold in the EU in each of the three scenarios, in 2020 and 2030 (in ktoe and in % energy content, of total diesel or petrol blend sales) (Source actual consumption: Eurostat)

		Actual consumption	Base case scenario		Scenario A, B and C	Scenario A	Scenario B	Scenario C
		2013	2020	2030	2020	2030	2030	2030
ktoe	FAME	10,293 (FAME and fungible biodiesel)	10,817	10,987	13,620	13,836	18,713	23,476
	Ethanol	2,717	2,202	1,667	4,390	3,325	6,402	8,027
	Fungible biodiesel		569	578	10,551	21,437	17,150	17,150
%	FAME	5.2% (FAME and fungible biodiesel)	5.2% (FAME and fungible biodiesel)	5.2% (FAME and fungible biodiesel)	6.5%	6.5%	8.7%	11.0%

62 Where it should be noted that no separate statistics for HVO and biodiesel consumption are available

	Ethanol	3.4%	3.4%	3.4%	6.8%	6.8%	13.1%	16.4%
	Fungible biodiesel				5.0%	10.0%	8.0%	8.0%

1.7.4 What would be necessary to achieve these scenarios?

In **Scenario A** no additional EU-level policy measures are required to achieve this scenario at this point in time. Member States take the actions necessary to implement the ILUC decision and meet the RED and FQD targets in 2020. In particular, all Member States would have to move to B7 and E10 before 2020, and increase biofuel obligations and/or financial incentives in order to increase biofuel volumes fully exploiting these allowed blending levels. Member State policies for the post-2020 period would be a continuation of these policies. Increasing the level of fungible fuels such as HVO can then be the result of increasing the biofuel obligations and targets in Member States levels that can be accommodated by the blending limits.

As was concluded in Chapter 2, Section 2.5.2, expansion of B7 blend use to all EU Member States does not require changes to vehicle technology and can be implemented immediately. Chapter 2, Section 2.5.2 furthermore concludes that roll-out of E10 does not create any technical issues in the EU.

As noted above, this scenario assumes a relatively limited contribution of biofuels to the overall climate and renewable energy targets and ambitions for 2030, in the EU as a whole and in individual Member States. This means that other sectors will need to contribute more to these goals, or alternative renewable energy options in transport, notably, electricity or hydrogen need to be increased more than in scenarios B and C.

It is furthermore recommended to revisit the FQD blending limits on a regular basis to ensure that these limits do not create barriers to the further development of biofuels.

Scenario B and C, require a lot more effort including at EU level: the specifications for the higher blends need to be decided on, vehicle manufacturers need to develop fully compatible vehicles as described in Chapter 2, the technical and non-technical barriers described in Sections 1.4.5 and 1.4.6 need to be removed and the necessary R&D and investments into advanced biofuels must be realised. EU and Member State policies and actions are crucial to provide the right incentives to ensure that all stakeholders involved take the necessary actions.

Scenario C is more ambitious than scenario B as it assumes an even faster growth of (advanced) biofuel volumes on the market, and B30 and E25 are blends that require more effort to introduce than B10 and E20 (as discussed in Chapter 2 and Section 1.4.5 above). Nevertheless, both scenarios require the same type of actions.

The following list, derived from the various assessments and findings throughout this report, provides an overview of what would be necessary to achieve these higher blend scenarios in addition to and as prerequisite for a legislative change of the fuel specifications under FQD:.

- **Development of fuel standards for B10 and E20 (scenario B) or for B10, E25 and B30 (scenario C).** This requires
  - A detailed assessment of potential issues with quality control and aging of FAME, to ensure that technical issues with higher blends of FAME are prevented.
  - An assessment of options to reduce the need for a different BOB (relevant for higher ethanol blends, see Section 1.4.5.1).
  - A decision on a possible range of biofuel blends in the standards. A smaller range (for example, E20 has to contain between 15 and 20 vol% ethanol, rather than between 0 and 20%) will reduce or remove overlap between the higher blends and the protection grade fuels, which allows governments to provide specific incentives for these higher blend. A smaller range is also desirable from vehicle manufacturer point of view, as these stakeholders have stated (in interviews for this study). However, fuel suppliers prefer a broader range, as they can use the resulting flexibility to optimise operations.

- **Development of fully compatible and optimised vehicles**
  - Once the standards are defined, a timeline for the introduction of compatible vehicles can be decided on (for example stating that all new petrol vehicles must be E20/E25 compatible by 1.1.2020). The vehicle manufacturers can then develop these vehicles and optimise the engines, to meet air quality regulations with these new fuels and, in case of new ethanol standards, to make use of any fuel efficiency benefits that the higher ethanol blends may offer (Chapter 2, Section 2.3.3.2).
- **Availability of blends at refuelling stations**
  - As in scenario A, E10 will become the base grade in an increasing number of Member States, by 2020 all Member States will have switched from E5 to E10. Likewise, all Member States will need to move to B7 as base grade for diesel by 2020.
  - In countries where E20/E25 enters the market from 2020 onwards, E10 will replace E5 as a protection fuel. As discussed in Chapter 2, Section 2.3.3.4, there will still be a share of the vehicle fleet (possibly between 1.3 and 6.8%) of older petrol vehicles that have to drive on E5 by 2020. This needs to be resolved by retrofitting, government incentives (scrappage schemes) or by a limited number of E5 filling stations, typically located in regions where there are relatively high shares of these vehicles. Compared to overall fuel consumption, these volumes will be negligible, and reduce further over time, between 2020 and 2030.
  - As recommended in (Chapter 2, Section 2.3.2), auto manufacturers should identify the exact vehicle models that are incompatible with E10, and develop (retrofit) solutions to resolve the issues that may arise when E5 is discontinued.
  - Member States and fuel suppliers may introduce the higher blends once the FQD has been adapted. It is assumed in the scenarios that this introduction will take place gradually over time, by 2020 all Member States will have these higher blends on their market.
  - It is recommended to analyse and assess the potential market distortion that the introduction of a higher blend may have in the various Member States, in order to address and possibly alleviate any issues that this may cause (see Section 1.4.4).
- **Availability of the biofuels**
  - Production and consumption of biofuels from food-based feedstock can still grow in the coming years, until the 7% cap on these types of biofuels is reached (assuming that the cap is continued after 2020, at EU and/or MS level, see above). Production capacity for FAME seems to be sufficient, potential shortages for ethanol may be resolved via imports (Section 1.6.2).
  - The development of advanced biofuels is a crucial precondition to ensure future growth of biofuel consumption within the boundary conditions of the sustainability criteria for biofuels and the ambition expressed by the Commission to move away from first generation biofuels (EC, 2014a) (see Chapter 1.6 and Section 1.7.2). This requires further R&D into various types of biofuels, and then investments to develop and expand commercial-scale production plants. The latter can be supported by targeted Member State policies, for example by sub-targets for advanced biofuels.
  - R&D into advanced fungible biofuels (i.e. from feedstocks included in Part A of Annex IX of the ILUC Directive) should also be supported, as these may have significant longer term advantages over the non-fungible advanced biofuels: they do not require additional fuel grades or blends to be introduced.
  - Biomass availability for these advanced biofuels can also be a barrier to their future development and growth. It is recommended to further assess the potential availability, including the potential competition with other users and the cost of these sources.
  - Fuel suppliers need to be incentivised to increase the share of biofuels on the market. The biofuel obligations, implemented by 25 of the 28 Member States (status 2014, see Section 1.3.3.1) have proven to be an effective means to achieve this.
- **Harmonisation of the EU fuels market**

  - Introducing new blends may further diversify and possibly fragment the fuel market, as different countries make different choices regarding blends on their market, shares of advanced biofuels in their mix, etc. Even in the current situation, refineries and fuel suppliers may need to supply many different blends to their customers, depending on the national policies and regional circumstances (see Section 1.4.6.4). It is therefore recommended to assess the possible impacts of new blends on the EU market, and, if necessary, identify potential solutions to resolve negative impacts.

- **Cost of biofuels**
  - There is currently only limited evidence regarding cost of advanced biofuels, and therefore of the financial implications of increasing biofuel consumption with a cap on biofuels from food-based feedstock in place. It is recommended to further assess these costs, to ensure that future biofuel policies can be designed in a cost-effective way.
  - For the same reason, it is also recommended to assess cost of introducing the higher blends.

- **Acceptance of consumers**
  - Consumers that have bought a vehicles that is compatible with the high blends are crucial to the successful roll-out of the higher blends: they need to accept and trust these blends. This requires clear and adequate communication to the public, about the reasons for these high blends, and regarding vehicle compatibility.
  - Consumers also need to be incentivised to fill their vehicles with the high blend and not with the protection grade fuel. This can be either done by financial (government) incentives such as a CO_2-tax or differentiated excise duties (see Section 1.3.3.2 for examples) or by implementing a biofuel obligation that is set at a level that encourages fuel suppliers to implement price incentives themselves (see Section 1.3.4.1).

- **Monitoring and reporting**
  - It is also recommended to improve the statistical data gathering and monitoring in the EU, so that the statistics distinguish between biofuels from food-crops and biofuels from waste and residues (non-ILUC biofuels), as well as between the various types of biodiesels (e.g. FAME and HVO) and biopetrols. This enables closer monitoring of the developments, in particular of the shift from food-based biofuels to advanced (non-ILUC) biofuels.

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2 Implications for automotive technology

Abbreviations/acronyms

ACEA	European Vehicle Manufacturers Association
API	American Petroleum Institute
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
CO	Carbon Monoxide
CR	Compression ratio
DI	Direct injection
DISI	Direct injection spark ignition
DOC	Diesel Oxidation Catalysts
EGR	Exhaust gas recirculation
EPA	US Environmental Protection Agency
ESC	EU Steady State Cycle
ETBE	Ethyl tertiary-butyl ether
ETC	European Transient Cycle
FAME	Fatty Acid Methyl Esters
FE	Fuel Economy
FFV	Flex Fuel Vehicles
FQD	Fuel Quality Directive
FTP	US Federal Test Procedure
GHG	Greenhouse gas
GTL	Gas-to-Liquids
HCCI	Homogeneous charge compression ignition
HVO	Hydro-treated Vegetable Oils
MON	Motor Octane Number
NEDC	New European Driving Cycle
NMHC	Non-methane hydrocarbons
PM	Particulate Matter
PZEV	Partial Zero Emissions Vehicle
RON	Research Octane Number
RVP	Reid Vapour Pressure
SAE	Society of Automotive Engineers
SCR	Selective catalytic reduction
THC	Total hydrocarbon
UDC	Urban Driving Cycle
VVT	Variable valve timing
WLTC	World Light-duty Test Cycle

2.1 Summary

This chapter presents a review of the implications of different ethanol-petrol and bio-diesel blends for automotive technology, in terms of the tailpipe emissions, impact on energy efficiency, impact on engine and emissions after-treatment durability, and impact on future engine designs. The assessment has been based on literature review, and stakeholder consultation.

In the EU, petrol engines are used almost exclusively in personal use light duty vehicles and all commercial vehicles use diesel engines. Future improvements in petrol engine technology is expected to progress along two pathways. The approach favoured by European manufacturers relies upon increased turbocharger boost and engine downsizing to improve fuel economy. The second approach, favoured by Japanese manufacturers, will use very high compression ratios (13 to 15) in combination with Atkinson or Miller cycles. For diesel engines, future technology improvements are not expected to alter diesel fuel combustion requirements but engines will see further increases in turbocharger boost pressures and engines will be further downsized. Regardless of the approach to improve petrol and diesel engine technology in the future, the analysis indicates that there will be no change in the impact of biofuel blends relative to their impact on current engines.

2.1.1 Petrol engines

Based on the analysis, the following summarises the impacts of three possible options for the expansion of ethanol use in petrol vehicles:

Expansion of E10 option availability and use to all countries in the EU with E5 blend as the protection fuel maintained available. There are no technical issues related to this option, as most post-2003 vehicles are E10 tolerant. The use of E5 will produce some small positive benefits for emissions of regulated pollutants and air toxics (e.g., 5% lower carbon monoxide (CO) emissions; 5-10% lower particulate (PM) emissions) when compared to current engines using E0 fuel. No change in carbon dioxide (CO_2) emissions is expected; although nitrogen oxide emissions could be slightly higher.

Replacement of E5 as the protection fuel with E10 across the EU in 2020. There are technical issues related to this option, which could affect vehicles produced before 2003, which comprise between 1.3 to 6.8% of the 2020 EU light duty fleet. In these older vehicles, fuel leaks or fuel system corrosion could occur. This could be addressed by upgrading fuel system gaskets and elastomers for costs of <200 Euros, but there may be some vehicles requiring hardware changes. There is no public data on affected models and the EU must work with auto-manufacturers to identify affected vehicles, upgrade costs and affected populations in 2020. There are small positive benefits for emissions of regulated pollutants 10% lower CO, 10-20% lower PM) and air toxics (from lower benzene) associated with this approach; however, there could be small absolute increases aldehyde emissions.

Implementation of E20 for purpose designed cars starting in 2020. Manufacturers are favourably disposed towards E20, but only if the new E20 fuel is a splash blend fuel rated at 98 to 100 RON as a premium fuel that can be used by purpose designed cars starting in 2020. Although most post-2011 vehicles are E20 tolerant, the use of E20 fuel with the same octane rating as current E5 and E10 fuels (i.e., 95 RON) will produce a 6.5 to 7% increase in fuel consumption and, thus, offers no benefit to the consumer. In contrast, the high octane E20 strategy has the advantage of providing a 3% to 6.4% energy efficiency benefit potential for the auto-industry and provides value to the customer from the high octane rating of ethanol. (Volumetric fuel consumption would change by -2.5% to +1%).This high octane E20 fuel could slowly displace hydrocarbon based premium petrol (98+ RON) in the EU starting in 2020 as auto-manufacturers introduce more vehicle models capable of exploiting the octane advantage of E20 and eventually become the mainstream fuel by 2030.The fuel could result in positive benefits for regulated pollutants (20% lower CO, 20-30% lower PM, 1-7% lower CO_2) and toxic emissions (lower benzene). Unlike purpose built engines, which will likely see no change in aldehyde emissions compared to current engines using E0 fuel; the use of E20 in current “E20 tolerant” vehicles could result in higher aldehyde emissions. It is assumed that the costs of this approach will be near zero for naturally aspirated engines and under Euro 50 for turbocharged engines if the changes are incorporated in the design stage. This approach will affect future manufacturer product plans as engines will need to be modified to take advantage of the high octane of E20 splash blends. A lead time for 4 to 5 years will be required for manufacturers to design such engines.

2.1.2 Diesel engines

The analysis indicates the following possible implications from the expansion of biodiesel use in diesel vehicles:

Expansion of B7 blend use with FAME to 7% limit to all countries in the EU requires no changes to vehicle technology and can be implemented immediately. This approach could lead to decreases in PM, hydrocarbon (HC) and CO emissions from most vehicles, although the PM decreases from trap equipped vehicles may be undetectable due to measurement limitations. NOx emissions could increase by zero to 1%.

Replacement of B7 with B10 FAME blends across the EU will have similar but slightly higher regulated pollutant emissions impacts as B7. However, vehicles with duty cycles having short trip lengths and many cold starts daily could experience significant oil dilution issues. The technical solution to this problem is improved monitoring of engine oil and more frequent oil change intervals. This option will not impact manufacturer product plans or new technology but could result in the oil change interval being reduced from current levels of 25,000 to 30,000 km to less than 20,000 km. In addition, the use of B10 during winter months may need to be prohibited.

Expansion of B30 FAME bio-diesel to captive fleets. This approach would only be applicable if used in "captive" fleets across the EU, where owners of large fleets could implement an oil dilution monitoring program and ensure careful oversight of fuel quality. Due to significant concerns related to oil dilution and cold storage problems, B30 FAME blends may not be suitable for consumer use. It is unclear if any upgrades of the fuel system are needed for modern (post-2010) vehicles to use B30, but vehicle hardware changes, if any, are expected to be minor. With the use of B30, in modern vehicles certified to Euro 5 and 6 standards, HC and CO emission declines of 15% are likely, when compared to the use of B0 diesel fuel; however, NO_x and PM changes, if any, may be too small to be reliably detected. Fuel consumption penalties are small, in the range of 0 to 2% for B30 in light duty vehicles. For heavy-duty vehicles data suggests that for each 10% increase in the bio-diesel content, there will likely be a 1% reduction in fuel efficiency with about the same 1% degradation in available torque.

The use of HVO+FAME blends that could utilize 7% FAME-diesel with any level of HVO up to 26% is possible without any negative performance effects for all diesel vehicles. In general, HVO use with diesel or B7 FAME-diesel blends will result in emission declines for all regulated emissions, but volumetric fuel consumption could increase by about 0.5% for every 10% increase in HVO content in the blend. This option will likely have no effect on auto-manufacturers, but fleet test data to confirm this is not yet available (but could be available later in 2015).

There are concerns about the oxidation stability of FAME when used in plug-in vehicles where the tank fuel can be used over several months if the vehicle is operated primarily in electric mode. Not much is known about this issue as plug-in diesels have entered the market only in 2014, but is an area of manufacturer concern for the future.

2.2 Introduction

The following assesses the implications of different bio-diesel blends and different ethanol-petrol blends for automotive technology, in terms of the tailpipe emissions, impact on energy efficiency, impact on engine and emissions after-treatment durability, and impact on future engine designs. The range of blends examined was based on the current policy framework (FQD) and the recently announced climate and energy policy framework for 2030 (COM(2014)) 15 final, which recommends no new targets for renewable energy or the greenhouse gas intensity of fuels used in the transport sector.

All data and information for this assessment has been obtained from literature review, and stakeholder consultation. For the latter, discussions were held with Renault, Volkswagen (VW), Daimler and Bosch to obtain their inputs. Auto-manufacturer inputs on the range of acceptable blends were also a major factor in the selection process.

Section 2.3 below reviews biofuel blend options for petrol engines in the context of future engine technology developments, and selected auto manufacturer inputs. The impacts of higher blends on petrol engines is then assessed in more detail in Section 2.3.3. Section 2.4 presents blend options for diesel engines, followed by a review of their potential impacts (Section 2.4.3). Chapter 2 closes with a summary of the main conclusions for ethanol and biodiesel blends (Section 2.5).

2.3 Biofuel blend options for petrol engines

2.3.1 Future directions in petrol engine technology in the EU

In general, auto-manufacturers design cars based on their expectations of available fuels, but future fuels can be tailored to expected changes in engine technology to enhance the future performance of vehicles. This Section examines how petrol technology will change through 2030, and estimates the properties of future fuels that could enhance the performance of future engine technology. In the EU petrol engines are used almost exclusively in personal use light duty vehicles and all commercial vehicles use diesel engines. ICF's report to the American Petroleum Institute (ICF, 2013) is the basis for the following discussion.

A wide range of technological options are either under consideration or are being introduced for the next generation of spark ignition engines. Examination of data on product plans shows that manufacturers are proceeding on two divergent pathways. The first involves turbo-charging and downsizing the engine. A more novel variant includes lean burn with turbo-charging and downsizing the engine; this technology may have only limited market penetration to 2020 but could be dominant by 2030. The second path involves using high compression ratios and preventing knock by novel methods such as the use of a Miller or Atkinson cycle with late intake valve closing. Both paths also can involve using a common set of new technology such as variable valve timing (VVT), valve actuation and cooled exhaust gas recirculation (EGR). The advantages and disadvantages of the pathways are examined below.

2.3.1.1 Direct Injection Turbocharged Engines

Stoichiometric direct injection spark ignition (DISI) engines are now being used by most auto-manufacturers. The technology trend is moving toward higher injection pressures and more sophisticated injection strategies such as pulsed-injection. There are many applications of direct injection (DI) with naturally aspirated engines but many manufacturers have also introduced DISI in combination with turbo-charging and variable valve timing as a package.. Suppliers such as Bosch have claimed that with higher boost pressures, the Turbo-DI package will achieve up to 25% increase in fuel economy if the engine is resized for constant performance. In combination with additional technology packages and extreme downsizing, Mahle (2011) indicated that up to 35% improvement in fuel economy is achievable. Further synergies can be found with other technologies including electrification. One measure of the boost pressure is the mean operating cylinder pressure at wide open throttle, which is referred to as brake mean effective pressure or BMEP[63]. As a reference, a non-turbocharged engine has a typical BMEP of about 12 bar.

Many first generation Turbo DISI engines in the EU market are representative of 18 bar BMEP-level technology. VW/Audi was one of the first manufacturers to sell these engines (which they refer to as TSFI) in the mass market on a wide variety of vehicle platforms, but all European manufacturers offer this technology as of 2015. The trend continues towards higher boost pressures and most engines today with this technology have maximum brake mean effective pressure (BMEP) levels of 19.5 to 20 bar. As of 2015, most mass market vehicles have not yet moved to boost levels of 24 bar and higher, but it is expected that this trend towards higher boost and smaller engines will continue. European auto-makers like Audi, Porsche and BMW already offer high performance models with engines having a BMEP up to 24 bar and maintain the compression ratio (CR) at 10, but some require premium fuel (98+ RON). It is anticipated that by 2025, most mass market cars will employ boost levels of 22 to 24 bar with regular 95 RON petrol while automakers of high priced vehicles (Mercedes, BMW, Audi, Porsche) will increase boost to 28 to 30 bar with premium petrol (at 98 to 100 RON).

2.3.1.2 Lean-Burn DISI Engines

The 1st generation lean burn direct injection engines marketed in Europe in the 2000 time frame achieved fuel-air mixture stratification through a special combustion chamber design which is referred to as “wall-guided” mixture formation. The technology did not achieve wide success since combustion was difficult to control at different engine speeds. The newer technology variants use a centrally placed injector to achieve a “spray guided” mixture stratification. This process uses a small spacing between the injector and the spark plug electrode and the air-fuel mixture formation near the spark plug takes place almost independent of gas flow and piston movement. Use of lean burn systems can typically improve fuel economy by 12 to 15 percent over the New European Driving Cycle (NEDC).

The spray guided systems, however, use high pressure piezo-injectors to achieve the desired level of mixture control, with attendant high injection system cost. Automakers makers such as BMW and Mercedes have been introducing the spray guided DISI lean burn engines in Europe since 2014 with up to 20% fuel consumption improvement and there is renewed optimism that such technology can be widely used. Mercedes uses a sophisticated conical spray piezo-fuel injector and fuel injection is done in multiple pulses (Breitbach, et al., 2013). At light throttle (up to 4 bar BMEP), the engine runs very lean at an overall lambda[64] of over 3. There is a transition region from 4 bar BMEP to 7 bar at medium throttle levels where the combustion mode is termed “Homogeneous- Stratified” (HOS) where most of the mixture is homogeneous and the air-fuel mixture (lambda) is about 2 but the region near the spark plug is near stoichiometric. Beyond 7 bar BMEP or close to full throttle, the engine operates like a conventional engine with the air-fuel ratio at stoichiometric (lambda of one).

More recently, Mercedes has extended this concept to a 2L turbo-charged engine with a maximum BMEP of 23 bar. The turbocharged lean burn engine also showed similar benefits relative to a turbocharged stoichiometric engine. This suggests that combining the concepts of DI/ Turbo with stratified lean-burn can provide a total fuel consumption benefit of 25 percent from the engine alone, with 10% to 12% from turbo-charging and 12% to 15% from lean operation. However, the piezo fuel injector and the emission control system are currently expensive, and lean burn technology will likely be restricted to expensive cars to 2020. During the 2020 to 2030 time frame, there is considerable optimism that the technology can be transferred to mass market cars.

[63] BMEP is the engine maximum torque divided by the displacement and is a measure of the specific engine output

[64] Lambda is a measure of the air-to-fuel ratio and is equal to one when all of the available oxygen in the air results in complete combustion of the fuel. Lambda values higher than one indicate excess air, or lean combustion.

2.3.1.3 High Compression Ratio Engines

Theoretically, an engine's efficiency will increase with increased Compression Ratio (CR). Modern petrol engines generally operate in a CR range from 10:1 to 11:1 but the trend is to develop engines with higher CR, particularly with DI available to cool the charge mixture. Mazda has introduced the Skyactiv-G engine with CR of 14:1 and claims up to 15% increase in fuel efficiency and torque (Goto, et al., 2011). The technology was enabled by using a redesigned exhaust manifold that minimizes hot residual gases, multi-hole DI injectors, injection pressure of 2,900psi and a re-worked control system. Mazda has claimed that the brake specific fuel consumption (BSFC) is close to that of a current diesel engine, and in a vehicle application, Mazda has demonstrated fuel consumption reduction of 15% based on certification data. However it appears that only 5 to 6 percent of the improvement is attributed to the CR increase since the engine uses a Miller cycle at part load to reduce pumping loss, while reduced friction loss and idle speed reduction, as well as reduced accessory loss (in the oil pump and water pump), contribute to the 15% total.

In 2013, Honda introduced a 13 CR 2.0L 4 cylinder engine with port fuel injection (PFI) and cooled exhaust gas recirculation (EGR), as well as Atkinson cycle operation at part load by using a 2 stage variable valve lift and timing (VVLT) system. The cooled EGR suppresses knock and enables operation at near optimal spark timing without knock even with the very high compression ratio. Honda has published an SAE paper showing a BSFC of 214 g/kW-hr which is one of the lowest levels ever achieved on a spark ignition engine (Yonekawa, et al., 2013). In addition, the cooled EGR and VVLT system reduces pumping loss at part load so that the engine has very good fuel consumption over a wide range of torque and speed. Although the engine is currently used only in the Accord hybrid, the engine power rating is only a little lower than that of other 2L PFI engines, at 140 HP. In comparison, Mazda's 2L DI engine is rated at 154 HP. It is possible that the Accord hybrid engine strategy could be adapted to conventional drivetrains with some modifications in the near future, by 2020.

Other Japanese manufacturers are also working on similar concepts such as high CR engines with an Atkinson cycle instead of a Miller cycle. The Toyota Prius and other hybrid vehicle models use the Atkinson cycle with a CR of about 12, but the power loss has restricted the use of these engines to hybrid models exclusively. Nissan has introduced a 1.2L 3 cylinder engine with 13 CR, and the engine is unique in that it also employs supercharging. In order to enable use of high CR, many of the same technologies used by Mazda such as a high tumble intake port, shallow cavity piston, a multi-hole GDI injector, and the Miller cycle are also used in the Nissan engine (Kishi and Satou, 2012). The engine also employs many new friction reduction technologies. The net fuel economy improvement is substantial, with the Nissan Micra equipped with this engine is certified at 95 g/km CO_2 on the NEDC cycle, which is equal to that of the best diesel engine powered car of similar size and performance.

ICF contacts with Japanese automobile industry staff suggest that high CR technology is the preferred direction for the next generation of engines emerging from Japan. ICF expects high CR engines with Miller or Atkinson cycles to be offered by Honda, Toyota and Nissan later this decade. The next step with such engines is to use "homogeneous charge compression ignition" (HCCI) combustion which is a form of lean burn that allows ultra-lean combustion at light loads. The technology becomes more feasible with high CR and advanced valve control, and Mazda plans to introduce this technology by 2018/19. Other manufacturers are more cautious but optimistic about HCCI emerging in the 2020 time frame. HCCI has the potential to improve engine efficiency additionally by as much as 10%.

For all future technologies, the use of ethanol blends as opposed to hydrocarbon petrol and E5 is not expected to cause any unique problems as the combustion characteristics of ethanol are quite similar to those of hydrocarbon petrol. One aspect of ethanol that will be useful for future technologies is its higher Research Octane Number, while a second aspect that can be useful is its high latent heat of vaporization[65].

2.3.2 Manufacturer Inputs on Biofuel Blend Options for Petrol

As noted discussions were held with three manufacturers and one major fuel system supplier, and their opinions on the bio-fuel market are summarized. Our discussions suggest that they have lost interest in first generation bi-fuels. All of the manufacturers stated that NGO support and public opinion has turned against such fuels due to the food-for-fuel and land use issues, as well as costs of bio-fuels. More recently, with the financial crisis, subsidies for bio-fuels are being reduced in most EU countries. Renault stated that investments to prepare for fuels like E85 in France and Sweden have not paid off and public interest in even E10 is poor. None of the auto-makers expect commercial scale second generation ethanol plants to be operational before 2020, and are not optimistic such fuels can be cost competitive with conventional fuel in the next 10 to 15 years. Hence, there is a great deal of reluctance to invest in vehicle design changes for any new bio-fuels program. Our discussion focused on what can be done technically to increase bio-fuel use to meet the 10% energy requirement for 2020 to 2030.

The selected auto-manufacturers stated that they saw considerable potential for expansion of ethanol use in the EU even with no changes to the basic market structure of having E5 as the protection fuel and E10 as an option. This is because many southern European countries are not using any ethanol blends and hence, using E5 in these countries will boost EU wide ethanol volumes considerably. In addition, E10 availability is currently restricted to 3 countries in the EU, and more widespread availability in all EU countries will ensure greater ethanol use.

These manufacturers are also relatively open to the prospects of using E10 as the protection fuel starting in 2020. Most vehicles manufactured after 2003 are E10 tolerant, but there are a number of models (many of which are identified in consumer alerts issued in Finland[66] and Germany[67]) that are not, with one such example being some early direct injection systems introduced in the 1998 to 2001 time frame that use aluminium high pressure pumps that can be damaged by E10. By 2020, manufacturers expect that only a portion of the fleet (>2%) may experience problems with ethanol and hence provisions for the upgrading of these vehicle's fuel systems must be made if E10 becomes the protection fuel in the EU. However, inputs from all EU based vehicle manufacturers are required before this option can be implemented. E10 can be expanded to 100% of the market in the 2020+ time frame.

Manufacturers suggest that E15 will not be a possible choice in 2020 as the base (protection) fuel since a large fraction (>10%) of the fleet could have problems with this blend in 2020. Manufacturers noted that as of 2011, a majority of the cars made in the EU are E20 tolerant (in the sense that there will be no efficiency advantage in using E20 in these vehicles but they will not have safety or performance issues with this fuel). These issues are not related to a different type of E20 fuel with higher octane, which is discussed below.

A third option recommended by some of the manufacturers is to enhance the value of ethanol to customers by using its higher RON value and creating a new high octane fuel that can be used only in purpose designed cars for the future. Mercedes and Ford, in particular, have suggested that 15% to 20% of ethanol be "splash blended" or specially blended with current E5 95 RON fuel that is the base fuel available in much of the EU today. Other manufacturers are more cautious but supportive of the trend towards a higher octane fuel. (Splash blending is a term used to denote a simple mixing of ethanol with current base petrol blend stock with no adjustments to the properties of the blend stock but some prefer the use of the term "tailored blend"). Splash blending will result in an E20/25 fuel with a RON of about 100 to 102 when starting from a 92 RON blend-stock used for E5, or 102 to 104 if

[65] A high latent heat of vaporisation means that ethanol may contribute to lower combustion temperatures and, therefore, potentially reduce NOx emissions.

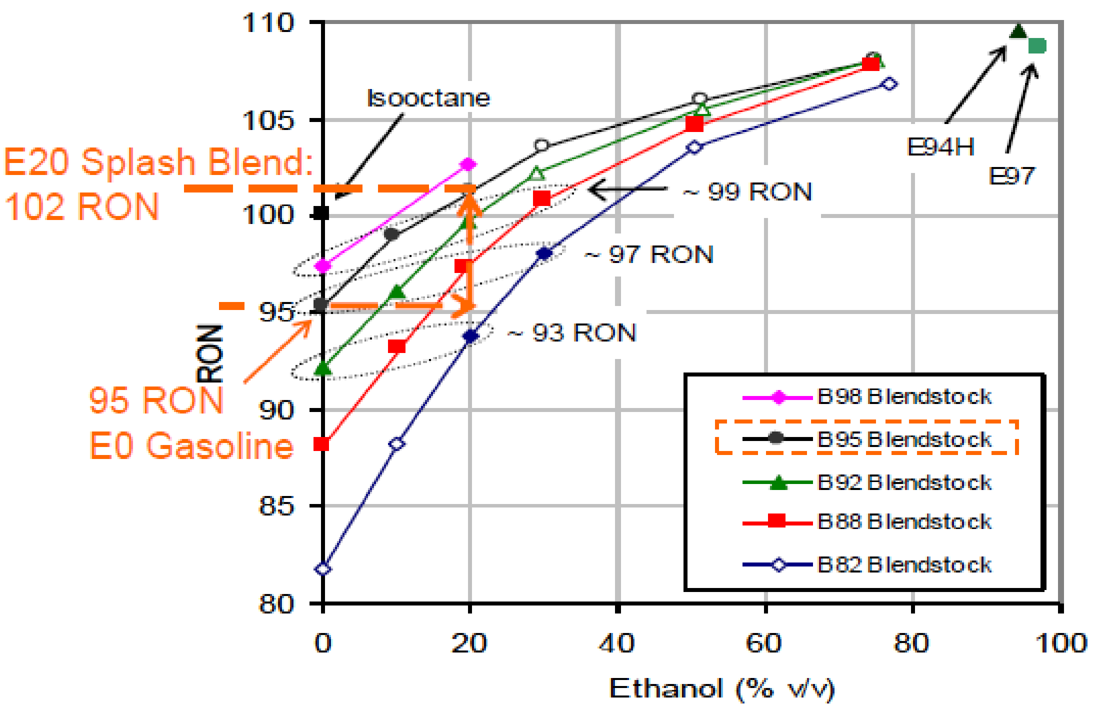
[66]http://www.e10bensiini.fi/e10_compatible_motors (Finland)

[67]http://www.dat.de/e10liste/e10vertraeglichkeit.pdf (Germany)

splash blended with E0 95 RON fuel (Sieler and Kramer, 2014) as shown in Figure 2.1. The vapour pressure of this E20/25 blend will be lower than that of E5 so that any waivers for blend volatility do not need to be increased but will need to be made applicable to E20/25.

The strategy of using E20 as a premium fuel is to allow market introduction of this fuel without a complete overhaul of the fleet and the refuelling infrastructure. The ultimate goal is to make E20 a mainstream fuel of choice for all consumers, but the slow turnover of the fleet implies that a transition will occur over the 2020 to 2030 period. Introducing this fuel as a premium high octane gasoline blend has been suggested by some auto-manufacturers.

Figure 2.1 Blend Octane Number as a Function of Base Petrol Blend-stock RON and Ethanol Content



Source: Sieler and Kramer, 2014

The increased RON of the E20 blend can be used to increase the CR of the engine or the boost level of the turbo (or some combination of the two) which in turn can enhance fuel efficiency. However, such engines must be purpose-designed for 100 RON fuel and cannot typically use 95 RON fuel except as a “limp home” emergency fuel. This option can potentially grow ethanol sales in the 2020 to 2030 time frame.

2.3.3 Impact of using higher ethanol blends

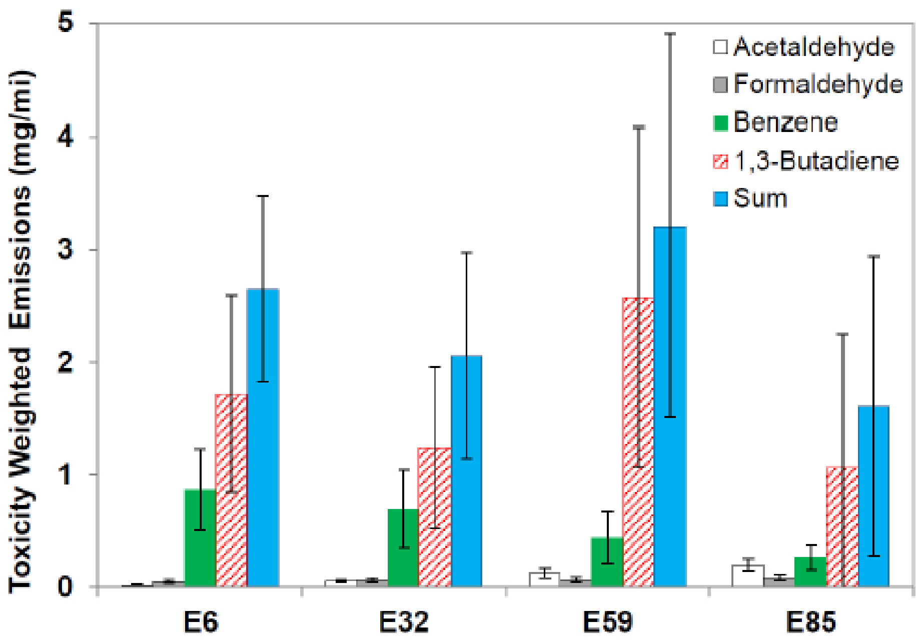
2.3.3.1 Exhaust Emissions

Ethanol petrol blends ranging from E5 to E85 have been used in the EU for decades and the emissions impact of higher ethanol blends (relative to the current E5) are well understood, as are the technical challenges to the fuel system and engine. Broadly speaking, there is a consensus that ethanol results in cleaner combustion than petrol because it is a simpler molecule that yields lower levels of complex combustion by-products such as 1,3- butadiene (a carcinogen). The blending of ethanol also results in the displacements of toxic compounds in petrol such as benzene.

In a summary study of the effects of ethanol blends, Ford researchers provide an overview of all emission effects (Stein, Anderson and Wallington, 2013). Increased blend levels of ethanol are typically accompanied by reduced engine-out levels of the regulated pollutants such as hydrocarbons and carbon monoxide as well as toxic emissions of compounds such as benzene and 1,3- butadiene. However, as detailed below, there are increases in aldehyde emissions, notably those of formaldehyde and acetaldehyde. When all of the toxic emissions are weighted by toxicity factors utilized by the California Air Resources Board, the sum of toxics is far lower for E85 relative to E0.

The Ford paper states that results from studies examining E5 to E32 blends have not been as consistent in reporting reduced toxics with increased ethanol content, which they attribute to absolute emissions levels being so low that the measurement errors can influence the results.

Figure 2.2 Results of CRC study on Toxic Emissions from Flex-Fuel Vehicles



Source: CRC, 2011

One such study was conducted by the Coordinating Research Council (CRC) and published in 2011, where Flex Fuel Vehicles (FFV) were tested on ethanol petrol blends ranging from E6 to E85, using the US Federal Test Procedure. Flex fuel vehicles automatically change spark timing and injection timing as a function of ethanol content and their emissions are likely to be similar to an optimized engine from an engineering perspective since the only difference is associated with the Compression ratio (CR). CR changes and turbo boost changes in optimized engines have modest emission effects on light load cycles like the NEDC and WLTC, so that future high CR engines are not likely to display different emission response to ethanol blends from those of current flex fuel vehicles.(Thomas, West and Huff, 2015) The results shows toxicity weighted emissions generally decreasing with increased ethanol content, except for the emissions of the E59 blend being higher than that for the E32 blend (Figure 2.2), but the size of the error bars show that this anomalous result can be explained by measurement uncertainty.

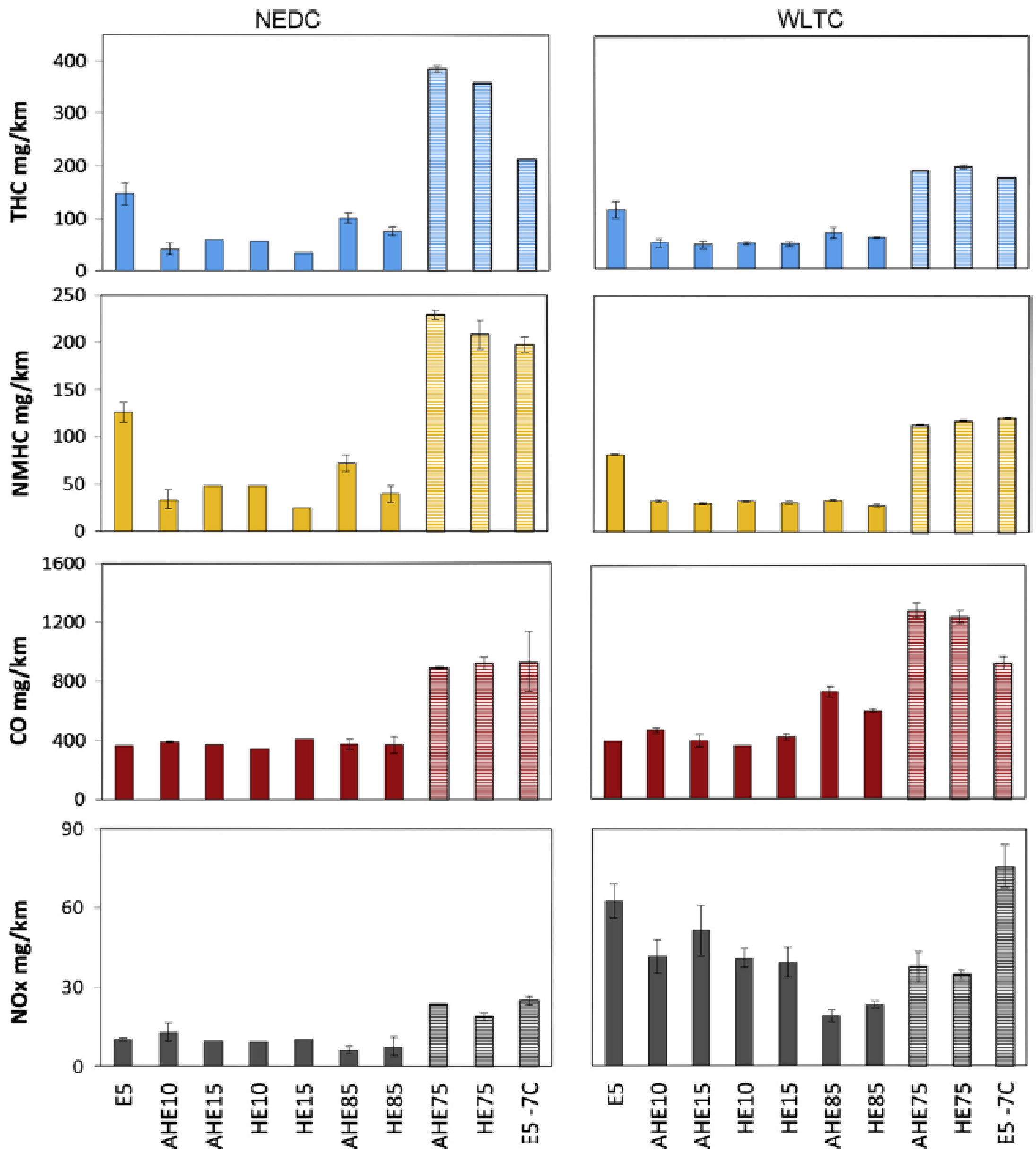
Emissions of the regulated pollutants of hydrocarbons, carbon monoxide and oxides of nitrogen do not show any significant trends with increased ethanol content because catalysts remove 99+% of the emissions from the engine and tailpipe levels are very low so that changes in engine-out emissions are not reflected at the tailpipe. The CRC study referenced above found no significant trends for any of these emissions with increased ethanol content but some studies have noted decreases in non-methane hydrocarbons (NMHC) with increased ethanol content.

Flex-fuel vehicles of recent vintages have also been tested at the European Commission's Joint Research Center at Ispra (Dardiotis, et al., 2015). A Turbo-charged Direct Injection Euro 5 compliant vehicle and a Port Fuel Injected Euro 4 compliant vehicle were tested with E5 as the reference fuel and E85 as a summer fuel along with E75 as a winter fuel. Tests were conducted on the NEDC test cycle at 22° C and -7° C. The results for the two vehicles were not directionally similar, with the Euro 5 vehicle showing reductions in all regulated emissions with increased ethanol content blends but the Euro 4 vehicle showing increased HC emissions and NO_x emissions with increased ethanol content blends.

The JRC also conducted additional tests on the Euro 5 vehicle to measure toxic emissions and also to measure emissions on the harmonized World Light-duty Test Cycle (WLTC) (Suarez-Bertoa, et al., 2015, p.173-182). It should be noted that virtually all flex-fuel vehicles have been withdrawn from the EU market and the JRC stated that this Euro 5 vehicle was the only flex-fuel vehicle left in the EU market in 2014. Fuels included four blends of E10, E15, E75 and E85 with anhydrous ethanol and 4 with hydrous ethanol (the water content of the hydrous ethanol blends were in the range of 1% by weight for the E10 blend, which was almost ten times higher than the content with anhydrous ethanol). Figure 3-4 provides the results across all tests and fuels. Note that the hatched bars are results for tests conducted at -7 C and should be compared to the right most bar of the E5 reference fuel tested at -7 C. It can be seen that there are no strong tendencies for emissions increases in the E5 to E15 range at 20° C but there is some increase in non-methane hydrocarbons (NMHC) and total hydrocarbon (THC) for the E75 and E85 blends when tests are conducted at -7° C using the NEDC test.

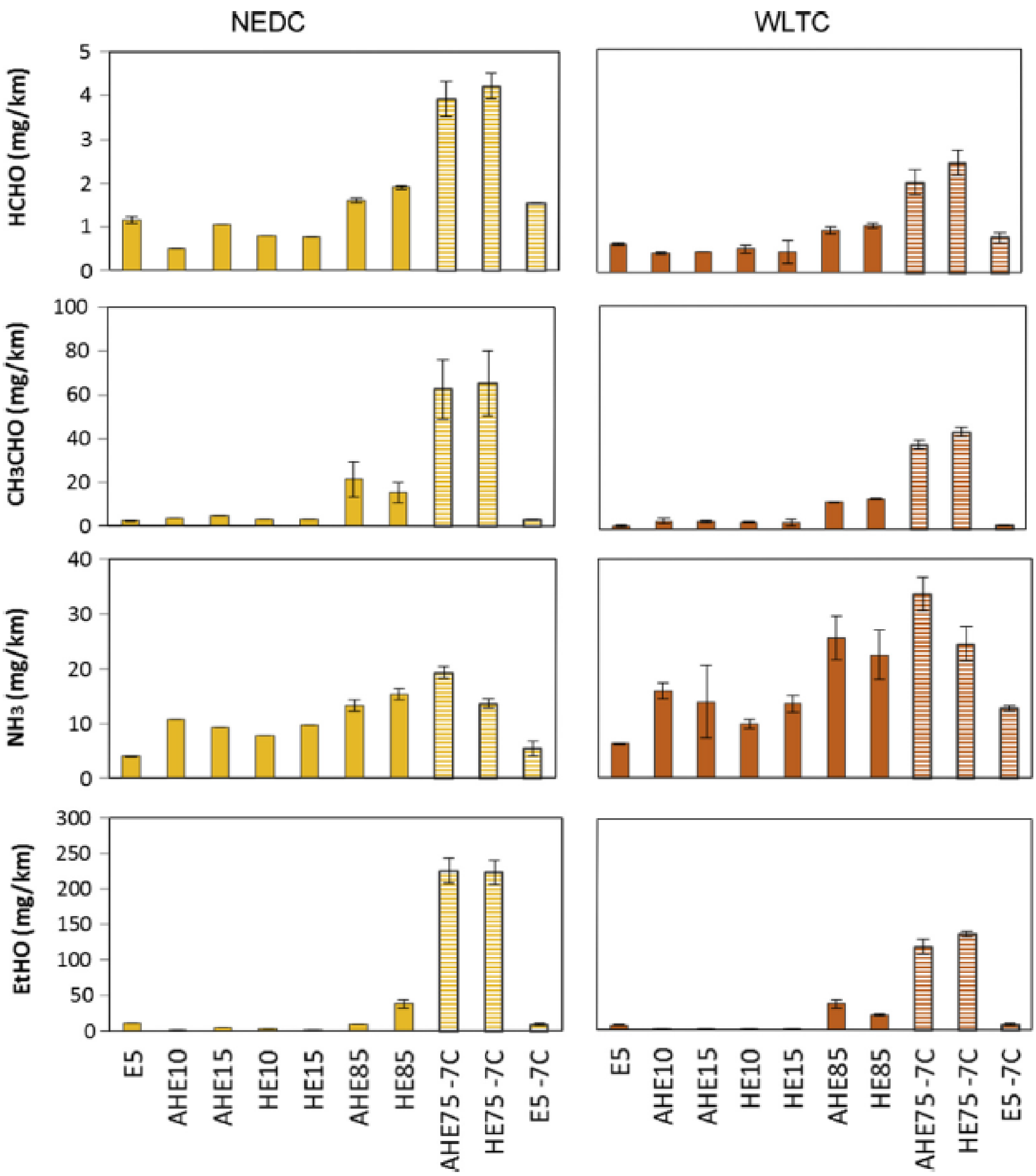
The study also reported a modest increase in aldehyde emissions with increased ethanol content for E75 and E85 blends but no statistically significant change in emissions was noted in the E5 to E15 range of blends. Formaldehyde emissions were between zero and 1mg/km for the E5 to E15 blends (near the detection limit) but about 1 mg/km for the E85 blend, while acetaldehyde emissions were 3mg/km for the E5 to E15 blends compared 11 to 12 mg/km for E85. The paper did not report on benzene and 1, 3- butadiene emissions, but provided information on ammonia emissions and ethanol emissions. This data is shown in Figure 2.3 which employs the same format as Figure 2.4.

Figure 2.3 JRC Study Results on Tests of Euro 5 Compliant Vehicle with Different Ethanol-Petrol Blends (Hatched Bars are Tests Conducted at -7° C)



Source: Suarez-Bertoa, et al., 2015, p.173-182

Figure 2.4 JRC Study Results for Emissions of Toxics on Tests of Euro 5 Compliant Vehicle with Different Ethanol-Petrol Blends (Hatched Bars are Tests Conducted at -7° C)

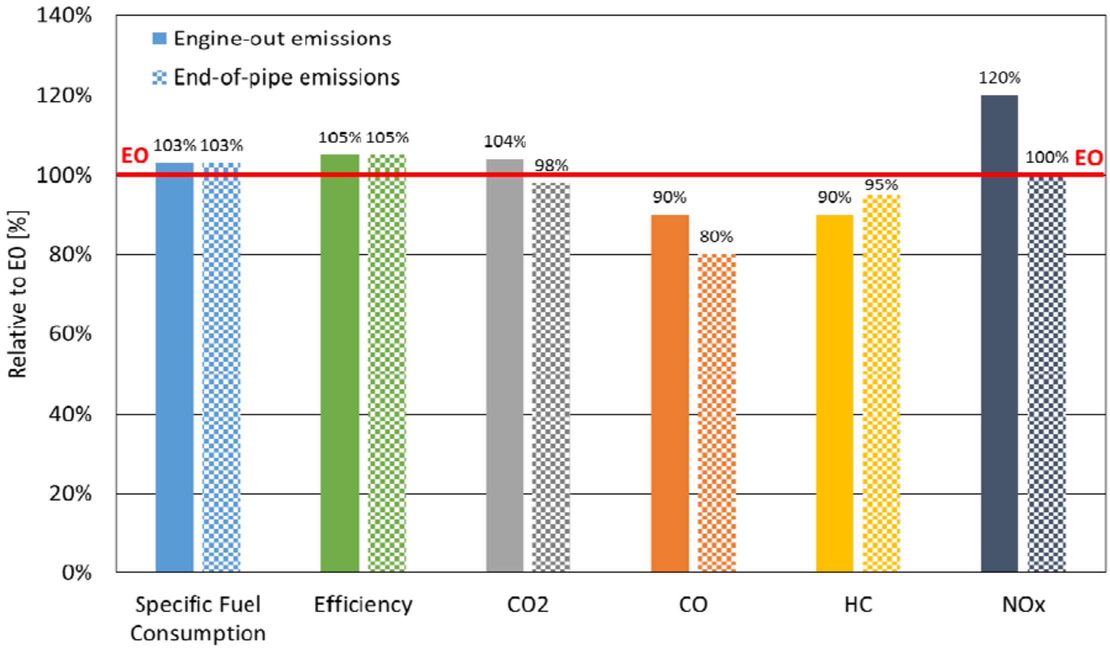


Source: Suarez-Bertoa, et al., 2015, p.173-182

Numerous studies have examined Particulate Matter (PM) emissions from direct injection engines and concluded that PM emissions decline with increasing ethanol content in petrol blends. In a 2010 study conducted by Oak Ridge National Laboratory (Storey, et al., 2012), a vehicle equipped with a 2L turbocharged, direct injection engine was tested on a variety of transient and steady state cycles including the US Federal Test Procedure (FTP), the high load USO6 cycle and full load accelerations. As the fuel ethanol content was increased from E0 to E20, PM emissions decreased by 30% on the FTP cycle and 42% on the USO6 cycle, suggesting that the benefits increase with ethanol content and average load factor. It should be noted that absolute levels of PM emissions were quite low at 2.3 mg/km with E0. Ford's own tests with a 3.5L V6 turbocharged DI engine showed PM mass reductions of about 20% for a E17 fuel relative to an E0 fuel. Since petrol engine PM was uncontrolled at that time, engine-to-engine variability in response is to be expected depending on the contribution of lubricating oil to total PM emissions, but the emission decreases are directionally consistent.

In 2014, CEN commissioned a study of E20 to E25 blends when used with non-optimized vehicles that are tolerant of these blends. The study consisted of a literature review of emissions data from the EU on the emissions effects of E20 and E25 blends, as well as testing of two Euro 5 compliant vehicles with E20 blends. The literature review was conducted by the Vienna University of Technology (Geringer, et al., 2014) and the study concluded that all tailpipe emissions were either reduced or stayed constant relative to pure hydrocarbon petrol (E0). The summary of the study is shown in Figure 2.5 below. This study examines the CEN study results to gauge its consistency with other reported results, as some have suggested the results are controversial.

Figure 2.5 EU meta-study results of engine-out and tailpipe emissions of E20/25 vs. E0

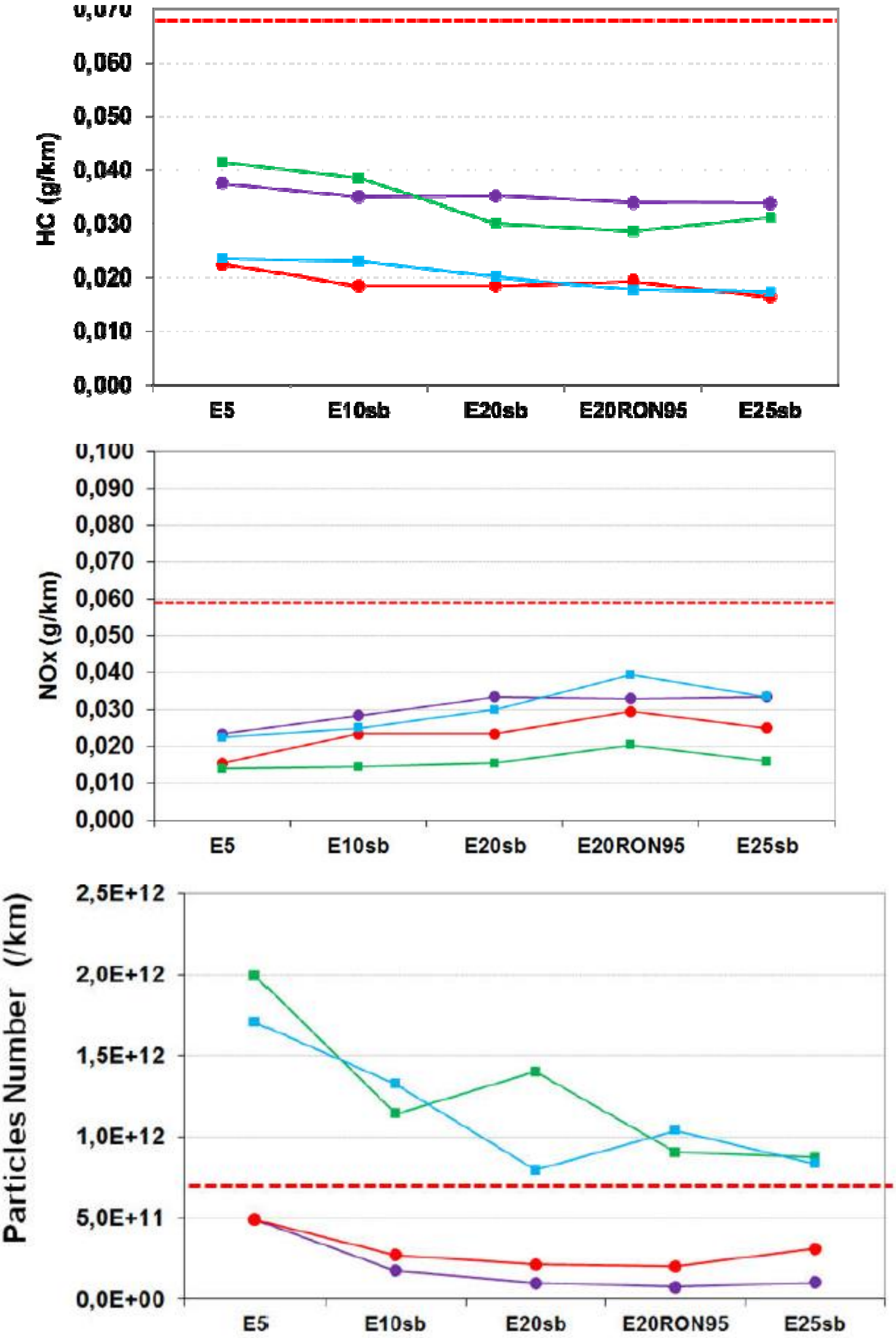


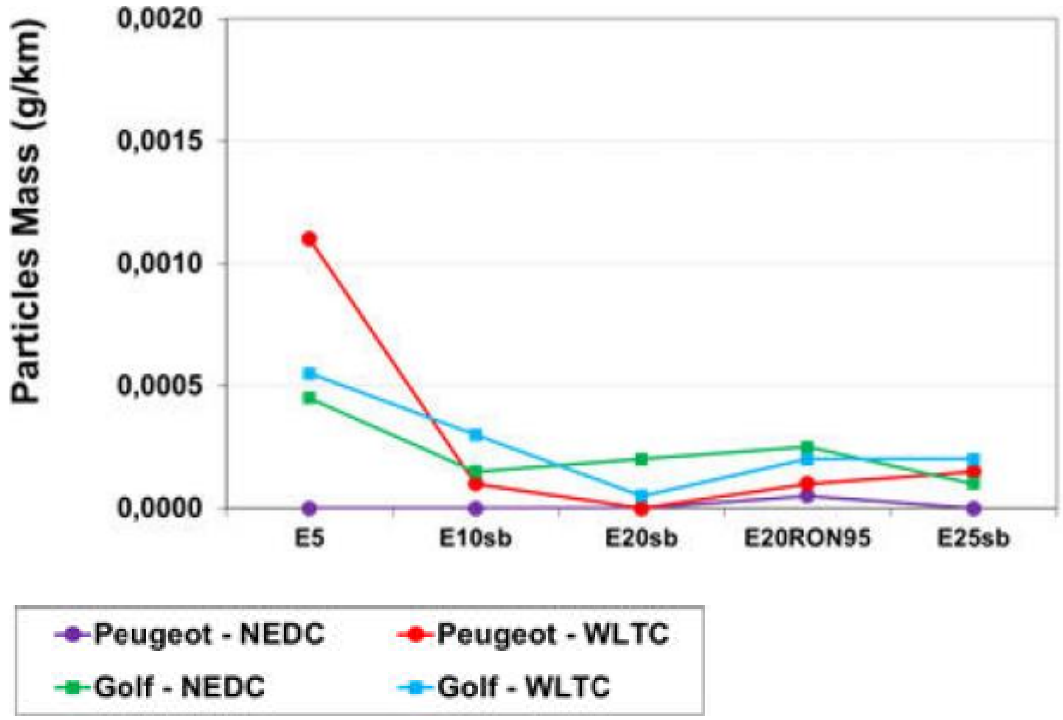
Source: Geringer, et al., 2014

The literature survey concluded that better results could be obtained if the engines were optimized for the higher octane number of the E20/25 fuels, and that the authors expected PM emissions to be reduced but the data was inadequate in the available literature. However, the zero change in NOx is not reported by other studies which show small absolute increases

The testing of two vehicles in the parallel study was conducted by the French Organization, IFP Energies Nouvelles (Fortunato, 2014). Tests were conducted on a 1.2L naturally aspirated, port fuel injected Peugeot 208 and a 1.4L turbocharged direct injected VW Golf. Fuels tested included commercial E5 and E10 blends, E20 and E25 splash blends and an E20 match blend where the base petrol was modified so the E20 also had a RON of about 95, similar to the E5 and E10 blends. Tests were conducted using the NEDC and WLTP test procedures. The results for HC, NO_x, particulate mass and particulate number are shown in Figure 2.6.

Figure 2.6 Emission test results from IFP testing (fuels designated 'sb' are splash blended)





Source: Fortunato, 2014

As can be seen from the figure, HC and particulate mass and number are reduced with higher ethanol content while there appears to be a slight upward trend in NOx emissions with increased ethanol content, but all NO_x emission values are well below Euro 5/6 standards. Toxics emissions were not investigated, except for benzene emissions which declined for all fuels relative to E5. CO_2 emissions were found to be proportional to the fuel hydrogen to carbon ratio while volumetric fuel consumption increased with increased ethanol content.

All of the CEN and JRC based test results are broadly consistent with the summary report from Ford and it can be concluded that increases in ethanol content of petrol ethanol blends in the E5 to E20 range will have either minor or favourable impacts on regulated and total toxic emissions from vehicles, although acetaldehyde emissions will increase significantly by around 10mg/km.

Vehicle test results

To assess and corroborate the literature review findings, a vehicle testing programme was implemented. Emission tests were conducted on a Euro VI compliant petrol vehicle, 1.2L Peugeot 308sw, to the World Harmonized Light Vehicles Test Cycle (WLTC). The vehicle was not optimised for the two fuels examined, E10 and E20.[68] Table 2.1 presents full details of the testing programme, including the approach, assumptions, and results.

Table 2.1 presents the average recorded figures for E10 and E20 test fuels. Each figure is an average of three test results on that fuel.

Table 2.1 Emission summary averages over WLTC cycles – Petrol

Test Fuel	NMHC (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)
E10	18	20	287	49	142.4	2.3	1.33E+12

[68] One of the key approaches to addressing air quality issues is to optimise vehicle engine settings according to the fuel (diesel or petrol) being used. Typically, automakers utilise a single set point for engine management, regardless of fuel composition. Consequently, fuel blends that are different to the optimised setting, could lead to poorer fuel utilisation and higher pollutant emissions.

Test Fuel	NMHC (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)
E20	17	20	458	32	139.9	1.3	1.28E+12
Diff (%)	-4%	0%	+60%	-33%	-2%	-44%	-4%

Overall, both E10 and E20 meet exhaust emission limits defined by the Euro 6 standard for passenger cars.[69] Specifically, total hydrocarbon (THC), particulate mass (PM) and particulate number (PM) are 80% lower than Euro 6 emissions limits, while non-methane hydrocarbon (NMHC) is over 70% lower. Carbon monoxide (CO) and Nitrogen oxides (NOx) vary between 50-70% and 18-46%, respectively, below Euro 6 emission limits. Nonetheless, the particulate emissions from this vehicle would struggle to meet the Euro 6 particulate number limit of 6,0 $x10^{11}$ that will be introduced in 2017. For CO_2, Regulation (EC) No 443/2009,[70] requires that only the fleet average is regulated. As such, all new cars in 2015 should not emit more than an average of 130 grams of CO_2 per kilometre (g CO_2/km). This target is set according to the mass of the vehicle, using a limit value curve, which means that heavier cars are allowed higher emissions than lighter cars. Consequently, although, it is not appropriate to compare the CO_2 test results to this average, for reference CO_2 emissions from both E10 and E20 were between 8 and 10% higher than the 130 g CO_2/km target.

The results indicate no change in the THC emissions between E10 and E20, and a slight decrease of 4% and 2% in NMHC and CO_2 emissions, respectively. PM emissions were between 1 and 2 mg/km; consequently, deviations in emissions between E10 and E20 are within measurement sensitivities.

Although the repeatability of emissions results was very good throughout the programme, as evidenced by low Coefficients of Variance (CoV) in fuel consumption over the WLTC cycles, in the case of NOx and CO, higher CoV were noted. For NOx, CoV figures of 45.6 and 39.3 were reported for E10 and E20, respectively. Although high, this was in part due to the low overall values of NOx produced (i.e., 49 mg/km (E10) and 32 mg/km (E20)), since a small change in mass will greatly affect the CoV values. Furthermore, on review of each tests' modal data, it was deduced that a large amount of NOx was produced during one acceleration period during the test, where the driver may have been overly aggressive. However, no driver violations were recorded with the drive trace being within legislative limits. For CO, the majority of the discrepancy, and reason for high CoV, was observed to be in phase 1 of the test Annex 5. Again, no other significant deviations in vehicle or driver traces were observed during the test period.

2.3.3.2 Fuel Consumption and Energy Efficiency

Ethanol has only two-thirds the energy per unit volume (nominal) of pure hydrocarbon petrol and an E5 blend will have about 1.7% lower energy content while an E10 blend while have about 3.4% lower energy content per unit volume than E0. E5 and E10 blends sold in the EU today uses a different base petrol blend-stock relative to E0 95 RON petrol so that the blend octane number remains at 95. There may be small differences in the energy content of the blend-stock relative to E0 95 RON fuel so the volumetric energy content of E10 maybe 3 to 4 % lower, while that of E5 may be 1.5% to 2 % lower.

When used in current petrol engines that tolerate E0 to E20 blends, the calibration of the engine does not change with the fuel type, although it is possible that higher latent heat of vaporization results in a slightly cooler charge in the engine. The engine may experience less heat transfer loss, and spark retard initiated by a knock limiter could be affected during normal driving. However, studies conducted by the US Department of Energy and the US EPA over the last 20 years (for example see website fueleconomy.gov) have concluded that energy efficiency of the engine remains near constant and the volumetric fuel consumption

[69] Regulation (EC) No 715/2007

[70] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009R0443-20130508

increases by the same amount as the decrease in energy density, so that efficiency benefits are lost in the noise. Studies on Flex Fuel Vehicles (FFVs) with higher ethanol blends like E75 and E85 have shown some modest energy efficiency benefits. For example, the testing at JRC (Dardiotis, et al., 2013and Suarez-Bertoa, et al., 2015) found that the fuel consumption increase was somewhat smaller with E85 than expected from the energy content difference with E5, and the paper concluded that the Turbo DI engine showed a 2.6% energy efficiency gain with E85 while the port fuel injected engine showed a 1.5% energy efficiency gain. The IFP test results (Fortunato, 2014) also showed that the VW Golf with the DI engine obtained some benefit with E20/25 blends in engine efficiency, while the port fuel injected Peugeot 208 had no change in efficiency. JRC testing (Suarez-Bertoa, et al., 2015) with E5, E10 and E15 blends showed no trend in CO_2 emissions or energy efficiency improvement, possibly because the effects are small and difficult to detect. Hence, the simple formulation that volumetric consumption varies inversely with the volumetric energy content of the blend is widely accepted as a good approximation for blends up to E25 when used in engines optimized for pure petrol or E5/10.

Vehicle test results

The 1.2L Peugeot 308sw that was used for the vehicle tests is tolerant to the higher ethanol blends; i.e., it can drive on these blends without technical or safety issues. Consequently, since it has not been optimised for the higher blends, it should, technically, receive no fuel efficiency benefit. As presented in Table 2.2, this observation was substantiated by the test results which indicated a decline in fuel consumption by 5% between E10 and E20.

Table 2.2 Fuel consumption averages over WLTC cycles – Petrol

Test Fuel	Fuel Cons (L/100km)
E10	6.25
E20	6.57
Diff (%)	+5%

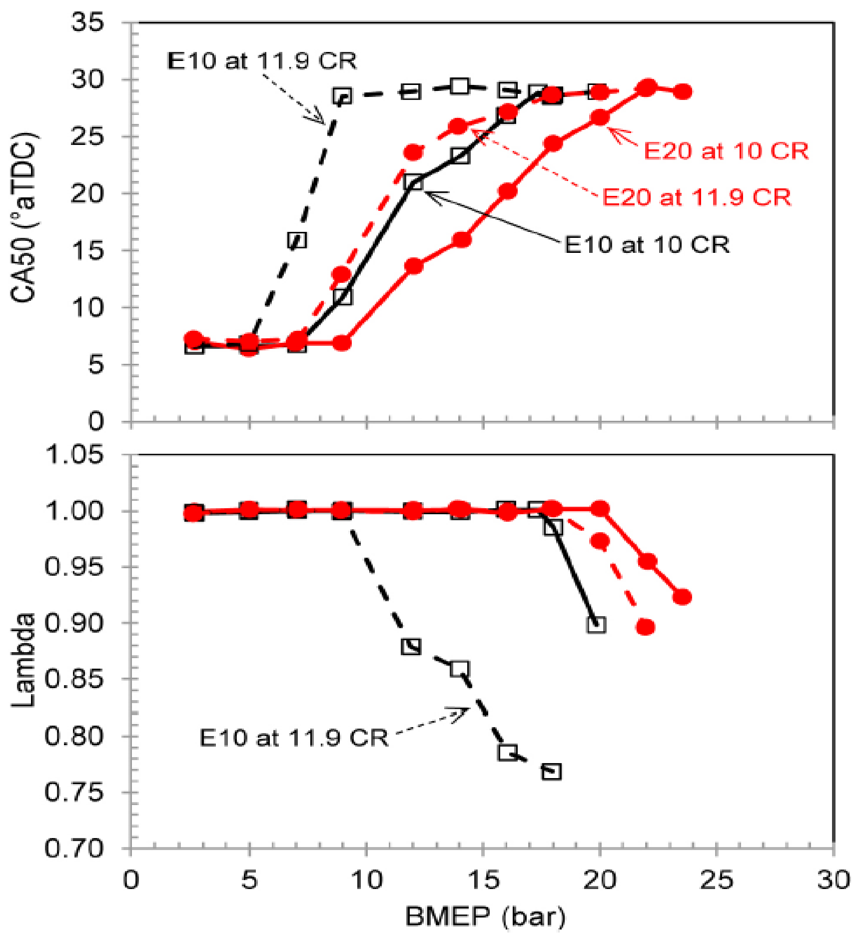
2.3.3.3 *Potential with E20 High Octane Fuel*

The issue of the fuel economy benefit possible from a purpose designed engine optimized to take advantage of E20 with 100 RON has been extensively investigated by Ford in conjunction with researchers from AVL and from the Oak Ridge National Laboratory. More recently, Ford conducted a study (Leone, et al., 2014) on a production 3.5L turbocharged DI engine, and conducted tests both at the stock 10 CR and with special pistons designed for 11.9 CR and 13.0 CR. The stock valve timing was used at all values of CR. This engine was tested with a variety of fuels and the base fuel was an E10 91.8 RON fuel for reference which is similar to a US specification regular petrol. Splash blended E20 and E30 fuels that has RON values of 96.2 and 100.7 as well as E20 and E30 blends matched to the 91 RON of the fuels were tested, along with an E85 rated at ~108 RON.

Tests conducted with the stock 10 CR engine and the 91 RON fuels with 10, 20 and 30 percent ethanol showed very little difference is spark advance requirements across fuels, and 17 bar BMEP was attained on all 3 fuels with only spark retard and no enrichment. With enrichment to an air-fuel ratio λ = 0.75, the E20 fuel allowed operation up to 23 bar, while the E10 fuel was a lower at 22 bar. (The E30 fuel was limited by low speed pre-ignition to 18 bar BMEP at 1500 RPM but had nearly equivalent performance as the E20 fuel at 2000 and 2500 RPM). These results show that the cooling effect has much more limited role in production engines' performance, and the fuel RON is the dominant factor controlling peak output.

Tests conducted with the splash blended fuels illustrate the benefits of the RON increase. While the E10 fuel became knock limited at BMEP over 7 bar, the E20 fuel extended the limit to over 9 bar and the E30 to 14 bar BMEP. Similarly, the E20 96 RON fuel could sustain operation to 22 bar and the E30 to 27 bar BMEP without enrichment. The study found that the combustion phasing for E10 at 10 CR was nearly equivalent to the phasing of the E20 fuel at 11.9 CR as shown in Figure 3-8. Similarly, the combustion phasing for E30 at 11.9 CR was similar to that of E20 at 10 CR. Tests at 13 CR were limited to the E30 101 RON fuel and the E85 fuel, but operation was limited by low speed pre-ignition.

Figure 2.7 Combustion Phasing and Equivalence Ratio for Load Sweeps at 1500 RPM



Source Leone, et al. 2014

The data suggests that a 4 point octane increase allows a 2 point CR increase in turbocharged engines, or alternatively a 4 bar increase in maximum BMEP. The latter effect is confirmed in today's production cars as boosted engines with 10 CR designed for regular petrol (95 RON) operate at 18 to 19 bar BMEP, while those designed for premium fuel (98+ RON) operate at 22 to 23 bar. Hence, the benefit to boost appears to be largely driven by the octane effect and no significant benefit from the high latent heat of vaporization of ethanol is shown in the production engine data.

Ford also explored the vehicle fuel economy benefits using the engine data and simulation modelling. Volumetric fuel economy for the 11.9 CR engine operating on E20-96 RON fuel was about 1% better than the fuel economy of the 10 CR engine operating on E10-91 RON fuel. Since the volumetric energy content for E20 is 3.6% lower than the energy content of E10, the net benefit in energy efficiency is about 4.6%. Based in this data, for E20 relative to a European 95 RON base fuel, the efficiency benefit would be about 3%. However, the energy content of E20 is 5.5% lower than that of E5, so volumetric fuel consumption would increase by 2.5%. (Note that these estimates have been adjusted for the difference between US and EU petrol RON)

An alternative strategy would be to keep the CR at 10 to 10.5 and increase boost so that the maximum BMEP is increased by 5 bar to 24 bar from 19 bar associated with 5 to 6 point increase in RON for E20. The engine can be downsized by 20% so that maximum torque is kept near constant. H-D Systems (2015) conducted a "matched pair" analysis of 23 models from model year 2014 spanning a wide inertia weight range and offering both Turbo and NA engines with the same transmission, using the 2014 official fuel economy data (Fuel Economy Guide, 2014). The analysis showed that the fuel economy (FE) ratio of turbocharged vehicles to naturally aspirated vehicles is very well explained by only the displacement reduction and torque change (which specifies the BMEP change) and the regression equation limited to situations where the torque ratio is between 0.7 and 1.4 is as follows :

FE Ratio = 1.48 – 0.32*Displacement Ratio – 0.16 * Torque Ratio

For a **20% displacement reduction**, the displacement ratio is 0.8, and at constant torque, the equation yields a FE ratio of 1.064 or a 6.4% efficiency benefit, so that this strategy could achieve even better results, and could actually improve volumetric fuel consumption with E20 by 1%. However, the above equation was derived for conventional hydrocarbon based premium fuels (98+ RON), and E20 of the same RON would have lower Motor Octane Number (MON) which may lead to other pre-ignition or hot spot ignition issues. In summary, the use of E20 with a 100+ RON rating offers the prospect for engine efficiency improvement from 3% to 6.4% depending on the path chosen, but this needs to be proven in production.

A key issue to be noted is that the E20 or E25 high octane fuel is intended as a premium fuel option (98+ RON) so that high octane pumps can be gradually converted to E20/E25 as more E20/E25 optimized vehicles are added to the fleet. The E20/E25 optimized vehicles can use available premium fuel (98+ RON) if E20/E25 is not available at a specific station so that transition issues are minimized. The main advantage of this option is that it captures the octane value of ethanol and allows manufacturers additional pathways to comply with the 2021 CO_2 standards for light vehicles

2.3.3.4 *Costs Imposed by E10 and E20/E25 Blend Strategies*

The strategy of using E10 blends as the base or protection fuel in the 2020+ time frame will affect only a fraction of the total fleet, including potentially vehicles manufactured before 1990 and a subset of vehicles manufactured in the 1990 to 2007 time frame. In 2020, the 1995 and earlier model year vehicles will be 25+ years old, and this sub-fleet will consist mostly of antique vehicles. The pre-2007 vehicles will be 13 to 25 years old but as noted, a fraction of the vehicles in this sub-fleet may be negatively affected by E10 blends. Unfortunately, no specific details of which vehicle models would be affected are available from the manufacturers, and the EU will have to request ACEA (the European Vehicle Manufacturers Association) to compile such information from its members. ACEA has provided data on the percent of E10 compatible vehicles in the EU and this is shown in Figure 2.8 below as summarized in a report from CE Delft (CE Delft, 2013), which indicates that 90% of vehicle are compatible with E10 for model years 2000 to 2005 and the fleet is 100% compatible from 2008 onwards.

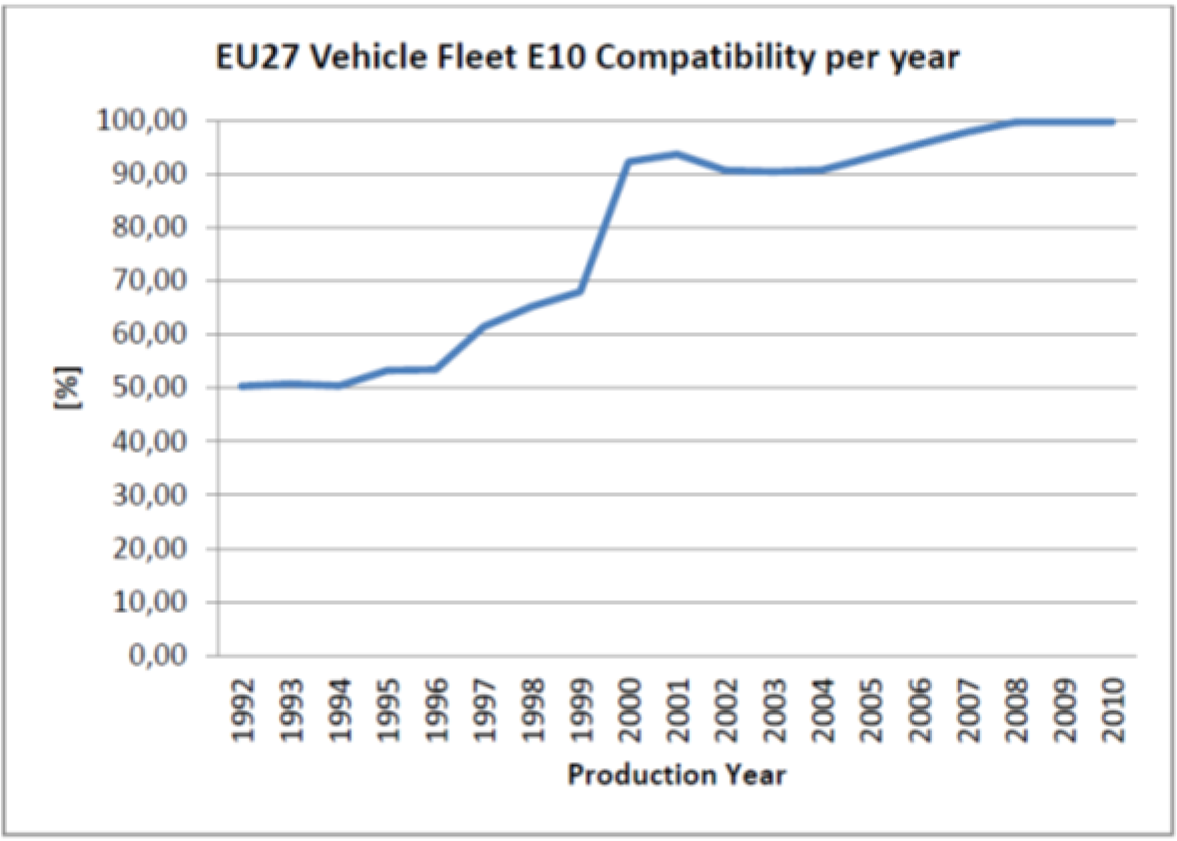
In general, most affected pre-2003 vehicles are expected to need only new fuel system gaskets. The gaskets themselves are not very expensive (~ Euro 20 to 30) but the labour cost of installation could be Euro 100 to 200, depending on the ease of access to injectors and fuel system hoses and seals. In a few cases, some components such as the high pressure injection pump may need modification or replacement and this can be a high cost item (in the range of Euro 400 to 500) for an aftermarket retrofit. These issues have been identified based purely on anecdotal comments made by manufacturers and suppliers during our meetings described in Section 2.3.2, and we have no quantitative data to make an assessment of total EU costs. The selected auto manufacturers who were interviewed during this study also stated that they would have to conduct some research internally to even identify which models would be significantly affected by E10 and E20. On the other hand, we should note that similar issues arose when E10 was introduced in the US in the late 1990s but actual problems encountered in the field were minor and did not cause any major public dissatisfaction. ACEA representatives state that E10 could cause engine fires due to fuel leaks in some cases, but the fraction of vehicles with problems having serious consequences is not known. Bosch has provided a figure of 365,000 vehicles which appear to be the total number of vehicles sold (not the 2020 fleet population) that could have serious problems.

Using the fleet registration distribution likely for 2020 based on 2010 registration distribution data and the ACEA ethanol compatibility data, we computed that 1.3% of the total gasoline fleet would be affected by E10 blends in 2020, although this figure includes vehicles affected in both a minor and major way. Alternately, analysis conducted using outputs of JRC's DIONE 2.0 model (Katsis, P., Ntziachristos, L. and Papageorgiou, T. (2014)) indicate that 6.8% of the 2020 EU passenger vehicle fleet could be non-compatible to E10, and thus potentially impacted. However, the registration fraction of vehicles over 20 years old is sensitive to economic conditions and difficult to estimate with accuracy; thus, the actual number is likely to fall within this range.

The need to retain a protection grade E5 fuel beyond 2020 has been stressed by some fuel system suppliers. The presence of E5 fuel however, will limit the transition to E10 and partially defeat the intent of this scenario. One option is for EU governments to offer a free upgrade of the fuel system to make the vehicles E10 tolerant, or pay for accelerated scrappage of the affected vehicles if the cost of the upgrade of an old vehicle exceeds its value. For example if the vehicle population of the seriously affected vehicles is about 100,000 vehicles (corresponding to the remaining 2000 to 2005 model year vehicles that Bosch suggests has serious issues) in 2020, then payments can be made to those select vehicles to have their owners scrap them.

The cost of a purpose built E20 capable vehicle is also very small if the changes are incorporated into the engine at design stage. Interviews with the selected manufacturers indicate that a lead time of 4 to 5 years will be required to design such engines. In a naturally aspirated engine, increasing the compression ratio from 10.5 to 11.5 or 12 is essentially a zero hardware cost item when the engine is being designed or upgraded for future production. In a turbocharged engine, increasing the turbocharger boost and raising BMEP by 5 bar can incur some costs for a larger intercooler, strengthened piston pins and crankshaft bearings and increased coolant flows, but the costs are only around 40 to 50 Euro for a 4 cylinder engine based on information received from suppliers and auto-manufacturers in analyses for the US Department of Energy (H-D Systems, 2015). Hence, this is a very cost effective strategy for auto-manufacturers to reduce CO_2 emissions by 4 to 7 percent.

Figure 2.8 E10 vehicle compatibility in the EU27 for vehicles produced in the years 1992-2010



2.4 Biofuel blend options for diesel engines

2.4.1 Future directions in diesel engine technology in the EU

Diesel engines are used in all heavy-duty commercial vehicles and most light duty commercial vehicles in the EU. In addition, almost half of all light duty vehicles are diesel powered, which is a level unique to the EU. Unlike the situation for petrol engines, we do not anticipate any fundamental changes in diesel combustion technology to 2030 based on the report to the American Petroleum Institute (ICF-HD Systems, 2013). However, engine specific output has been increasing over the last decade and many light duty engines now provide specific outputs of 80 kW/ litre (or average 100 hp per litre of displacement), with operating BMEP at 25 bar. In the future, we expect that average operating pressures will continue to increase as turbocharger boost is increased and sequential turbo-charging (now available in some BMW engines) is more widely deployed, and engines will be further downsized. By 2020, the API report anticipated that engine operating at 30 bar BMEP and having specific outputs of 100 kW/litre or higher will start to become the norm. The API report review of diesel technology suggested that diesel combustion improvements have made moves to any new form of combustion such as “HCCI” unlikely. The situation for heavy-duty engines is similar in that average BMEP is increasing with time and engines of up to 40 bar BMEP are likely by 2020, but combustion processes will not change. Hence, there will be no new requirements on diesel fuel quality or composition that will be helpful for manufacturers to attain their technology goals

Light Duty diesel engines did not rely on any exhaust after-treatment to meet emission standards until the advent of the Euro 4 standards in 2005. While these standards could be met without after-treatment, early introduction of PM traps by some manufacturers in 2002-03 led to consumer driven demand for traps and virtually all light duty diesels have been trap equipped since 2005. The traps have resulted in tailpipe PM emissions levels very close to zero. Euro 5 standards introduced in 2009 led to the introduction of some NO_x adsorbers in heavier diesel vehicles although most vehicles met the standards with only PM after-treatment. The imposition of Euro 6 standards in 2014 has required urea-SCR after-treatment on vehicles with engine of 2L displacement and larger, while NO_x adsorber technology is popular in smaller vehicles. At present, it appears that urea-SCR systems will be the likely choice for all vehicles if NOx standards are further tightened by 2030.

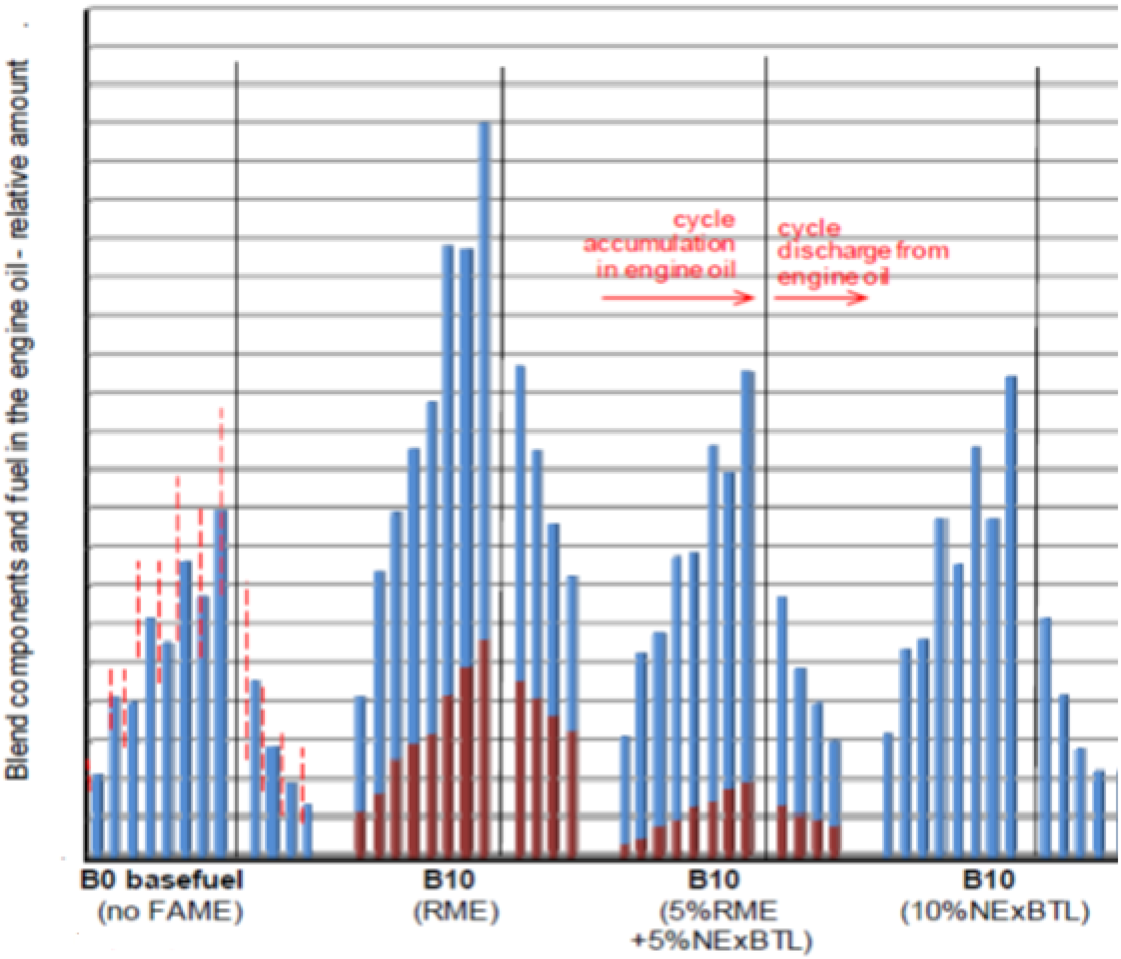
The market share of light-duty diesel hybrid and plug-in hybrids is expected to grow to 2030, and this could result in fuel staying in the vehicle tank for months (if much of the driving is powered electrically), which has raised concerns about the long term oxidation stability of bio-diesel fuel. This has increased concern about FAME blends but there is little data on long term effects since diesel plug-in vehicles have been introduced only in 2014.

EU heavy-duty vehicles also followed a nearly similar path in that PM traps were widely used since the imposition of Euro 4 standards in 2005, while the imposition of Euro 5 standards resulted in many but not all vehicles adopting urea-SCR systems as of 2009. The conversion to urea-SCR systems for NOx control is standard on all trucks following the imposition of Euro 6 standards in 2014.

2.4.2 Manufacturer Inputs on Blends

Interviews with selected auto-manufacturers suggest that they have accepted the use of B7 FAME blends only grudgingly and their main issue with FAME blends is that they cause oil dilution problems. In many PM trap equipped diesel engines, the trap regeneration is initiated by injection of fuel during the exhaust stroke, which in turn initiates ignition of the particulate matter collected on the filter. The exhaust stroke injection often results in some fuel wall wetting and subsequent dilution of the oil with fuel. Diesel fuel has a lower boiling point than FAME so that under the right combination of duty cycle (short trips where the engine never fully warms up) and low ambient temperature, the oil dilution becomes a serious problem. In recent testing, VW and Daimler reported on the oil dilution phenomenon (Baumgarten, et al., 2008) using FAME based B5 and B10 blends and compared these to HVO based B5 and B10 blends as well as a pure hydrocarbon diesel. VW bench tested engines, running for 40 hours with each fuel (with periodic PM trap regeneration), followed by oil analysis before and after every third regeneration of the trap. After 40 hours, the engine was run on hydrocarbon diesel (reference) fuel without trap regeneration. As shown in the figure below, the blends with FAME based on rapeseed methyl ester(RME) exhibit significantly higher oil dilution relative to pure diesel or the HVO blend labelled as NExBTL.

Figure 2.9 Oil dilution pattern with different fuels on the VW bench test



Source: Baumgarten, et al., 2008

Tests conducted by Mercedes using a slightly different procedure confirmed that FAME blends cause significantly higher oil dilution. As a result, manufacturers believe that oil drain intervals will need to be shortened (from current levels of 30,000 km drain intervals) to 20,000 km or lower. Other manufacturers concede that the oil dilution problems would be serious only for a subset of consumers with relatively short use duty cycles and would be more of a problem in winter, but these factors have made auto-manufacturers opposed to any increase in FAME blending beyond the B7 level accepted now.

In heavy-duty trucks, the short duty cycle may be less of an issue but oil dilution with FAME is still considered a significant problem. With more careful oil dilution monitoring and fuel quality monitoring, some captive fleets (both light and heavy duty) are operating with B20 and B30 FAME blends notably in Italy and France. During our discussions, Renault stated that the vehicles are specially prepared for B20/30 but we could not document any specific changes to the fuel system to use B20/ B30 blends. Although such information was requested from manufacturers, we did not obtain any specific data, and it is unclear if any hardware changes are required to enable engines to use B30.

Cold storage issues can be particularly acute for FAME blends. Both pure hydrocarbon diesel and FAME will gel at common winter temperatures; however, FAME's gel point may be much higher depending on the source of the FAME. Soy FAME, for example, has a cloud point (the temperature at which crystals begin to form) of 0ºC. In contrast, most petroleum diesels have cloud points of about -12º to -15º C. Blending with FAME can significantly raise the cloud point above that of the original diesel fuel. For example, a study by CRC (2008) showed that, when the soy FAME was blended into cold weather diesel fuel (cloud point of -38ºC), the cloud point of the B20 blend was -20ºC. Rapeseed based FAME has fewer issues, but manufacturers have complained about fuel filter plugging with FAME blends in winter.

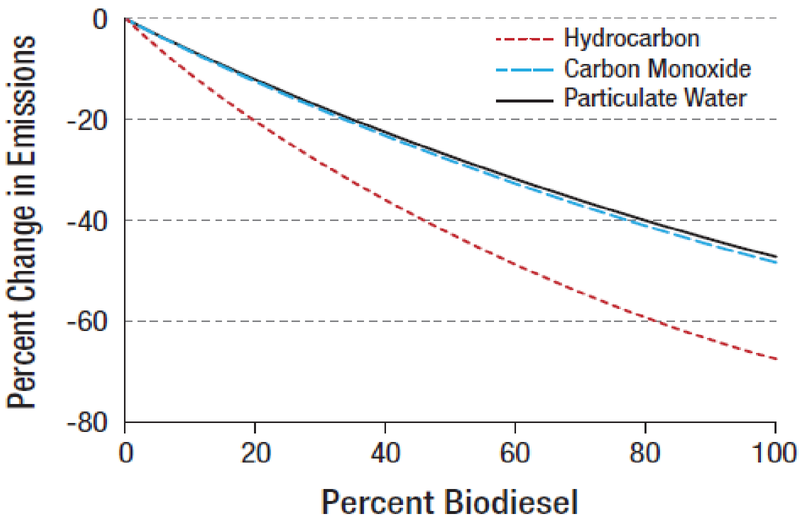
In contrast, manufacturers have no issues with HVO blends since HVO closely resembles diesel fuel. One option being considered in Germany is a blend of FAME and HVO called R33 which is 7% FAME and 26% HVO blended with diesel. This blend has been road tested by the University of Coburg in 250 vehicles since around September of 2013, and the website for the University states that the program was successful with no problems encountered. However, there is no formal or scientific report on the findings available publicly to date (March 2015).

2.4.3 Impact of higher biodiesel blends

Since FAME is the primary bio-diesel component in use today, its emission effects are explored for heavy-duty and light duty vehicles respectively.

FAME is an ester that contains 11 $\pm$ 1% oxygen by weight (Lopes, et al., 2014). Typically, when oxygen-rich fuels are combusted, a reduction of Particulate Matter (PM), Hydrocarbon (HC), and Carbon Monoxide (CO) is expected. One of the earliest analyses of the effects of FAME was completed by the US EPA in 2001. The agency reviewed 80 FAME emission tests on heavy-duty diesel engines from the 1990 to 2000 time frame corresponding approximately to Euro 1 and 2 emissions certification levels, and concluded that the emission benefits are predictable over a wide range of FAME blends.

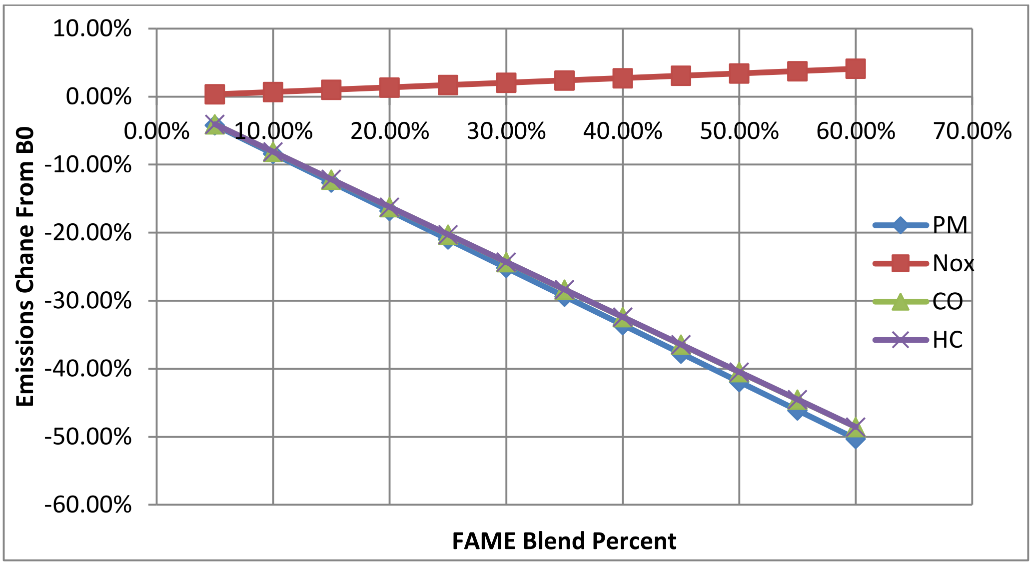
Figure 2.10 Emission Impacts of FAME Blends for 1991-2000 Heavy –Duty Diesel Engines.



Source: US EPA, 2002

The EPA data was collected through literature review using selective screening criteria and regression analysis was used to correlate the concentration of biodiesel in a conventional diesel fuel with changes in emissions. The results shown in Figure 2.10 indicate that a B20 blend would reduce PM and CO by 10% and HC emissions by 20%, with the curves being approximately linear to B30. NO_x emissions were found to increase and the EPA study noted that a B20 blend would increase NO_x by 2%. However, the EPA study is quite dated (from 2002) as the engine sample included 2 stroke engines that were no longer in production after 1995 and had few or no European and Japanese engines. In 2012, the National Technical University of Athens has published a statistical investigation of emissions reductions from bio-diesel blends, based on comprehensive literature review of published data (Giakoumis, 2012, p.273-291).

Figure 2.11 Emissions Reductions in Heavy-Duty Euro 3 and 4 Certified Engines with FAME Blends (Engine Based Transient Cycle Testing)



Source: Giakoumis, 2012

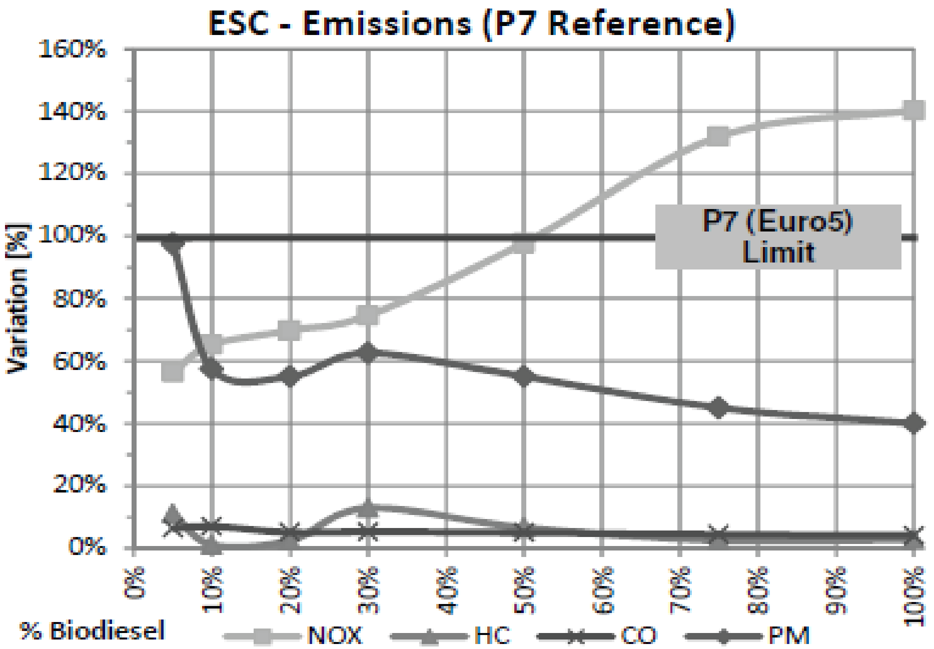
Data up to the end of 2011 was gathered and reported results were statistically analysed as a function of biodiesel content, test cycle, engine type (i.e., heavy or light-duty) and dynamometer schedule (chassis or engine). Separate best-fit curves were developed each case and for each exhaust pollutant. Although the sample included Euro 4 and Euro 5 certification engines with PM traps, only engine-out emissions were analysed. The sample did not contain any vehicles with NOx after-treatment devices.

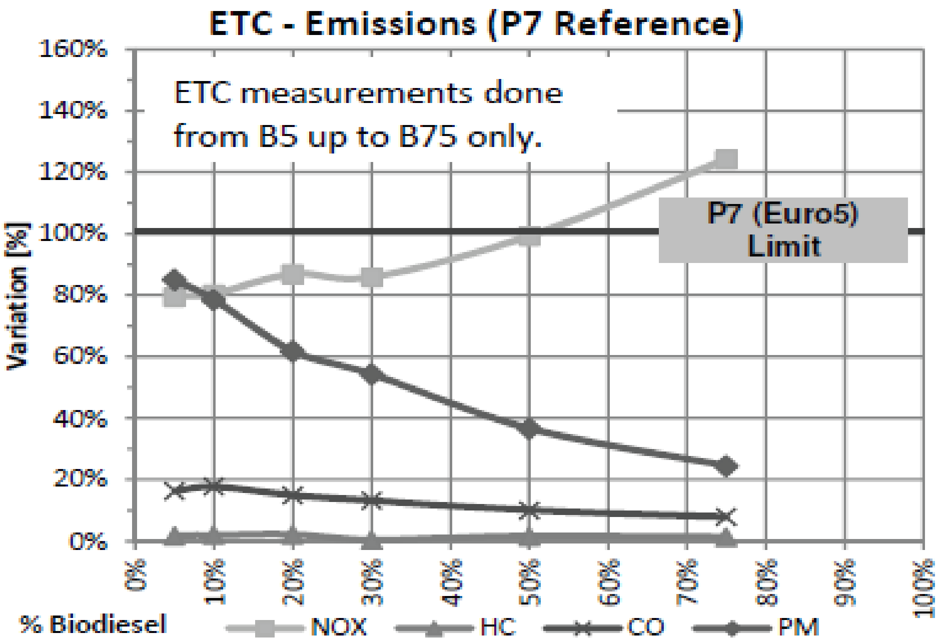
The emission trends, as represented by engine dynamometer testing data were established using published European Transient Cycle (ETC) and the World Harmonized Test Cycle (WHTC) results. The author concluded that the trends based on the heavy-duty engine dynamometer test results are consistent with EPA historical observations. The results for the heavy duty emissions regressions are shown in Figure 2.11. The regressions fitted were quadratic and while the square term coefficient is significant in some cases, it is quite small so that the results appear almost linear. The HC, CO and PM reductions with increased FAME blends are very similar to each other at about 16% reduction for a B20 blend and 24% for a B30 blend, (or about a 8% decrease for every 10% increase in FAME content) which are generally similar in magnitude to the results reported by EPA on older engines, except for PM emissions. The author thought the larger PM reduction observed by EPA was due to the high sulfur content of diesel fuel used in the older tests, so that sulfate PM reduction by FAME blending increased the PM reductions. The NO_x emissions increase is also quite linear, increasing by 0.7% for every 10% increase in FAME content, which is smaller than the increase reported by the EPA. Many, but not all, Euro 2 and 3 heavy-duty engines were equipped with an oxidation catalyst, which should result in significantly smaller benefits for HC and CO emissions, but only slightly lower PM emission benefits since the catalyst is not effective in oxidizing black carbon.

Tests of Euro 5 certified heavy duty engines with different bio-diesel blends are quite limited in the public literature. Mercedes-Benz Brazil published a paper with test results for biodiesel blends ranging from B5 to B100 (Machado, et al., 2013). The dynamometer test setup was equipped with Mercedes-Benz OM926LA Euro-5 certified heavy duty engine equipped with Urea Selective Catalytic Reduction (SCR) NO_x after-treatment system but no PM trap. The engine was tested following the ESC and ETC (EU Steady State Cycle and EU Transient Cycle) test methods, a B5 FAME blend was used as the reference fuel and B10, B20, B30, B50 and B75 blends were tested on both steady state and transient cycle tests.

Emission trends with increased FAME content were directionally similar on the two tests as shown in Figure 2.12. HC and CO emissions were far below standards on both tests with the base B5 blend, and showed some decline with increased FAME content. PM emissions were close to applicable standards with the B5 base fuel, and declined almost linearly with increased FAME content on the transient test. On the steady state test, PM emissions were near flat over the B10 to B50 range with a more modest decline for higher FAME blends. NOx emissions increased by about 20% on the transient test when FAME content increased from B5 to B50, but there was a larger increase on the steady state test between the B5 and B50 fuels. It should be noted that there was no adjustment of the urea dosing rate when tested with different fuels.

Figure 2.12 Emissions test results for various biodiesel blends versus B5 reference fuel on the Heavy-Duty ESC and ETC cycles.



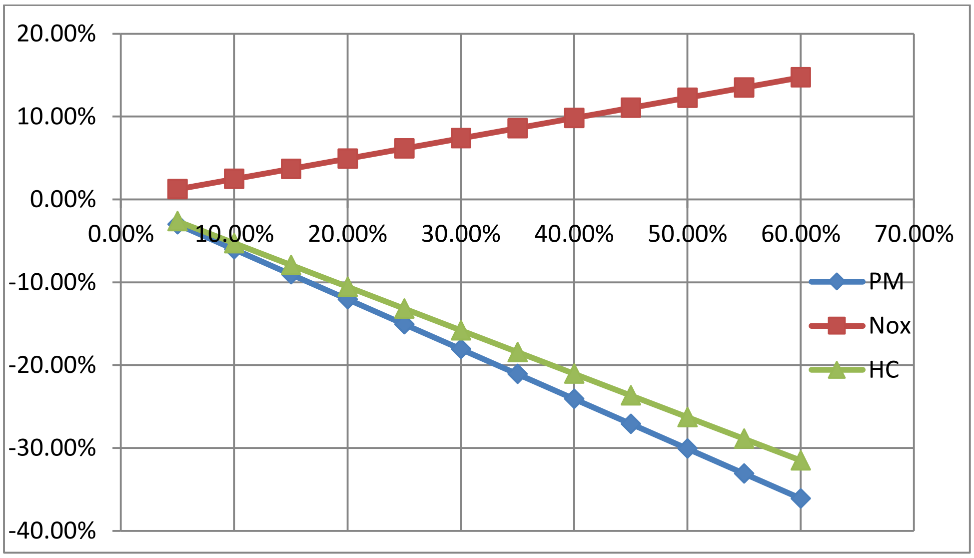


Source: Machado, et al., 2013

2.4.3.2 Light Duty Diesel Emissions with FAME Blends

As described in the heavy-duty Section, the National Technical University of Athens has published a statistical investigation of emissions reductions from bio-diesel blends, based on comprehensive literature review of published data (Gaikoumis, 2012, p.273-291) for light duty vehicles as well. Data was mostly on vehicles conforming to Euro 2, 3 and 4 certification gathered and reported results were statistically analysed as a function of biodiesel content, test cycle, and dynamometer schedule (chassis or engine). For light duty vehicles, most of the test results were chassis dynamometer based and most of the testing was on the NEDC cycle. Separate best-fit curves were developed each case and for each exhaust pollutant. Although the sample included Euro 4 and Euro 5 certification light vehicles with PM traps, only engine-out emissions were analysed. The sample did not contain any vehicles with NO_x after-treatment devices.

Figure 2.13 Changes in Light Duty Emissions (NEDC Cycle) with increasing FAME blends



Source: Gaikoumis, 2012, p.273-291

Emission reductions relative to B0 were modelled as a quadratic function of blend FAME content. The light duty regressions had much less explanatory power than the heavy-duty regressions, implying significantly higher car-to-car variation, and the regressions for CO emissions were not statistically significant. The light duty regression results are shown in Figure 2.13.

As in the case of heavy-duty emissions, the changes are almost linear with increased FAME content up to 60%, and PM emissions decrease by 6% for every 10% increase in FAME content, while HC emissions decrease by 5.2%. NOX emissions increase by 2.5% for every 10% increase in FAME. The PM and HC decreases are a little lower than those estimated for heavy-duty engines while the NO_x increase is somewhat larger. Other researchers have reported that NO_x emissions with bio-diesels made from saturated esters (such as animal fats) are lower than NO_x emissions from pure diesel.

Data from PM trap and urea-SCR after-treatment equipped vehicles certified to Euro 5 or 6 standards are less common. Researchers from the University of Aveiro (Lopes, et al., 2014) published results of emissions characterization from a Euro 5-certified passenger car using various biodiesel blends including B7 and B20. The tested vehicle was a MY2011 Renault Megane with a 1.5L Turbocharged Direct Injection diesel equipped with EGR and a catalyzed PM filter. The vehicle was tested on chassis dynamometer over the NEDC cycle, and tests were repeated four times for each fuel blend.

The criteria emissions results for CO and PM were found to have no specific direction with increased bio-diesel content in the fuel. The PM difference could not be established by weighing the PM filter after each test cycle, as the differences were at measurement noise levels. The CO difference could not be detected due to the exhaust measurement equipment resolution. The HC emissions factors were higher for all biodiesel blends, particularly for the B7 blend. However, HC emissions with B20, while higher than those with B0, were significantly reduced compared to the B7. The researchers attribute this decrease to higher cetane number and higher oxygen content for the B20 fuel, which leads to more complete combustion. The B7 emissions increase was related to specific HC species present in the low biodiesel blend versus pure diesel.

NO_x emissions were higher for the B7 relative to B0, but only slightly, by about 0.5%, and were still lower than the Euro 5 limits. Interestingly this study demonstrated that the NOx emissions were lower for B20 by 10.8% and 11.4% relative to the emissions with B0 and B7, respectively. The researchers speculated that the B20 result was due to higher EGR contribution to the combustion process which compensated for the higher oxygen content in the B20. The test results indicate that the emissions from PM trap and urea-SCR after-treatment equipped vehicles are much less sensitive to the presence of bio-diesel but large scale confirmatory testing of many vehicles is required to validate this conclusion.

Vehicle test results

Emission tests were conducted on a Euro VI compliant diesel vehicle, 2L Peugeot 508, to the WLTC. The vehicle was not optimised for the three fuels examined, B7, B10 and B30.

Table 2.3 presents the average recorded emissions, based on three vehicle tests, for the three test fuels. Further details of the test programme are presented in Annex 5.

Table 2.3 Emission summary averages over WLTC cycles – Diesel

Test Fuel	NO_2 (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)
B7	219	6	80	572	152	1	8.60E+09
B10	217	10	89	557	151	1	2.60E+10
B30	259	9	89	609	151	1	2.64E+10

Carbon monoxide (CO), particulate mass (PM) and number (PN) are approximately >80%, >75% and >95% lower, respectively, than the exhaust emission limits defined by the Euro 6 standard for passenger cars. More significantly, NOx emissions are over 7 times higher than Euro 6 limits. As noted earlier, CO_2 emissions targets for new cars (130 g/km) as defined by Regulation (EC) No 443/2009[71] are based on the car fleet, and not individual vehicles. Since CO_2 emissions will vary based on the power and size of the engine tested, the results presented in Table 2.3 are not comparable to the CO_2 regulated target.

Emissions for THC, CO, and PN increase from B7 to B30, while there is no noticeable change for PM. However, differences in emissions are within the standard deviation of the measurements; so they are not statistically different from zero. As such, no conclusions can be drawn on the emissions trends.

For NOx, the results were very high compared to the Euro 6b M1 limit of 80mg/km. Average NOx results were 572mg/km for B7, 557mg/km for B10 and 609mg/km for B30, which range from 7.2 to 7.6 times greater than the Euro 6b limits. However, the Euro 6b limits refer to a vehicle run over the New European Drive Cycle (NEDC) cycle, for this project the Worldwide Light-duty Test (WLTP) cycle was used. NOx is primarily produced during high load and high temperature combustion, and so more NOx is typically emitted during acceleration. As such, the higher emissions are likely due to the different acceleration profiles of the NEDC and WLTC cycles.

For reference, the Peugeot 508 2.0L BlueHDI diesel test vehicle achieved a NOx level of 57mg/km during type approval test work (data obtained from http://carfueldata.direct.gov.uk). Whilst the test vehicle achieved NOx levels in magnitudes higher than the type approval

[71] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02009R0443-20130508

limit, it is likely that this behaviour is attributable to the diesel vehicle rather than the biofuels, as directionally similar results have been observed in other studies when running cycles other than the NEDC. For example, (J. May, 2014), noted that when testing 2 diesel vehicles, NOx emissions using WLTC was nearly 4 times greater than the Euro 6 limit. Furthermore, a recent study by (ICCT, April 2014), which tested 15 diesel cars from 6 different manufacturers, noted that using a Real Driving Emissions (RDE) test programme resulted in average NOx emissions which were 7.1 times greater than the Euro 6 limit. The variations in results between tests are likely due to the different vehicle/engine types, since outcomes will be dependent on engine design, engine calibration, and the after-treatment system.

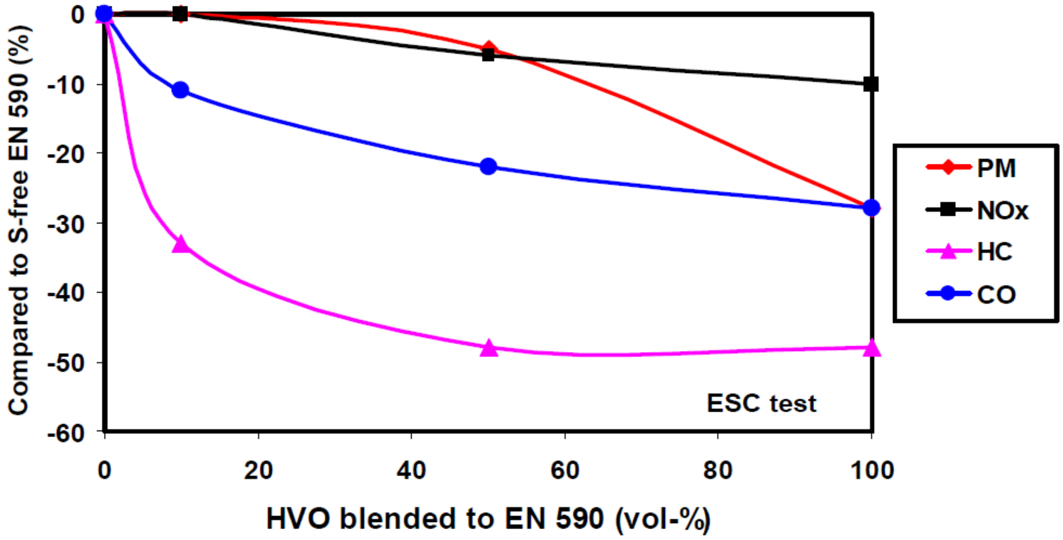
As a precaution, the vehicle was checked for any trouble codes (none were present), the Selective Catalytic Reduction (SCR) system was checked for distance remaining until refill of the AdBlue tank was required and found the level to be greater than required for project completion. The vehicle literature was also checked, which confirmed that it's AdBlue system warns when low levels are present and prevents the vehicle engine from starting if the SCR system is deemed not to be working (empty/faulty).

Overall, although the vehicle tests represent a small sample size, the results for NOx indicate a broader issue surrounding the impact of different test cycles on vehicle emissions. This warrants further investigation.

2.4.3.3 Emissions with HVO Blends

HVO has a different set of properties compared to FAME fuels. Neste Oil has researched the emissions implications for its blends extensively and the company claims that, compared to the neat diesel fuel, HVO reduces NO_x, CO, HC and PM emissions. However, the magnitude of reductions depends on EGR and exhaust after-treatment strategies (Neste Oil, 2014).Neste claims are substantiated by emissions tests for 32 heavy duty trucks and buses or their engines and several passenger cars. The tests results from a recent SAE paper are summarized in Figure 2.14.

Figure 2.14 HVO Heavy Duty Engine Emission Test Results over the ESC Cycle.as a Function of HVO Content

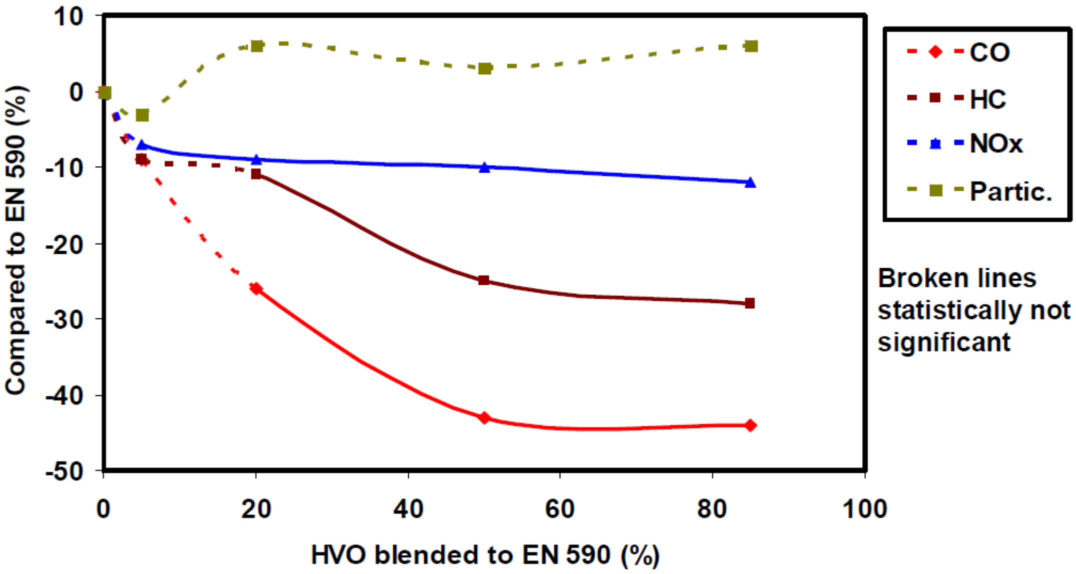


Source: Aatola, et al., 2008

The heavy duty results were obtained following the ESC test procedure. The engines were certified to Euro IV standards, equipped with EGR but had no PM or NO_x after-treatment. Neste observed that NO_x emissions were <u>reduced</u> linearly in proportion to the HVO blend content increase. The PM reduction for low level HVO blends was small but increased for mid-level blends. The CO and HC reduction was more significant for low level blends (Aatola, et al., 2008).

Passenger car data was obtained from New European Driving Cycle (NEDC) testing using test vehicles equipped with EGR and Diesel Oxidation Catalysts (DOC) but without a PM trap or urea-SCR after-treatment. The results indicate that, for low HVO blends the emissions changes were highly variable, hence the trends were deemed to be statistically insignificant. For higher blends the PM results remained "flat" indicating that HVO blending has little influence on PM emissions. Starting from the 5% blend level, the NOx reduction was statistically significant (reduction by about 7% for B10) and the benefit increased to 10% for HVO B20. The HC and CO emissions reductions were statistically significant starting from HVO B20 blends.

Figure 2.15 Passenger Car Emissions Test Results over the NEDC Cycle Compared to Regular EN590 Diesel as a Function of HVO Content



Source: Neste Oil.

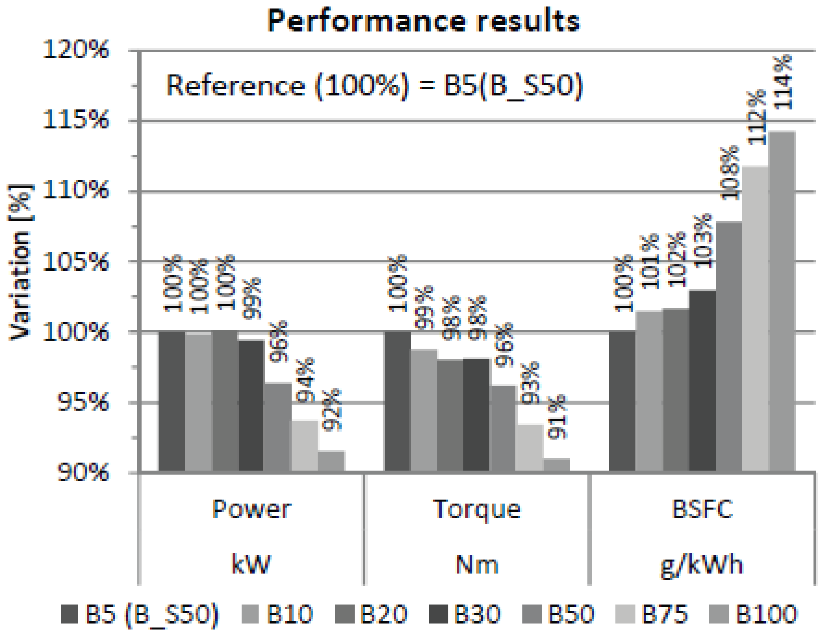
From this literature review it can be concluded that, for the light duty diesel vehicles, the use of modern after-treatment devices results in very small, if any, emissions penalty for low HVO blends such as B7. Recent tests indicate that PM and CO reduction cannot be easily confirmed due to measurement limitations. The NO_x emissions penalty appears to be detectable but the difference for low HVO blends is very small.

2.4.3.4 *Fuel Consumption Effects*

FAME has an energy content that is 10 to 12 percent lower than that of hydrocarbon diesel fuel, and a B7 FAME blend will have about 0.8% less energy per unit volume than the energy in B0. Historic test data has correlated bio-diesel blend energy content to volumetric fuel consumption although the small differences of 1% or less makes measurement accuracy an issue. Tests on newer engines such as those conducted by researchers at the University of Aveiro (Lopes, etal., 2014) showed fuel consumption impacts over NEDC, UDC and EUDC cycles. The data showed that, compared to pure hydrocarbon diesel fuel, fuel consumption for B7 increased from 5.86 l/100km to 5.92 l/100km or about 1% (the comparison represents average fuel consumption over the NEDC cycle). However, the tests performed with B20 revealed a decrease in fuel consumption by almost 1%, when compared to neat diesel. The researchers opined that B20 combustion in the EGR-equipped engine resulted in more efficient operation, although more data is needed to confirm this trend. Nevertheless, it should be noted that impacts of FAME blends on fuel consumption are quite small, in the range of 0 to 2%.

For the heavy-duty fuel efficiency assessment, the Mercedes-2013 study (Machado, et al., 2013) provides the Brake Specific Fuel Consumption (BSFC) performance using different biodiesel blends. The table above provides the results summary with B5 being the reference fuel (since Brazilian diesel fuel currently has 5% biodiesel content). The results for low-level blends B10, B20 and B30 seems to suggest that for each 10% increase in the biodiesel content, roughly 1% BSFC-based consumption penalty should be expected with about the same 1% degradation in available torque.

Figure 2.16 Nominal power, torque and BSCF for various biodiesel blends, when compared to B5 base fuel



(Results are presented an Index Format with B5 being 100% and other Blends ComparedRelative to B5).

Source: Machado, et al., 2013

Neste Oil has documented that the vehicle-level fuel consumption relationship for various HVO blends is basically linear with the measured caloric heating values (on MJ/l basis). Since HVO has about 3 to 4% lower energy per unit volume compared to diesel, a HVO 20 blend will have only 0.6% to 0.8% lower energy with similar volumetric fuel consumption increases.

In conclusion, the literature review for low-content biodiesel blends (in the B5 to B30 range) on fuel efficiency effects appears to indicate that fuel consumption is inversely related to blend energy content. There will be a volumetric fuel consumption penalty for both FAME and HVO fuel blends, as expected based on their lower energy content. For B5 to B20 blends the penalty will be small, in the order of 0.5% to 2% for FAME blends and about half that for HVO blends, versus conventional B0 diesel for both light duty and heavy-duty diesels.

Vehicle tests

As with the petrol vehicle, the 2L Peugeot 508 used for the vehicle tests was tolerant, but not optimised, to the higher biodiesel blends. Against the B7 reference fuel, a +1.5% and +1% improvement in volumetric fuel consumption was achieved by B10 and B30, respectively. These results are contrary to observations from literature, which indicate that fuel consumption will increase as the blend energy content decreases. Nonetheless, the impacts of FAME blends on fuel consumption are still very small.

Table 2.4 Fuel consumption averages over WLTC cycles – Diesel

Test Fuel	Fuel Cons (L/100km)
B7	5.81
B10	5.72
B30	5.75

2.5 Conclusions

2.5.1 Petrol blends

Future improvements in petrol engine technology is expected to progress in two directions. Both approaches would in principle not be negatively impacted by the use of higher ethanol blends. The first, favoured by European manufacturers, will rely on increased turbocharger boost and engine downsizing to improve fuel economy. The second, favoured by Japanese manufacturers, will use very high compression ratios (13 to 15) in combination with Atkinson or Miller cycles. Both approaches will not change the impact of ethanol blends relative to their impact on current engines, but can be assisted by the higher octane number of ethanol. The European approach of higher turbocharger boost pressures is likely to be more favourably impacted by higher octane fuel than the Japanese approach.

Expansion of E10 availability to all countries in the EU with E5 blend as the protection fuel maintained available. This is the least controversial option and there are no technical issues related to this option. There are small positive benefits for emissions of regulated pollutants and air toxics. This option would have no impact on the auto-manufacturers future products

Replacement of E5 as the protection fuel with E10 across the EU in 2020. This option will negatively affect between 1.3% and 6.8% of the 2020 EU passenger vehicle fleet; i.e., mostly older vehicles produced before 2003, in which fuel leaks or fuel system corrosion could occur. Upgrading these vehicles with new fuel system gaskets and elastomers could solve most issues satisfactorily but there will be a subset of these vehicles where there may be more serious consequences like engine fires, and these would require hardware changes. Unfortunately, there is no public data on affected models and the EU must work with auto-manufacturers to identify affected vehicles, upgrade costs and affected populations in 2020. There are small positive benefits for emissions of regulated pollutants and total air toxics associated with this strategy, although aldehyde emissions can increase significantly (see table below).

Manufacturers are favourably disposed towards E20, but only if the new E20 fuel is a tailored (“splash”) blend fuel rated at 100+ RON as a premium fuel that can be used by purpose designed cars starting in 2020. E20 fuel with the same octane rating as current E5 and E10 fuels will have a 6.5 to 7% increase in fuel consumption and would offer no benefit to the consumer in vehicle models not capable of exploiting the octane advantage of E20 . In contrast, the high octane E20 strategy would have the advantage of providing a 3% to 6.4% energy efficiency benefit potential for the auto-industry and provides value to the customer from the high octane rating of ethanol in vehicle models capable of exploiting the octane advantage of E20 (that auto-manufacturers would yet have to introduce). (Volumetric fuel consumption would change by -2.5% to +1%).

A high octane E20 fuel could slowly displace hydrocarbon based premium petrol (98+ RON) in the EU over the 2020 to 2030 period provided auto-manufacturers introduce more vehicle models capable of exploiting the octane advantage of E20. The intent of this scenario would be to introduce E20 as a premium fuel but work towards making it the mainstream fuel of choice for most consumers by 2030. The fuel would have negligible effects on regulated pollutants but could result in reduced toxics emissions. In purpose designed cars the costs of this phasing in of E20 are near zero for naturally aspirated engines and estimated under Euro 50 for turbocharged engines if the changes are incorporated in the design stage. This strategy will affect future manufacturer product plans, which would need to be changed to accommodate this phasing in of E20 as engines will be modified to take advantage of the high octane of E20 splash blends. A lead time for 4 to 5 years will be required for manufacturers to design such engines.

A quantitative summary of the literature review (Section 2.3.3.1) is provided in the table below with values relative to E0 fuel for Euro 2 to Euro 5 certified vehicles except in the case of purpose designed E20 engines.

Table 2.5 Petrol blends - quantitative summary based on literature review

	E5	E10	E20 on current vehicles	E20 on purpose designed engine
Hydrocarbon (HC)	No trend	No trend	3 to 5% lower	No trend
Carbon monoxide (CO)	~ 5% lower	~ 10% lower	~ 20% lower	~ 20% lower
Nitrogen oxides (NO_x)	~ 1% higher (Euro 2/3), small* absolute increase for Euro 4/5	~ 1 to 2% higher (Euro 2/3), small* absolute increase for Euro 4/5	~ 2 to 3% higher (Euro 2/3), small* absolute increase for Euro 4/5	No change
Particulate mass (PM)	~ 5 to 10% lower	~ 10 to 20% lower	~20 to 30% lower	~20 to 30% lower
Toxics	Undetectable change	Lower benzene, higher (~5 mg/km) acetaldehyde	Lower benzene, ~+10 mg/km acetaldehyde	Lower benzene, but potentially similar aldehydes
Carbon dioxide (CO_2)	No change	No trend	~ 1 to 2% decrease	4% - 7% decrease potential
Other Issues	None	May cause problems in some pre-2003 models	Tolerated only by post-2011 models	Requires splash blend with RON of about 100

**Increase in the range of 10 to 20 mg/km*

Vehicle emissions testing results indicate that pollutant emissions from both E10 and E20 will meet exhaust emission limits defined by the Euro 6 standard for passenger cars.[72] Specifically, results indicate that total hydrocarbon (THC), particulate mass (PM) and particulate number (PN) are 80% lower than Euro 6 emissions limits, while non-methane hydrocarbon (NMHC) is over 70% lower. Carbon monoxide (CO) and Nitrogen oxides (NOx) vary between 50-70% and 18-46%, respectively, below Euro 6 emission limits. Particulate emissions from this vehicle would struggle to meet the Euro 6 particulate number limit of 6,0 $x10^{11}$ that will be introduced in 2017.

THC, NMHC, CO_2 and PM emissions trends between E10 and E20 agree directionally with observations from the literature review, but NOx and CO results were inclusive. Similar to the results presented in Table 2.5, there was no change in the THC emissions between E10 and E20, and a slight decrease of 4% and 2% in NMHC and CO_2 emissions, respectively. PM emissions decreased from E10 to E20; however, the percentage change was greater than that presented in Table 2.5 due to the low values reported and the emissions being within measurement sensitivities. NOx and CO data was subject to high Coefficients of Variance (CoV), in part due to low emissions values (NOx) and due slight

[72] Regulation (EC) No 715/2007

changes in vehicle handling (NOx and CO), although, overall, the drive trace was within legislative limits.

2.5.2 Diesel blends

Future improvements in diesel engine technology is expected in principle not to be negatively impacted by the use of higher biofuels blends. Light and heavy duty diesel engine technology is expected to progress along a path of increased turbocharge boost pressures, and engines being further downsized. However, fundamental changes in diesel combustion technology are not expected in the 2030 timeframe. As such, current diesel fuel properties will be suitable for future diesel engines.

Expansion of B7 blend use to all countries in the EU with max. FAME content up to the allowed 7% requires no changes to vehicle technology and can be implemented immediately. Additional B7 use will result in decreases in PM, HC and CO emissions from most vehicles, although the PM decreases from trap equipped vehicles may be undetectable. NOx emissions could increase by zero to 1%. This option will have no impact on auto-manufacturers.

Use of B10 with 10% FAME blends instead of B7 will have emission effects similar, although slightly larger, to that of B7. However, vehicles with duty cycles having short trip lengths and many cold starts daily can experience significant oil dilution issues. The technical solution to this problem is improved monitoring of engine oil and more frequent oil change intervals. This option will not impact manufacturers new technology or require changes in product plans or but could result in the oil change interval being reduced from current levels of 25,000 to 30,000 km to less than 20,000 km. In addition, B10 use may not be allowed in winter months.

Expansion of B30 FAME bio-diesel use in "captive" fleets across the EU can be implemented by owners of large fleets in conjunction with an oil dilution monitoring program and more careful oversight of fuel quality. B30 FAME blends may not be suitable for consumer use. The duty cycle of these captive fleets should not include extensive low speed short trip operations. It is unclear if any upgrades of the fuel system are needed for modern (post-2010) vehicles to use B30, but vehicle hardware changes required, if any, are expected to be minor. The fleets can also use B7 seasonally if necessary, under cold winter weather conditions to avoid any filter plugging problems. With the use of B30, HC, PM and CO emissions from Euro 4 and earlier certification vehicles can decrease by 15% to 25%, while NO_x emissions and volumetric fuel consumption may increase by 1% to 2% relative to B7 fuel. In modern vehicles certified to Euro 5 and 6 standards, PM and HC emission declines and NO_x increases if any may be too small to be reliably detected. This option is more likely to affect heavy-duty diesel engine manufacturers who will have to coordinate the fuel use with improved oil dilution monitoring.

Addition of a new HVO+ FAME blend that could utilize 7% FAME-diesel with any level of HVO up to 26% is possible without any negative performance effects for all diesels. In general, HVO use with diesel or B7 FAME-diesel blends will result in emission declines for all regulated emissions, but volumetric fuel consumption could increase by about 0.5% for every 10% increase in HVO content in the blend. It is possible that with modern diesels with EGR, there may be no fuel consumption penalty with HVO, but this cannot be confirmed without more test data. This option will likely have no effect on auto-manufacturers, but fleet test data to confirm this is not yet available (but could be available later in 2015)

There are concerns about the oxidation stability of FAME when used in plug-in vehicles where the tank fuel can be present for several months if the vehicle is operated primarily in electric mode. Not much is known about this issue as plug-in diesels have entered the market in 2014, but is an area of manufacturer concern for the future.

The quantitative results of the literature review (Section 2.4.3.2) are summarized for all bio-diesel blends considered relative to pure hydrocarbon diesel or B0 in the Tables below.

Table 2.6 Summary of blend effects on light duty diesels

	B7 FAME	B10 FAME	B30 FAME	B30 HVO
Hydrocarbon (HC)	~ 4% reduction	~ 5% reduction	~ 15% reduction	~ 15% reduction
Carbon monoxide (CO)	~ 4% reduction	~ 5% reduction	~ 15 % reduction	~ 35% reduction
Nitrogen oxides (NO_x)	0 to 1% increase	0 to 1% increase	7 to 8% increase for Euro 2, 3 and 4, no change for Euro 5 vehicles	~ 10% decrease for Euro 2, 3, 4 no change for Euro 5, 6.
Particulate mass (PM)	~ 6% reduction for Euro 2, 3, 4, no change for Euro 5	~ 8% reduction for Euro 2, 3, 4, no change for Euro 5	~ 18% reduction for Euro 2, no change for Euro 3, 4 and 5	0 to 10% increase for Euro 2, no change for Euro 3, 4 and 5.
Carbon dioxide (CO_2)	No trend	No trend	No trend	No trend
Other Issues	FAME must meet EN14214 standards	Oil dilution by FAME can be a problem for some vehicles.	Careful check of fuel properties and oil dilution required.	No significant issues

Table 2.7 Summary of blends effects on heavy duty diesels

	B7 FAME	B10 FAME	B30 FAME	B30 HVO
Hydrocarbon (HC)	~ 6% reduction, 0 to 2% with oxidation cat.	~ 8% reduction, 0 to 2% with oxidation cat.	~ 25% reduction, 10 to 15% with oxidation cat.	~ 35 to 40 % reduction, 20 to 25% with oxidation cat.
Carbon monoxide (CO)	~ 6% reduction, 0 to 2% with oxidation cat.	~ 8% reduction, 0 to 2% with oxidation cat.	~ 25% reduction, 5 to 10% with oxidation cat.	~ 15% reduction, 3 to 5% with oxidation cat.
Nitrogen oxides (NO_x)	0 to 1% increase	0 to 1% increase	1 to 2% increase for Euro 2, 3 and 4, no change for Euro 5 vehicles	~ 0 to 1% decrease
Particulate mass (PM)	~ 6% reduction, no change for Euro 4/5	~ 8% reduction, no change for Euro 4 and 5	~ 25% reduction, no change for Euro 4 and 5	No change
Carbon dioxide (CO_2)	No trend	No trend	No trend	No trend
Other Issues	FAME must meet EN14214 standards	Oil dilution by FAME can be a problem for some vehicles.	Careful check of fuel properties and oil dilution required.	No significant issues

Vehicle emissions testing results indicate that CO, PM, and PN emissions from B7, B10 and B30 will meet Euro 6 exhaust emission limits for passenger cars.[73] Carbon monoxide (CO), particulate mass (PM) and number (PN) are approximately >80%, >75% and >95% lower, respectively, than the exhaust emission limits defined by the Euro 6 standard for passenger cars. Emissions for THC, CO, and PN increase from B7 to B30, while there is no noticeable change for PM. However, differences in emissions are within the

[73] Regulation (EC) No 715/2007

standard deviation of the measurements; so they are not statistically different from zero. As such, no conclusions can be drawn on the emissions trends.

NOx emissions were over 7 times greater than Euro 6 limits, due to issues associated with the test cycle rather than biofuel blends. Euro 6b limits are based on vehicles using NEDC tests. For type approval testing (NEDC), the test vehicle, Peugeot 508 2.0L BlueHDI, achieved a NOx level of 57mg/km (within the 80 mg/km Euro 6 limit). However, this study used the WLTC cycle, where NOx emissions on the order of 550-600 mg/km were observed. These test results are directionally similar to results from other studies which have compared NOx emissions from NEDC against other test cycles, such as WLTC and RDE. Overall, although the vehicle tests represent a small sample size, the results for NOx indicate a broader issue surrounding the impact of different test cycles on vehicle emissions. This warrants further investigation.

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3 Effects on air quality and implications for vapour pressure

Abbreviations/acronyms

API	American Petroleum Institute
CO	Carbon monoxide
CO_2	Carbon dioxide
DPVE	Dry vapour pressure equivalent
EEA	European Environment Agency
FFV	Flex fuel vehicle
HDV	Heavy duty vehicle
LDV	Light duty vehicle
NMHC	Non-methane hydrocarbons
NMVOC	Non-methane volatile organic compounds
NOx	Nitrogen oxides
PM	Particulate matter
RVP	Reid vapour pressure
SOx	Sulphur oxides
THC	Total hydrocarbons
VOC	Volatile organic compounds
VP	Vapour pressure

3.1 Summary

Increasing biofuel blends may result in air quality impacts at various points in the supply chain. Starting with the refining of biofuels, emissions will also occur at storage tanks, transport of the biofuel to the point of use, and during vehicle use. Although some emissions are likely during transport and storage (e.g., tailpipe, evaporative), the primary focus of Chapter 3 will be refinery emissions, and vehicles, both tailpipe and evaporative emissions.

Refinery emissions were calculated using refinery fuel consumption estimates from the EnSys WORLD model analyses and industry average emission factors[74]. Vehicle tailpipe emissions were developed using the results from vehicle emissions tests, literature and TREMOVE vehicle fleet projections. Evaporative emissions impacts were assessed based on literature review.

3.1.1 Refinery air quality impacts

In the refinery sector, emissions of air pollutants and CO_2 in the Base Case are expected to decline through 2030 from 2010/2013 levels. SOx, NOx and NMVOC emissions are about 55%, 45% and 35%, respectively, below 2013 levels. For CO and PM, emissions in 2030 are

[74] CONCAWE, "Air Pollutant Emission Estimating Methods for E-PRTR Reporting by Refineries," Report No. 3/15, Brussels (April 2015)

approximately 50% and 55%, respectively, lower than 2010 levels as reported by the European Environment Agency. These declines are directly linked to reduced refinery throughput, and associated lower refinery fuel consumption. However, for Scenarios A, B and C that assume the production of higher biofuel blends through 2030 (Chapter 1, Section 1.7.3), the emissions of NOx, SOx, CO, CO_2, PM and NMVOC are estimated to be 2-5% higher than the Base Case scenario. This increase is primarily due to increased biorefinery production.

Even though there is a slight increase in emissions in the higher biofuel scenarios, compared to the Base Case, there will not be a detrimental impact on air pollution from the refinery sector as emissions are still greater than 30% lower than current levels.

3.1.2 Vehicle use air quality impacts

In vehicles, the level of exhaust emissions that results from the burning of biofuels depends upon the fuel (e.g. feedstock and blend), vehicles technology, and vehicle tuning and driving cycles. Most studies agree that using biofuels can significantly reduce most pollutants compared to petroleum fuels, including reductions in controlled pollutant as well as toxic emissions. However, it has noted that biofuels can lead to a slight (~1-2%) increase tailpipe NOx and hydrocarbon emissions.

Modelling results, under the analysed scenarios, indicate that regardless of the blending ratio (E10, E20, E25, B7, B10 or B30), vehicle tailpipe emissions compared to a Base Case using current biofuel blending levels, do not negatively impact air pollution. Pollutant levels of THC, NMHC, CO, and PM decline with higher biofuel blends. In 2030, LDV emissions of these pollutants across each scenario were on average 3%, 3%, 6% and 8% lower than the base case. For NOx, emissions were on average 1% higher than the base case in 2030. However, in the context of issues reported during vehicle tests (Chapter 2, Section 2.4.3.2), where NOx emissions were over 7 times greater than Euro 6 limits, due to issues associated with the testing cycle, the biofuel-related increases are comparatively marginal. CO_2 emissions for scenarios A, B and C were the same in 2020, and 0.2% lower in 2030 than the base case. For HDV, the trends were similar, although no declines in CO_2 were noted through 2030.

3.1.3 Vapour pressure

Fuel vapour pressure (VP) directly affects the quality of ignition, atomization, and combustion of a fuel. Thus, low pressures can have detrimental impacts, including delayed ignition, poor atomization, and problematic combustion. Ethanol and biodiesel by themselves have low vapour pressures; consequently, the magnitude of this property depends upon the composition of the biofuel. During the summer, pollution is a frequent concern due to increased levels of smog and ozone. As such, summer blends have a lower VP to prevent excessive evaporation when outside temperatures rise. However, if temperatures remain low, a higher VP would be required because the fuel must be able to evaporate at low temperatures for the engine to operate properly, especially when the engine is cold.

Annex III of the Fuel Quality Directive (FQD; 2009/30/EC) sets out allowed VP waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. The vapour pressure of ethanol in petrol gradually declines as its concentration rises above 5 volume %. As a result, going to higher ethanol blends does not mean increases in the ethanol waiver, rather the required waiver (in kPa) gradually declines out to and beyond 30 volume % ethanol.

Furthermore, an assessment of literature indicates that there would be no appreciable adverse evaporative emissions impacts from raising ethanol concentration in petrol. Ethanol content has some effect on permeation emissions but little effect on diurnal, running loss, and hot-soak emissions. Studies indicate that diurnal, refuelling and hot-soak emissions were unaffected by higher ethanol content in petrol. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but not within the E10 to E25 range. Any reduction in VP from blends above E5 should tend to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

3.2 Introduction

Increasing biofuel blends will result in air quality impacts at various points in the supply chain; i.e., refining, storage tanks, transport of the biofuel to the point of use, and during vehicle use. Although some tailpipe and evaporative emissions are likely during fuel transport and storage, the primary focus of this analysis will be refinery and vehicle emissions. During refining, combustion products include sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2), carbon monoxide (CO), non-methane hydrocarbons (NMHC), and particulates. In vehicles, the level of exhaust emissions that results from the combustion of biofuels depends upon the fuel (e.g. feedstock and blend), vehicle technology, and vehicle tuning and driving cycles. Furthermore, evaporative emissions or non-combustion emissions derive from fuel vapour generated in the vehicle fuel tank and the fuel distribution system to the engine. The magnitude of evaporative emissions is generally a function of fuel vapour pressure.

Based on the scenarios discussed in Chapter 1, Section 1.7.3, an assessment of the potential impacts of biofuel blends on CO_2 and air pollution emissions from refining and vehicle use has been conducted. As mentioned previously, the scenarios that are described and used in this assessment are not intended to represent precise predictions of the future, but rather provide a means to assess a hypothetical situation rooted in a technically feasible reality. Furthermore, the assumptions of the variables used in the modelling are often quite crude (for simplicity, but also to improve transparency) and the modelling itself can only provide a rough approximation of reality (for the same reasons). Nevertheless, the results for the three scenarios provide useful insight into the potential impacts and trends through 2030. The next sections list the main assumptions and air emissions results during refining (Section 3.3) and vehicle use (Section 3.4). Section 3.5 discusses work undertaken to examine the effects on petrol vapour pressure of higher ethanol blends, leading to a proposed extension to the “Annex III” ethanol waiver table, and also to research into literature on the impacts of higher ethanol blends on petrol emissions of volatile organic compounds (VOC’s), toxics and other regulated compounds

3.3 Refining air quality impacts

Petroleum refineries are complex systems of multiple linked operations. The specific operations utilized at a refinery depend on the type of crude refined and the desired products. For this reason, no two refineries are exactly alike. Depending on the refinery age, location, size, variability of crude and product slates and complexity of operations, a facility can have different operating configurations. This will result in relative differences in the quantities of air pollutants emitted and the selection of appropriate emission management approaches.

Refinery air emissions can generally be classified as either hydrocarbons or combustion products. When handling hydrocarbon materials, there is always a potential for emissions through seal leakage or by evaporation from any contact of the material with the outside environment. Thus, the primary hydrocarbon emissions come from piping system fugitive leaks, product loading, atmospheric storage tanks and wastewater collection and treatment. In terms of combustion products, a refinery uses large quantities of energy to heat process streams, promote chemical reactions, provide steam and generate power. This is usually accomplished by combustion of fuels in boilers, furnaces, heaters and the catalytic cracker. Combustion-related emissions account for the majority of pollutant emissions within a refinery.

In addition to petroleum refineries, pollutant emissions will occur at biorefineries. The likely sources of emissions within these facilities, include cellulose enzyme production (i.e., bioreactor), boilers, storage, water treatment facilities, and product recovery and upgrading (e.g., preheater, hydrotreating process). However, the boiler has been noted by NREL, 2014 as likely the single largest emitting source for CO, NOx, PM, SO_2, and GHG within a biorefinery.

3.3.1 Assumptions

The changes in EU refinery operations to meet the Base and Scenario A, B and C assumptions will lead to varying refinery fuel demands, which will produce changes to refinery emissions of air pollutants.

Estimates of refinery air pollutant emissions have been based on the emissions associated with fuel combustion only. Based on the assumptions described in Chapter 1, Section 1.7.3, refinery fuel consumption for each of the scenarios has been estimated by the WORLD model. Table 3.1 presents a summary of the type and quantity of fuel consumed in European refineries for each of the scenarios.

Table 3.1 Refinery fuel consumption in million barrels of fuel oil equivalent from the WORLD model

Fuel	2020 Base	2020 Scenario A, B and C	2030 Base	2030 Scenario A	2030 Scenario B	2030 Scenario C
Natural Gas	0.43	0.43	0.39	0.39	0.39	0.39
Refinery fuel gas	0.38	0.37	0.30	0.30	0.29	0.29
Residual fuel oil	0.10	0.10	0.08	0.08	0.08	0.08
Fluid catalytic cracking (FCC) Coke	0.07	0.07	0.04	0.04	0.04	0.04
Natural Gas to Hydrogen	0.03	0.02	0.02	0.02	0.02	0.02

Nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxide (CO), particulate matter (PM), non-methane volatile organic compounds (NMVOC), and benzene pollutant emissions have been calculated by applying industry average emission factors from CONCAWE, “Air Pollutant Emission Estimating Methods for E-PRTR Reporting by Refineries,” Report No. 3/15, Brussels (April 2015), to the fuel consumption data in Table 3.1. Carbon dioxide (CO_2) emissions are directly calculated from the WORLD model analysis.

For biorefineries in the EU, fuel consumption is primarily renewable energy from its biomass feedstock (F Cherubini et al., 2013); however, there is a lack of information about the quantity and type of fuel consumed in Europe. Furthermore, biorefinery design specifications can vary significantly based on the feedstock and conversion technology, and include some novel unit operations; e.g., boiler using a combination of biogas, sludge, lignin and other residues. Since biorefinery-based emissions factors are not readily available from literature, a simplified, but conservative assumption has been applied to account for biorefinery air pollution emissions. That is, biorefinery pollutant emissions (e.g., tonnes of NOx, SOX, CO, PM) per unit of production (million barrels per day) is assumed to be the same as refinery emissions per unit of throughput (million barrels per day).

3.3.2 Results

Combustion source emissions at petroleum refineries and biorefineries have been projected to change in line with forecasts of EU refinery throughput and biorefinery production due to the impact of increasing biofuel blends. As discussed in Section 5.4.1, The 2020/2030 Base Case outlook embodies a substantial reduction in EU petrol demand in combination with some increase in diesel demand, which significantly aggravates the already problematic diesel:petrol ratio in the EU and so sets up 2020 and especially 2030 Base outlooks which strain EU refining and lead to projected lower regional refinery throughputs by 2030. This issue is further exacerbated by higher biofuel consumption, since a primary impact of higher biofuels is to reduce EU refining sector throughputs. The overall impact of this effect is a reduction in refinery pollutant emissions in both the Base and each of the alternate scenarios (A, B and C). Table 3.2 presents a summary of the pollutant emissions per scenario in 2020 and 2030 for the refinery sector only, as well as combined refinery and biorefinery emissions. Furthermore, 2010, and where available, 2013 European Environment Agency (EEA) data is presented for comparison.

Table 3.2 Refinery sector pollutant emissions per scenario in kilo tonnes per year

Pollutant	Assumption	Scenario	2010[a]	2013[b]	2020	2030
NMVOC	Refinery	Base	7.3	5.7	4.4	3.7
		Scenario A	7.3	5.7	4.3	3.7
		Scenario B	7.3	5.7	4.3	3.7
		Scenario C	7.3	5.7	4.3	3.7
	Refinery + Biorefinery	Base	7.3	5.7	4.6	3.9
		Scenario A	7.3	5.7	4.6	4.0
		Scenario B	7.3	5.7	4.6	4.0
		Scenario C	7.3	5.7	4.6	4.1
NOx	Refinery	Base	139.7	75.3	48.3	40.6
		Scenario A	139.7	75.3	47.2	40.6
		Scenario B	139.7	75.3	47.2	40.0
		Scenario C	139.7	75.3	47.2	40.0
	Refinery + Biorefinery	Base	139.7	75.3	50.1	42.7
		Scenario A	139.7	75.3	49.8	44.2
		Scenario B	139.7	75.3	49.8	43.6
		Scenario C	139.7	75.3	49.8	44.2
SOx	Refinery	Base	324.3	199.7	104.2	83.0
		Scenario A	324.3	199.7	103.7	83.0
		Scenario B	324.3	199.7	103.7	82.9
		Scenario C	324.3	199.7	103.7	82.9
	Refinery + Biorefinery	Base	324.3	199.7	107.9	87.3
		Scenario A	324.3	199.7	109.3	90.2
		Scenario B	324.3	199.7	109.3	90.4

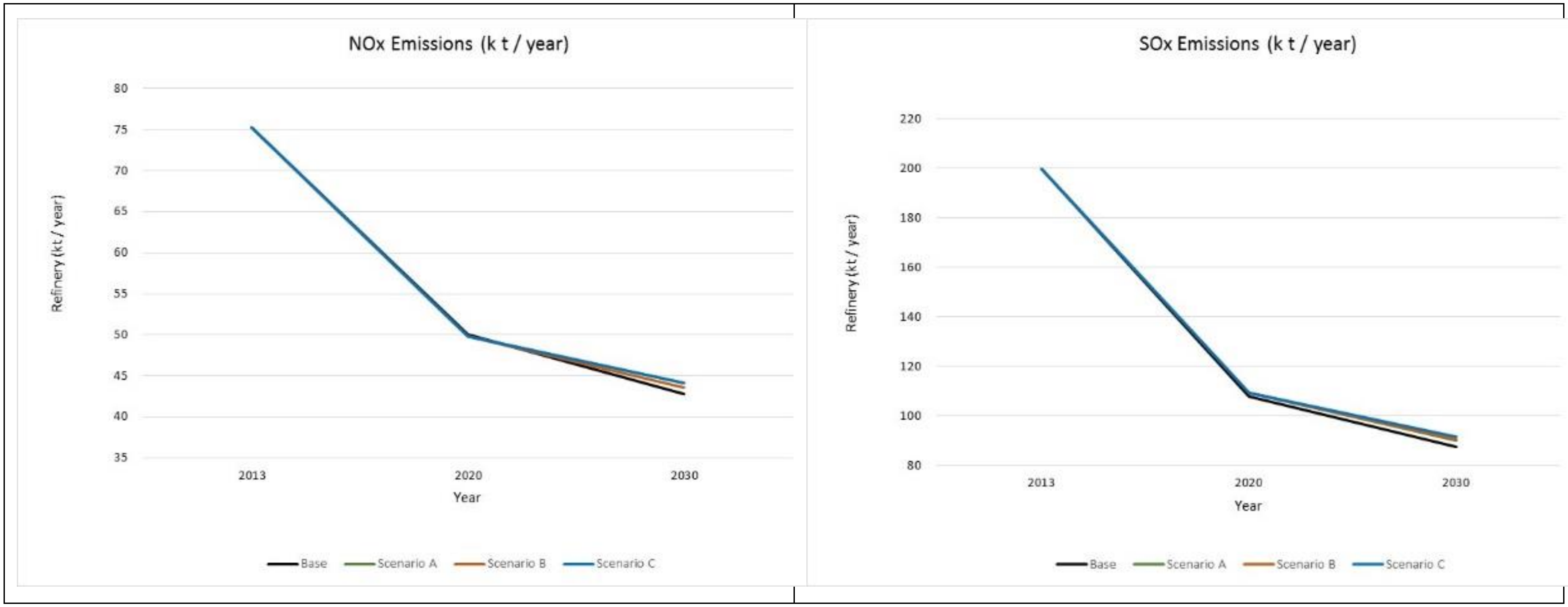
Pollutant	Assumption	Scenario	2010[a]	2013[b]	2020	2030
		Scenario C	324.3	199.7	109.3	91.6
PM	Refinery	Base	8.8		4.8	3.9
		Scenario A	8.8		4.7	3.9
		Scenario B	8.8		4.7	3.8
		Scenario C	8.8		4.7	3.8
	Refinery + Biorefinery	Base	8.8		4.9	4.1
		Scenario A	8.8		5.0	4.2
		Scenario B	8.8		5.0	4.2
		Scenario C	8.8		5.0	4.2
CO	Refinery	Base	35.2		21.2	17.8
		Scenario A	35.2		20.7	17.8
		Scenario B	35.2		20.7	17.6
		Scenario C	35.2		20.7	17.6
	Refinery + Biorefinery	Base	35.2		22.0	18.8
		Scenario A	35.2		21.9	19.4
		Scenario B	35.2		21.9	19.2
		Scenario C	35.2		21.9	19.4
CO2	Refinery	Base			326,714	296,787
		Scenario A			324,905	293,661
		Scenario B			324,905	293,568
		Scenario C			324,905	291,678
	Refinery + Biorefinery	Base			338,287	312,169
		Scenario A			342,315	319,188
		Scenario B			342,315	320,102
		Scenario C			342,315	322,161

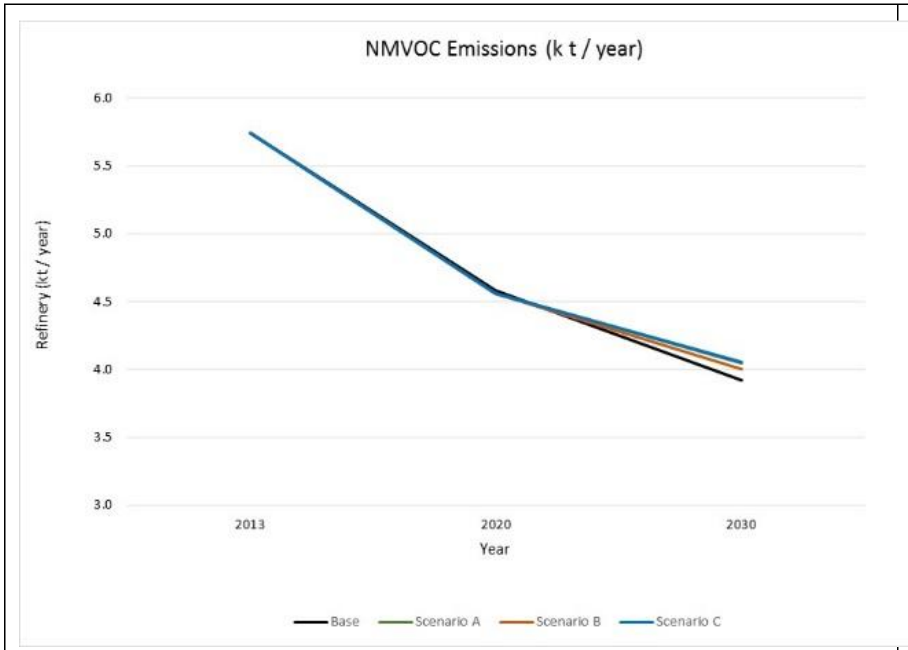
[a]*European Environment Agency (EEA), 2010 air pollutant inventory for refineries (sector code 1A1b); http://www.eea.europa.eu/data-and-maps/indicators/main-anthropogenic-air-pollutant-emissions/*

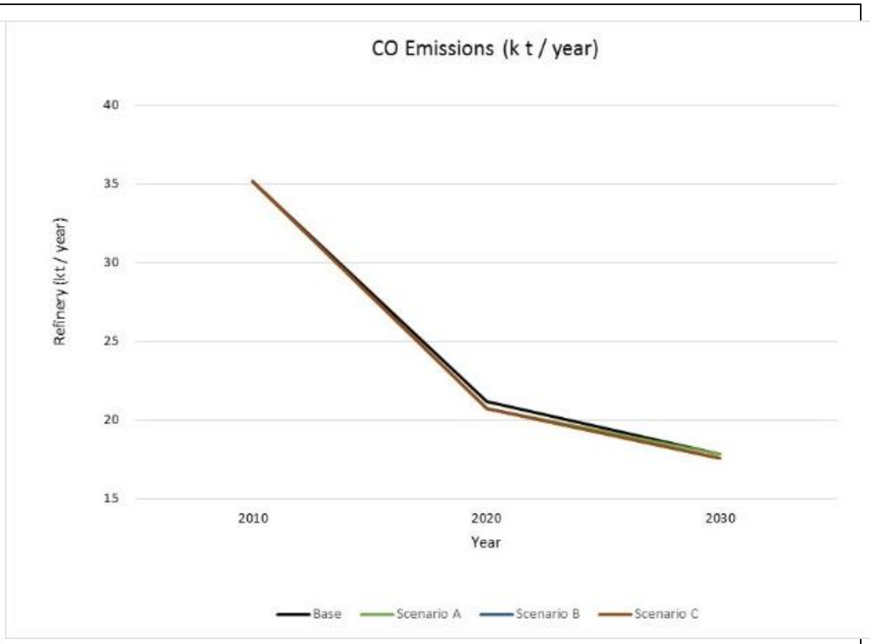
[b]*European Environment Agency (EEA), 2013 air pollutant inventory for refineries (sector code 1A1b); http://www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-nec-directive-viewer*

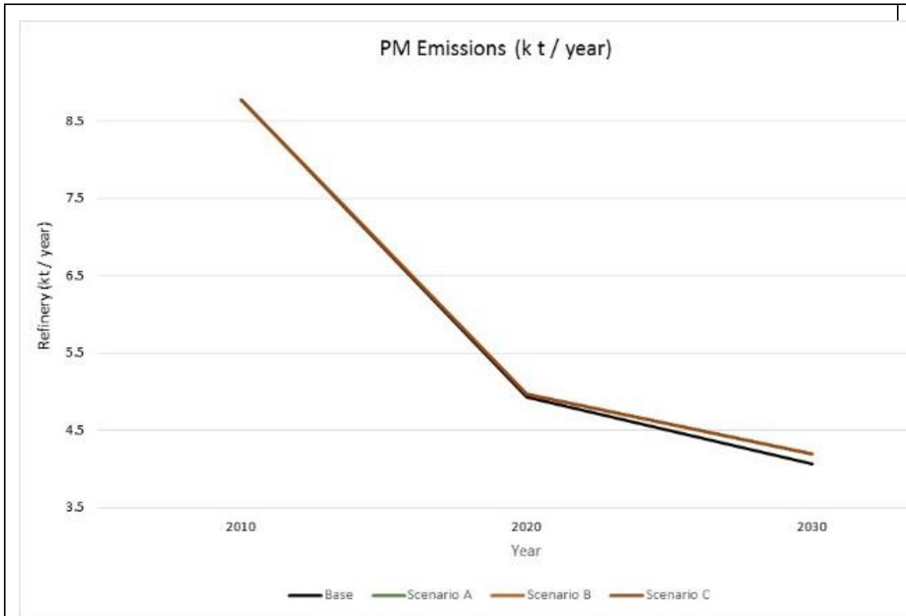
The results of this analysis are also presented in Figure 3.1.

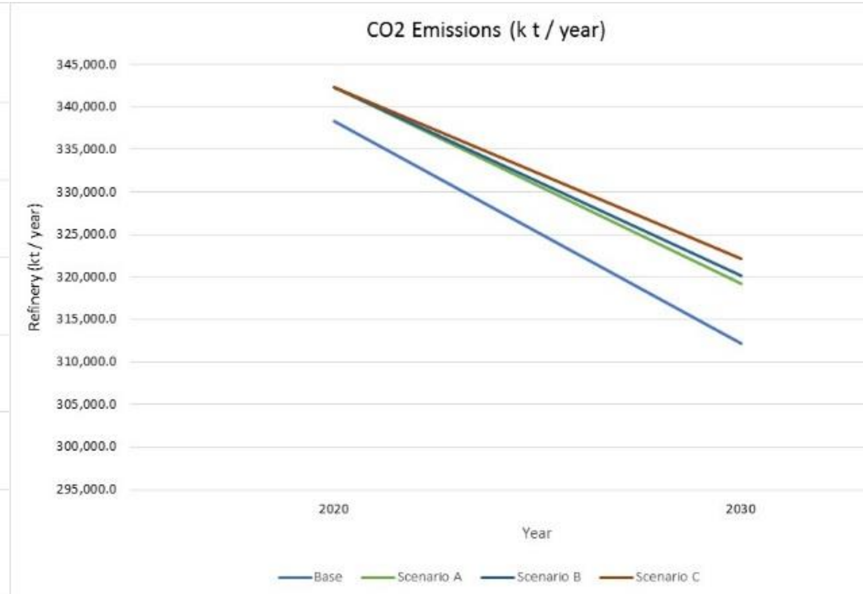
Figure 3.1 Refinery emissions per scenario (k tonnes/year)




NMVOC Emissions (k t / year)
Refinery (kt / year)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2013
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C


CO Emissions (k t / year)
Refinery (kt / year)
40
35
30
25
20
15
2010
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C


PM Emissions (k t / year)
Refinery (kt / year)
8.5
7.5
6.5
5.5
4.5
3.5
2010
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C


CO2 Emissions (k t / year)
Refinery (kt / year)
345,000.0
340,000.0
335,000.0
330,000.0
325,000.0
320,000.0
315,000.0
310,000.0
305,000.0
300,000.0
295,000.0
2020
2030
Year
Base
Scenario A
Scenario B
Scenario C

In the Base scenario, there is a 65% reduction in NOx between 2010 and 2020, which continues the trend reported by EEA between 2010 and 2013 (i.e., over 45% reduction). Between 2020 and 2030, a further 9% reduction in NOx in the Base scenario occurs. In 2030, NOx emissions in Scenario A, B and C are 2-3% above the Base, as a reduction in refinery emissions is assumed to be offset by increases in the biorefinery sector. Nonetheless, sector emissions are still over 40% lower than 2013 pollutant levels.

Similar trends are observed for the other pollutants, SOx, CO, PM and NMVOC. In all cases, pollutant emissions in Scenarios A, B and C vary between 2-5% above the Base case in 2030. However, SOx and NMVOC emissions are still 50% and 30%, respectively, below 2013 levels[75]. For CO and PM, emissions in 2030 for Scenarios A, B and C are 45% and 50%, respectively, lower than 2010 levels as reported by the EEA.

For CO2, emissions reduce in the base and alternate scenarios between 2020 and 2030 by 6-8%. Again, this stems from a reduction in fuel consumption and associated combustion emissions within each scenario. In 2030, CO_2 emissions are estimated to be 2-3% greater than the base due to increased emissions from biorefineries, which offset reduced throughput in the refineries.

3.4 Vehicle tailpipe air quality impacts

Various factors affect the amount of emissions produced by vehicles, including vehicle class and weight, driving cycle, vehicle location, fuel type, engine exhaust after treatment, vehicle age, and the terrain travelled. In addition, engine control effects (such as injection timing strategies) on measured emissions can be significant. The following presents vehicle emissions for 2020 and 2030 for the Base scenario and three alternate scenarios (A, B and C) for both light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs). For the different biofuels considered in the analysis, emissions quantified include oxides of nitrogen (NO_X), total hydrocarbons (THC), non-methane hydrocarbons (NMHC) (for gasoline vehicles only), carbon monoxide (CO), carbon dioxide (CO_2), and particulate matter (PM).

3.4.1 Assumptions

TREMOVES Model (TREMOVE 3.3.2)[76] outputs were used to define Base scenario emissions for 2020 and 2030 for light duty vehicles (LDVs) and heavy duty vehicles (HDVs).[77] It was also used to define the baseline transport demand; that is, the composition of LDV and HDV fleet by fuel type and average annual vehicle kilometres. The total number of vehicles and the annual vehicle kilometres were taken to be constant in all scenarios, and equal to the TREMOVE baseline.

Pollutant emission factors for petrol vehicles in the Base Case (i.e., E5 % v/v (equivalent to E3.4 % energy) were derived from literature (Suarez-Bertoa et al. 2015), while for diesel vehicles emission factors for B5.7 (B5.2 % energy) were estimated by linearly extrapolating vehicle test emission factors for B7 to B10 fuels based on their biodiesel content (7% and 10%, respectively). This is based on the assumption noted in literature (Section 2.4.3.2) that emissions are directly proportional to the biodiesel content of the fuel.

[75] European Environment Agency (EEA), 2013 air pollutant inventory for refineries (sector code 1A1b);

[76] http://www.tmleuven.com/methode/tremove/home.htm

[77] For CO_2, Regulation (EC) No 443/2009 requires that only the fleet average is regulated; as such, it was assumed that EC mandatory 2020 emission reduction targets for new passenger cars and vans would be met[77]. As such, base case CO_2 emissions in 2020 were assumed to decrease in line with these targets. Since no CO_2 targets have been set for 2030, it was assumed that 2020 targets would remain constant through 2030.

Changes in pollutant and CO_2 emission factors from the base case for the different biofuel blend assumptions in scenario A, B and C were obtained literature, specifically the summation of data presented in Section 2.5.1, Table 2.5 for petrol; and Section 2.5.2, Table 2.6 and Table 2.7 for diesel LDV and HDV. These percent reductions for petrol and diesel-based biofuels described in were applied to the baseline emission factors to calculate emission factors for the higher biofuel blends for LDV and HDV. Although, the level of exhaust emissions is dependent on the vehicle and engine type, vehicle tuning and driving cycles, for this analysis, it has been assumed that these results apply to all vehicle types in the EU fleet. Furthermore, the changes in emission factors are assumed to be homogeneous across the EU.

The analysis assumes that emission factors remain constant over time; thus the key determinant driving emissions is the number of compatible vehicles and their use of higher biofuel blends in each scenario, which is described in Chapter 1, Section 1.7.3.

A detailed description of the modelling approach and calculations can be found in Annex 4.

3.4.2 Results

Table 3.3 presents a summary of the pollutant emissions per vehicle type and scenario for 2013, 2020 and 2030. Since the vehicle fleet assumptions in 2020 for scenarios A, B and C are the same, there is no difference between vehicle emissions for these scenarios in 2020. As previously discussed, the analysis has applied some simple assumptions to enable transparent comparison between scenarios. As such, the emissions represent a conservative estimate, as clearly, emissions will be expected to reduce significantly over time due to the tightening of EU emission regulations. Although we have attempted to address this for CO_2, where we have assumed that Base scenario emissions will decline in line with EC targets for new passenger cars and vans, for other pollutants we have maintained emissions outputs reported by TREMOVE.

Consequently, more useful when assessing the air emissions impact of higher biofuel blends is to compare the results against the base case scenario. Table 3.4 presents a summary of the pollutant emission reductions by scenario in 2020 and 2030 against the base case scenario. This information is also presented in Figure 3.2 and Figure 3.3. The results indicate that using biofuels can reduce pollutant levels of THC, NMHC, CO, and PM. In 2030, LDV emissions of these pollutants across each scenario were on average 3%, 3%, 6% and 8% lower than the base case. For NOx, emissions were on average 1% higher than the base case in 2030. CO_2 emissions for scenarios A, B and C were the same in 2020, and 0.2% lower in 2030 than the base case. For HDV, the trends were similar, although no declines in CO2 were noted through 2030.

Table 3.3 Summary of Emissions by Scenario

Vehicle/ Pollutant	Emissions by Calendar Year and Scenario (kilotonnes/year)								
	2013	2020				2030			
	Base	Base	Scenario A	Scenario B	Scenario C	Base	Scenario A	Scenario B	Scenario C
LDV									
CO_2	773,469	721,437	721,437	721,437	721,437	640,502	640,502	639,044	638,557
NOx	1,407.8	817.8	826.0	826.0	826.0	585.5	591.3	592.2	591.8
THC	843.6	532.6	519.5	519.5	519.5	506.3	493.9	489.6	486.5
NMHC[a]	765.1	485.4	473.5	473.5	473.5	462.4	451.1	447.2	444.4
CO	4,047.2	1,960.4	1,874.4	1,874.4	1,874.4	1,520.0	1,453.4	1,426.6	1,417.5

Vehicle/ Pollutant	Emissions by Calendar Year and Scenario (kilotonnes/year)								
	2013	2020				2030			
	Base	Base	Scenario A	Scenario B	Scenario C	Base	Scenario A	Scenario B	Scenario C
PM	63.6	30.6	28.6	28.6	28.6	21.7	20.2	19.8	19.7
HDV									
CO_2	178,955	189,613	189,613	189,613	189,613	201,657	201,657	201,657	201,657
NOx	1,318.6	941.4	950.8	950.8	950.8	901.0	910.1	910.1	909.2
THC	34.4	11.2	11.0	11.0	11.0	5.1	5.0	5.0	4.9
NMHC[a]	-	-	-	-	-	-	-	-	-
CO	203.7	83.8	82.2	82.2	82.2	45.9	45.0	45.0	44.7
PM	23.9	12.1	11.4	11.4	11.4	10.0	9.4	9.3	9.2
Total									
CO_2	952,423	911,050	911,050	911,050	911,050	842,159	842,159	840,701	840,215
NOx	2,726.5	1,759.2	1,776.8	1,776.8	1,776.8	1,486.5	1,501.4	1,502.2	1,501.1
THC	877.9	543.8	530.6	530.6	530.6	511.4	498.8	494.5	491.4
NMHC[a]	765.1	485.4	473.5	473.5	473.5	462.4	451.1	447.2	444.4
CO	4,250.9	2,044.2	1,956.5	1,956.5	1,956.5	1,565.9	1,498.3	1,471.6	1,462.2
PM	87.5	42.7	39.9	39.9	39.9	31.7	29.6	29.1	28.8
Notes: NMHC was estimated for gasoline vehicles only									

Table 3.4 Summary of emission reductions by scenario against the base case

Vehicle/ Pollutant	Emission Reductions Compared to Base Case Emissions (ktonne/year)[a]					
	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
LDV						
CO_2	0	0	0	0	1458	1944
NOx	8	8	8	6	7	6
THC	13	13	13	12	17	20
NMHC[b]	12	12	12	11	15	18
CO	86	86	86	67	93	103
PM	2	2	2	1	2	2
HDV						
CO_2	0	0	0	0	0	0
NOx	9	9	9	9	9	8
THC	0	0	0	0	0	0
NMHC[b]	-	-	-	-	-	-
CO	2	2	2	1	1	1
PM	1	1	1	1	1	1
Total						
CO_2	0	0	0	0	1458	1944

NOx	18	18	18	15	16	15
THC	13	13	13	13	17	20
NMHC[b]	12	12	12	11	15	18
CO	88	88	88	68	94	104
PM	3	3	3	2	3	3
Notes: Black = emission reductions; Red = emission increases. NMHC was estimated for gasoline vehicles only						

Figure 3.2 Summary of Emissions by Scenario for LDV and HDV Combined for 2020

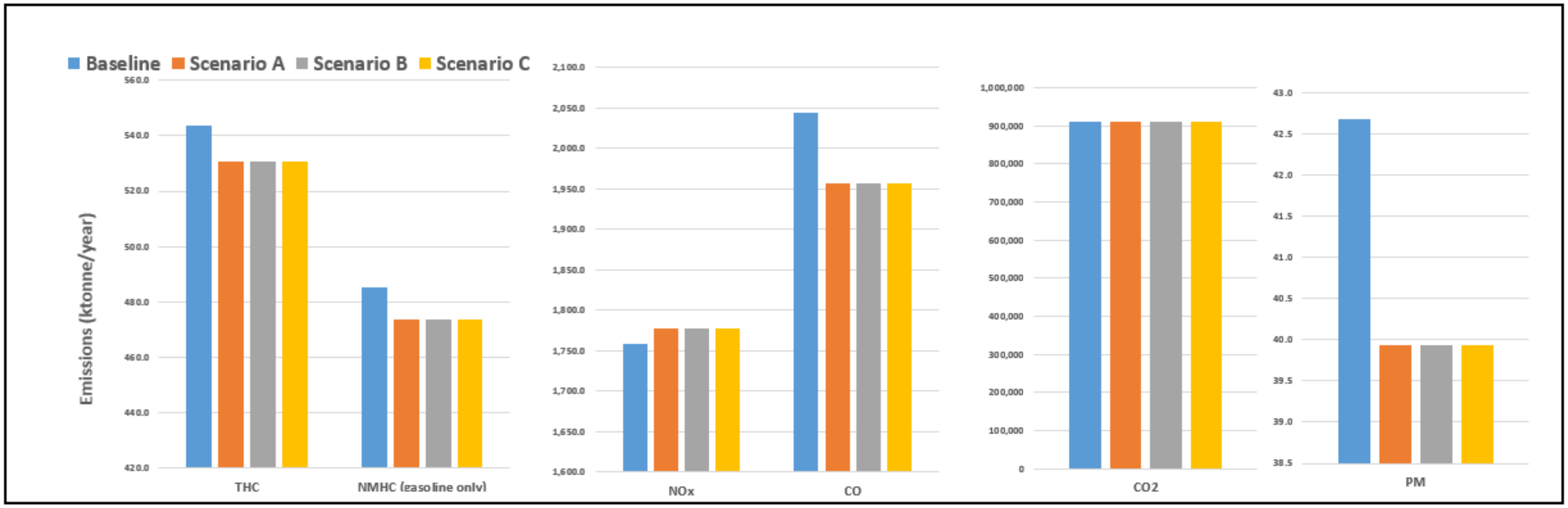
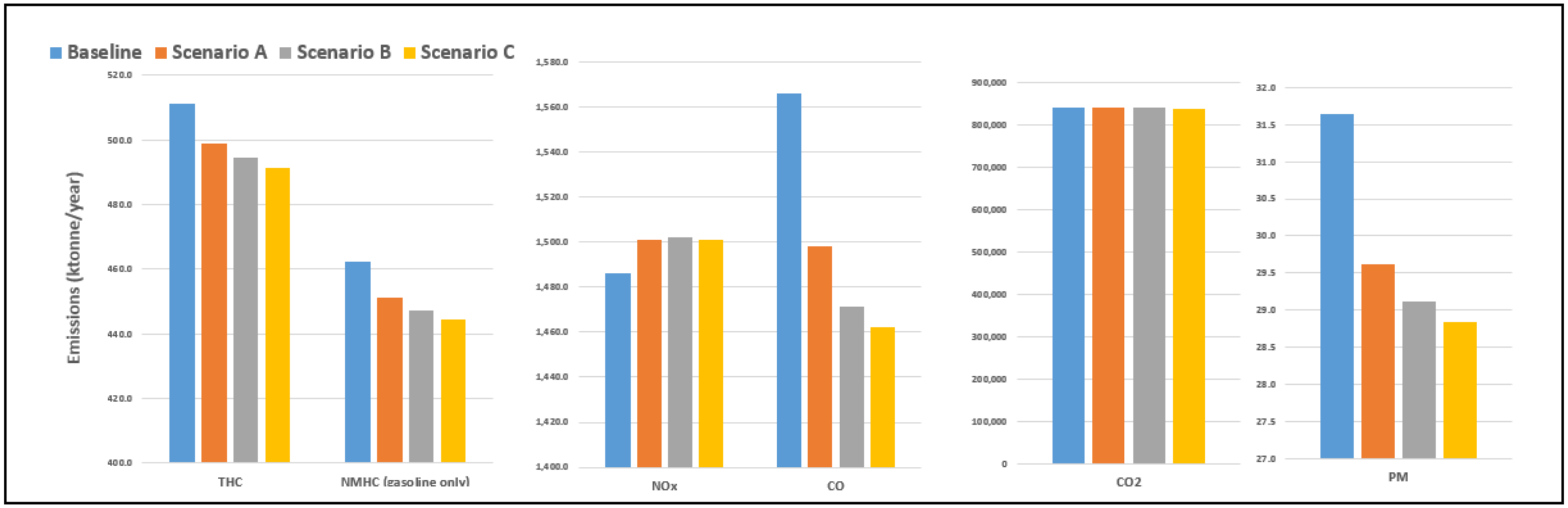


Figure 3.3 Summary of Emissions by Scenario for LDV and HDV Combined for 2030



3.5 Vehicle evaporative emissions impacts

3.5.1 Introduction

Evaporative emissions or non-combustion emissions are a form of emissions that derive from fuel vapours generated in the vehicle fuel tank and the fuel distribution system to the engine. The magnitude of evaporative emissions is generally a function of fuel vapour pressure. Several sources of data illustrate the instrumental effect that vapour pressure has in producing evaporative emissions at varying levels. For example, in the "Joint EUCAR/JRC/CONCAWE Study on: Effects of Gasoline Vapour Pressure and Ethanol Content on Evaporative Emissions from Modern Cars" (G. Martini, 2007), the authors assert that Dry Vapour Pressure Equivalent (DVPE)[78] is a key factor in assessing evaporative emissions; a higher DVPE value denotes higher volatility and is associated with a higher rate of fuel evaporation. Beyond vapour pressure, other factors such as vehicle design can play a role in the emissions impacts of higher ethanol content in petrol. In total, several specific emission types comprise the generalized category of evaporative emissions. Each is discussed below.

3.5.2 Ethanol blends and their effect on vapour pressure

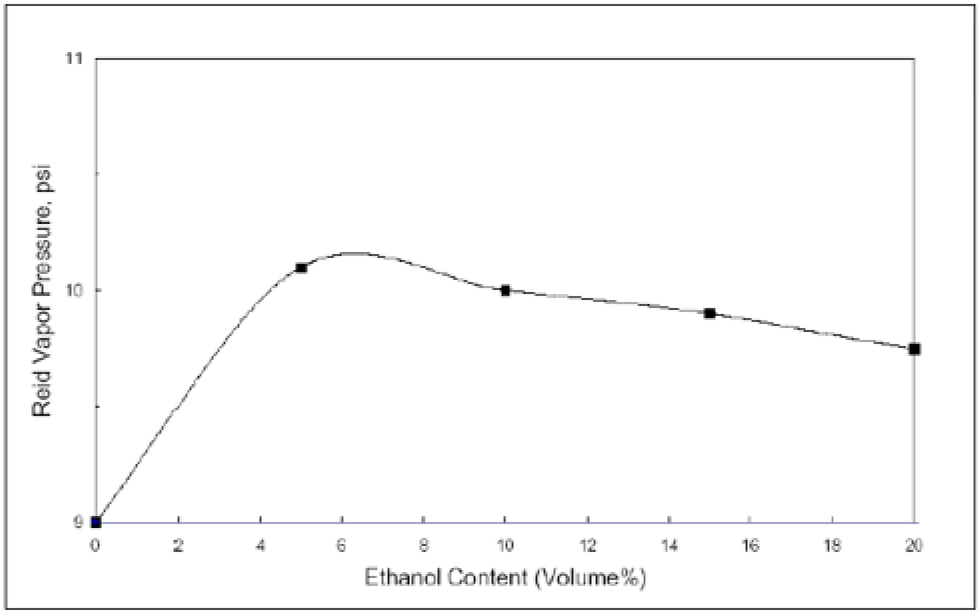
Because significant variation in total evaporative emissions occurs for different fuel blend vapour pressures, it is essential to examine the change in vapour pressure at different concentrations of ethanol in petrol. Figure 3.4 from the Joint Research Centre (JRC) report "Review of the European Test Procedure for Evaporative Emissions: Main Issues and Proposed Solutions" shows that the blend vapour pressure (VP) peaks near 5% ethanol blend concentration and then gradually declines as the effective vapour pressure of the ethanol blend decreases with increasing ethanol concentration (G. Martini, et al., 2012).

The interaction between petrol and ethanol in solution, taken at a molecular level, explains why ethanol in petrol blends first increase in vapour pressure (from E0 to E5) but then, beyond this level, increasing concentrations of ethanol in petrol result in decreased blend vapour pressure. While pure ethanol has a lower vapour pressure than petrol, when ethanol is added to petrol in low proportions (E0 to E5), the more numerous hydrocarbon molecules disrupt the attractive forces between the ethanol molecules, allowing the ethanol to more readily evaporate and this, in turn, raises the blend vapour pressure. Beyond the initial boost in vapour from adding ethanol, a trend emerges from E5 to E100 in which increasing concentrations of ethanol reduce the vapour pressure of the blend because the disruptive impact on the ethanol molecules diminishes. The effect of this phenomenon is that, after reaching a peak vapour pressure in the vicinity of E5, the petrol vapour pressure slowly trends downward thereafter with increasing ethanol concentration.

A key consequence of this phenomenon is that increasing ethanol concentration above 5% leads to minimal impacts on blend vapour pressure with consequently limited impacts on evaporative emissions, although, as discussed below, ethanol can have specific impacts on permeation and canister emissions depending in part on vehicle design and materials of construction.

[78] Reid Vapour Pressure, RVP, or what is more properly called the Dry vapor pressure equivalent (DVPE), or more simply called vapor pressure, is the vapor pressure of a fuel measured at 100 °F (37.8 °C) in a vessel with a vapor/liquid volume ratio of 4:1 by ASTM D5191 or similar method"(McCormick, Yanowitz, 2012). In absence of direct usage of the wording "DVPE" in supporting source material, the generalized wording "vapour pressure" is used throughout this section.

Figure 3.4 Effect of ethanol content on blend vapour pressure



Source: G. Martini, et al., 2012 – pg. 22

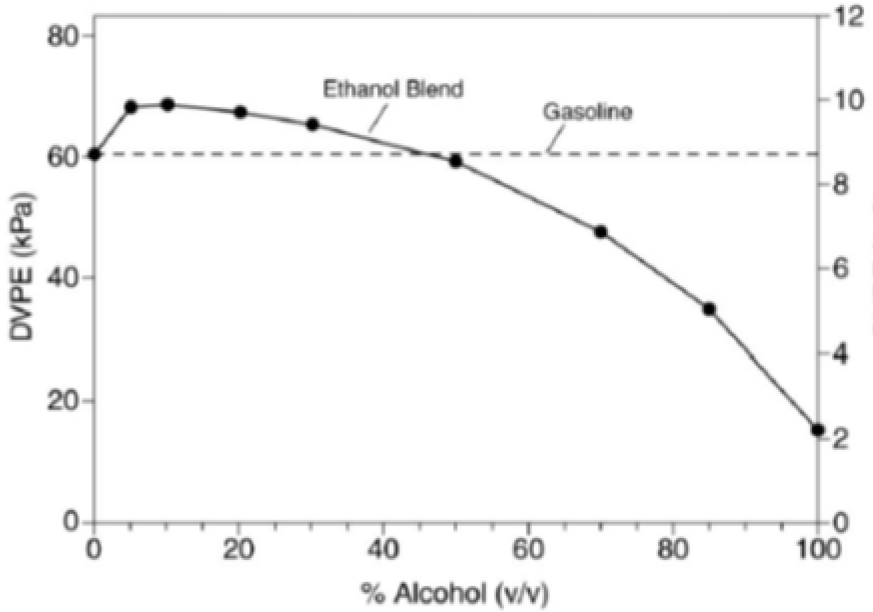
A study conducted by the U.S. National Renewable Energy Laboratory concluded that the RVP impact of a 15% ethanol blend of petrol on emissions is indistinguishable from that of a 10% ethanol blend (McCormick, Yanowitz, 2012). Recognizing that only a small ethanol blend RVP difference – indeed a decline - is depicted between the E10 and E15 blends in the graph above, this conclusion would be expected. Other studies of vapour pressure changes for E5 to E20 blends, such as NREL (2002)[79] and American Petroleum Institute (API) (2010)[80], reflect the same finding that the vapour pressure impact above E5 is marginal and trends down (as depicted in the above graph).

A March 2012 NREL letter to the US Renewable Fuels Association entitled “Discussion Document – Effect of Ethanol Blending on Gasoline RVP” provided extensive information on ethanol VP effects up to 100 vol%. The document references experimental results from a 2010 API report, which examined vapour pressure effects across a wide range of fuels and blendstocks with ethanol concentrations at 0, 10, 12.5, 15, 20 and 30% (Figure 3.5).

[79] Issues Associated with the Use of Higher Ethanol Blends (E17-E24), C. Hammel-Smith, J. Fang, M. Powders, and J. Aabakken, National Renewable Energy Laboratory, October 2002.

[80] American Petroleum Institute, Determination of the Potential Property Ranges of Mid-Level Ethanol Blends, Final Report, April 23, 2010.

Figure 3.5 Effect of ethanol blending on vapour pressure of gasoline

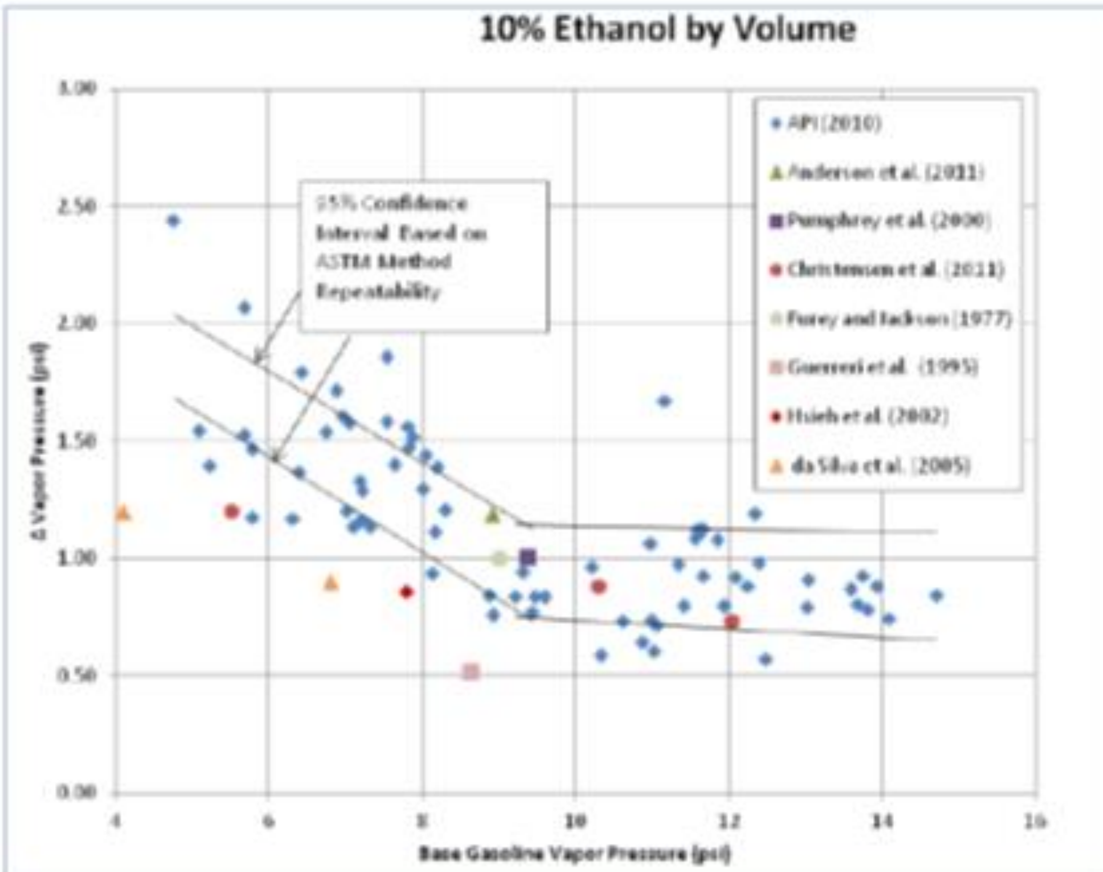


Because vapour pressure has been shown to have a profound effect on evaporative emissions, various studies have quantitatively assessed the impact that blend vapour pressure has on total evaporative emissions for a range of ethanol concentrations in petrol. For example, the JRC (2012) evaluated one of the highest levels of vapour pressure for a petrol blend, around 75 kPa (10.9 psi). The study concluded that ethanol blends with high vapour pressures around 75 kPa showed significantly higher evaporative emissions than lower volatility fuels in most of the vehicles; in short that – as would be expected – higher vapour pressure leads to higher evaporative emissions. Likewise, and again not surprisingly, a separate study by the Coordinating Research Council used the U.S. EPA's MOVES air emissions model and found that reducing summer RVP by 1 psi will reduce evaporative VOC emissions by 5% and total emissions (tailpipe plus evaporative) by approximately 2.5% (McCormick, Yanowitz, 2012).

JRC (2012) also found, however, that evaporative emissions differences were relatively small between ethanol-containing fuels with vapour pressures in the more typical range of 60-70 kPa (8.7 to 10.15 psi). This indicates that, for ethanol blends within the typical narrow (summer) petrol vapour pressure range, total evaporative emissions differences due to vapour pressure are likely to be small. In another study, evaporative emissions were tracked for four vehicles running E0, E10, and E20 blends. All three of the non-splash blended fuels were in the narrow vapour pressure range of 59.3 to 60.6 kPa (8.6 to 8.8 psi) and the differences in evaporative emissions from the fuel blends were found to be not statistically significant (Graham, Belisle and Baas, 2008).

NREL (2012) assessed the impacts of underlying blend composition on ethanol vapour pressure impact. Figure 3.6 illustrates that base gasoline vapour pressure and underlying blendstock composition do tend to have an effect on the level of vapour pressure increase at the 10% ethanol content examined but that the impact is mainly below 1 psi (6.895 kPa) except at low base blendstock vapour pressures where the impact can be 1.5 psi (10.3 kPa) or higher.

Figure 3.6 Change in RVP for blending 10% ethanol into gasolines and blendstocks



The JRC (2012) study examined whether the presence of ethanol in petrol blends could have additional impacts on evaporative emissions beyond purely the direct influence on blend vapour pressure. A series of extra tests was undertaken with same-vapour-pressure fuels. These indicated that ethanol-containing blends could lead to higher total evaporative emissions as a result of increased fuel permeation and/or reduced canister efficiency (see Section 3.5.5). There was significant variation in total evaporative emissions among test vehicles, as such effects are a function of vehicle design and materials of construction. Some vehicles evaporative emission control systems simply perform better than other systems in preventing evaporative emissions. Low permeation hoses, active purge systems, and carbon canisters are some of the components that can play a significant role in reducing emissions.

3.5.3 Vapour Pressure Waiver and Commingling Effect

3.5.3.1 Vapour Pressure Waiver

Because vapour pressure plays such a significant role in total evaporative emissions, the maximum vapour pressure for petrol is regulated. In Europe, the maximum summer season vapour pressure for petrol blends is 60 kPa (8.7 psi). By way of comparison, in the United States, the maximum summer vapour pressure ranges from 49.6 kPa (7.2 psi) to 62 kPa (9 psi) depending on the region (and attendant summer temperature level) and the fuel type – reformulated or conventional.

As discussed, adding ethanol at low concentrations increases the blend vapour pressure unless steps are taken to reduce the volatility of the base blend (pre ethanol addition). As a result of this, and in an effort to not discourage the use of blending of ethanol into petrol, regulations have been enacted to allow petrol with ethanol to have slightly higher vapour pressures. This is generally referred to as a vapour pressure waiver. Under the Fuel Quality Directive 2009/30/EC, EU Member States may apply for a relaxation of the summer vapour pressure limit for petrol blends with ethanol. To date, three EU Member States—Czech Republic, Poland, and Spain—have applied for and received the vapour pressure waiver. In the United States, there is also a waiver for “conventional gasoline” petrol blends with ethanol during summer months and many individual states also have their own regulations for allowing a 6.89 kPa (1 psi) increase in vapour pressure, enabling the petrol blend to reach up to 68.9 kPa (10 psi) versus the typical 62 kPa (9 psi) vapour pressure maximum.

Because evaporative emissions are largely a function of the vapour pressure, higher evaporative emissions generally result from petrol produced under the waiver. Several U.S. states have opted out of the waiver (e.g., New York, Pennsylvania and Texas), the waiver does not apply to reformulated (RFG) petrol (one-third of the US market in 2010) and the waiver will not apply to U.S. E15 fuel. If and when the U.S. does transition from E10 to E15 fuel, in regions that are currently utilizing the vapour pressure waiver for conventional gasoline, the RVP of the blend will decrease to conform to the “no-waiver” maximum RVP specification and, as a result, the evaporative emissions will be reduced (Air Improvement Resources, 2011).

The existence of waivers can be considered an indirect consequence of ethanol’s higher vapour pressure at relatively low ethanol concentrations in petrol. Whether the higher vapour pressure has any material impact is a function of the regulations for petrol vapour pressure. Where no waiver is allowed (e.g., as in the case of US RFG) the effect is for ethanol use to cause refiners to have to reduce the vapour pressure of the base blend stock, generally through the rejection of butane and other light streams. Since these streams are generally low value/price blend stocks, the effect is often a small increase in the produced cost of the petrol.

Section 3.5.6 discusses the implications of higher biofuel blends on the EU VP waiver.

3.5.3.2 Commingling

Even where all petrol grades have to comply with the same vapour pressure specification, (no waivers in place), blend vapour pressures will be higher in areas which have fuel blends at different ethanol concentrations, for example E0 and E10, than in areas with a uniform ethanol level. The effect of different ethanol-petrol blends being mixed with one another by motorists filling up their fuel tanks is dubbed the commingling effect. For example, if a motorist refuels a tank that is half full with E0 at a given DPVE, but adds a 10% ethanol blend at the same DVPE, the overall effect will be to turn the non-ethanol petrol into a 5% ethanol blend by volume. This situation would cause the DVPE of the non-oxygenated petrol to increase by about 1 psi; since that petrol represents 50% of the fuel in the tank, the average DVPE of all the fuel will increase by about half that amount, or about 0.5 psi. (JRC, 2012)

3.5.4 Splash Blending

Another consideration with regard to fuel vapour pressure and thus evaporative emissions is splash blending, or how the ethanol is blended into the petrol. The ethanol is either “splashed” into what is already a finished petrol grade, thus potentially impacting the fuel blend properties, or the ethanol is added to a specifically prepared petrol base stock so that the final blend has met a specified set of properties (Air Improvement Resources, 2011). Splash blending may result in increased evaporative emissions but the emissions difference is likely small. In the 2008 study by Graham, Belisle and Baas, evaporative emissions were tracked for four vehicles running E0 to E20 blends, differences between splash-based fuels were not found to be statistically significant. Another study, showed no statistically significant difference in evaporative emissions for E10 splash blended fuel vs. E10 non-splash blended fuel (Morris, Brondum, 2000).

Thus both studies reported a lack of any statistically significant differential in evaporative emissions. This lack of any observed emissions differential indicates that the base blendstock(s) may have been pre-configured for the addition of ethanol. As use of ethanol expands, the trend is generally to replace splash blending with the more rigorous preparation of specific blendstocks in order to optimize the total blend and minimize costs.

3.5.5 Specific Emission Forms

Evaporative emissions result from refuelling, diurnal temperature change, running loss, hot-soak, and permeation. At present the US has the most stringent evaporative emissions standards while those in the EU are similar to levels in force in the US in 1994. Most evaporative emissions derive from fuel vapours generated in the fuel tank and thus their magnitude is generally a function of fuel RVP. Ethanol added to petrol at low to moderate concentrations (E5-E30) increases fuel RVP and thus vapour generation, but the peak RVP occurs at a 5 to 10% ethanol blend. However, blend-stocks for ethanol-petrol blends are modified as needed to meet seasonal and regional fuel RVP limits. While petrol is regulated based on vapour pressure measured at 40º C, the fuel in the vehicle is exposed to both higher and lower temperatures. Vapour pressures of ethanol-petrol blends exhibit a greater change with temperature than petrol containing no ethanol. In addition, splash blending of E20 from an E5 base will reduce RVP.

The emissions from the different sources have been evaluated in various studies but it is important to note that there are often conflicting findings associated with the tracking of these specific emissions because small emission differences are difficult to accurately measure and the vehicle sample size of these studies is often small. The following paragraphs outline the different sources of evaporative emissions: permeation, diurnal, running loss, hot soak, and refuelling, their main drivers, and the conclusions regarding the particular emissions based on available literature.

3.5.5.1 Permeation Emissions

Permeation Emissions comprise fuel compounds that escape through the fuel tank and distribution system. Permeation emissions can be an important driver of total evaporative emissions and generally increase with blend vapour pressure, temperature, aromatic hydrocarbon content, and solubility in the fuel system materials. As a result, permeation emissions generally increase with increasing ethanol content in the very low concentration range (E0 to E5). JRC (2012) show that evaporative emissions increased 13 and 23 percent about two weeks after switching from E0 (vapour pressure 57.2 kPa) to E5 (vapour pressure 64.3 kPa), a switch the authors contend is due to fuel permeation. Additionally, for all test vehicles, permeation emissions increased in a statistically significant manner for E6 to E20 blends as compared to reference E0 blends (JRC, 2012). In a separate study, the Coordinating Research Council in 2010 found that permeation rates are higher with E10 or E20 fuels as compared to E0 fuel (Coordinating Research Council, Inc., 2010). This study noted a “trend” towards lower permeation emissions from E10 to E20 fuels, although the magnitude of the emissions difference and sample sizes for the vehicles tested was too small to firmly establish the decrease in permeation emissions from E10 to E20. However, when evaluating the transition all the way to E85, lower permeation emissions resulted as compared to reference E0 fuels because of decreased blend vapour pressure. (As illustrated previously, there is a constant yet slow trend towards lower vapour pressure beyond E5 blends. Pure ethanol has a vapour pressure of only 15.8 kPa (2.3 psi) at 100°F, 37.8°C).

Beyond the fuel used, permeation emissions are significantly driven by vehicle design (materials used for the tank and distribution system and layering[81], if any). JRC (2012) indicate that lower permeation emissions result from multilayer tanks or ones made of metal, as compared to the much more common plastic ones. In modern plastic multi-layer coextruded fuel tanks, ethanol can negatively interact with the ethylene vinyl alcohol barrier layer designed to control hydrocarbon permeation and increase hydrocarbon permeation. While multilayer tanks are common in the United States where stricter emission limits generally apply, about 35 percent of the vehicles in Europe are still equipped with monolayer tanks. Overall, higher permeation emissions result from having monolayer fuel tank designs and thus some European cars will continue to see higher permeation emissions directly as a result of having these monolayer tanks, regardless of whether ethanol has been added to the petrol. As one would expect, the usage of advanced evaporative systems (LEV II and PZEV1 systems), has been found to result in decreased permeations emissions compared to the usage of conventional systems. Study methodology is also a consideration in measuring permeation emissions: it takes up to 20 weeks to stabilize a low-permeation, multi-layer tank to steady state conditions and the U.S. tends to have stricter standards in measuring emissions (JRC, 2012).

3.5.5.2 Diurnal emissions

Diurnal emissions are those that result from fuel evaporation and escape (from a stationary vehicle) due to the temperature variation between day and night, **running loss emissions** are those that result from fuel evaporation and escape while the engine is running, and **hot soak emissions** are comprised of fuel that evaporates during the one hour period after the engine is shut-off (Tanaka, 2007). Diurnal emissions do not occur through a specific opening but, rather, individual molecules escape through areas such as fittings, openings, or plastic or rubber materials in the distribution system (California Environmental Protection Agency, 2008). Carbon canisters play a role in diurnal emissions, both in canister design and in how saturated the canister is before testing. Diurnal test results show higher evaporative emissions when the canister is fully saturated and, also, fuel vapour pressure plays a role because higher fuel vapour pressure reduces the time to saturate the canister. JRC (2012) indicates diurnal emissions did not change between E6 and E10 but appeared to increase in a non-statistically significant manner between E6 and E20. There remains a significant degree of uncertainty in quantifying the effect of particular emission forms though. In their 2009 Report, G. Martini, et al. state “What is not very well known is the contribution of the fuel permeation to the total evaporative emissions.”

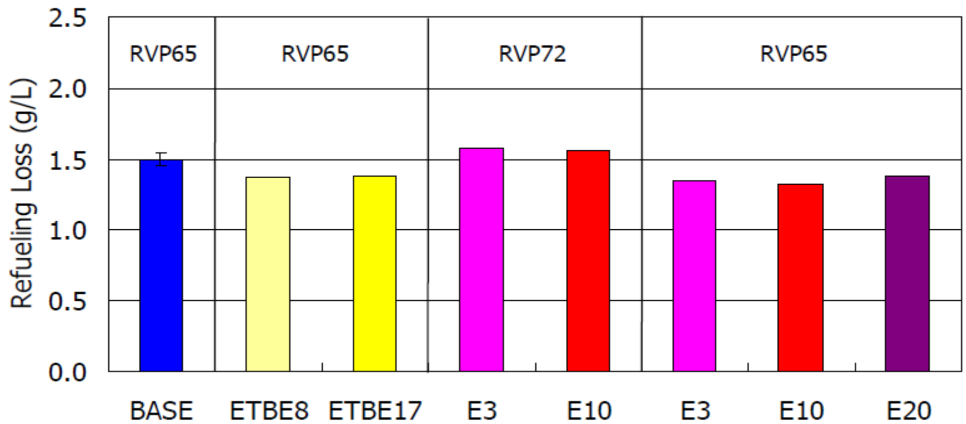
3.5.5.3 Refuelling Emissions

Refuelling Emissions result from liquid petrol flowing into the tank and displacing petrol rich vapour during the refuelling process. These emissions generally increase and decrease with petrol vapour pressure. Thus refuelling emissions will generally rise in the very low ethanol in petrol range, and then gradually decline with declining vapour pressure above the E5-E10 threshold, assuming that the blend vapour pressure is not re-adjusted to account for the presence of ethanol. Refuelling evaporative emissions tests are generally conducted at temperatures less than 40 °C, thus for E0 and E10 fuels with equal RVP, E10 yields lower refuelling emissions than E0. JRC (2012) showed that refuelling emissions increased because of reduced effectiveness of vapour recovery systems running fuels with higher vapour pressures. A Japanese study supports the finding that vapour pressure is the driving force. The graph below shows that refuelling loss emissions are very similar across fuel grades for a particular vapour pressure level. However, refuelling loss is greater for RVP72 (both E3 and

[81] Standard high density poly-ethylene (HDPE) tanks show higher emissions than multilayer tanks that are composed of HDPE and a film of ethylene-vinyl alcohol as one of the layers.

E10) as compared to RVP65 (E3, E10 and E20), indicating once again the importance of blend vapour pressure in determining evaporative emissions (Tanaka, 2007). However, this benefit may be offset by a greater frequency of refuelling events because of lower volumetric energy content of higher blends.

Figure 3.7 Effects of Ethanol or ETBE Blending in Petrol on Refuelling Loss Evaporative Emissions (Tanaka, 2007)



Recent published studies suggest that ethanol content has some effect on permeation emissions but little effect on diurnal, running loss, and hot-soak emissions. For example, in a Canadian government sponsored study (Graham, Baas and Belisle, 2008), diurnal and hot-soak emissions were unaffected by ethanol content using E0, E10, and E20 fuels with equal vapour pressure and an E10 splash blend with higher RVP.

A subsequent CRC study (Haskew and Liberty, 2011) examined evaporative emissions from four US certified MY2006-2007 FFVs with E6, E32, E59, and E85 with matched RVP. Running loss and hot-soak emissions did not show a trend with ethanol content. Diurnal emissions for E6 and E32 were similar, but an increase for the E59 and E85 fuels was indicated. The reactivity of these emissions showed no clear trends with ethanol content.

Hence mid-level ethanol blends (e.g., E20 or E30) with equal RVP are expected to have little impact on refuelling, diurnal, running loss, and hot-soak emissions. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but this is not directly relevant for the fuel choices considered here. Any reduction in RVP from blends above E5 should tend to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

3.5.6 EU vapour pressure waiver: Extension of Annex III

Directive 2009/30/EC of the European Parliament and of the Council of 23 April 2009 sets out allowed vapour pressure (VP) waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. Annex III in that Directive tabulates allowed petrol vapour pressure waivers at ethanol concentrations from 1 to 10 volume percent. The following summarises the potential impacts on petrol vapour pressure of blends with ethanol contents above 10 % and proposes an extension to Annex III to cover such blends.

Table 3.5 below sets out Annex III values for volume percent of ethanol in the blend and the associated vapour pressure (VP) waivers at ethanol concentrations of 1 to 10 volume percent, (columns B and C) and then adds proposed waiver values for ethanol concentrations up to 30%. EnSys worked on the basis that the underlying base blend was at 60 KPa (column d) and used this assumption to compute first the indicated blend vapour pressure (base plus waiver value), (column E), and then the implied ethanol vapour pressure (column F). The deduced ethanol vapour pressures drop as ethanol concentration rises. EnSys crossed checked that the vapour pressure at 10 volume % was close to values commonly used.

We then applied the results from the sources discussed above which evaluated the effect of ethanol concentration on vapour pressure. EnSys used the data from Figure 3.5 and Figure 3.6 to trace out ethanol vapour pressures from 10 out to 100 volume %. The data are shown in columns B and F of Table 3.5. Note that ethanol VP drops from some 425 kPa (61.6 psi) at 1% concentration to 15.9 kPa (2.3 psi) at 100% concentration. EnSys then used the ethanol vapour pressures to extend the Annex III table to ethanol concentrations up to 30 volume %. As part of this assessment, we plotted ethanol vapour pressure, blend vapour pressure and vapour pressure waiver level against volume percent ethanol. The results are presented in Figure 3.8, Figure 3.9 and Figure 3.10. These plots were essential to ensure smooth progressions in the data points in the extended Annex III.

The net effect of this extension is that it shows, consistent with third party papers, that ethanol's effective vapour pressure in petrol declines as its concentration increases, initially sharply to about 10% concentration and then more slowly. As a result, for a given base petrol, the blend vapour pressure peaks at an ethanol concentration of around 5% and then steadily declines. Consequently, raising ethanol content from 0 to 5% has a marked upward impact on blend VP, but increasing concentrations further actually lowers blend VP, e.g. in the calculation used, from 68 kPa at 5% to 67.8 kPa at 10% and 66.8 kPa at 30%. Thus, going to higher ethanol concentrations beyond 5% does not cause increased pressure on petrol blend VP; rather the effect is to gradually reduce the vapour pressure waiver effect.

Table 3.5 Annex III waiver table – existing and draft proposed extension

	Volume content of ethanol in petrol - percent	Vapour pressure waiver permitted (kPa)	base petrol assumed kPa	blend kPa	ethanol kPa
A	B	C	D	E	F
	0	0	60	60	
	1	3.65	60	63.65	425.0
	2	5.95	60	65.95	357.5
	3	7.2	60	67.2	300.0
	4	7.8	60	67.8	255.0
	5	8	60	68	220.0
	6	8	60	68	193.3
	7	7.94	60	67.94	173.4
	8	7.88	60	67.88	158.5
	9	7.82	60	67.82	146.9
original	10	7.76	60	67.76	137.6
new	*15*	*7.55*	*60*	*67.55*	*110.3*
	20	*7.31*	*60*	*67.31*	*96.5*
	25	*7.06*	*60*	*67.06*	*88.3*
	30	*6.82*	*60*	*66.82*	*82.7*
	40				*71.0*

	Volume content of ethanol in petrol - percent	Vapour pressure waiver permitted (kPa)	base petrol assumed kPa	blend kPa	ethanol kPa
	50				*59.0*
	70				*41.4*
	85				*27.6*
	100				*15.9*

Figure 3.8 Ethanol vapour pressure versus concentration in petrol

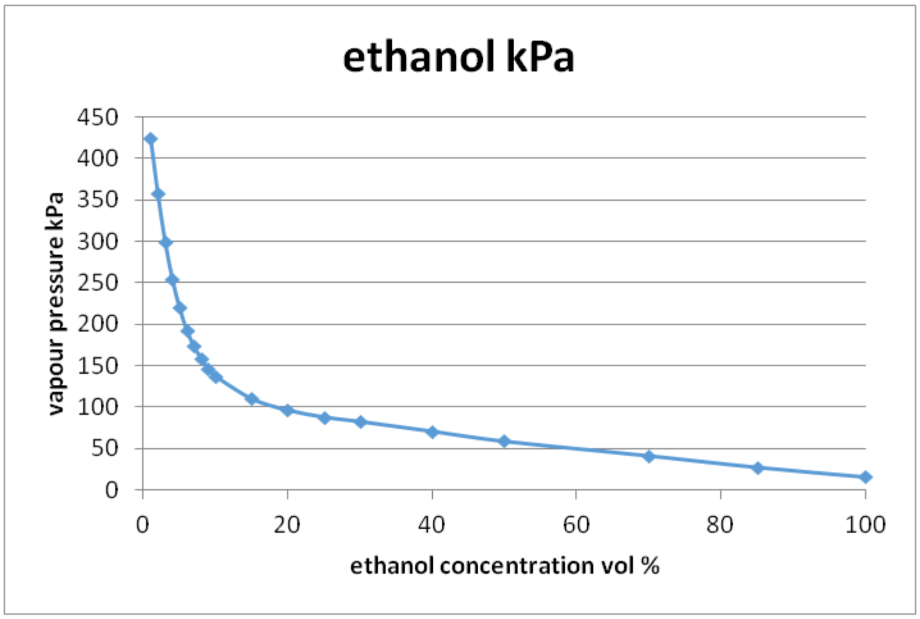


Figure 3.9 Petrol blend vapour pressure at different ethanol concentrations

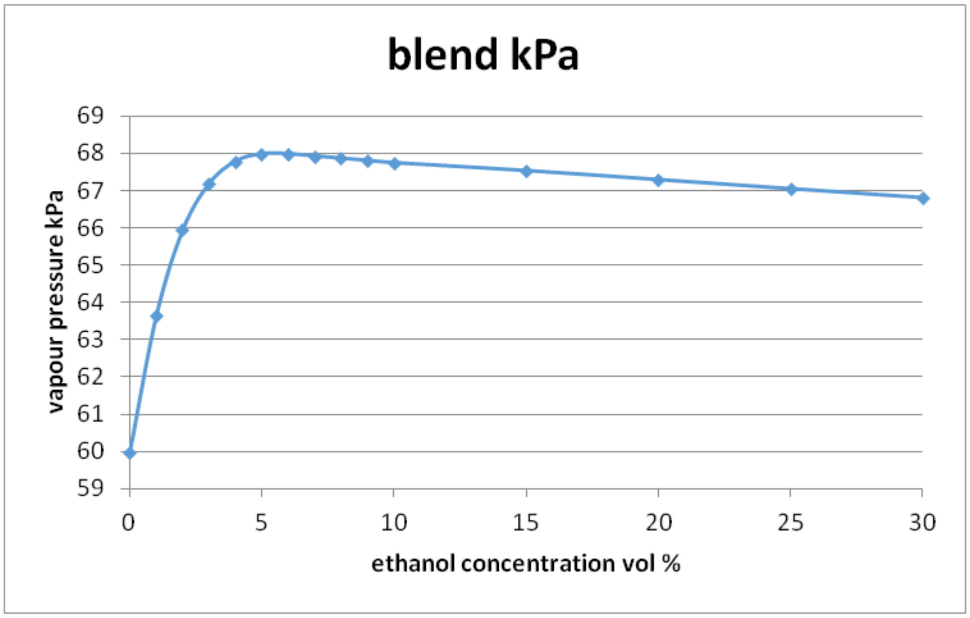
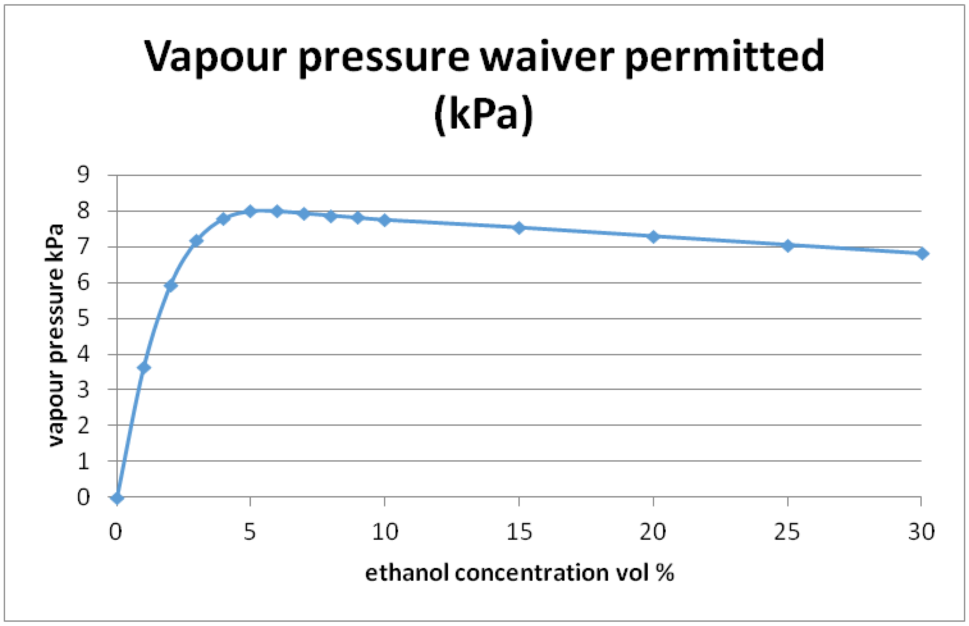


Figure 3.10 Petrol vapour pressure waiver permitted & proposed



There is an option in the EU for countries to apply for a vapour pressure waiver (increase) for blends which contain ethanol. As laid out in Annex III of the FQD, the allowed level of vapour pressure increase is a function of the ethanol concentration in the petrol blend. As also noted, to date, only three EU countries have requested a waiver under this programme. However, should ethanol content in EU petrol increase, it is possible more countries would apply for the vapour pressure waiver. If that happened, then the increasing ethanol content could indirectly lead to increased evaporative emissions as a consequence of more countries obtaining waivers which in turn bring increases in (summer) petrol vapour pressure.

3.6 Conclusions

Higher biofuel blends will not detrimentally impact air pollution from the refinery sector. In the refinery sector, through 2030, emissions of air pollutants are expected to continue their ongoing decline from 2010/2013 levels. These declines are directly linked to reduced refinery throughput, and associated lower fuel consumption, in the Base and all alternate scenarios (A, B and C) analysed in this study, even though biorefinery production will likely offset some of the air pollution reduction due to refinery throughput reduction. The refinery sector accounts for only a small fraction of pollutant emissions when compared to vehicle tailpipe emissions.

The use of the higher blends analysed will not negatively impact air pollution from vehicle tailpipe emissions. Modelling results illustrate that compared to a base case (i.e., current biofuel blending levels), pollutant levels of THC, NMHC, CO, and PM will decline with higher blends. In 2030, LDV emissions of these pollutants across each scenario were on average 3%, 3%, 6% and 8% lower than the base case. For NOx, emissions were on average 1% higher than the base case in 2030. CO_2 emissions for scenarios A, B and C were the same in 2020, and 0.2% lower in 2030 than the base case. For HDV, the trends were similar, although no declines in CO_2 were noted through 2030.

Moving to higher ethanol blends will not result in adverse evaporative emissions impacts in petrol. The upward impact is highest at around 5% ethanol concentration and then gradually declines as ethanol concentration is raised. Research shows that evaporative emissions do, as would be expected, increase potentially significantly with petrol blend vapour pressure—irrespective of whether ethanol is present in the blend. (For example, butane or other light streams could be added which would raise blend vapour pressure.)

Moving to higher ethanol blends does not mean increases in the ethanol waiver, rather the required waiver (in kPa) gradually declines out to and beyond 30 volume % ethanol. Annex III of the Fuel Quality Directive (FQD; 2009/30/EC) sets out allowed VP waivers (i.e. increases) versus the standard specifications for EU petrol blends containing ethanol. The vapour pressure of ethanol in petrol gradually declines as its concentration rises above 5 volume %.

Ethanol content has some effect on permeation emissions but little effect on diurnal, running loss, and hot-soak emissions. Studies indicate that diurnal, refueling and hot-soak emissions were unaffected by higher ethanol content in petrol. Some impacts on permeation have been observed for high-level ethanol blends (e.g., E51-E85) but not within the E10 to E25 range. Any reduction in VP from blends above E5 should tend to reduce the magnitude of these emissions. The overall reactivity of the emissions also tends to decrease with increasing ethanol content.

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4 Impacts on greenhouse gas emissions

Abbreviations/acronyms

API	American Petroleum Institute
CO_2	Carbon dioxide
GHG	Greenhouse gas
HVO	Hydrotreated vegetable oil
ILUC	Indirect land use change
MJ	Mega joule
RED	Renewable energy directive

4.1 Summary

The life-cycle GHG emissions impacts of higher biofuel demand was assessed using three key factors:

- The percent of biofuel blended with petrol and diesel. This factor accounts for both the increase in biofuel consumption as well as the decrease in petrol or diesel consumption, as is defined by the hypothetical scenarios presented in Chapter 1, Section 1.7.3 (Base Case, and Scenarios A, B, and C).
- The feedstock of biofuels blended with petrol and diesel. The feedstock determines the corresponding emissions factor to be used in the calculation–in terms of grams of carbon dioxide equivalent (CO2-eq) per unit energy (megajoule, MJ) of fuel, gCO2-eq/MJ. The feedstock also determines the impact of indirect land use change (ILUC). This factor was addressed via research and assessment of the EU's potential for producing and importing biofuels from various feedstocks.
- Projected changes in lifecycle emissions of biofuels over time as a result of process improvements. To the extent that there is potential to reduce GHG emissions over the lifecycle of biofuel production – from cultivation through to production at the biorefinery, this variable characterizes changes over time. This factor could also include other parallel impacts, such as changes in the emissions factor of petrol and diesel as a result in crude slate shifts, for instance. This factor was addressed by reviewing emissions estimates e.g., via differences between default and typical values, as well as other potential improvements in the lifecycle of biofuels.

The range of lifecycle GHG emissions under the scenarios in this study were estimated using the following two very different sets of assumptions:

- It is assumed that the carbon intensity of biofuels would significantly reduce over time as a result of future technological improvements made in the lifecycle. Emissions from indirect land use change (ILUC) were not included in the approach 1.
- The GHG emissions was estimated by applying the default values for biofuels as set out in current legislation (Fuel Quality Directive (2009/30/EC), Annex IV) and indirect land use change (ILUC) emissions (Directive 2015/1513) and the default factors were held constant over time.

The estimated benefits of biofuels are dependent on a) reducing the carbon intensity of biofuels over time as a result of improvements made in the supply chain of biofuels, b) expanded use of waste-based feedstocks, particularly for FAME and HVO production and c) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030,[82] including for ethanol, biodiesel, and renewable diesel. Assuming a reduction in the carbon intensity emission factors of biofuels over time and excluding indirect land use change (ILUC) GHG emissions, the analysis yields an estimated reduction in the range of 7.1 to 9.4% for the three higher blend limits and use scenarios in 2030. However, if no reductions in the carbon intensity of biofuels are assumed over time, and the emission factors as set out in current legislation are used, including default carbon intensity values for biofuels (included in FQD Annex IV) and indirect land use change factors (in the ILUC Directive), the analysis yields GHG emission reductions between 0.8 to 1.5% compared to the base case scenario.

4.2 Introduction

This chapter assesses the greenhouse (GHG) impacts of blending higher levels of bio components in transport fuels. Under the assumed scenarios of increases in the volume of biofuels blended in petrol and diesel, the life-cycle GHG emissions impacts are determined by three key factors:

1. **The percent of biofuel blended with petrol and diesel**. This factor accounts for both the increase in biofuel consumption as well as the decrease in petrol or diesel consumption. This variable was determined previously as part of the development of the Base Case Scenario, Scenario A, Scenario B, and Scenario C.
2. **The feedstock of biofuels blended with petrol and diesel**. The feedstock determines the corresponding emissions factor to be used in the calculation–in terms of grams of carbon dioxide equivalent per unit energy of fuel, gCO_2-eq/MJ. The feedstock also determines the impact of indirect land use change (ILUC).
3. **Projected changes in lifecycle emissions of biofuels over time as a result of process improvements**. To the extent that there is potential to reduce GHG emissions over the lifecycle of biofuel production – from cultivation through to production at the biorefinery, this variable characterizes changes over time. This factor could also include other parallel impacts, such as changes in the emissions factor of petrol and diesel as a result in crude slate shifts, for instance.

The first factor is described in Chapter 1, Section 1.7.3, where four biofuel blend scenarios are presented (Base Case Scenario and Scenarios A, B, and C) for the period through 2030. The second factor, focusing on the feedstock of biofuels blended with petrol and diesel, was addressed via research and assessment of the EU's potential for producing and importing biofuels from various feedstocks. The third factor was addressed by reviewing emissions estimates e.g., via differences between default and typical values, as well as other potential improvements in the lifecycle of biofuels.

4.3 Overview of the EU biofuels market: Current status and potential changes

The market for biofuel blending today is nearly exclusively linked to so-called first generation biofuels – those that are produced from conventional feedstocks or primary agrocommodities. More specifically:

- The biodiesel market is primarily supplied by rapeseed oil (~65%), palm oil (~20%),[83] and soybean oil (~10%). The balance of feedstocks come from sunflower oil, cotton seed oil, and pine oil.

[82] However, the factor of 10 growth in 2nd generation biofuels is still assumed to represent only 5% of total EU biofuel production capacity today, estimated at approximately 25,000 ktoe.

[83] Primarily imported from Southeast Asia.

- The ethanol market is primarily supplied by corn/maize (42%), wheat (33%), and sugar beet (17%). The balance of feedstocks come from cereals such as rye and barley.[84]
- The HVO market is dominated by a single supplier today, Neste Oil; Neste reports a mix of feedstocks, mostly palm oil and other virgin vegetable oils, and waste oils and residues.[85]

Moving forward, the biofuels market is constrained by a combination of policy and technical issues. Firstly, the EU has incentivized biofuel production and consumption through the RED, requiring 10% renewable content in transportation fuels by 2020. Recently, however, the EU agreed to cap the volume of biofuels from agricultural crops (which currently account for more than 90% of overall biofuel consumption) that can count towards the target at 7% of transportation fuels by 2020 (by energy content, not volume). Furthermore, the FQD includes sustainability provisions, namely that for biofuels to count towards the GHG emission reduction targets, the GHG emissions must be at least 35% lower than from the fossil fuel they replace. From 2017, this will increase to 50% and, from 2018, the saving must be at least 60% for newly installed production facilities.

It is important to note that while the aforementioned components of the RED and FQD incentivize low carbon intensity biofuels, and disincentivize higher carbon intensity biofuels, none of them explicitly prohibit the production, distribution, or sale of first generation biofuels between now and 2030.The imposition of a hard cap or firm limit on the types of biofuels that can be supplied to the EU market to help achieve the hypothetical blending scenarios outlined in this report becomes methodologically challenging. In other words, we are left with two broad methodological approaches regarding biofuel supply assumptions: 1) assume that RED and FQD will prevent the blending of conventional biofuels derived from agrocommodities *and* that there are drastic increases in second and third generation biofuel production in the next 15 years or 2) assume that the RED and FQD can be achieved with a mix of first generation biofuels and modest volumes of second generation biofuels, and that additional biofuel blending may not count towards RED or FQD compliance because of programmatic constraints. This analysis relies on the second approach. More specifically:

- For the purposes of this analysis, the deployment of biofuels from agrocommodities was *not* limited to 7% (by energy content). ICF assumed that the RED target of 10% would be met with a mix of biofuels from agricultural crops, waste-based biofuels, and 2nd generation biofuels. In 2020, only small volumes of 2nd generation biofuels are assumed to come online and account for less than 1% of all biofuels. By 2030, however, we assumed a five-fold increase (discussed in more detail below) in 2nd generation ethanol production, accounting for about 3–3.5% of all biofuels. In each case, ICF ensured that the analysis yielded RED compliance with a *maximum contribution* of 7% from biofuels via agricultural crops.
- ICF made similar assumptions and exceptions regarding the FQD. For instance, it is assumed that biofuels that do not achieve the 50% emissions reduction target will still enter the market place. Although these fuels may not contribute to FQD compliance because of the sustainability requirements, the biofuels with higher emission factors are required to achieve the higher blending scenarios outlined in this report. The alternative approach, which was *not* employed, would have been to assume that higher volumes of 2nd and 3rd generation biofuels would be available.

It is critically important to understand that the GHG emissions analysis laid out in this chapter is not a compliance-based optimization exercise. In that type of analysis, one would consider the costs (e.g., on a €/tonne basis) of various abatement options and optimize the solution based on supply constraints. In this analysis, however, the starting point is simply a specified

[84] Desplechin, E from ePURE. *Ethanol's role in meeting the EU 2020 targets – perspectives up to 2030*, 23 September 2015.

[85] For instance, palm fatty acid distillate (PFAD), and animal fats, used cooking oil, and in smaller volumes, tall oil pitch, technical corn oil, and spent bleaching oil

volume of liquid biofuel developed in the scenarios, and from there, ICF estimates the associated GHG emissions while ensuring FQD and RED compliance are achieved.

Consider Scenario A for illustrative purposes:

- The higher biofuel blends yield a renewable energy content of 14.2% for transport fuels in 2020 and 2030.
- ICF assumed that 7% of the total energy is attributable to biofuels from agrocommodities.
- ICF's assumed growth in waste-based biofuels (1st generation) and 2nd generation biofuels yields 1.6% of the energy. After accounting for the double-counting of these fuels, it yields a 3.2% contribution towards RED compliance.[86]
- At this point in the illustrative analysis, there is still a balance of 5.6% energy content in transport fuels that must be accounted for in some way. In this analysis, the additional energy content can be supplied by first or second generation biofuels, regardless of other considerations, such as feedstock, ILUC emissions or lifecycle GHG emissions. We fulfil that energy demand based on availability of first and second generation biofuels.

To develop feedstock shares into the future (namely 2020 and 2030), the analysis assumed modest changes to the share of biofuels from agricultural feedstocks (note: these fuels are assumed to have indirect land use change emissions, per the footnote on the previous page), including:

- A modest decrease in the share of biodiesel produced from rapeseed oil and sunflower oil, with an offsetting increase in biodiesel from waste feedstocks (e.g., used cooking oil) and palm oil.
- The modest decrease in biodiesel produced from rapeseed oil and sunflower oil is in part due to diverting those feedstocks to HVO production. HVO production is also increased from palm oil.
- An increase in sugarcane ethanol imports by 2030 because of the lower carbon intensity.

The amount of biodiesel and HVO from waste feedstocks (including used cooking oil and animal fats) was constrained based on assumptions presented by Chapter 1, Section 1.6.2.4, which estimates about 80–85 PJ of potential for biodiesel from used cooking oil and another 10–48 PJ of potential for biodiesel from by-products in the food industry (e.g., animal fats).

For second generation biofuels, growth was forecasted in each biofuel category, including second generation ethanol, biodiesel, and renewable diesel (which is akin to HVO; however, the feedstocks are not virgin oils). ICF assumed a doubling of capacity by 2020 yielding about 270 ktoe of biofuels; this growth is consistent with that expected in the U.S., Canada, and other markets that have incentives for advanced biofuel production[87] and is less than the 700 ktoe assumed by a report released by the JEC Biofuels Programme.[88] ICF assumed a five-fold increase from 2020 to 2030, yielding about 1.4 ktoe of 2nd generation biofuels. This is modest growth and only represents 5% of total EU biofuel production capacity today, estimated at around 25,000 ktoe.

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[86] ICF notes that the RED also applies to electricity used in transport; most of which is currently used in rail applications. The 2010 NREAPs estimated a 1.4% contribution towards RED compliance, thereby putting downward pressure on the demand for advanced biofuels in meeting the 10% target. For the purposes of this analysis, we assumed that the 10% target would be met exclusively through deployment of liquid biofuels.

[87] EurObserv'ER, EU Biofuels Barometer, July 2014. Available online at: http://www.energies-renouvelables.org/observ-er/stat_baro/observ/baro222_en.pdf

[88] JRC, EU Renewable Energy Targets in 2020: Revised analysis of scenarios for transport fuels, 2014. Available online at https://www.concawe.eu/uploads/Modules/Publications/jec_biofuels_2013_report_final.PDF

4.4 Potential reductions in lifecycle GHG emissions

The range of lifecycle GHG emissions under the scenarios in this study were estimated using the following two very different sets of assumptions:

1. Approach 1: It is assumed that the carbon intensity of biofuels would significantly reduce over time as a result of future technological improvements made in the lifecycle. Emissions from indirect land use change (ILUC) were not included in the approach 1.
2. Approach 2: The GHG emissions was estimated by applying the default values for biofuels as set out in current legislation (Fuel Quality Directive (2009/30/EC), Annex IV) and indirect land use change (ILUC) emissions (Directive 2015/1513)[89] and the default factors were held constant over time.

Our assumptions of improvements to the carbon intensity of biofuels focused on changes to a) crop yield and b) processing efficiencies.

For crop yields we used yield improvements based on global averages of land-use efficiency of biofuels crops and expected yield improvements from the IEA, as shown in the table below.

Table 4.1 Average Crop Yield Improvements for Ethanol and Biodiesel Feedstocks

Biofuel	Feedstock	Average Improvement per year % litres per hectare	Main co-products, 2010 values (Kg/L biofuel)
Ethanol	Conventional (average)	0.70%	
	Sugar beet	0.70%	Beet pulp (0.25)
	Corn	0.70%	DDGS (0.3)
	Sugar cane	0.90%	Bagasse (0.25)
	Cellulosic -SRC	1.30%	Lignin (0.4)
Biodiesel	Conventional (average)	1.00%	FAME: Glycerine (0.1)
	Rapeseed	0.90%	Presscake (0.6)
	Soy	1.00%	Soy bean meal (0.8)
	Palm	1.00%	Empty fruit bunches (0.25)
	BtL - SRC	0.013%	Low temperature heat; pure CO_2
	HVO	1.30%	Same as for conventional biodiesel feedstock above

Source: IEA, 2011 analysis based on Accenture, 2007; BRDI, 2008; Brauer et al., 2008; E4Tech, 2010; ECN, 2009; FAO, 2003; FAO, 2008; GEMIS, 2010; IEA, 2008; Jank et al., 2007; Kusters, 2009; Kurker et al., 2010; and Schmer et al., 2008.

For process efficiency measures, ICF reviewed the so-called "typical" and "default" emission factors from Annex I of the Commission's 2011 proposal for a Directive laying down calculation methods and reporting requirements pursuant to Directive 98/70/EC. ICF notes that the default values are derived from the typical values by adding an increase to the processing/refining emissions, thereby taking a conservative viewpoint of emissions. Absent more rigorous projections on the possible carbon intensity of biofuels that would be delivered to the EU to achieve the hypothetical blending scenarios, however, ICF used the difference between the default values and the typical values to characterize the type of changes that could occur over time to reduce emissions. More specifically:

[89] Available online at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:JOL_2015_239_R_0001&from=EN

- We assumed that all production matures to achieve "processing typical values" reported in the FQD and RED. This yields a 10–13% improvement.
- We assumed that processing emissions can be decreased mainly from energy efficiency and similar measures, leading to an additional reduction of 12–33%, depending on the fuel. These levels are consistent with improvements in plant efficiencies and conversion technologies. For instance, Table 4.2 below includes potential improvements in processing efficiencies (based on data from by the IEA)

Table 4.2 Biofuel plant efficiencies for large-scale energy pathways

Primary Energy Source	Process	Current Technology	Mature Technology
Oil-seed crops	Biodiesel	45%	52%
Grain crops	Ethanol / Alcohol	38%	42%
Sugar crops	Ethanol / Alcohol	36%	40%
Biomass from crops/waste products	Biodiesel	46%	53%
	Ethanol / Alcohol	34%	39%
	Methane	62%	69%

Source: IEA, Production Costs of Alternative Transportation Fuels, 2013. Available online at https://www.iea.org/publications/freepublications/publication/FeaturedInsights_AlternativeFuel_FINAL.pdf

- Emissions from processing sugarcane ethanol and wheat ethanol are assumed to remain constant 2020–2030.
- Finally, ICF's approach does *not* take into account reduction potential through co-products or improvements in transport and distribution.

It is likely that there will be changes in the carbon intensity of petrol and diesel over time as a result in crude slate shifts and adoption of upstream emission reduction strategies (e.g., flare reductions from associated petroleum gas in upstream oil and gas production). However, with a focus on the impact of higher biofuel blending, the emission factors for petrol and diesel were held constant over time for both scenarios. Furthermore, the feedstock shares remained the same for both approaches.

4.4.2 GHG emission factors

The table below includes the changes implemented for the GHG emissions from cultivation (Table 4.3) and processing (Table 4.4) between 2010 and 2030. GHG emission factors employed in the analysis and the corresponding ILUC factors that were used for sensitivity analysis are presented in Table 4.5.

The GHG emissions for petrol and diesel are calculated using 93.3 g/MJ and 95.1 g/MJ, respectively.

Table 4.3 Disaggregated values for emissions from cultivation of feedstocks for biofuel production

Biofuel and bioliquid production pathway	Carbon Intensity from FQD		Potential Improvement		Assumed Carbon Intensity (gCO2eq/MJ)	
	Typical	Default	10 years, %Liters/hectare	% Conversion	2020	2030
sugar beet ethanol	12	12	7.0%	10.0%	10.09	9.43
wheat ethanol	23	23	7.0%	9.5%	19.45	18.18
corn (maize) ethanol, Community produced	20	20	7.0%	9.5%	16.91	15.81
sugar cane ethanol	14	14	9.0%	10.0%	11.56	10.61
rape seed biodiesel	29	29	9.0%	13.5%	23.02	21.12
sunflower biodiesel	18	18	10.0%	13.5%	14.16	12.87
soybean biodiesel	19	19	10.0%	13.5%	14.95	13.59
palm oil biodiesel (process not specified)	14	14	10.0%	13.5%	11.01	10.01
palm oil biodiesel (process with methane capture at oil mill)	14	14	10.0%	13.5%	11.01	10.01
waste vegetable or animal oil biodiesel	0	0	0	13.2%	0.00	0.00
hydrotreated vegetable oil from rape seed	30	30	9.0%	13.5%	23.82	21.85
hydrotreated vegetable oil from sunflower	18	18	10.0%	13.5%	14.16	12.87
hydrotreated vegetable oil from palm oil (process not specified)	15	15	10.0%	13.5%	11.80	10.73
hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	15	15	10.0%	13.5%	11.80	10.73
pure vegetable oil from rape seed	30	30	9.0%	13.5%	23.82	21.85

Table 4.4 Disaggregated values for emissions from biofuels processing

Biofuel and bioliquid production pathway	Carbon Intensity from FQD		Potential Improvement	Assumed Carbon Intensity (gCO2eq/MJ)	
	Typical	Default	% Conversion	2020	2030
sugar beet ethanol	19	26	10.0%	23.40	19.00
wheat ethanol	32	45	9.5%	40.71	32.00
corn (maize) ethanol, Community produced	32	45	9.5%	40.71	32.00
sugar cane ethanol	21	30	9.5%	27.14	21.00
rape seed biodiesel	14	19	9.5%	17.19	14.00
sunflower biodiesel	1	1	9.5%	0.90	0.90
soybean biodiesel	15	21	9.5%	19.00	15.00
palm oil biodiesel (process not specified)	1	1	10.0%	0.90	0.90
palm oil biodiesel (process with methane capture at oil mill)	16	22	13.5%	19.04	16.00
waste vegetable or animal oil biodiesel	16	22	13.5%	19.04	16.00
hydrotreated vegetable oil from rape seed	18	26	13.5%	22.50	18.00
hydrotreated vegetable oil from sunflower	35	49	13.5%	42.40	35.00
hydrotreated vegetable oil from palm oil (process not specified)	13	18	13.5%	15.58	13.00
hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	9	13	13.2%	11.28	9.00
pure vegetable oil from rape seed	10	13	13.5%	11.25	10.00

Table 4.5 Carbon intensity values used in analysis for liquid biofuels

Biofuel and bioliquid production pathway	Carbon Intensity Values (gCO2eq/MJ)			ILUC (gCO2eq/MJ)
	2010	2020	2030	
Sugar beet ethanol	40	35	30	13
Wheat ethanol (process fuel not specified)	70	62	52	12
Wheat ethanol (lignite as process fuel in CHP plant)	70	62	52	12
Wheat ethanol (natural gas as process fuel in conventional boiler)	55	49	41	12
Wheat ethanol (natural gas as process fuel in CHP plant)	44	39	34	12
Wheat ethanol (straw as process fuel in CHP plant)	26	22	21	12
Corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant)	43	38	33	12
Sugar cane ethanol	24	21	21	12
FAME rape seed	52	43	38	55
FAME sunflower	41	34	30	55
FAME soybean	58	50	45	55
FAME palm oil (process not specified)	68	58	50	55
FAME palm oil (process with methane capture at oil mill)	37	32	28	55
Waste vegetable or animal oil biodiesel	14	12	10	0
Hydrotreated vegetable oil from rape seed	44	36	33	55
Hydrotreated vegetable oil from sunflower	32	26	24	55
Hydrotreated vegetable oil from palm oil (process not specified)	62	53	46	55
Hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	29	23	20	55
Pure vegetable oil from rape seed	36	29	27	55

4.4.3 Feedstock Shares

The GHG emissions are also dependent on feedstock shares assumed for biofuel production. Table 4.6 below includes ICF assumptions for 2010, 2020, and 2030; ICF notes that forecasting feedstock shares is non- trivial and dependent on parameters including but not limited to feedstock costs, agricultural policy, proximity to production facilities, ethanol imports, trade policy, and duties in place. The text following the table highlights ICF's assumptions regarding feedstock shares.

Table 4.6 Feedstock shares used in the analysis

Fuel	Feedstock	2010	2020	2030
Ethanol[90]	Sugar beet	18%	10%	7%
	Wheat (average)[91]	62%	40%	42%
	Corn	20%	45%	51%
	Sugar cane (import)	0%	6%	0%
FAME	Rape seed	73%	63%	52%
	Sunflower	2%	6%	10%
	Soybean	12%	11%	10%
	Palm oil (average)	5%	10%	15%
	Waste vegetable oil or animal oil	8%	10%	14%
HVO	Rape seed	37%	23%	10%
	Sunflower	1%	3%	6%
	Soybean	6%	4%	3%
	Palm oil (average)	3%	14%	23%
	Waste vegetable oil or animal oil	54%	56%	59%

ICF made the following assumptions related to feedstocks for ethanol:

- Corn shares increase consistent with recent trends based on feedstock availability, and its competitive pricing compared to wheat. The EU FAS posts forecast an annual increase in corn of 1%; however, data from ePURE indicate higher levels of corn utilization than the EU FAS documentation. ICF assumed 3% growth every five years moving forward.
- ICF assumes that wheat's contribution, along with other cereals, will stay in the range of 40%.
- Regarding imports, corn ethanol from the US is the most competitive import over the last several years. However, anti-dumping duty may disappear after 2017-2018, and sustainability criteria via FQD will encourage sugar cane. Current preferential trade is with Guatemala, Peru, and Pakistan; we characterize these as sugar cane
- With the market share for corn ethanol production increasing, wheat staying more-or-less constant, and the potential for imports, ICF assumes that sugar beets will decrease over time. This is in part linked to the abolishment of sugar production quotas in 2016/2017.

ICF made the following assumptions related to feedstocks for FAME/biodiesel:

- Rapeseed oil has an important share in the market that could be sustained to meet FAME biodiesel specifications. However, the feedstock has been displaced mostly due to higher use of palm oil and recycled vegetable oil. Palm oil has become the second most important

[90] Feedstocks shares for ethanol in 2010 come via Desplechin, E from ePURE. *Ethanol's role in meeting the EU 2020 targets – perspectives up to 2030*, 23 September 2015.

[91] ICF assumed that the emissions from wheat ethanol are similar to the emissions from ethanol produced with other cereals, including rye and barley.

feedstock because of Neste's renewable diesel plant; in 2013, increased palm oil use in conventional biofuel happened also because of palm oil price.

- Soybean oil use is limited due to EU biodiesel standard DIN EN 14214, which require the use of other biodiesel (rapeseed oil) to meet specifications. Inclusion of sustainability requirements might lead to an increase in rapeseed oil use at the expense of soybean oil.
- ICF assumed that the average annual increase in waste oil usage (and displacement of vegetable oils) is 1%, with a corresponding decrease in rapeseed oil of 1%. This is also linked to potential changes in palm oil prices.
- Attractive palm oil pricing and supply availability yields an average annual increase in palm oil 0.6%, and an annual average increase in sunflower oil of 0.4%. Note that from a GHG life cycle emissions perspective, the impact of this assumption is the same as assuming an increase in the share of rapeseed oil because the carbon intensity values for rapeseed and sunflower oils are similar.
- We also assume an average annual decrease in the share of soybean of -0.06% due to potential changes in palm oil prices and the introduction of sustainability criteria.

ICF made the following assumptions related to feedstocks for HVO:

- ICF assumed that the average annual increase in waste oil usage (and displacement of vegetable oils) is about 1%.
- We assumed an average annual decrease in rapeseed oil of about 3% due to potential changes in palm oil prices; other oils are to be displaced by rapeseed
- We assumed an average annual increase 2.5% and 0.6% for palm oil and sunflower oil, respectively. From a GHG life cycle emissions perspective, the impact of this assumption is the same as assuming an increase in the share of rapeseed oil as RED and FQD GHG values do not establish differentiate significantly between the processing and the transportation of these two type of feedstocks. This "additional increase of rapeseed oil" can be attributed to any impact sustainability requirements might lead to.
- We assumed an average annual decrease in the share of soybean of -0.3% due to potential changes in palm oil prices and the introduction of sustainability criteria.

4.5 Lifecycle Greenhouse Gas Impacts

Table 4.7 presents the GHG emissions of each biofuel blend scenario based on approach 1, where the carbon intensity of biofuels is assumed to reduce over time, and ILUC emissions are not included.

Table 4.7 GHG Emissions (million metric tonnes (MMT)) for each biofuel blend scenario

	2020		2030			
Feedstock	Base	Scenario A-C	Base	Scen A	Scen B	Scen C
Petrol	245	236	185	179	166	160
Diesel	827	776	840	745	743	724
Ethanol	4	8	3	6	11	15
FAME	21	25	19	24	33	42
HVO	1	19	1	31	25	25
Total	1,092	1,055	1,047	985	979	966
% change from Baseline	--	3.5%	--	7.1%	7.8%	9.4%

Table 4.8 presents GHG emissions estimates assuming default carbon intensity values and accounting for indirect land use change (ILUC) emissions.

Table 4.8 GHG Emissions (MMT) in for each biofuel blend scenario, with ILUC emissions

	2020		2030			
Feedstock	Baseline	Scenario A-C	Baseline	Scen A	Scen B	Scen C
Petrol	245	236	185	179	166	160
Diesel	827	776	840	745	743	724
Ethanol	5	11	3	7	15	18
FAME	43	50	39	50	69	87
HVO	2	43	2	81	64	64
Total	1,121	1,115	1,069	1,061	1,057	1,054
	--	0.5%	--	0.8%	1.2%	1.5%

The analysis indicates that the higher biofuel blending scenarios yield GHG benefits compared to the base case scenario, depending on the set of assumptions related to the emission factors for biofuels and ILUC emissions (2020 results in Figure 4.1 and 2030 results in Figure 4.2).The analysis yields GHG emission reductions of 7.1–9.4% for approach 1 with assumed significant improvements of the emission factor s and when not accounting for ILUC emissions. However in approach 2 when applying the default values for biofuels as set out in current legislation and taking indirect land use change (ILUC) emissions into account emission reductions of only 0.8–1.5% are estimated. It should be emphasised that these results are also significantly dependent on assumed a) expanded use of waste-based feedstocks, particularly for FAME and HVO production and b) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030, including for ethanol, biodiesel, and renewable diesel (chemically equivalent to HVO; but the term is inclusive of a broader set of production processes and feedstocks).

Figure 4.1 GHG emissions estimated for biofuel blending scenarios in approach 1 (left) and approach 2 (right; with ILUC emissions), 2020

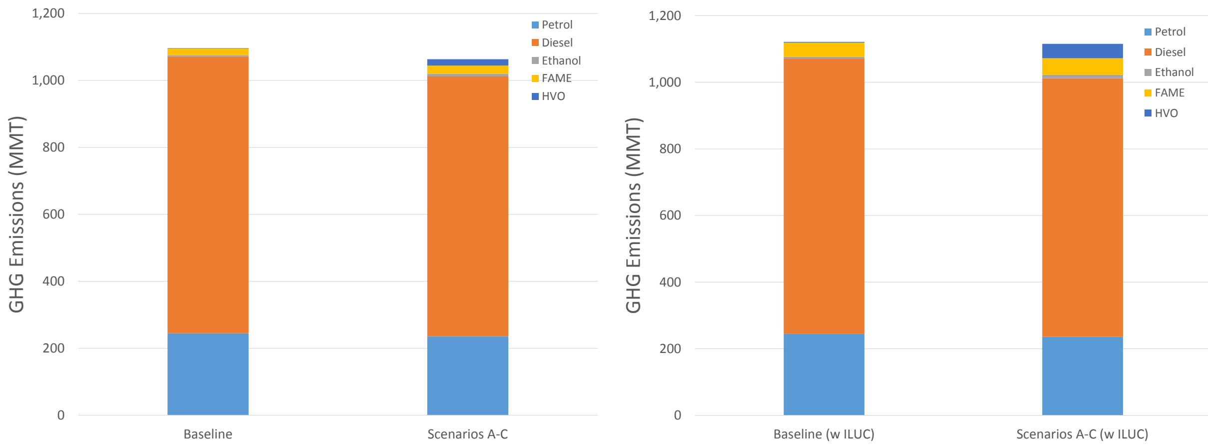
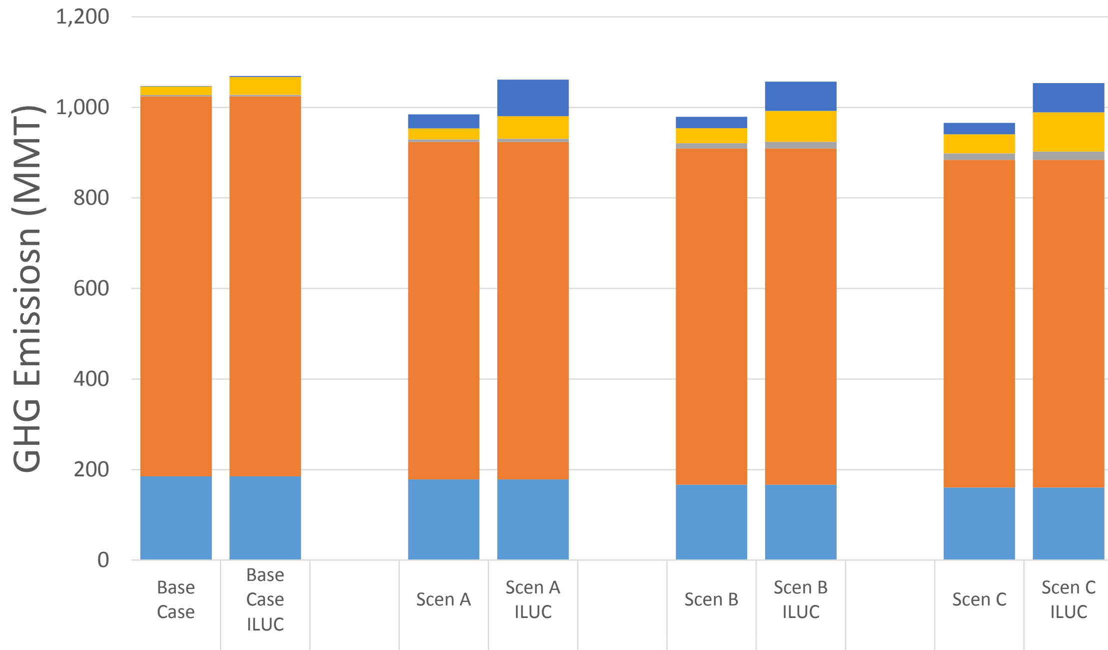


Figure 4.2 GHG Emissions (MMT) for each biofuel blend scenario, 2030



	Base Case	Base Case ILUC	Scen A	Scen A ILUC	Scen B	Scen B ILUC	Scen C	Scen C ILUC
HVO	1	2	31	81	25	64	25	64
FAME	19	39	24	50	33	69	42	87
Ethanol	3	3	6	7	11	15	15	18
Diesel	840	840	745	745	743	743	724	724
Petrol	185	185	179	179	166	166	160	160

4.6 Conclusions

Higher biofuel blending scenarios yield GHG benefits compared to the Base Case scenario, depending on applied assumptions related to the emission factors for biofuels and ILUC emissions.

The greenhouse gas (GHG) impact analysis of three hypothetical scenarios for higher bio blends suggests that these can yield benefits compared to the base case scenario. The estimated benefits are dependent on a) reducing the carbon intensity of biofuels over time as a result of improvements made in the supply chain of biofuels, b) expanded use of waste-based feedstocks, particularly for FAME and HVO production and c) significant expansion (i.e., by a factor of 10) of 2nd generation biofuel production between now and 2030, including for ethanol, biodiesel, and renewable diesel. Assuming a reduction in the carbon intensity emission factors of biofuels over time and excluding indirect land use change (ILUC) GHG emissions, the analysis yields an estimated reduction in the range of 7.1 to 9.4% for the three higher blend limits and use scenarios in 2030. However, if no reductions in the carbon intensity of biofuels are assumed over time, and the emission factors as set out in current legislation are used, including default carbon intensity values for biofuels (included in FQD Annex IV) and indirect land use change factors (in the ILUC Directive), the analysis yields GHG emission reductions between 0.8 to 1.5% compared to the base case scenario.

5 Impacts on refining and fuel supply

Abbreviations/acronyms

CTL	Coal to liquids
EIA	Energy information administration
FIMM	Full Industrial Market Model
GTL	Gas to liquids
IEA	International energy agency
IMO	International Marine Organisation
Ktoe	kilo tonnes of oil equivalent
Mb/d	Million barrels per day
MTBE	Methyl tert-butyl ether
NGL	Natural gas liquids
OECD	Organisation for Economic Co-operation and Development
PED	Price elasticity of demand
WEO	World energy outlook
WORLD	World Oil Refining Logistics & Demand model

5.1 Summary

Two different modelling methods were applied to evaluate the impacts of different biofuel blend scenarios (Chapter 1, Section 1.7.3) on the refinery sector and fuel supply in the EU.

1. EnSys Energy's WORLD model, which is a linear programming model that simulates the operation and economics of the world regional petroleum industry (Section 5.3 and 5.4); and
2. Vivid Economics' economic model of the EU refining market (Section 5.5 and 5.6)

While each model takes a different analytical route, their overarching messages are the same.

5.1.1 Impact of petrol and diesel projections in the Base Case

The 2020/2030 Base Case scenario (based on *EU Energy, Transport and GHG Emissions Trends to 2050, Reference Scenario 2013*) is itself significant since it embodies a further substantial reduction in EU petrol demand in combination with some increase in diesel demand. Under the Base Case outlook, EU diesel to petrol demand ratio continues to shift from 2:1 in 2007 and 2.4:1 in 2011 to 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis). This significantly aggravates the already problematic diesel:petrol ratio in the EU and so sets up 2020 and especially 2030 Base case outlooks which further strain EU refining and lead to projected lower regional refinery throughputs particularly by 2030.

Under the Base Case, petrol exports from and diesel/gasoil imports into the EU are far higher than has recently been the case. In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. The continuing distortion in projected regional demand ratio (petrol decline, diesel increase) relative to refinery yield capability contributes to reduced refinery throughputs while at the same time necessitating higher petrol exports in order to enable diesel production. As a part of this strained outlook, petrol prices in the EU and in non-EU regions are further depressed relative to crude price versus today's levels and – conversely – those for diesel and other distillates including jet fuel are elevated. Thus, at these depressed petrol prices, EU refiners find additional export markets for petrol, (The alternative would be for more extreme reductions in EU refinery throughputs and associated high levels of imports not only of diesel but also of other petroleum products. This would in turn necessitate added capacity and investments in non-EU refineries, raising costs of product supply into the EU and so creating even more price distortion, while EU refineries stood idle. It is thus an unlikely situation. The most economic / least uneconomic balance is projected to be for limited reduction in EU refinery throughputs and an expansion of petrol exports at depressed prices. This strained situation in turn affects the impacts from higher biofuels.

5.1.2 Impact of higher biofuel blend scenarios

EU ethanol and/or biodiesel supply was assumed to increase based on the higher biofuel scenarios in order to prevent significant increases in EU biofuels imports. The net effect of this approach was that the assessed EU biofuel supply increases were entirely biodiesel in 2020 for all Scenarios A, B and C, and predominantly biodiesel in 2030. Increases ranged from 0.2 million barrels per day (mb/d) in 2020 for all Scenarios to as high as 0.5 mb/d under 2030 Scenario C.

Mineral road fuels demand (petrol and diesel) is expected to decrease through 2030 with increasing biofuel demand. By 2020 (all scenarios), the EU mineral road fuels production could fall by 104,000 ktoe/yr (4.4 per cent) from its 2014 level due to the Base Case fuel supply projections, and by an additional 124,000 ktoe (5.5 per cent) due to higher biofuel demand. Mineral road fuels production could fall by 203,000 ktoe/yr (8.6 per cent) from its 2014 level due to Base Case assumptions, and, due to increasing biofuel demand, could fall by an additional:

- 209,000 ktoe/yr (9.7 per cent) in Scenario A;
- 240,000 ktoe/yr(11.1 per cent) in Scenario B; and
- 293,000 ktoe/yr (13.5 per cent) in Scenario C.

This assessment and premise has a key impact on the outlook. Because the European industry operates with a petrol/diesel imbalance which worsens under the Base Case scenario, a primary impact of higher biofuels is to reduce diesel/gasoil imports into the EU such that the bulk of the refinery impacts are projected to be felt in regions outside the EU. Put another way, in the 2020 and 2030 Base Case scenarios, and as stated under the Base Case impacts discussion above, the EU petrol:diesel imbalance is projected to be more severe than today, such that both diesel imports and petrol exports are higher. Since they incur added transport costs, the imports are generally the most expensive products supplied. Consequently, when EU biodiesel production is increased, as in the higher biofuels scenarios, the main impact is to reduce imports of diesel fuel into the EU. This reduction in imports means that production of diesel is reduced in one or more of the regions (Russia, USA etc.) that were exporting diesel to the EU. Consequently, it is in those regions that refinery throughputs drop and where, as a result, there is the potential for closures (relative to the Base Case scenario).

In contrast, increasing EU ethanol supply for use in petrol consumed in the EU leaves EU refineries with the choice of exporting yet more petrol (which is increasingly uneconomic to do since it must be further discounted in order to yet further increase flows into foreign markets) and/or of reducing throughputs to offset the increased ethanol supply. Given the premise that the higher biofuels scenarios increase primarily biodiesel production, the modelling results indicate the primary impact of higher EU biofuels supply is reduced diesel imports, as stated, and the secondary; i.e., smaller impacts are increases in petrol exports combined with limited reductions in EU refinery throughputs.

Implied refinery closures, relative to the Base Case, are driven by the increases in biofuels supply. Every barrel of increased EU biofuels supply reduces required global refinery throughputs by essentially one barrel. Since refineries are projected to be operating in the Base Case and higher biofuels scenarios at an average of around 80% of their capacity, a reduction of 1 barrel per day in throughput would imply approximately 1.25 barrels per day (1 ÷ 0.8) in closures. The modelling results reflect this. They indicate capacity closures due to higher biofuel supply could be 0.27-0.29 mb/d globally in 2020 (for all scenarios) and between 0.4 million barrels/day (mb/d) and 0.6 mb/d globally in 2030 under Scenario A and C, respectively. Of these, and for the reasons stated above, the majority of implied closures are indicated as occurring outside the EU with some 0.07 mb/d (2020; all scenarios) and between 0.08 mb/d and 0.2 mb/d (2030; Scenario A and C) inside the EU, as estimated by the WORLD model. These estimates are based on the assumption that refineries would maintain utilisations at around their 2014 levels (i.e., 79-80%). Conversely, if lower refinery utilisation levels were still considered sustainable, closures would be correspondingly lower. In addition, preliminary model cases indicated that the split of closures between EU and Non-EU regions is sensitive to how strained the Base Case scenario is. In a less strained scenario (meant here as EU petrol:diesel demand more in line with normal refinery yields) the indication is that total global throughput reductions and implied closures would not change but the proportion of capacity closures could be higher in the EU and lower in other regions.

Whether defined in terms of crack spread or refinery gross margins[92], the overall impact in the EU across the scenarios, compared to the Base Case, is estimated to be small, with a reduction on the order of 2-7% in 2020 and a change of +2% to -4% in 2030 on average. For example, for gross margins, which vary between refineries, the absolute impact is a reduction of 7 $¢/bbl in 2020 for all Scenarios (compared to a base case margin of 3.93 US$/bbl) and 11 $¢/bbl in Scenario A, 13 $¢/bbl in Scenario B and 16 $¢/bbl in 2030 for Scenario C (compared to a base case margin of 3.83 US$/bbl).

Impacts on product prices within the EU, relative to the Base Case, are projected to be limited. In 2020, adding in greater quantities of biofuels could reduce the aggregate cost of products in major demand centres although the effects would be small, about a 0.6% reduction in the EU and a global reduction of 0.3% (for all scenarios). Conversely in the 2030 scenarios, product supply cost hardly changes. This relates to the stresses inherent in the 2030 Base Case. As described above, the positive impact on EU refining of raising regional biodiesel production and thereby lowering diesel/gasoil imports with that the pressure to produce diesel, is negated by the further stresses placed on the EU refining system from the increase regional ethanol production and use. One move (more biodiesel) takes EU refiners a little closer to a situation that would be optimal, the second (more ethanol) does the opposite. The net effect is little change in overall costs of supplying products to major EU market centres.

The increase in consumer prices may be 2.3 €¢/l in 2020 (2 per cent) and, in 2030:

- 4.8 €¢/l (4 per cent) in Scenario A
- 5.0 €¢/l (4.1 per cent) in Scenario B and
- 5.8 €¢/l (4.8 per cent) in Scenario C.

Consumer prices are comprised of mineral road fuel wholesale prices, biofuel wholesale prices and the EU average current fuel duty and Value Added Tax. Mineral road fuel wholesale prices are 55.2 €¢/l for an 85 $/bbl crude oil price and biopetrol and biodiesel wholesale prices, which are weighted by their respective share in total biofuels, could be 91.9 €¢/l in 2020, rising to 97.8 €¢/l in 2030. Including taxes, the average price at the pump is 121.5 €¢/l in 2020 and 121.1 €¢/l

[92] Gross margins are the difference between the revenue derived from products and cost of raw materials, primarily crude but including other additives.

in 2030. The difference in biofuel and mineral road fuel prices drives the consumer price increase as the biofuel share increases from the baseline, as laid out above.

Higher crude oil prices would narrow the differential between mineral road fuel and biofuel prices and would make smaller the increase in consumer prices. At 124 $/bbl crude price, consumer prices increase by 1.0 €¢/l in 2020 across all scenarios and, in 2030, by 2.0 €¢/l in Scenario A; by 1.8 €¢/l in Scenario B and 1.9 €¢/l in Scenario C.

5.2 Introduction

This chapter focuses on the work undertaken by EnSys Energy and Vivid Economics to assess the impacts of higher biofuel scenarios in 2020 and 2030 on refining and fuel supply.

1. EnSys Energy utilised its proprietary World Oil Refining Logistics & Demand (WORLD) Model. WORLD captures and simulates the total global "liquids" downstream system from crudes and non-crudes supply through refining, transport and demand and which can be used to address a wide range of strategic questions. It marries top down oil price/supply/demand outlooks, such as are developed by the IEA, EIA, OPEC and others, with bottom up detail: around 200 crude oils, non-crudes breakdown (NGL's, biofuels, GTL/CTL etc.), data on every refinery worldwide with aggregation into regional or sub-regional groups, multiple products and product quality detail, detailed marine, pipeline and minor modes transport representation, refining sector GHG emissions, projects, investments. This combination is used to model any current or future horizon out to (currently) 2040, simulating how the industry is likely to operate and react under any given scenario and capturing the interactions and competition inherent in the global downstream.
2. Vivid Economics' Full Industrial Market Model (FIMM) estimates competitiveness impacts quantitatively. The model allows analysis of interactions between rival firms and consumers within capital-intensive industries. The model depicts firms in individual economic markets and captures the impact of changes in market structure, including the entrance or exit of individual firms, changes in the nature of demand, and changes in production costs. The model is well-suited to industrial sectors where firms have high fixed costs, such as energy-intensive industries. The model is based around the Cournot model of oligopoly, and is conceptually similar to the qualitative Porter's Five Forces model, widely used in corporate strategy analysis. It is a partial equilibrium model, solved algebraically. The results span the changes in: consumer prices, EU mineral road fuel (diesel and petrol) production, mineral road fuel imports, EU refining gross profit margins, and potential utilisation decline and/or exit of EU refining capacity.

The conclusions from this analysis reflect the outcomes of two models that each take a different analytical route to assessing the impacts of higher biofuel blends.

- Section 5.3 provides a review of the EnSys WORLD modelling methodology and assumptions.
- Section 5.4 presents the key results and findings from the WORLD modelling analysis.
- Section 5.5 presents a summary of the methodology and assumptions of Vivid's FIMM
- Section 5.6 discusses the consumer price, gross profit margins and refinery capacity results from FIMM
- Section 5.7 integrates the main findings from sections 5.4 and 5.6 and presents the overarching conclusions from this analyses.

5.3 WORLD model methodology and assumptions

This section provides an overview of the modelling tool used by EnSys Energy (EnSys) and then focuses on the premises applied in the analysis of higher biofuel scenarios.

5.3.1 Model inputs and outputs

As illustrated in Figure 5.1 (below), model inputs combine top down and bottom up data covering:

- Supply/demand
  - Overall world oil price/supply/demand scenario for case year e.g. from EIA or IEA projection
    - Includes marker crude price
  - Supply projection detail (crudes, non-crudes) matched to supply scenario
  - Crude oil supply detail
  - Non-crudes comprise NGLs, petchem returns, biofuels, methanol, GTL, CTL
  - Product demand projection detail by region based on historical data plus growth rates tuned to demand projection
    - Multiple product grades:
    - Gasoline, distillates, residual fuels, other products
- Transport
  - Trade movement detail:
  - Crudes, non-crudes, products, intermediates
  - Marine, pipeline, minor
  - Built up freight rates / tariffs / duties
  - Pipeline and tanker fleet capacities / projects
- Refining
  - Base/current refinery capacity data
    - By refinery by unit worldwide
    - Regionally aggregated
  - Announced refinery projects
    - Categorized by stage of development
    - Selection of projects considered firm
  - Refinery closures
    - Firm announced closures plus optionally assessed additional potential closures
  - Refinery technology database
    - Multiple processes
    - Yields, utilities, OVCs

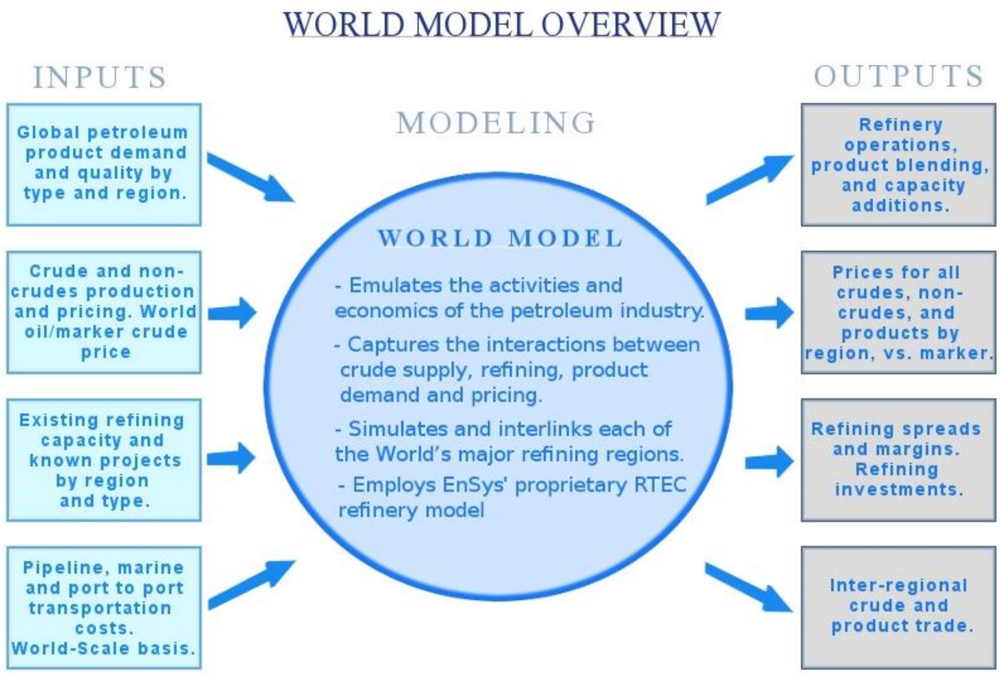
    - Current technologies but can accommodate/evaluate new processes
    - Merchant processes: MTBE, GTL, CTL
  - Product blending & specifications

Outputs comprise a combination of physical and economic parameters:

- Main results - physical:
  - Refinery throughputs, operations, capacity additions
  - Product blending & qualities
  - Crudes, non-crudes, products, intermediates inter-regional trade movements & pipeline throughputs
- Main results - economic:
  - Refining investment costs
  - Marginal costs / prices of all crudes, products by region
    - relative to marker crude
  - Total product costs (price * volume) delivered to major market centres regional and global
  - Refining margins / crack spreads

In summary, each WORLD Model case provides a summary of the way the global industry is projected as likely to operate under a given scenario and captures key physical and economic parameters. Much of the power of the approach lies in the ability to assess the impacts of changes off a base case, in this instance higher biofuels use in Europe, and the resulting refining and trade consequences both directly in the region(s) immediately affected and also worldwide.

Figure 5.1 Model inputs and outputs



5.3.2 Model regional formulation

Table 5.1 summarises the regional formulation of the WORLD Model as used for this study. As can be seen, Europe is represented as three regions. WORLD Europe regions are defined geographically and do not correspond to either the EU28 or OECD Europe. Constraints of timescale and budget did not allow for Model reformulation. Consequently data on EU28 (e.g. petrol and diesel demand) were ratioed up to fit the WORLD Europe definition and vice-versa. Available data from the Energy Information Administration on total petroleum product demand by country were used to establish the ratio. As shown on Table 5.2, this was estimated as a factor of 1.077 to go from EU28 to WORLD Europe and 1/1.077 to go in the opposite direction (e.g. in translating WORLD results on trade flows and refining operations – but not prices – back to their EU28 equivalent). This approach necessarily introduced a degree of approximation but was considered the best option available given the constraints noted. It was also the approach used in the *Impact Analysis of Options for Implementing Article 7a of Directive 98/70/EC (Fuel Quality Directive)*, ICF, August 2013.

In the Model reports generated for this study, refining activity and trade flows were reported at the level of 9 aggregate regions as set out in Table 5.1. Summary results were presented mainly at the level of “Europe” and “Global” for simplicity. References to “Europe” are marked as either WORLD Europe or EU28.

Table 5.1 WORLD Model Regional Formulation

Standard WORLD Model 23 Region Formulation	
Regional aggregations for reporting	Primary model supply / demand / refining regions
USA & Canada	US East Coast (PADD1)
	US Mid West (PADD2)
	US Gulf Coast (PADD3)

Standard WORLD Model 23 Region Formulation	
Regional aggregations for reporting	Primary model supply / demand / refining regions
	US Rocky Mountain (PADD4)
	US West Coast (PADD5)
	Canada East
	Canada West
Latin America	Mexico
	Greater Caribbean
	South America
Africa	Africa North & Eastern Med
	Africa West
	Africa South/East
Europe	Europe North West
	Europe South
	Europe East / EurAsia
Russia / Caspian (FSU)	Russia (or Russia/FSU) (1)
	Caspian
Middle East	Middle East
Pacific Industrialized	Pacific Industrialized (Japan / Australasia)
China	China
Other Asia / Pacific	Pacific Industrializing (High Growth)
	India / Rest of Asia

Note: Some users require Russia split out as its own region, others to stay with the FSU formulation.

Table 5.2 European Countries Total Petroleum Consumption

European Countries Total Petroleum Consumption and Allocation to Regional Groups (http://www.eia.gov/countries/data.cfm)				
(Thousand Barrels Per Day)				
European Country	**2011**	**EU 28**	**WORLD Europe**	**OECD Europe**
Albania	38.4		E	
Armenia	45.3			
Austria	264.5	U	N	O
Azerbaijan	152.9			
Belarus	188.8			

European Countries Total Petroleum Consumption and Allocation to Regional Groups (http://www.eia.gov/countries/data.cfm)

(Thousand Barrels Per Day)

European Country	2011	EU 28	WORLD Europe	OECD Europe
Belgium	647.4	U	N	O
Bosnia and Herzegovina	27.5		E	
Bulgaria	112.7	U	E	
Croatia	93.0	U		
Cyprus	58.4	U		
Czech Republic	192.4	U	E	O
Denmark	160.2	U	N	O
Estonia	26.3	U		O
Faroe Islands	4.9			
Finland	209.1	U	N	O
Former Czechoslovakia	--			
Former Serbia and Montenegro	--			
Former Yugoslavia	--			
France	1824.0	U	N	O
Georgia	17.3			
Germany	2423.0	U	N	O
Gibraltar	24.9			
Greece	336.8	U	S	O
Hungary	141.4	U	E	O
Iceland	17.4		N	O
Ireland	144.2	U	N	O
Italy	1455.5	U	S	O
Latvia	31.3	U		
Lithuania	70.4	U		
Luxembourg	62.2	U	N	O
Macedonia	17.5		E	

European Countries Total Petroleum Consumption and Allocation to Regional Groups (http://www.eia.gov/countries/data.cfm)

(Thousand Barrels Per Day)

European Country	2011	EU 28	WORLD Europe	OECD Europe
Malta	19.5	U		
Moldova	18.1		E	
Montenegro	4.4		E	
Netherlands	1005.7	U	N	O
Norway	245.0		N	O
Poland	579.3	U	E	O
Portugal	260.7	U	S	O
Romania	218.2	U	E	
Serbia	81.4		E	
Slovakia	80.6	U	E	O
Slovenia	52.9	U	E	O
Spain	1383.2	U	S	O
Sweden	328.4	U	N	O
Switzerland	236.1		N	O
Turkey	679.9		S	O
Ukraine	320.6			
United Kingdom	1602.1	U	N	O
TOTAL		**13783.3**	**14850.1**	**14358.1**
Ratio WORLD Europe to EU 28 Demand			**1.077**	
Count - number of countries		28	32	25

5.3.3 Model base case premises

The following summarises key premises proposed for the WORLD Model 2020 and 2030 base and higher biofuels cases developed and run to examine impacts of high biofuels scenarios for EU transport fuels. As noted in the table, key steps in the Model set up were to:

1. Build in IEA WEO New Policies world crude price profile and top down supply and demand outlook and tune WORLD bottom up numbers to these
2. Adjust global marine fuel demand to fit with latest IMO outlook (which differs from IEA) and assume MARPOL Annex VI global fuel standard goes ahead in 2020

3. Build in projected 2020 and 2030 Europe demand numbers for petrol and diesel and for ethanol and biodiesel supply which override the original WEO-based numbers - but leave all other WEO-based numbers unchanged.

Table 5.3 Key model base case premises

Premise	Value(s) Used	Comment
Global price/supply/demand outlook		
Top down outlook	IEA Nov 2014 World Energy Outlook (WEO) New Policies case.[93] This outlook was selected because (a) it originated from the IEA as distinct the US-based EIA or other organisations and (b) because it included projections to 2030 which were needed for the study. The IEA states in the WEO that New Policies is their "central" case. New Policies includes progressive worldwide implementation of efficiency and alternative fuel technologies such that global oil demand growth gradually slows. The oil price path has a moderate increase (versus the Current Policies case). Price reaches \$118/barrel in 2025 and \$132/barrel in 2040 (in real terms). Global oil demand reaches 101.3 mb/d in 2030 to which IEA adds 3.4 mb/d (oil energy equivalent) of biofuels. Translating the latter into volume barrels leads to a total 2030 volume "liquids" demand of just over 106 mb/d. This outlook is broadly in line with those from other agencies such as the EIA and OPEC (unlike the Current Policies and 450 Scenarios).	Note, the WEO New Policies case is a "high" price outlook that did not fully take into account the recent crude price drop, i.e. effectively it assumes a return to high prices for the 2020 – 2030 time frame. (See below.) The Nov 2014 WEO is however the latest available IEA outlook that goes beyond 2020. Overall, the WEO New Policies scenario presented the most plausible available outlook which also covered to 2030. In addition, the WEO New Policies scenario provides more detail on supply and demand for the New Policies than for the other two scenarios. The Feb 2015 IEA Medium Term Oil Market Report (MTOMR) includes projections from 2015 to 2020. These were used as a cross-check.
Crude price	Per WEO basis. WEO New Policies prices (\$2013) are \$112/barrel for 2020 and \$122.67/barrel for 2030. These are adjusted for input to WORLD (a) for quality differential versus Saudi Light which is used as the marker crude in the WORLD Model and (b) to subtract off estimated freight to arrive at a Saudi Light FOB (loading port) price.	Basis for the WEO price is understood to be average IEA member import (landed) price.

[93] Based on IEA data from © 2014 World Energy Outlook, OECD/IEA, IEA Publishing. Modified by EnSys Energy. Licence: www.iea.org/t&c/termsandconditions.

Premise	Value(s) Used	Comment
Global supply / demand	WEO total supply and demand for 2020 under New Policies scenario is 99.0 mb/d including biofuels in volume barrel terms and 106.1 mb/d for 2030 on the same basis. The WEO New Policies tables include data for OPEC and non-OPEC crude, NGL's and non-conventional supply and for the same breakdown of supply by major world region. EnSys used these to tune embedded bottom up WORLD detail to the WEO top down numbers.	As noted above, WEO projections show biofuels supply/demand stated as barrels of equivalent gasoline/diesel. Since WORLD works on volume barrels, the biofuels volumes are adjusted to their estimated volume barrels equivalent and global volume supply and demand correspondingly adjusted. WEO Tables 3.1 through 3.9 and tables in Annex A contain New Policies scenario supply and demand projections.
Global biofuels supply	WEO New Policies projects biofuels at 2.2 mb/d 2020 and 3.4 mb/d 2030 <u>oil equivalent volume</u>. EnSys adjusted these to respectively 3.08 and 4.76 mb/d total volume barrels. Embedded WORLD data and cross checking with MTOMR were used to establish the regional splits and the splits of ethanol versus biodiesel.	IEA 2015 MTOMR Tables 5 and 5A provide a detailed regional breakdown for each of ethanol and biodiesel production 2014 - 2020. EnSys used this as a basis for regional breakdown for 2020 and 2030 but EU biofuel supply was adjusted to fit projections for the EU from Chapter 1, Section 1.7.3.[94] (See below.)
Crudes supply	Within WORLD, "top level" regional supply of oil liquids is taken from a third party projection, as above, and then broken down to first subtract out non-crudes supplies (often these are split out in the projection). Total crude supply for a given region is then split out between the relevant crude grades based on extensive in-house research and data on current and projected crude production by main crude grade. This process includes both conventional and non-conventional crude oils. In any WORLD case, production levels are fixed for all individual crude grades except for the balancing marker/marginal crude (generally Saudi Light is used). An input price is assigned to the marker crude based on the projection for world crude price.	

[94] Based on IEA data from © 2015 Medium Term Oil Market Report, OECD/IEA, IEA Publishing. Modified by EnSys Energy. Licence: www.iea.org/t&c/termsandconditions.

Premise	Value(s) Used	Comment
Non-crudes supply	Non-crudes supplies for all except methanol (for MTBE feed) and natural gas (for hydrogen plant feedstock and refinery fuel) are also projected and fixed in any given case. (Prices are assigned to methanol and natural gas.)	
Product demand	Product demands are worked up in a similar way (tuning embedded bottom up detail to top down numbers) and are fixed for all except the refinery by-products of sulphur and fuel grade petroleum coke (which are given prices and allowed to float).	The effect is that, within any one case, the prices of every crude except the marker and of every non-crude and product are outputs from the case – not inputs.
Global marine fuels demand	For 2020 and 2030, total global demand was based on the average of International Marine Organisation (IMO) 3rd GHG Study scenario cases (which run to 2050); these as the most authoritative available source. (The IMO 3rd GHG Study was released in July 2014. It summarized comprehensive assessments of historical demand based on AIS vessel tracking. It also included a matrix of projections for global demand through 2050 across 16 scenarios.)	IEA data are known to understate marine fuels consumption (notably international). The IMO 3rd GHG discusses this at length. EnSys has built in methodology for adjusting to accommodate IMO-based marine fuels demand outlook.
EU/Europe Specific Demand & Affected Fuels & Biofuels		
Europe regional formulation in WORLD Model	WORLD covers Europe geographically with all countries included in one of three regions plus Eurasia and Russia regions. As described in the main text, WORLD Europe formulation does not correspond to either EU or OECD Europe, therefore an adjustment procedure used.	2012 approach was to use historical demand data by European country to establish a ratio between WORLD Europe demand and EU demand and to apply that in reports. That process was repeated as described in the body of the text. Resulting factor to go from EU28 demand to WORLD Europe demand was 1.077.
EU petrol and diesel demand	On-road demands by scenario (see Table 5.4).	
EU ethanol supply and demand	Required volumes to meet EU demand levels 2020 and 2030 (see Table 5.4).	Based on client guidance, Europe ethanol demand under higher biofuel scenarios was assumed to be met by increasing European ethanol production as necessary to ensure no significant increase in ethanol imports.

Premise	Value(s) Used	Comment
EU biodiesel supply and demand	Required volumes to meet EU demand levels 2020 and 2030 (see Table 5.4).	Based on client guidance, Europe biodiesel demand under higher biofuel scenarios was assumed to be met by increasing European biodiesel production as necessary to ensure no significant increase in biodiesel imports.
EU Base and higher biofuels scenarios	See Table 5.4	For 2020, all the higher biofuels scenarios were in fact the same so treated as one All Scenarios case in the WORLD modelling. For 2030, Scenarios A, B and C represented different levels of higher biofuels use and were modelled separately
Differences between EU and WEO supply and demand projections	The projections for EU ethanol and biodiesel production volumes and for petrol and diesel demand used in this study were different from those in the WEO. These were handled by introducing them as “overrides” that replaced the corresponding WEO numbers. All other WEO-based supply and demand numbers were left unchanged	
EU demand for products aside from petrol and diesel	Internal WORLD data were used adjusted to IEA New Policies	
Product Quality / Regulatory		
Product blending and quality / specifications	Internal WORLD data and projections taking account of actual blended qualities versus specifications. Progressive trend to low sulphur (LS)/ ultra-low sulphur (ULS) standards in non-OECD regions	
Marine fuels	Global 0.5% standard assumed implemented in 2020. Projection of volume of high sulphur IFO to be shifted to 0.5% sulphur compliant fuel taken from IEA Feb 2015 MTOMR which projected a shift volume of 2.2 mb/d. HS IFO assumed shifted to 0.5% sulphur marine distillate. There is uncertainty over the critical question of what role onboard scrubbers will play and by when – and hence what volume of HS IFO would actually need to be shifted to 0.5% sulphur fuel. EnSys considers the IEA MTOMR outlook to	

Premise	Value(s) Used	Comment
	be a "mid-level" projection in this regard. No new ECA's by 2020 beyond existing Europe (2) and Canada/USA. Additional ECA's by 2030. EU 2012 directive to use 0.5% sulphur fuel in 2020 in all EEZ waters recognized	
EU petrol and diesel specifications	Internal WORLD data used. EU petrol vapour pressure allowed for ethanol vapour pressure waiver	
EU Carbon regime / cost	WORLD Model embodies carbon costs for refineries. For Europe, EU ETS prices taken as €10/ tCO2E 2020 and €35/ tCO2E 2030 based on *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013, Figure 11.	Note, an energy efficiency trend is allowed for in WORLD but the option to "buy" more energy efficient means to generate steam/power and/or to consume fuel/steam/power more efficiently is not built in to the Model
Other carbon regimes	No other major regimes assumed except for California Low Carbon Fuel Standard (LCFS) and then only to extent of blocking Western Canadian oil sands crudes from being processed in the state	
Refining		
Base capacity	Internal WORLD data basis January 2015 used based on review completed May 2015	Note, in current WORLD model, total refining capacity is aggregated in each of the 3 European Model regions
Closures	Recent refinery closures incorporated into January 2015 base capacity. Firm announced closures in 2015 and 2016 also incorporated together with additional assumed closures for a total of 2 mb/d worldwide by 2020. No further closures built in beyond 2020	2020 and 2030 base cases and especially higher biofuels cases were expected to and did lead to lower Europe refinery utilisations hence implied further closures which can be estimated from Model results (as amount needed to get back to a sustainable utilisation level)
Projects	Internal WORLD data based on review completed May 2015	
Process technology and economics	Internal WORLD data based on recent (2Q 2015) technology review and update	

Premise	Value(s) Used	Comment
Logistics & Trade		
Marine routes, tanker types, freight rates	Extensive movements for crudes and products embodied in WORLD with freight rates based on WorldScale. Gradual return assumed to balanced tanker markets by around 2020 (from recent extremely low rates) Panama Canal expansion by 2016 (reduces freight rates for tanker routes that transit the Canal).	Movements generally not constrained other than where there are clear known situations that force or prevent specific movements e.g. for geo-political reasons or where crudes are known to be refined locally. Examples that are actively incorporated within the WORLD Model include: Venezuelan crude to China, no Iranian crude to USA, requirements that selected crude oils in oil-producing countries be refined locally based on knowledge of the refineries there.
Pipelines & Rail – USA & Canada	Inter-regional pipelines, basis WORLD internal data/projections, including USA/Canada pipelines and rail. Trans Mountain expansion to 890,000 b/d assumed by 2020; Northern Gateway by 2025 (affects volumes of WCSB crudes moving to BC and Asia versus into US/eastern Canada). Energy East assumed 2020 at 0.8 million bpd and post 2020 at 1.1 million bpd. Keystone XL assumed online pre 2020. Rail costs assumed raised because of new regulations but that in 2020/2030 rail will act in balancing role after pipelines are filled.	Basis is extensive and regular monitoring through EnSys' Monthly North America Logistics service.
Canadian crude to Europe	Shipping allowed from Canada East at levels dependent on pipeline capacity. (Movements to Europe from Montreal already exist.) No restriction on oil sands crudes into Europe based on recent EU announcement	
Pipelines - ESPO	Expansion plans assumed trimmed to 1.3 mb/d 2020 and 1.5 mb/d 2030	Affects volumes of Russian crude moving east
FSU product exports	New laws passed in Russia are likely to lead to higher exports of product from Russia and less crude oil – although there is uncertainty. Historical trends and also data and commentary from the IEA and others used to set potential 2020 and 2030 exports within a range.	In the WORLD Model, Former Soviet Union (FSU) exports are an exception in that EnSys has found it necessary to extrapolate trends and assume future export levels (within a range).

Premise	Value(s) Used	Comment
Notes: WORLD marries "top down" projections as from the IEA, EIA, OPEC or others with "bottom up" detail. The details in the WORLD Model used for this case have been built up from multiple sources (and 25 years of experience with the Model) including recent studies with and for the U.S. Departments of Energy and State, EPA, American Petroleum Institute, International Maritime Organisation, World Bank and OPEC Secretariat, with whom EnSys undertakes a joint annual study of the global downstream outlook that is now published as part of the annual OPEC World Oil Outlook.		

5.3.4 Model biofuel scenario premises

The specific volumes used for the Base and alternate scenarios for European biofuel supply and demand and for total petrol and diesel demand are shown in Table 5.4. These projections incorporate data from Table 1.18 and projections from *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013 (Table 5.5). The figures were transposed from ktoe to million bpd for use in WORLD and also factored up (by 1.077) to translate from EU28 to WORLD Europe basis.

The higher biofuels case premises were examined to assess in which instances either ethanol or biodiesel demand exceeded base level supply. Based on client guidance, in those situations where the EU scenario demand exceeded the available base EU supply, the EU supply of the affected biofuel was raised to match the EU demand. The intent behind this was to avoid a situation where a higher EU biofuels demand scenario would have necessitated "pulling" either ethanol or biodiesel away from other world regions. Put another way, the intent was to avoid any significant need to increase biofuel imports into the EU.

Table 5.4 summarises base and incremental ethanol and biodiesel volumes across the various scenarios in both ktoe/yr and mb/d. Figure 5.2 and Figure 5.3 illustrate the volumes of respectively ethanol and biodiesel against each scenario. Figure 5.4 summarises total ethanol plus biodiesel in each scenario and expresses the numbers in volume terms.

Table 5.4 EU Biofuels Supply Base Case and Higher Biofuels Scenarios

EU Biofuels Supply Base Case and Higher Biofuels Scenarios						
ktoe/yr	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol base	4521	4521	4882	4882	4882	4882
Ethanol incremental	0	0	0	0	1510	3140
ktoe/yr	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Biodiesel base	15179	15179	20530	20530	20530	20530
Biodiesel incremental	0	10170	0	17258	17305	22064
Total incremental	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol	0	0	0	0	1510	3140
Biodiesel	0	10170	0	17258	17305	22064
Total	**0**	**10170**	**0**	**17258**	**18815**	**25204**

EU Biofuels Supply Base Case and Higher Biofuels Scenarios						
mb/d	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol base	0.098	0.098	0.106	0.106	0.106	0.106
Ethanol incremental	0.000	0.000	0.000	0.000	0.033	0.068
mb/d	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Biodiesel base	0.299	0.299	0.405	0.405	0.405	0.405
Biodiesel incremental	0.000	0.200	0.000	0.340	0.341	0.435
Total incremental	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol	0.000	0.000	0.000	0.000	0.033	0.068
Biodiesel	0.000	0.200	0.000	0.340	0.341	0.435
Total	**0.000**	**0.200**	**0.000**	**0.340**	**0.374**	**0.503**
Grand total	**2020 Base**	**2020 All Sc**	**2030 Base**	**2030 Sc A**	**2030 Sc B**	**2030 Sc C**
Ethanol base	0.098	0.098	0.106	0.106	0.106	0.106
Ethanol incremental	0.000	0.000	0.000	0.000	0.033	0.068
Biodiesel base	0.299	0.299	0.405	0.405	0.405	0.405
Biodiesel incremental	0.000	0.200	0.000	0.340	0.341	0.435
Total	**0.397**	**0.597**	**0.510**	**0.850**	**0.884**	**1.013**

Figure 5.2 EU Base & Incremental Ethanol Production

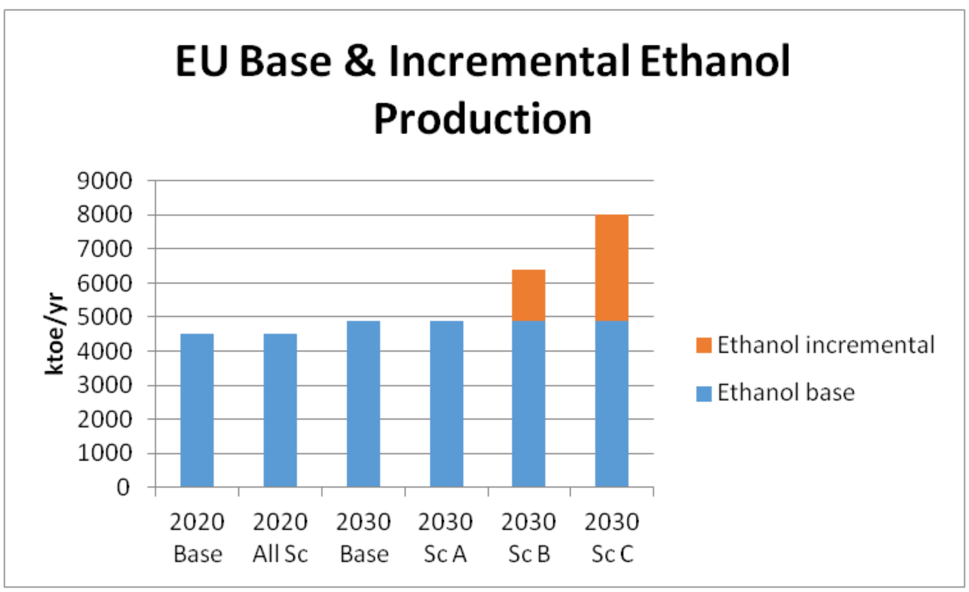


Figure 5.3 EU Base & Incremental Biodiesel Production

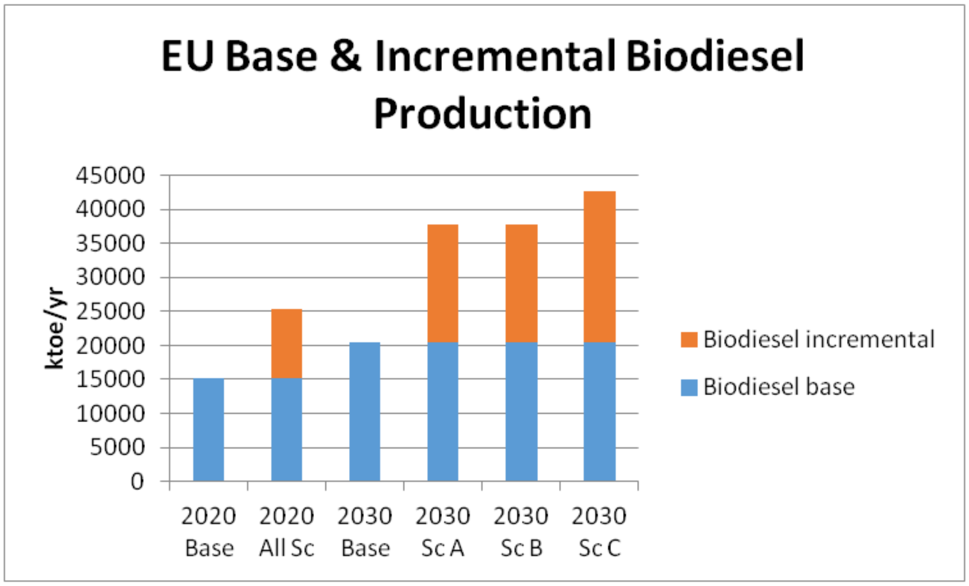
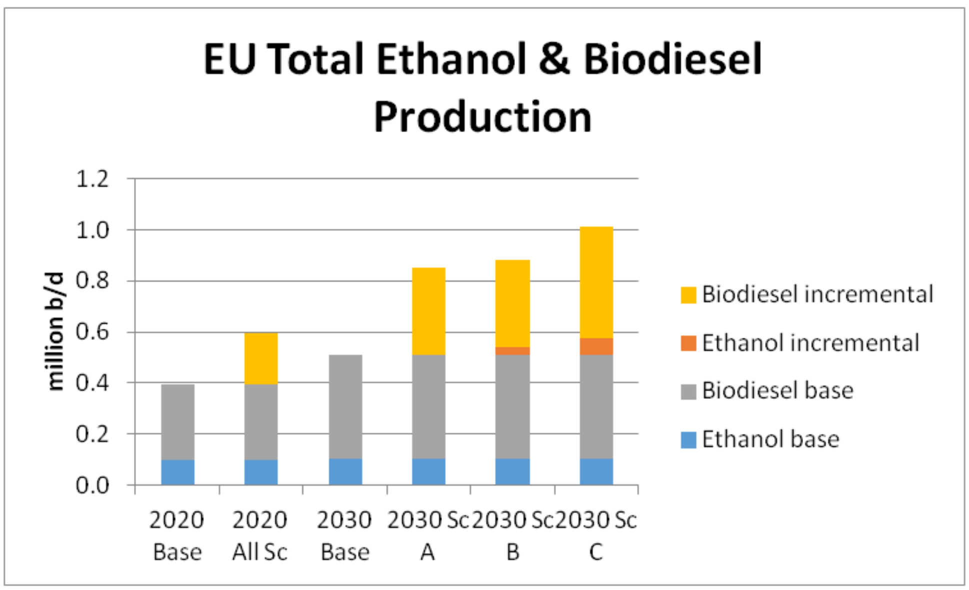


Figure 5.4 EU Total Ethanol & Biodiesel Production



What is evident from the figures above is that the major increases are in biodiesel production. This is because of the increases in biodiesel requirement in each higher biofuel scenario relative to the Base biodiesel availability. No incremental ethanol is projected as needed except in the 2030 Scenarios B and C and then the highest increment is 3140 ktoe/yr (0.068 mb/d). In contrast significant incremental biodiesel was projected as needed in every higher biofuel scenario 2020 and 2030. The largest required increment is just over 22,000 ktoe/yr (0.435

mb/d) in the 2030 Scenario C. The highest total incremental biofuel is just over 25,000 ktoe/yr (0.5 mb/d) in 2030 Scenario C.

The high proportion of incremental biodiesel in the total and the aggregate incremental production volume of up to 0.5 mb/d are key factors influencing the modelling results for the higher biofuels scenarios.

Table 5.5 EU petrol diesel and biofuel demand used in base cases and scenario A, B and C

EU petrol and diesel demand by scenario (ktoe/yr)						
ktoe/yr	**Base**	**All scenarios**	**Base**	**Scenario A**	**Scenario B**	**Scenario C**
	2020	**2020**	**2030**	**2030**	**2030**	**2030**
Petrol	62,564	60,376	47,354	45,696	42,619	40,994
Diesel	207,589	194,805	210,849	187,142	186,552	181,789
EU biofuel demand by scenario (ktoe/yr)						
ktoe/yr	**Base**	**All scenarios**	**Base**	**Scenario A**	**Scenario B**	**Scenario C**
	2020	**2020**	**2030**	**2030**	**2030**	**2030**
Ethanol	2,202	4,390	1,667	3,325	6,402	8,027
Fame	10,817	13,620	10,987	13,836	18,713	23,476
HVO	569	10,551	578	21,437	17,150	17,150
Biodiesel	11,387	24,171	11,566	35,273	35,863	40,626
EU Total Oil + Biofuel Demand (ktoe/yr)						
ktoe/yr	**Base**	**All scenarios**	**Base**	**Scenario A**	**Scenario B**	**Scenario C**
	2020	**2020**	**2030**	**2030**	**2030**	**2030**
Petrol	64,766	64,766	49,021	49,021	49,021	49,021
Diesel	218,976	218,976	222,415	222,415	222,415	222,415

5.4 WORLD model results

This section provides a review of the main results from the modelling of 2020 and 2030 Base and higher biofuels scenarios.

5.4.1 Base case outlook

As indicated in Table 5.5 above, the Base Case outlook embodies a sustained reduction in EU petrol demand through 2030 while diesel demand is projected to slowly increase over the period. Figure 5.5 further illustrates this by comparing the Base Case demand projections with recent demand history[95]. Thus these projections, taken from the *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013, constitute an assumed continued dieselisation in Europe, i.e. a continued decline in the ratio of gasoline to diesel demand[96].

The strains that the current dieselisation programme has placed on the European refining system and the consequences for petrol/diesel imbalance in Europe and more broadly in the Atlantic Basin are well known; equally the resulting large exports from Europe of excess petrol and imports of diesel[97]. The Base Case outlook has EU petrol demand (including any biofuel content) dropping to approximately 65,000 ktoe/yr (1.5 mb/d) by 2020 and to 49,000 ktoe/yr (1.1 mb/d) by 2030; this from around 103,000 ktoe/yr (2.4 mb/d) in 2007 and 87,000 ktoe/yr (2 mb/d) in 2011. In contrast, the Base Case outlook has EU diesel demand rising from around 205,000 ktoe/yr (4.2 mb/d) on average 2007-2013 to 219,000 ktoe/yr by 2020 and over 222,000 ktoe/yr by 2030, respectively just under and just over 4.5 mb/d.

In other words, the Base Case outlook is for the EU diesel to petrol demand ratio to continue to shift from 2:1 in 2007 and 2.4:1 in 2011 to 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis) as shown in Figure 5.6. Put another way, petrol demand drops from 50% of diesel demand in 2007 to 30% of diesel demand in 2020 and 22% in 2030. Since, in many refineries, the yield ratio of petrol to diesel is closer to 1:1, this outlook sets up further exacerbated yield and economic strain on European refineries moving forward to 2020 and 2030[98]. The resulting WORLD Model Base Cases indicate relatively flat European refining throughputs to 2020 but thereafter further declines to around 10 mb/d in 2030 versus 11.9 mb/d in 2012[99]. As illustrated in Figure 5.7, the Base Case outlook is for an overall continuing downward trend.

[95] The demand history data were taken from Interim Report Figure 3.2 Temporal trends in EU fuel sales (Ricardo AEA, to be published).

[96] Recent energy/fuel tax proposals in the EU may act to shift consumer pricing advantage away from diesel and back somewhat toward petrol which, over time, could reduce or even reverse the dieselization trend. In addition, current concerns over NOx and particulates emissions from diesel and associated health impacts could have the same effect.

[97] Refining is a co-product industry and, generally, refiners in Europe have to produce a certain amount of petrol (which is relatively unprofitable since it must be exported) in order to produce diesel (which is comparatively profitable since its pricing is based on import parity).

[98] In addition, all modelling cases included EU ETS allowance costs at €10/tonne of CO2e in 2020 and €35/tonne in 2030 again based on the EU Trends to 2050 report (Figure 11). Based on modelled European refinery fuels consumptions, these equated to approximately $0.80/barrel of added European refinery operating cost in 2020 and $2.80/barrel in 2030.

[99] There was a sharp drop in 2013 to around 11.2 mb/d. In addition, there have been substantial refinery closures in Europe in the past two years and more are planned.

Figure 5.5 EU Petrol & Diesel Consumption History and Base Case Outlook

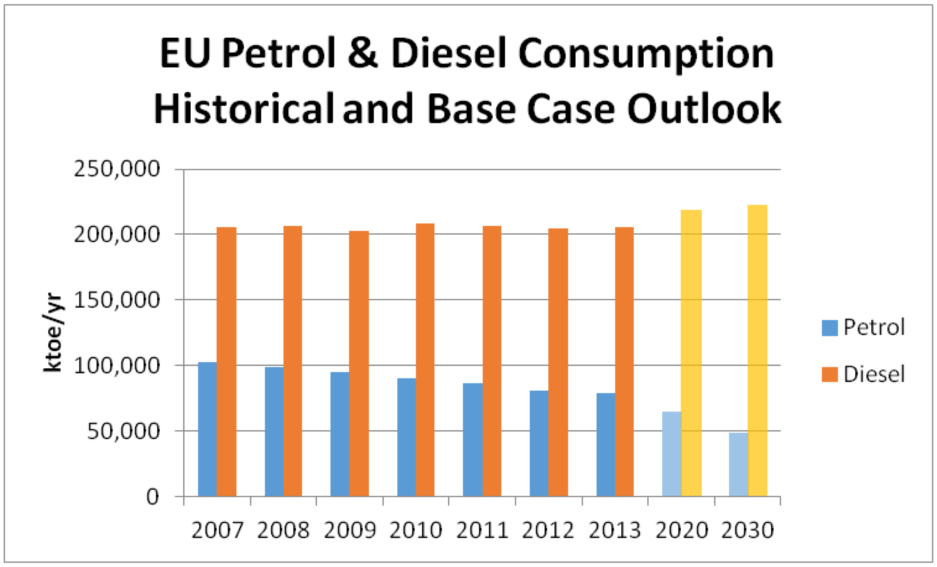


Figure 5.6 EU Petrol to Diesel Ratio History and Base Case Outlook

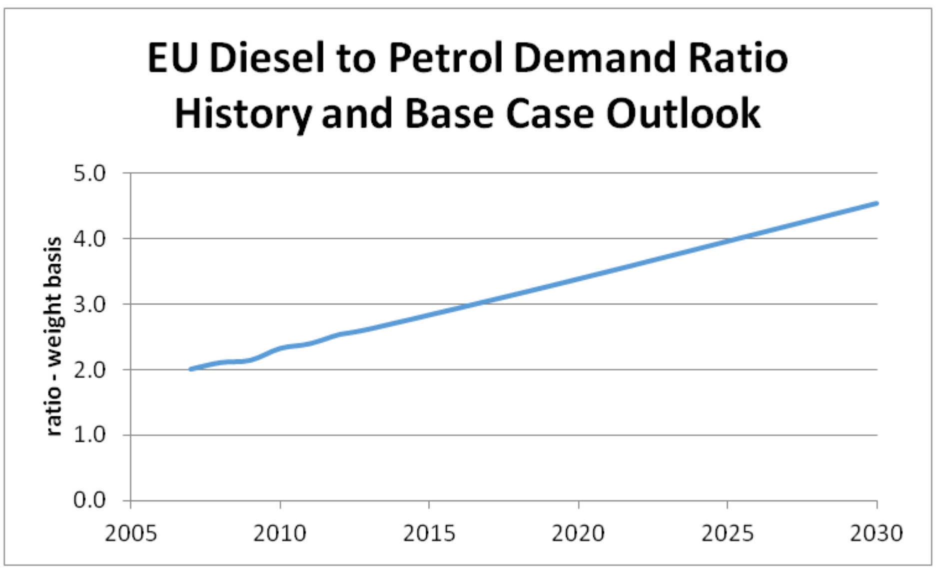
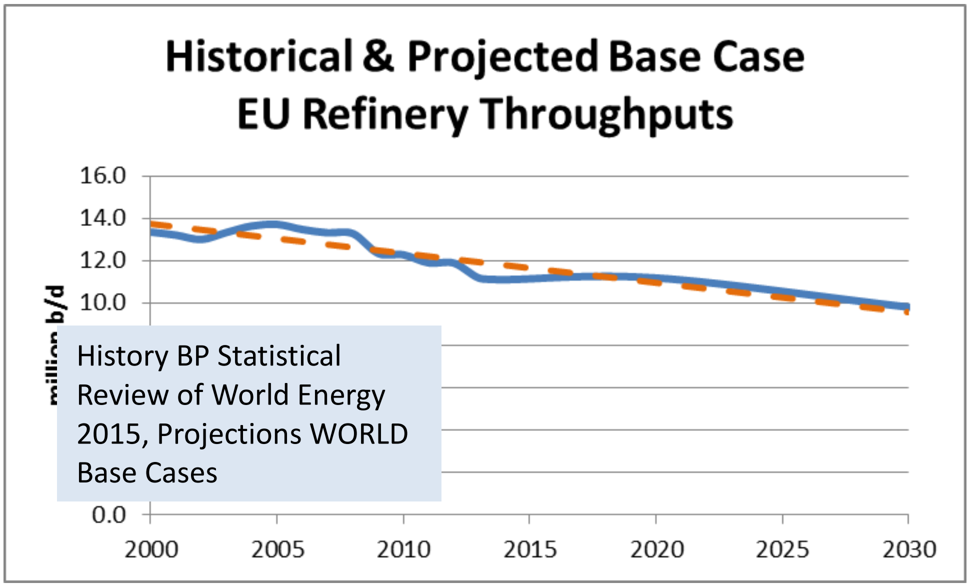


Figure 5.7 Historical and Base Case EU Refinery Throughputs



The strain in the European refining system is evident in the levels of petrol exports and diesel imports projected in the Base cases. For 2020, petrol exports are projected at nearly 54,000 ktoe/yr (1.24 mb/d) and distillate (diesel/gasoil) imports at 71,000 ktoe/yr (1.44 mb/d). For 2030, the corresponding figures are petrol 56,000 ktoe/yr (1.3 mb/d) and distillate (diesel/gasoil) 104,000 ktoe/yr (2.1 mb/d). In comparison, in 2013, Europe's refineries were reported as having excess petrol production at a level of around 34,000 ktoe/yr (0.8 mb/d) and a diesel/gasoil deficit of around 33,000 ktoe/yr (0.67 mb/d).[100]

In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. The continuing distortion in projected regional demand ratio (petrol decline, diesel increase) relative to refinery yield capability contributes to reduced refinery throughputs while at the same time necessitating higher petrol exports in order to enable diesel production. Figure 5.10 compares Base Case and Higher Biofuels projections for EU petrol exports and diesel/gasoil imports with reported 2013 levels. Versus 2013, the Base Case outlook leads to a 50 – 60% increase in petrol exports and a doubling by 2020 then tripling by 2030 in diesel/gasoil imports.

In short, the Base Case outlook is for a highly strained situation for European refiners which both reduces throughput and leaves little flexibility remaining.

5.4.2 Higher biofuel scenarios

Figure 5.8 through Figure 5.13 and Table 5.6 through Table 5.8 summarise key results from the higher biofuel scenarios. The primary impact (Figure 5.8) is that total global refinery throughputs drop by approximately the volume of the EU biofuel supply increases that were assumed in the higher biofuel scenarios. This is to be expected since the added biofuel correspondingly reduces the amount of refined product needed.[101] Thus the assumed biofuels supply increases

[100] http://www.hydrocarbonprocessing.com/Article/3321653/European-refiners-hit-by-diesel-deficit-gasoline-glut.html.

[101] The match between biofuel supply increase and crude supply/processing reduction is not exact since the two have different qualities.

in the EU of just over 0.2 mb/d (2020 All Scenarios) up to just over 0.5 mb/d (2030 Scenario C) lead to broadly equal reductions in refinery throughputs and crude production.

A related key aspect is the split of the refining impacts between the EU and Non-EU regions. The results indicate the majority of the throughput reductions would occur in Non-EU regions – some 70-85%. Why is this the case? The answer lies in the case premises and Base Case outlook. As previously described, the bulk of the increases in biofuels supply across the Higher Biofuels cases were assessed to be for biodiesel. As also shown, and expanding on what is happening today, in the 2020 and 2030 Base cases, the EU is projected to be importing significantly more diesel/gasoil than today. Since the bulk of the assessed biofuel increase is biodiesel and since it is diesel/gasoil that is imported, the primary impact of the higher EU biodiesel supply is to back out diesel/gasoil imports. These imports by definition would have been produced in regions outside the EU, therefore it is in those regions that the bulk of the refinery throughput reductions occur[102].

Increases in biodiesel supply thus tend to help EU refiners by reducing some of the strain to produce diesel/gasoil in competition with imports. Increases in regional ethanol supply have the opposite effect. They exacerbate an already strained situation in which EU refiners have to coproduce and export petrol in order to co-produce diesel. While raising EU biodiesel production if anything eases the situation for EU refiners, increasing ethanol production leaves refiners with the option of either maintaining throughputs or exporting additional petrol – to offset the additional ethanol now feeding in to EU petrol – and/or to accommodate to the increased ethanol supply by reducing refinery production of petrol and thus refinery throughputs. What was evident in the modelling cases was a mix of both adjustments coming into play – some increases in petrol exports in conjunction with some reductions in refinery throughputs.

The results obtained were dependent on the degree of petrol:diesel stress inherent in the Base Case scenario and the volume and mix of incremental EU biofuel supply. Given the premises that were required for the Base case scenario, EU refinery throughputs are projected to drop by 0.15 mb/d in 2030 Scenario C and around 0.05-0.06 mb/d in 2020 All Scenarios and 2030 Scenarios A and B. Again, given the premises applied, the bulk of the refinery throughout reductions are shown as occurring outside the EU, 0.35 mb/d under 2030 Scenario C. This is because, as stated, EU biodiesel supply increases reduce EU diesel/gasoil imports essentially with the consequence that throughputs must necessarily drop in the regions whose exports to the EU have dropped.

Table 5.6 sets out these results and also the implied refinery closures that could occur see also Figure 5.9. (These were estimated by taking the change in refinery throughput and dividing that by 0.8, equating to an assumed roughly 80% utilisation.) These are indicated as 0.27 mb/d global under 2020 All Scenarios and as lying in the range of 0.4 to 0.63 mb/d global in the 2030 Scenarios A through C. Of these some 70-86% are projected to occur outside the EU. So one key implication is that raising EU regional biofuel production, with the primary emphasis on biodiesel, would be expected to have substantial impacts on refineries outside the EU as well as inside. As discussed further below, these projections are sensitive to the assumptions used (Section 5.4.2.2).

Figure 5.10 illustrates the reductions in diesel/gasoil imports into the EU. In addition, it illustrates how the higher biofuel scenarios could be expected to lead to higher EU exports of petrol, this to partially offset the reduction in refined petrol needed for regional EU markets because of the increase in regional ethanol supply. The Figure also shows the scale of the

[102] The model results project diesel/gasoil imports would be flowing in from Russia followed by USA & Canada, Latin America, Middle East and Africa. All these regions would be affected by the increases in EU biodiesel production.

projected increases in both petrol exports and diesel/gasoil imports by 2020 and 2030 versus the situation in 2013.

Figure 5.11 shows the projected associated impacts on refinery investments. Again, because it is projected the bulk of the refinery throughput impact would be on refineries outside the EU, it is Non-EU regions where the bulk of corresponding reductions in investments (less refinery plant needed). For global refinery investments, the changes equate to reductions in the range of 2.4-3.3%. For the EU, the reductions are indicated as around 3.5-3.9% (off an already low total investment as shown in Table 5.6).

Figure 5.8 Effects of Higher Biofuels Scenarios on Refinery Throughputs

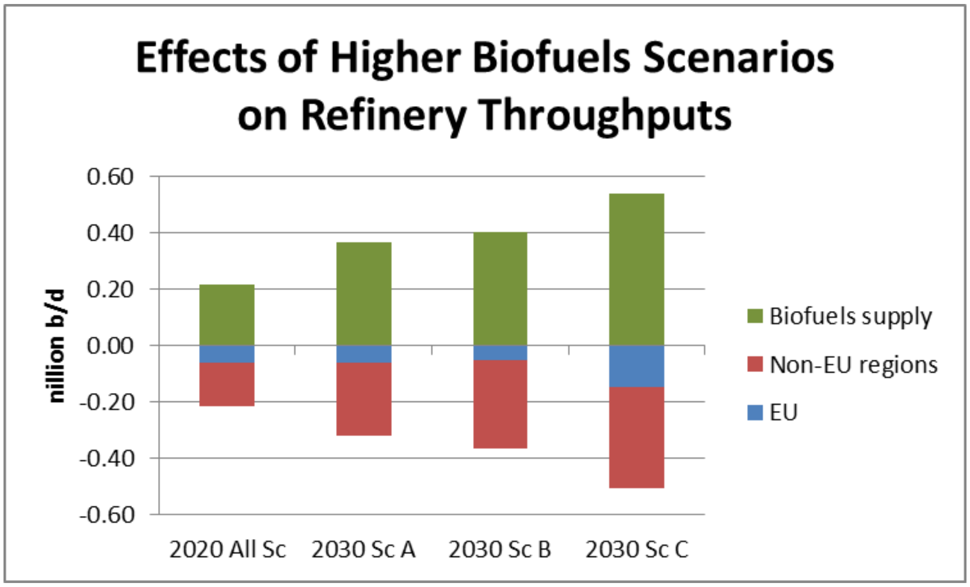


Figure 5.9 Potential Refinery Closures from Higher Biofuels

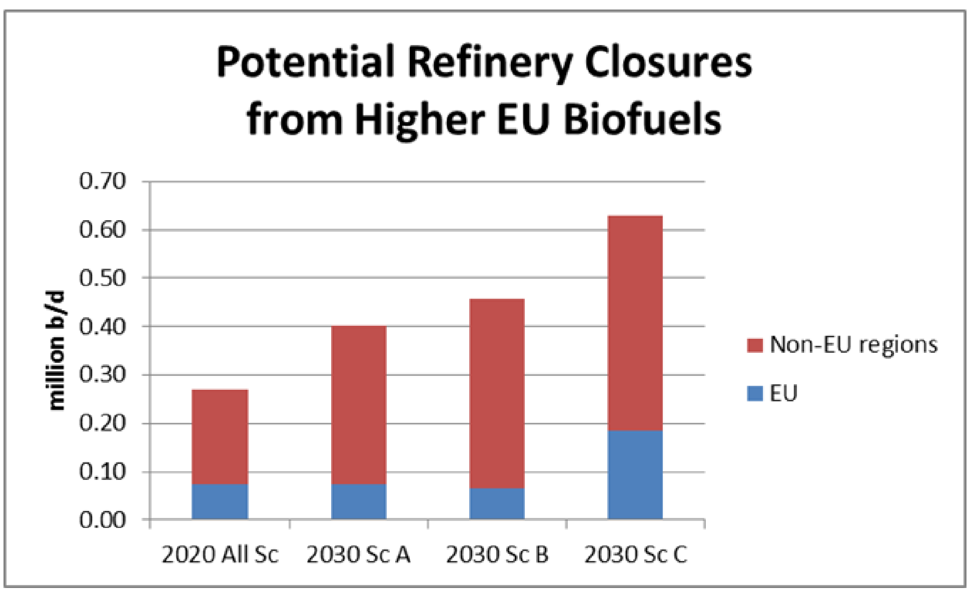


Figure 5.10 Effects of Higher Biofuels Scenarios on EU Imports and Exports

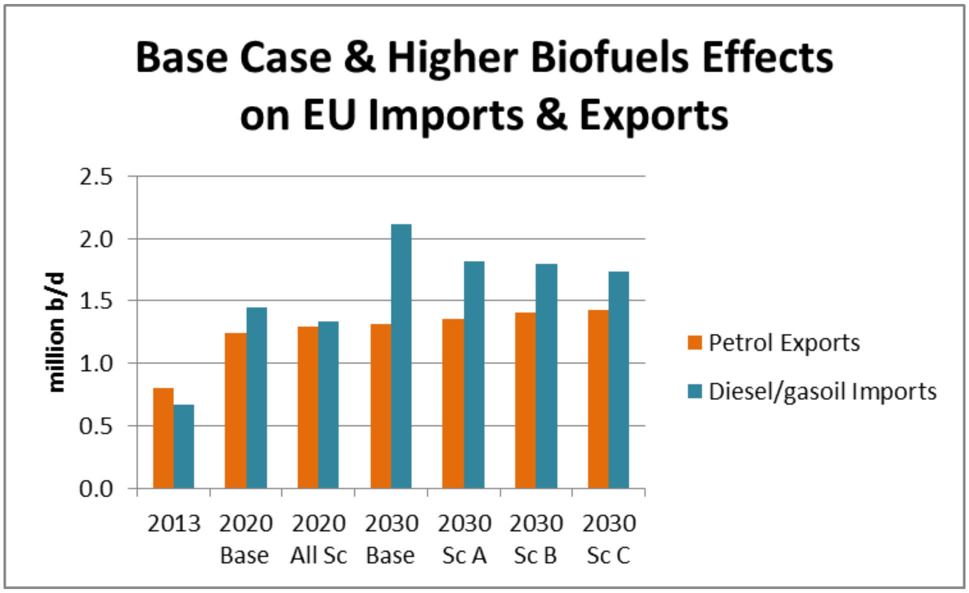


Figure 5.11 Effects of Higher Biofuels Scenarios on Refinery Investments

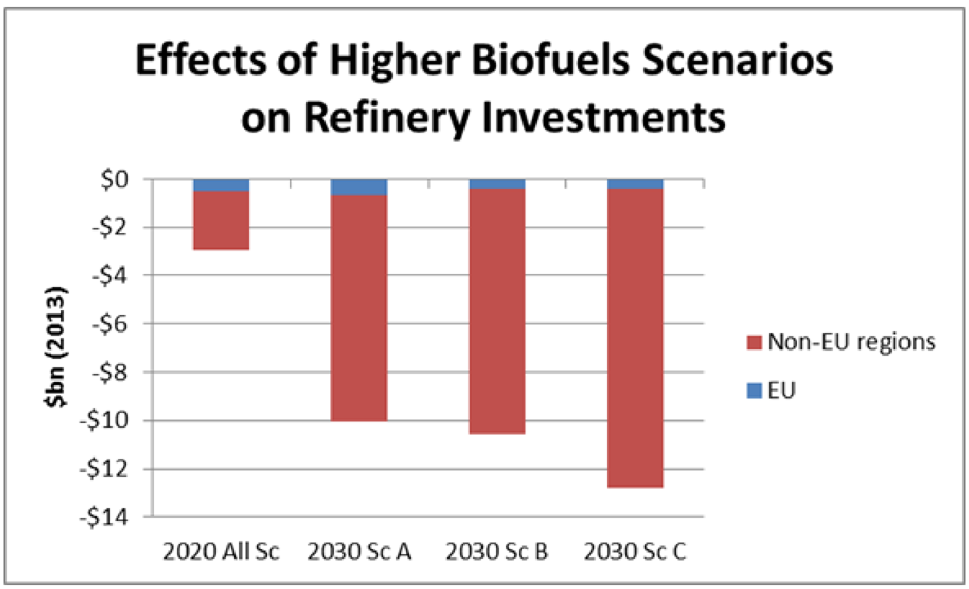


Figure 5.12 illustrates the impacts of the higher biofuel scenarios on refinery margins – with details in Table 5.7 which also summarises key price impacts. The refinery margins are expressed simply in terms of what are in the industry are referred to as "crack spreads":

- The margin for a complex refinery oriented toward gasoline is represented by a 3-2-1 crack spread wherein the price of 3 barrels of crude (Brent) is deduced from the revenue from (price of) 2 barrels of petrol plus 1 of diesel and then expressed as $/barrel of crude

- The margin for a complex refinery oriented toward diesel is represented by a 2-1-1 crack spread wherein the price of 2 barrels of crude (Brent) is deduced from the revenue from (price of) 1 barrels of petrol plus 1 of diesel
- The margin for a less complex refinery is represented by a 5-2-2-1 crack spread corresponding to revenue from 2 barrels of petrol plus 2 barrels of diesel plus 1 of residual fuel minus the cost of 5 barrels of crude, again expressed as $/barrel of crude.

Firstly, the crack spread margins are projected as a whole to be markedly lower in 2030 than in 2020 (this with a top down projection for higher crude prices in 2030 than in 2020 which *a priori* would tend to support refinery margins). There are a number of underlying causes. Key is the projected continuing overall demand decline in Europe, (most notably for petrol), under the Base Case scenario. Another factor is that EnSys did not build in any firm refinery closures for the period post 2030. EU refinery utilisations are projected to drop from the 80% range in 2020 to the 70% range in 2030 – with clear implications for further Base Case closures by 2030 (before considering the higher biofuel scenarios). These closures were left implied in the results although clearly a 70% level is unsustainable; therefore the Base Case outlook implies significant closures before considering the added effects of higher biofuels. Had EnSys enacted further closures in the 2030 cases then we would have expected the reported margins to be somewhat higher. Similarly, EnSys did not build in any assumed closures post 2020 for Non-EU refining regions. As a result, global utilisations are projected to average 79.9 – 79.6% in the 2030 cases versus 81.9-81.7% in the 2020 cases.

A second effect is that relative margins on the gasoline oriented refinery (3-2-1 crack spread) drop significantly between 2020 and 2030. This is because of a projected global slowing in petrol demand growth by 2030 in which the projected EU reduction plays an important role.

The third effect visible in Figure 5.12 (and Table 5.7) is that in 2020 introducing higher biofuels cuts margins across all three refinery types considered whereas, in 2030, the impacts are minimal. EnSys believes this is because, in the 2020 scenarios, the EU refining industry still has a measure of flexibility but that, under the 2030 scenario with its substantial further reduction in petrol demand, the industry is operating in a highly strained manner in the Base Case and has little flexibility to react to further changes. In 2020, both the biodiesel and the ethanol supply increases act to ease the costs of supplying diesel and petrol. Conversely, in 2030 and as explained above, the already severely strained Base Case situation means adding more ethanol has an adverse effect on strained petrol supply and exports which negates the benefit increasing biodiesel supply has in backing out diesel imports.

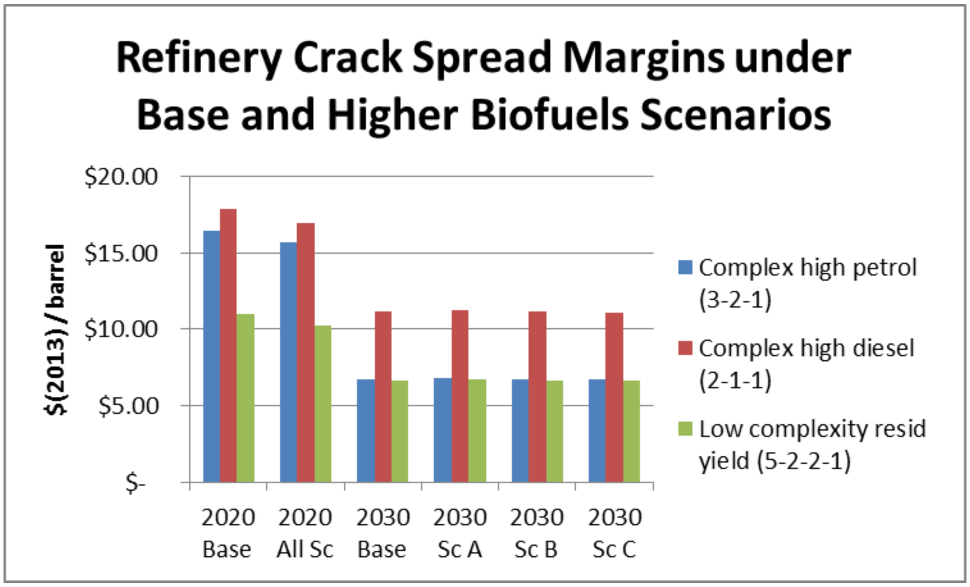
A similar story would appear to apply to projected product prices (Table 5.7) and delivered costs (the prices of each product at a major market centre times its demand volume then summed across all products), Figure 5.13 and Table 5.8. In 2020, delivered costs are projected to drop when more biofuel is introduced (in the EU) although the effects would be small, about a 0.6% reduction in the EU and a global reduction of 0.3%. Conversely in the 2030 scenarios, product supply cost hardly changes.[103] Again we believe this relates to the stresses inherent in the 2030 Base Case which then lead to the offsetting impacts from further biofuels additions.

[103] The WORLD modelling cases were undertaken using the same world crude oil price in each 2020 case ($2013 112/bbl) and in each 2030 case ($2013 122.67/bbl). Given the higher biofuels cases reduce crude oil demand by up to 0.5 mb/d, it could be argued that, therefore, crude oil prices and hence product prices would drop and that this price elasticity of demand should be allowed for in the assessment – essentially by lowering world crude price in line with the increase in biofuels supply. EnSys briefly examined the situation. Applying a (long run) price elasticity of demand for crude oil of -0.23 (taken from The Impacts of U.S. Crude Oil Exports on Domestic Crude Production, GDP, Employment, Trade, and Consumer Costs, March 31, 2014, by ICF International and EnSys Energy for the

Overall, our finding is that higher biofuels supply and use in the EU has adverse impacts on the refining sector in terms of throughputs – and hence implied further closures – but also that, because the European industry operates with a petrol/diesel imbalance which worsens under these scenarios, a primary impact is to reduce diesel/gasoil imports into the EU such that the bulk of the refinery impacts are projected to be felt in regions outside the EU.

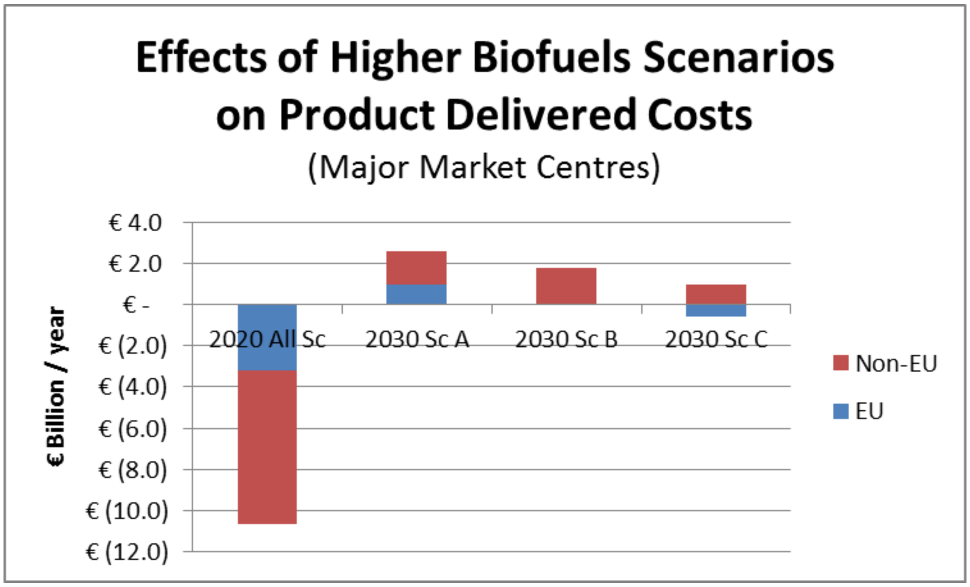
Impacts of higher biofuels on EU crack spread margins are negative in 2020, narrowing them by 4.5-7%. Under the more strained conditions projected for 2030, the positive impact of additional biodiesel is offset by the negative impact of additional ethanol with the result that crack spread margins are only minimally impacted. They vary by around +2 to -1%.

Figure 5.12 Refinery Crack Spread Margins under Base & Higher Biofuels Scenarios



American Petroleum Institute) implies that a 0.5 mb/d crude oil demand reduction would (given a global system running roughly 83 mb/d of crude – 2030 Scenario C) equate to a crude oil price reduction of around 2.5%. Recognising that the price of finished products includes other costs aside from just crude oil, the implied maximum change in product price (again 2030 Scenario C) would be of the order of 2% as a result of the reduction in crude oil demand and price. This equates to maximum effect of approximately 2 €¢/litre, i.e. a small impact.

Figure 5.13 Effects of Higher Biofuels Scenarios on Product Delivered Costs



5.4.2.2 *Sensitivity of Results*

The projections are sensitive to the premises used for the Base case outlook. As discussed above, this outlook embodies a severe reduction in Base case EU petrol demand by 2030. This, together with a projected predominance of global distillates demand growth (jet/kerosene plus gasoil/diesel) versus more moderate petrol demand growth by 2030 leads to a tightening in the market for distillates and a slackening in that for petrol. This can be seen in, for example, the trends in Northwest Europe petrol and diesel price differentials versus Brent crude oil. In the first 8 months of 2015, Brent price averaged $55.69/barrel, Northwest Europe 95 RON petrol $70.35 and Northwest Europe ultra-low sulphur diesel $71.08/barrel.[104] The corresponding price differentials versus Brent were thus $14.66/barrel for petrol and $15.39/barrel for diesel. By way of comparison, the corresponding modelled 2020 Base case differentials were petrol $13.26 and diesel $20.92/barrel, reflecting a gradual trend to tighter diesel demand. The corresponding projected Base case differentials for 2030 were negative almost $3/barrel for petrol and positive almost $24/barrel for diesel. Thus these Base case differentials reflect the projected extreme Base case surplus of petrol in the EU and extreme deficit for diesel – that is also reinforced by global trends. The high premium for diesel over crude (Brent) reflects the need to build high-cost incremental hydro-cracking and related process units at the margin in order to meet marginal distillate demand.[105] As discussed, those facilities are projected as being built in 2030 in Non-EU regions. They represent the highest-price forms of diesel supply (delivered cost to Europe) and thus are the sources of supply which are cut when biodiesel supply in Europe is raised in the Higher Biofuel cases.

[104] Source Bloomberg.

[105] The analysis indicates that, because of a combination of flat to declining regional demand and high operating costs, there is essentially no incentive or ability to invest within EU refineries to try to resolve the projected extreme 2030 petrol:diesel imbalance. Since EU refineries are also constrained by their ability to produce petrol, and consequently diesel since there is a limit to their feasible diesel:petrol ratio, the investment to product incremental diesel necessarily comes from Non-EU refineries.

The extreme price differentials in the 2030 Base case beg the question of whether such a scenario would indeed occur but they represent the EU demand outlook presented in *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013. Because of the extremely depressed EU petrol prices projected for 2030, EU refiners are – in the model cases - able to find expanded export markets for petrol. It is appropriate to question whether such exports would in fact exist. However, should they not be found, the situation that would apply would be one where, in 2030, EU refineries would be heavily constrained by their ability to produce petrol. Versus the levels of close to 10 mb/d projected in the 2030 cases, EU refinery throughputs would have to drop dramatically, potentially to as low as around 5 mb/d. In that scenario, Non-EU refineries would have to export around 5 mb/d of additional products to the EU, not only diesel but jet fuel and a range of other products from lubricating oils to asphalt. The Non-EU refineries would have to be expanded by at least 5 mb/d, with attendant major investment costs, while existing EU refineries sat idle. In the authors' view, such a scenario is not realistic – barring closure of EU refineries on a massive scale. Such major investments and import flows would not occur as long as there is EU refinery capacity available. Thus exporting large volumes of petrol while importing large volumes of diesel represents the most economic (or least un-economic) option as signified by the modelling results.

The European Commission Joint Research Council “refinery fitness test” analysis concluded that, in 2012, EU refineries suffered from severe competitive disadvantages versus refineries in several other regions, because of a combination of additional regulatory but especially energy costs. Natural gas prices in 2012 were some 3-4 times higher in Europe that in the USA (or Middle East). With the recent large drop in crude oil prices, the ratio has shrunk to around 2:1. While the IEA WEO used for this study comprised a “high price” outlook, the gaps between natural gas prices across the major regions of the world were assumed to slowly and partially narrow over the long term to 2030; this based on a gradual increase in international natural gas trade including an expansion of natural gas sources flowing into Europe. Thus the severe competitive energy cost disadvantage that EU refineries have been suffering at recent $100/barrel crude price levels was projected to have moderated to some degree by 2030. This in turn affected, to a limited degree, the projected long term relative energy costs for EU refiners.

The modelling analysis did indicate that the split in projected refinery throughput and implied capacity losses in 2030 is very sensitive to the projected ratio for EU petrol to diesel demand. In preliminary model cases, EnSys inadvertently set 2030 EU diesel demand at the correct level but EU petrol demand (including biofuel) close to recent levels of around 2 mb/d, i.e. at approximately twice the 1.1 mb/d called for in the 2030 Base case. The results obtained indicated that, since EU refineries would be less strained, (have the ability to produce petrol and diesel in somewhat more normal ratios without resorting to major expansion of petrol exports), they would correspondingly “share” more in the impacts of adding in higher biofuels supplies. EU refinery throughput reductions and implied closures would be higher than in the final model cases run with the correct (much lower) 2030 petrol demand. The indicated share of throughput reduction was closer to 50:50 between EU and Non-EU refineries.

5.4.2.3 Use of ETBE

As discussed, the higher biofuel scenarios were analysed on the basis that ethanol would be blended directly into petrol. The analysis did not assess the potential differences in outlook should ethanol be first processed into ETBE and the latter then blended into petrol in the EU. Such analysis is feasible to undertake but was beyond the scope of the current project. Processing ethanol into ETBE would entail an additional processing step to etherify ethanol into

ETBE by reacting it with iso-butylene.[106] This step would be undertaken either within a refinery of within a separate processing facility. Either way, the resulting ETBE would then be blended into petrol (in place of the ethanol). Using ETBE instead of ethanol would incur additional capital, operating and energy costs and associated GHG emissions for the etherification step but would ease the refinery petrol blending in part because ETBE has a vapour pressure much below that for ethanol. Thus, versus use of ethanol, there could potentially be reduced refinery capital/operating costs and or emissions which would help offset the increases from ETBE production. Again, this study did not include any examination of these trade-offs or whether there would be potential net benefits.

[106] The MTBE process entails reacting methanol with iso-butylene.

Table 5.6 Summary of Key Case Results – Refining & Trade

	2020 Base		2020 Scenario A		2030 Base		2030 Scenario A		2030 Scenario B		2030 Scenario **C**	
	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe
Total Investments (b$ 2013)	124.01	14.39	121.08	13.89	385.46	11.04	375.40	10.39	374.91	10.63	372.68	10.61
Refinery Throughput (mmbpd)	81.10	11.20	80.88	11.14	83.63	9.82	83.31	9.76	83.27	9.77	83.13	9.67
Refinery Utilization (%)	81.91%	80.37%	81.72%	79.94%	79.94%	70.59%	79.72%	70.17%	79.69%	70.21%	79.57%	69.53%
Implied Additional Closures (change in throughput divided by 80%)												
EU				0.07				0.07		0.07		0.19
Non-EU			0.19				0.33		0.39		0.44	
Global			0.27				0.40		0.46		0.63	
Percent Non-EU			72%				82%		86%		70%	
Net Imports into Europe (WORLD Europe Countries ratioed back to EU28)												
USLD (mmbpd)		1.21		1.08		1.55		1.29		1.29		1.24
Biodiesel (mmbpd)		0.00		0.00		0.01		0.07		0.08		0.07
Ethanol (mmbpd)		-0.05		0.00		-0.07		-0.03		0.00		0.00
Biodiesel Production (mmbpd)	0.68	0.30	0.89	0.50	1.33	0.40	1.69	0.74	1.69	0.74	1.79	0.84
Ethanol Production (mmbpd)	1.84	0.10	1.84	0.10	2.44	0.10	2.44	0.10	2.48	0.14	2.52	0.17
Total Biofuel Producton (mmbpd)	2.51	0.40	2.73	0.60	3.77	0.51	4.14	0.85	4.17	0.88	4.31	1.01
Change versus Base Case			0.22	0.20			0.37	0.34	0.40	0.37	0.54	0.50
Refinery Fuels												
Total Refinery Fuel Oil (mmboepd)	6.451	0.909	6.427	0.902	6.436	0.759	6.403	0.754	6.397	0.754	6.383	0.747

Table 5.7 Summary of Key Case Results – Crude, Product & Biofuel Prices, Refining Margins

Summary of WORLD Model Results for EC - Europe Higher Biofuel Cases

Note - results below are for WORLD Model definition of Europe countries but with volume results converted to EU28, by dividing by 1.077

	2020 Base		2020 Scenario A		2030 Base		2030 Scenario A		2030 Scenario B		2030 Scenario **C**	
	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe
CRUDE PRICES FOB												
SAUDI LIGHT (input marker crude price $/barrel)	$ 109.15		$ 109.15		$ 119.58		$ 119.58		$ 119.58		$ 119.58	
Brent ($/barrel) - output	$ 115.69		$ 115.66		$ 124.35		$ 124.32		$ 124.33		$ 124.31	
CRACK SPREADS - Output $/bbl												
NW Europe 3-2-1 Brent		$ 16.45		$ 15.69		$ 6.70		$ 6.83		$ 6.76		$ 6.72
NW Europe 2-1-1 Brent		$ 17.88		$ 16.91		$ 11.20		$ 11.22		$ 11.16		$ 11.11
NW Europe 5-2-2-1 Brent		$ 11.00		$ 10.22		$ 6.68		$ 6.71		$ 6.67		$ 6.63
EU ETS Allowance Prices - Input €/tonne CO2												
Source EU Trends to 2050 Fig 11		€ 10		€ 10		€ 35		€ 35		€ 35		€ 35
Key Product Prices (Output) €/litre												
Europe North												
Petrol (95 RON)		€ 0.739		€ 0.737		€ 0.698		€ 0.700		€ 0.699		€ 0.699
Diesel (ULS)		€ 0.788		€ 0.779		€ 0.852		€ 0.850		€ 0.850		€ 0.850
Europe South (Med)												
Petrol (95 RON)		€ 0.732		€ 0.731		€ 0.690		€ 0.692		€ 0.692		€ 0.692
Diesel (ULS)		€ 0.774		€ 0.767		€ 0.846		€ 0.843		€ 0.843		€ 0.842
Europe East												
Petrol (95 RON)		€ 0.740		€ 0.739		€ 0.691		€ 0.693		€ 0.692		€ 0.692
Diesel (ULS)		€ 0.781		€ 0.774		€ 0.846		€ 0.840		€ 0.840		€ 0.838
Key Biofuel Prices (Blending Value - Output) €/litre												
Europe North												
Ethanol		€ 0.781		€ 0.784		€ 0.681		€ 0.686		€ 0.691		€ 0.690
Biodiesel		€ 0.785		€ 0.804		€ 0.850		€ 0.850		€ 0.849		€ 0.849
Europe South (Med)												
Ethanol		€ 0.772		€ 0.783		€ 0.563		€ 0.679		€ 0.692		€ 0.690
Biodiesel		€ 0.770		€ 0.785		€ 0.840		€ 0.838		€ 0.838		€ 0.837
Europe East												
Ethanol		€ 0.792		€ 0.795		€ 0.692		€ 0.697		€ 0.700		€ 0.698
Biodiesel		€ 0.783		€ 0.798		€ 0.849		€ 0.849		€ 0.849		€ 0.849

Table 5.8 Product Delivered Costs

Summary of WORLD Model Results for EC - Europe Higher Biofuel Cases												
Note - results below are for WORLD Model definition of Europe countries but with volume results converted to EU28, by dividing by									1.077			
	2020 Base		2020 Scenario A		2030 Base		2030 Scenario A		2030 Scenario B		2030 Scenario **C**	
	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe	Global	Europe
TOTAL EXTERNAL PRODUCT COST (EXCLUDES INTERNAL REFINERY CONSUMPTION)												
(demand times open market price (from model) summed across all products by region and global)												
TOTAL COST - € BILLION / YEAR												
Petrol	€ 1,037	€ 65	€ 1,035	€ 65	€ 987	€ 46	€ 989	€ 46	€ 989	€ 46	€ 989	€ 46
Distillates (Jet/Kero,Gasoil/Diesel)	€ 1,642	€ 334	€ 1,636	€ 332	€ 1,902	€ 376	€ 1,901	€ 377	€ 1,900	€ 376	€ 1,899	€ 376
Residual Fuels	€ 157	€ 14	€ 157	€ 14	€ 217	€ 23	€ 217	€ 23	€ 217	€ 23	€ 217	€ 23
Other Products	€ 670	€ 90	€ 669	€ 90	€ 719	€ 95	€ 721	€ 95	€ 721	€ 95	€ 721	€ 95
Total	€ 3,507	€ 504	€ 3,497	€ 500	€ 3,825	€ 540	€ 3,828	€ 541	€ 3,827	€ 540	€ 3,826	€ 540
TOTAL COST - € MILLION /DAY	€ 9,609	€ 1,380	€ 9,582	€ 1,371	€ 10,480	€ 1,480	€ 10,487	€ 1,483	€ 10,485	€ 1,480	€ 10,481	€ 1,479

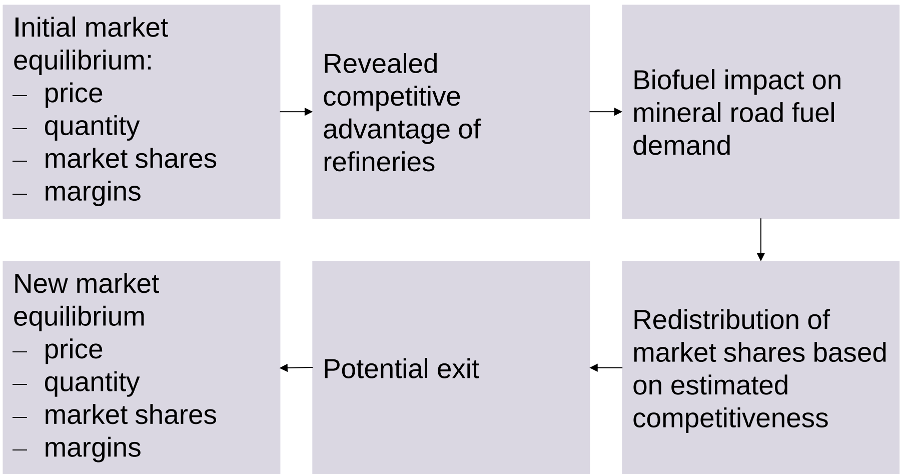
5.5 FIMM methodology and assumptions

This section presents a description of the methodology including input data and a market description

5.5.1 Methodology

Vivid Economics' (Vivid) Full Industrial Market Model (FIMM) was applied to the petroleum refining sector, in order to estimate competitiveness impacts quantitatively. Vivid's FIMM estimates the impact of the displacement of mineral fuel demand by biofuels. Figure 5.14 explains how the demand change works through the model.

Figure 5.14 Vivid's FIMM estimates the market impacts changes based on market shocks



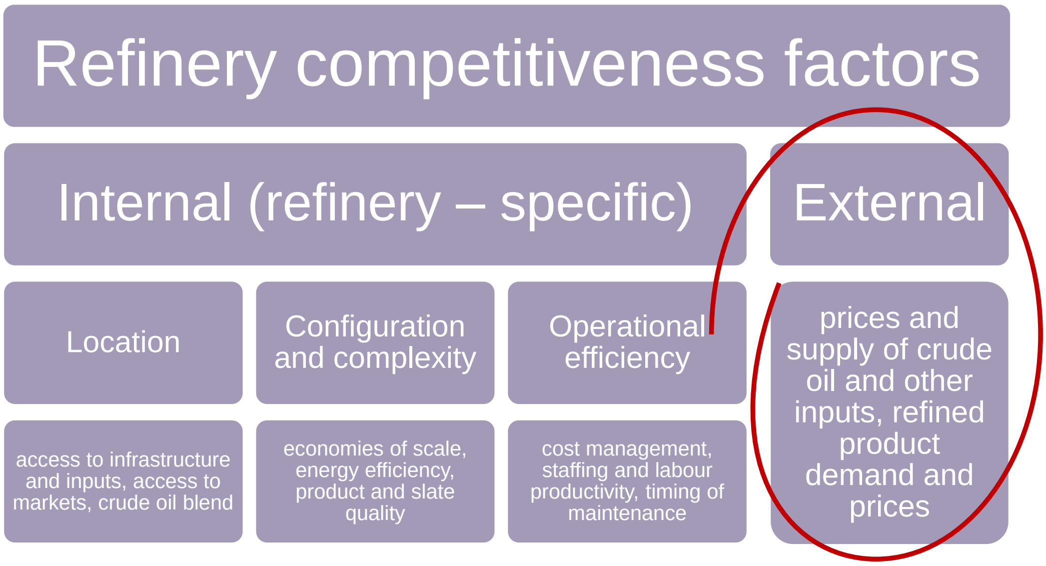
Source: Vivid Economics

The strength of competition in refining is determined from market data and largely drives the resulting sectoral cost pass-through rate. Competition in refining is a function of gross profit margins, the price elasticity of demand, and the market shares of firms (meaning the market shares of individual installations). . In conjunction with the absolute size of the shock that the industry is subject to, the strength of competition and price elasticity of demand determine the impact on quantity of production and market price. The impact on production can in turn be broken down into:

- the fall in production resulting from the decline in consumption as prices rise; and
- the loss of a refinery's market share to other refineries as profit margins decrease.

Refinery profitability is an outcome of the interplay between multiple drivers. Among the factors that influence a refinery's competitiveness, one can distinguish between variables that are within the control of an individual refinery and those that are external and apply to any refinery, independently of how it is constructed and managed. Among such external factors are, for example, general requirements on product and process specifications, or global market conditions determining the prices of crude oil and refined products. In turn, within the factors that can be controlled by a refinery, some are related to location (access to infrastructure and relevant markets; costs of inputs such as labour and energy; crude oil blend), others to refinery's configuration and complexity (economies of scale; energy efficiency; product slate and quality achievable), and some fall under operational efficiency (cost of management; staffing levels and labour productivity; timeliness of maintenance). These factors are schematically summarized in Figure 5.15. The internal factors are captured by the market shares in Vivid's analysis and are constant across scenarios.

Figure 5.15 Vivid's analysis looks at changes in the external factors affecting refinery competitiveness between scenarios



Source: *European Union (2015), Refinery Fitness Check*

5.5.2 Inputs

5.5.2.1 Assumptions

Table 5.9 lists the assumptions used in the model. Section 5.5.2.2 and 5.5.2.3 provide details on the price elasticity of demand and biofuel price assumptions respectively.

Table 5.9 Assumptions

Assumption	Units	Value	Source
Refinery utilisation in 2014	%	79%	European Union (2015), Refinery Fitness Check
Carbon price	€/tCO_2	5 in 2014; 10 in 2020; 35 in 2030	European Commission (2013), EU Trends to 2050
Average EU fuel duty in 2013*	€/l	0.53 (petrol) 0.41 (diesel)	European Environment agency (2013)
Average EU fuel duty in 2020 and 2030*	€/l	Same as 2014	Vivid assumption
Average EU VAT in 2013*	%	21%	DG Ener (2015)
Average EU VAT in 2020 and 2030*	%	Same as 2014	Vivid assumption
Wholesale road fuel price in 2014 in Member States	€/l	0.51 (petrol) 0.57 (diesel)	Eurostat (2014)
FQD baseline compliance cost level	€/tCO_2	10	Vivid Assumption based on 2013 FQD work
Share of petrol in EU in 2014 (in mineral road fuels)	%	30%	Internal report
Share of diesel in EU in 2014 (in mineral road fuels)	%	70%	Internal report
FQD baseline compliance cost level	€/tCO_2	10	Vivid Assumption based on 2013 FQD work
Petrol and diesel production shares for EU Member States throughout analysis	%	Assumed to be same in 2020 and 2030 as in 2012	UN (2012)

Assumption	Units	Value	Source
Crude oil price	$/bbl	85	2014 Brent average price

*Note: *Fuel duty and VAT do not influence the results of refinery competitiveness but the final consumer price level*

Source: Vivid Economics

5.5.2.2 Price elasticity of demand

The consumer price elasticity of demand (PED) for road fuels influences the interaction between supply and demand and resulting consumer market price and quantity, is obtained from Espey (1998), and takes the value -0.58. For refineries, the PED at the refinery gate is what determines their market response. It is lower than the PED for consumers because a fixed fuel duty is added to the pump price. Hence a change in refinery cost does not change the pump price one to one, but instead by a lower amount. Table 5.10 shows the calculation of price elasticity of demand at the refinery gate used in the FIMM, and its value is -0.32.

Table 5.10 Price elasticity of demand for the FIMM

Variable	Unit	Value	Calculation	Source
PED for consumers	unitless	-0.58	N/A	Espey (1998)
Price without taxes	€/l	0.55	diesel price * diesel share + petrol price * petrol share	prices: Eurostat (2014)
Price with fuel duty	€/l	1.00	road fuel price without taxes + average fuel duty	prices: Eurostat (2014)
Price with VAT	€/l	1.20	road fuel price with fuel duty * (1+VAT)	VAT: DG Ener (2015)
PED at the refinery gate	unitless	-0.32	PED for consumers * price without taxes / price with fuel duty	Calculation

Source: Vivid Economics

5.5.2.3 Price of biofuels

The biofuel prices for 2014, 2020 and 2030 shown in Table 5.11 are taken from the OECD FAO agricultural outlook 2014-23. The OECD ethanol and biodiesel price projections end in 2023, and in the calculations that follow, it has been assumed that the prices remain unchanged between 2023 and 2030.

Table 5.11 Biofuel prices

EUR/litre	2014	2020	2030*
Ethanol	0.57	0.68	0.73
Biodiesel	0.84	0.97	1.00

*Note: *The OECD ethanol and biodiesel price forecast end in 2023, which have been used as forecasts for 2030 prices.*

Source: Vivid Economics based on OECD FAO agricultural outlook 2014-23

5.5.2.4 Scenario inputs

Scenario inputs for demand of mineral road fuel were obtained from *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013. Table 5.12 shows the biofuel content in road fuels increasing from 14 per cent to 18 per cent by energy content on movement from scenario A to C in 2030. The consumption of mineral petrol and diesel in the EU decreases by 0.1 mb/d on each 2 per cent increase in biofuel content.

Table 5.12 Scenarios – consistent across tasks

	2020	2030		
	A/B/C	**A**	**B**	**C**
Biofuel share in road fuels by (energy)	10%	14%	16%	18%
EU consumption of mineral petrol and diesel (mbl/d)	4.9	4.5	4.4	4.3

Note: *The model uses biofuel shares by energy content and not volume since the energy content impacts the demand for mineral road fuels*

Source: Vivid Economics

The model was updated with the most recent input data and draws inputs from Chapter 1, Chapter 2 and Chapter 4 on biofuel availability and price. The model further accounts for expected changes in demand for refined products between today and 2020 and 2030, a period of projected demand decline. The changes in demand were be obtained from PRIMES-TREMOVE, and are consistent with projections presented in *EU Energy, Transport and GHG Emissions Trends to 2050*, Reference Scenario 2013. Consistency with other chapters is ensured by working on the same biofuel and mineral road fuel mix for 2014 and base case and scenarios in 2020 and 2030, as shown in Table 5.12 and Table 5.13.

Table 5.13 Biofuel mix

	2014	**2020**				**2030**			
		Base	A	B	C	Base	A	B	C
Ethanol	20%	14%	16%	16%	16%	8%	8%	14%	16%
Biodiesel	80%	86%	84%	84%	84%	92%	92%	86%	84%

Source: Vivid Economics

Table 5.14 Mineral road fuel mix

	2014	**2020**				**2030**			
		Base	A	B	C	Base	A	B	C
Petrol	30%	25%	26%	26%	26%	20%	21%	20%	18%
Diesel	70%	75%	74%	74%	74%	80%	79%	80%	82%

Source: Vivid Economics

5.5.3 Market description

Table 5.15 describes the EU refining industry in 2014, which is used to set up the 2014 base case scenario of the model.

Table 5.15 2014 EU refining industry

Variable	**Value**	**Note**
Total refining capacity (bbl/d)	14.2 million	15% of world refining capacity

Consumption of light and middle distillates* (bbl/d)	9.3 million	14.6% of world consumption, second largest in the world after US
of which petrol and diesel (bbl/d)	5.1 million	
Number of refineries producing petrol and diesel	90	Oil and Gas Journal (2014)
Average gross refining margins (€/bbl)	4	North West Europe average refining margins $4/bbl in 2014 (BP, 2015)
Ethanol share in petrol consumption (energy)	5.2%	Chapter 1, Table 1.7
Bio-diesel share in diesel consumption (energy)	3.4%	Chapter 1, Table 1.8

*Note: * 'Light distillates' consists of aviation and motor petrol and light distillate feedstock (LDF). 'Middle distillates' consists of jet and heating kerosene, and gas and diesel oils (including marine bunkers).*

Gross margins are margins after variable costs, that is it is price minus unit variable cost

Source: Vivid Economics, BP (2015)

5.6 FIMM results

This section presents the results of Vivid Economic's analysis of the impacts of biofuels scenarios on the profit margins of refineries (Section 5.6.1), consumer prices (Section 5.6.2) and refinery production and capacity reduction (Section 5.6.4). The results are presented as comparisons to the base case, which is explained in sub-section 5.6.1.

5.6.1 Base case

Demand for mineral road fuels falls even though biofuels content does not increase. Under the base case scenario, the biofuel energy content in road fuels does not change from 2014 levels. Consequently, 2020 and 2030 both have biofuel consumption at 5 per cent of road fuel energy content. However, due to a trend of declining mineral fuel demand, consumption of mineral petrol and diesel falls by 7.5 per cent between 2014 and 2030. This results in an estimated EU refinery capacity decline of 0.2 mb/d (2 per cent) by 2020 with a slightly reduced average margin, and no further EU capacity declines thereafter, coming at the cost of a reduction in the average margin. Imports of mineral road fuels also decline slightly. The reduction in mineral road fuel demand lowers mineral road fuel prices by 0.2% between 2014 and 2030, as some refining capacity becomes unprofitable and exits while margins fall for surviving capacity. All base case scenario results are summarised in Table 5.16.

Table 5.16 Under the base case scenario, demand for mineral road fuels falls even when biofuel content does not increase

Variable	Input/output	2014	2020 - base	2030 - base	Percentage change between 2030 and 2014
Consumption of mineral petrol and diesel (mb/d)	Input	5.5	5.3	5.1	-7.5%
Biofuel share in road fuels by (energy %)	Input	5%	5%	5%	no change
EU average gross margin ($/bbl)	Output	4.00	3.96	3.86	-3.5%
Average mineral road fuel price (€¢/l)	Output	55.2	55.1	55.1	-0.2%

Variable	Input/output	2014	2020 - base	2030 - base	Percentage change between 2030 and 2014
EU refinery capacity (mb/d)	Output	13.9	13.7	13.7	-1.5%

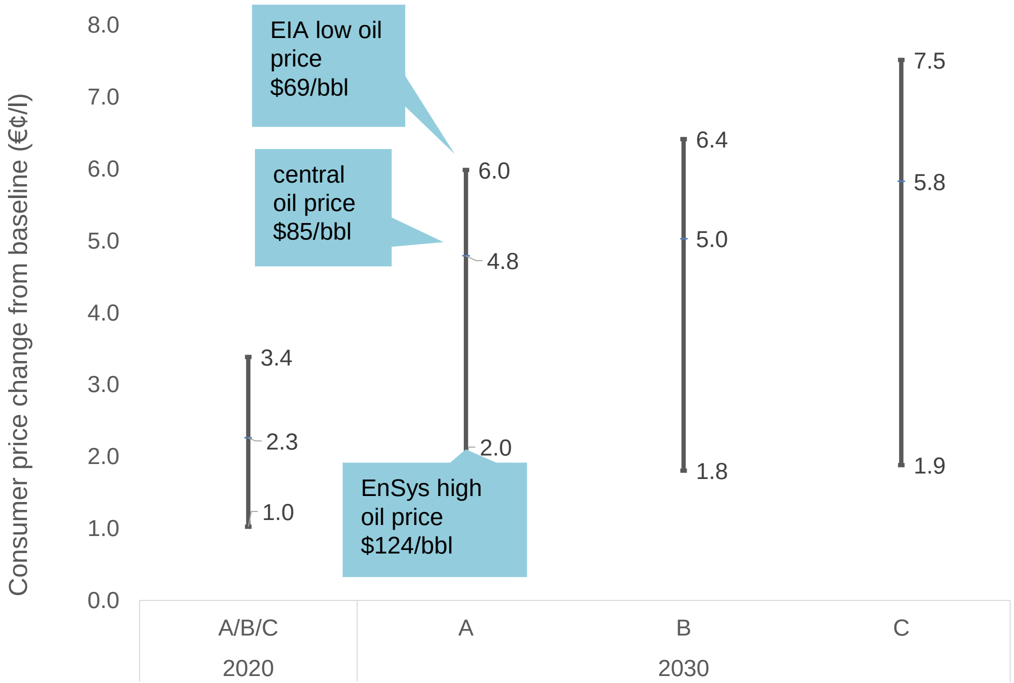
Source: Vivid Economics

5.6.2 Impact on consumer price

In Vivid's analysis, the consumer prices, including fixed fuel duty and VAT, increase by 2.3 €¢/l (2 per cent) in 2020 and up to 5.8 €¢/l (5 per cent) in 2030 relative to the base case scenario, as shown in Figure 5.16. The consumer prices are calculated as follows:

$$\text{consumer prices}(€/\text{l}) = [\text{mineral fuel price}(€/\text{l}) * \text{mineral fuel share } (\%) + \text{biofuel price}(€/\text{l}) * \text{biofuel share}(\%) + \text{fuel duty}] * (1 + \text{VAT})$$

Figure 5.16 The average consumer price might increase by 2.3 €¢/l in 2020 and up to 5.8 €¢/l in 2030 for a $85/bbl oil price



Note: Average mineral fuel price and average biofuel price are weighted by petrol and diesel and ethanol and bio-diesel shares, respectively, produced by the WORLD model. Average consumer price is weighted by mineral fuel and biofuel shares in road fuels. Taxes include average fixed fuel duty and VAT.

Source: Vivid Economics

Mineral fuel wholesale prices are 55.2 €¢/l in the base case and change negligibly between scenarios, as shown in Table 5.17. Biofuels are more expensive than mineral road fuels with an average wholesale price of 92.6 €¢/l in 2020, rising to 97.8 €¢/l in 2030, based on the prices and shares of biodiesel and ethanol shown in Sections 5.5.2.3 and 5.5.2.4. As the share of biofuels grows, from 5 per cent energy content in the base case to 10 per cent in 2020 scenario and up to 18 per cent in the 2030 scenario, and the relative shares of biodiesel and ethanol change, the consumer prices increase in response. Table 5.17 shows the calculations for consumer prices.

Table 5.17 Consumer price calculations

Unit: €¢//l	2020		2030			
	Base	A/B/C	Base	A	B	C
Mineral fuel price*	55.0	54.9	55.1	54.9	54.9	54.8
Biofuel price	92.6	91.9	97.8	97.8	96.1	95.7
Share of biofuels in road fuels (%)	5%	10%	5%	14%	16%	18%
Consumer price without taxes	56.8	58.6	57.1	60.9	61.3	62.1
Consumer price with fixed fuel duty and VAT	121.5	123.7	121.1	125.9	126.1	126.9

*Note: * For a crude price of $85/bbl. Average mineral fuel price and average biofuel price are weighted by petrol and diesel and ethanol and bio-diesel shares, respectively, produced by the WORLD model. Average consumer price is weighted by mineral fuel and biofuel shares in road fuels. Taxes include average fixed fuel duty and VAT.*

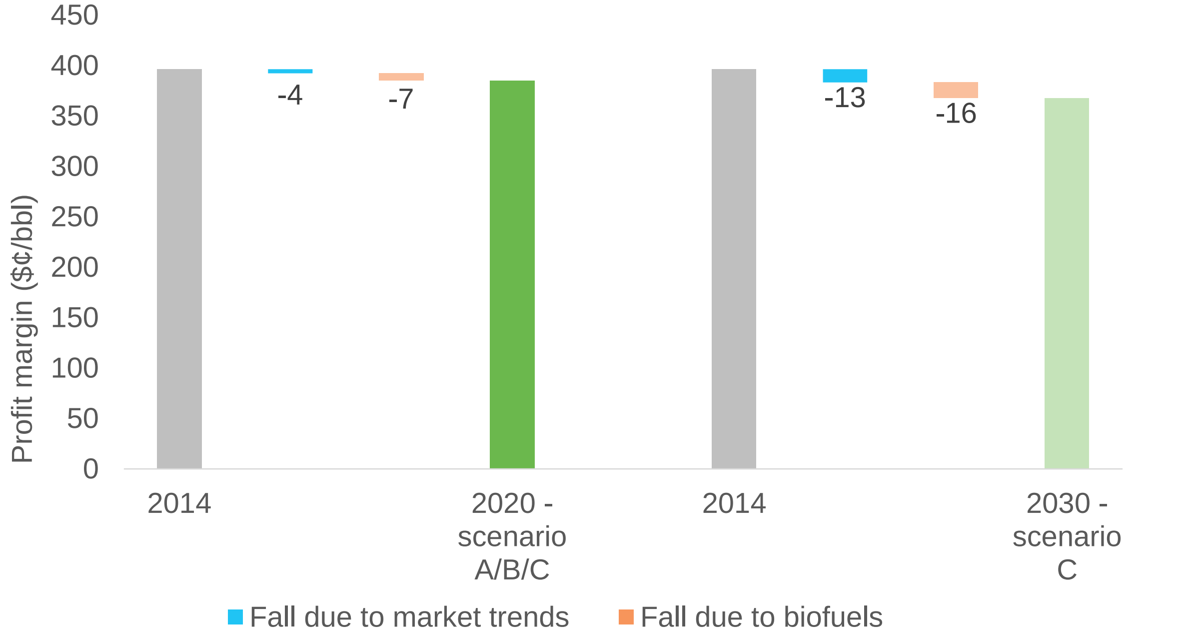
Source: Vivid Economics

Consumer price changes are sensitive to the crude oil price assumption. At a lower crude oil price, based on the EIA (2015) low oil price scenario of $58/bbl in 2020 and $69/bbl in 2030, the blending of a greater proportion of biofuels increases consumer prices by up to 7.5 €¢/l in 2030. If the oil price were higher, the price increase caused by sourcing a higher share of biofuels in the energy mix would be lower. For example, at the EnSys oil price of $116/bbl in 2020 and $124/bbl in 2030, which has been taken as the high oil price scenario, price increases are only 1 €¢/l in 2020 and up to 2 €¢/l in 2030.

5.6.3 Impact on refinery gross profit margins

Refinery gross profit margins decline by 7 US$¢/bbl in 2020 and up to 16 US$¢/bbl in 2030 due to biofuels. The decline is relative to the respective base case margin of 3.96 US$/bbl in 2020 and 3.87 US$/bbl in 2030 and represents the maximum declines in the highest biofuel energy share scenario (C). Margins decline as biofuels crowd out mineral road fuels and refineries compete for a smaller overall market. In scenarios A and B in 2030, the margins fall by 11 US$¢/bbl and 13 US$¢/bbl respectively relative to the base case scenario.

Figure 5.17 Profit margins decline by 7 US$¢/bbl in 2020 and up to 16 US$¢/bbl in 2030 due to biofuels



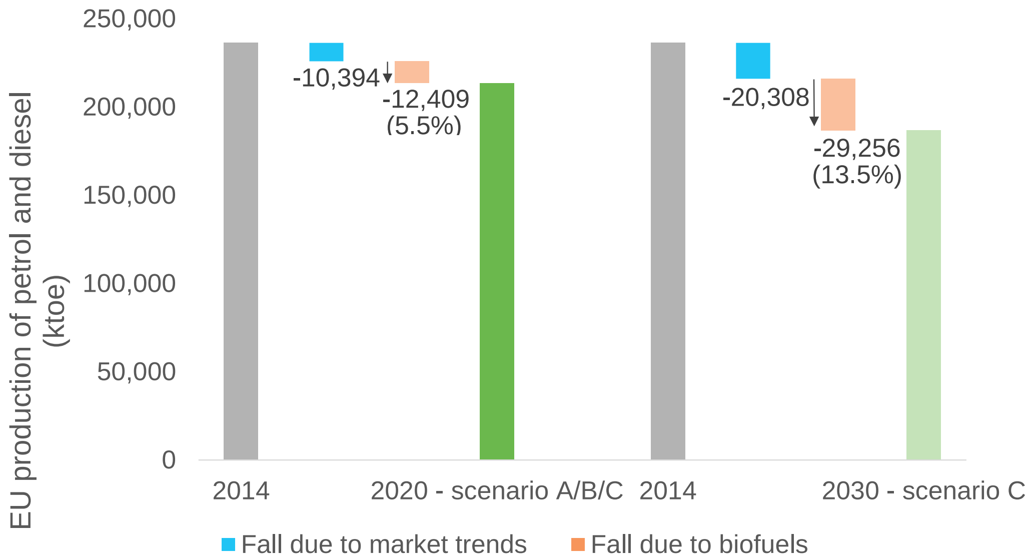
Note: North West Europe average refining margins were $4/bbl in 2014 (BP, 2015)

Source: Vivid Economics

5.6.4 Impact on production and capacity

Mineral petrol and diesel production in the EU falls by 5.5 per cent in 2020 and up to 13.5 per cent in 2030 due to biofuels. In comparison, underlying market trends (as described in the Base Case) shave off 4.4% of mineral road fuels demand in 2020 and 8.6% in 2030, as shown in Figure 5.18.

Figure 5.18 Petrol and diesel production falls by 5.5 per cent in 2020 and up to 13.5 per cent in 2030 due to biofuels



Source: Vivid Economics

Vivid Economics' Full Industrial Market Model (FIMM) estimates that the impact is felt by both EU refineries and importers. The absolute impact falls largely on EU refineries and they currently produce the majority of EU fuel supply. The FIMM is an economic model that estimates the value of mineral road fuels and the current share of imports. In contrast to the WORLD model, the FIMM is a top-down partial equilibrium model and does not model individual processes. As such, it does not account for the effects changes in the diesel/petrol ratio over time on the costs of refining. The WORLD model estimates a lower competitiveness of imports, that is, a higher cost of imports than is estimated by FIMM, and hence the WORLD model estimates a larger absolute and relative impact on importers than EU refineries, whereas the FIMM estimates impacts between the group of importers and the group of EU producers that are roughly in proportion to the market shares of those two groups.

The FIMM estimates an exit of 0.21 mb/d of EU refining capacity between 2014 and 2030. The FIMM estimates zero exit due to increasing biofuel shares in 2020 and 2030. EU refinery utilisations do not fall enough to force refineries to exit, when moving from the 2020 and 2030 base case scenario to the high biofuel blend scenarios. The fall in utilisation can be absorbed in margins. Some further EU refinery exits might occur, depending on market trends in refined product demand and import competition. If utilisation were to be sustained at its 2014 level of 79%, EU and import refining capacity would fall by 0.29 mb/d in 2020 and 0.69 mb/d in 2030.

5.7 Conclusions

The 2020/2030 Base Case scenario (based on EU Trends to 2050) will lead to a substantial reduction in EU petrol demand in combination with some increase in diesel demand. In order to continue to produce diesel and gasoil (and jet fuel), Europe's refineries have to co-produce petrol which must necessarily be exported. Considering that the EU diesel to petrol demand ratio is projected to shift from 2:1 in 2007 and 2.4:1 in 2011 to 3.4:1 in 2020 and 4.5:1 in 2030 (weight basis), an already problematic diesel:petrol ratio in the EU will be aggravated further by the impacts from higher biofuel demand. This will put a strain on EU refining and lead to projected lower regional refinery throughputs by 2030.

The impacts on refineries of increases in biofuel energy share are greater than the impacts of expected general trends in road fuel demand. By 2020, the EU mineral road fuels production could fall by 104,000 ktoe/yr (4.4 per cent) from its 2014 level due to market trends, and by an additional 124,000 ktoe/yr (5.5 per cent) due to biofuels (all scenarios). By 2030, mineral road fuels production could fall by 203,000 ktoe/yr (8.6 per cent) from its 2014 level due to market trends, and, due to increasing biofuel energy shares, by an additional:

- 209,000 ktoe/yr (9.7 per cent) in Scenario A
- 240,000 ktoe/yr (11.1 per cent) in Scenario B and
- 293,000 ktoe/yr (13.5 per cent) in Scenario C.

A primary impact of higher biofuel demand in the analysed scenarios is to reduce diesel/gasoil imports into the EU such that depending on assumptions the impacts may also be felt in refineries outside the EU. Because the European industry operates with a petrol/diesel imbalance which worsens under the Base case scenario, higher biofuels supply and demand in the EU has adverse throughput impacts on the EU and Non-EU refining sectors. In 2030, the implied further closures due to the higher biofuel scenarios could be over 0.6 million barrels per day (bbl/d) globally of which 0.2 million bbl/d might occur in the EU. The split of impacts between EU and Non-EU refining regions is, however, dependent on Base case scenario assumptions (e.g., a higher petrol demand in the EU, will result in a greater proportion of the total refinery throughput reductions and implied closures occurring in the EU than in Non-EU regions).

Impacts on product prices within the EU are projected to be limited. In 2020, biofuels could reduce the aggregate cost of products in major demand centres although the effects would be small, about a 0.6% reduction in the EU and a global reduction of 0.3%. Conversely in the 2030 scenarios, product supply cost hardly changes. It is assumed that this relates to the stresses inherent in the 2030 Base Case scenario which negates any positive blending value impacts from further biofuels additions.

Consumer prices increase as the biofuel energy share rises. For the analysed scenarios the increase in consumer prices may be 2.3 €¢/l in 2020 (2 per cent) and, in 2030:

- 4.8 €¢/l (4 per cent) in Scenario A
- 5.0 €¢/l (4.1 per cent) in Scenario B and
- 5.8 €¢/l (4.8 per cent) in Scenario C.

Consumer prices are comprised of mineral road fuel wholesale prices, biofuel wholesale prices and the EU average current fuel duty and Value Added Tax. Mineral road fuel wholesale prices are 55.2 €¢/l for an 85 $/bbl crude oil price and biopetrol and biodiesel wholesale prices, which are weighted by their respective share in total biofuels, could be 91.9 €¢/l in 2020, rising to 97.8 €¢/l in 2030. Including taxes, the average price at the pump is 121.5 €¢/l in 2020 and 121.1 €¢/l in 2030. The difference in biofuel and mineral road fuel prices drives the consumer price increase as the biofuel share increases from the baseline, as laid out above. (Chapter 5, Section 5.6.2).

Higher crude oil prices would narrow the differential between mineral road fuel and biofuel prices and would make smaller the increase in consumer prices. At 124 $/bbl crude price, consumer prices increase by 1.0 €¢/l in 2020 across all scenarios and, in 2030, by 2.0 €¢/l in Scenario A; by 1.8 €¢/l in Scenario B and 1.9 €¢/l in Scenario C.

Whether defined in terms of crack spread or refinery gross margins[107], the overall impact in the EU across the scenarios, compared to the Base Case, is estimated to be small, with a reduction on the order of 2-7% in 2020 and a change of +2% to -4% in 2030 on average. For example, for gross margins, which vary between refineries, the absolute impact is a reduction of 7 $¢/bbl in 2020 (for all scenarios) and between 11 $c/bbl and 16 $¢/bbl in 2030 for Scenario A and C, respectively. The decline is relative to the respective Base Case margin of 3.93 US$/bbl in 2020 and 3.83 US$/bbl in 2030. Margins decline as the demand for mineral road fuels falls and refineries compete for a smaller overall market

[107] Gross margin is the margin after variable cost, that is, price minus unit variable cost

Annexes

Annex 1 List of interviews conducted

In the context of this task, face-to-face or telephone interviews have been conducted with the following companies, organisations and governments:

- Argos Oil
- FuelsEurope (including Shell, Total, OMV, Exxon Mobil)
- Abengoa
- NesteOil
- Shell
- UPEI (Union of European Petroleum Independents, including member organisations from Germany, UK and Belgium)
- BMU (German government)
- Finnish government
- French government

In addition, a questionnaire was sent out by email to a wider range of stakeholders. Written responses were received from

- AS Olerex
- Austrian Petroleum Industry Association (APIA)
- Romanian Oil Association
- Unione Petrolifera
- UPEI (Union of European Petroleum Independents)

Annex 2 Description of main type of biofuels and conversion routes[108]

A2.1 FAME as diesel replacer

Fatty Acid Methyl Esters are the most common type of “bio-diesel” used in the EU. Production of fatty acid methyl esters concerns transformation of refined[109] natural vegetable or animal fats – in essence esters of fatty acids with glycerol – to methyl esters by a catalysed reaction with methanol. Types of fats applied include rapeseed, sunflower, soy, palm oil, coconut oil, tallow, used cooking oil and residual fats from meat processing.

In the reaction glycerol is replaced by three methanol molecules. The reaction yields three methyl fatty acid esters per molecule of fat with glycerol as a by-product.

FAME is a substitute for diesel in view of its boiling point or distillation curve.

The produced ‘biodiesel’ is however non fungible and can be added up to 7vol% to conventional diesel in view of the deviating properties (compared to conventional diesel).

- Lower energy density, higher cloud point and melting point (-15°C)
- Biodiesel acidity and related deterioration of lubricating oil and of elastomers (e.g. rubber) in the car fuel distribution system;
- Biodiesel tends to be less stable in storage and combustion processes. The reduced thermal stability results in formation of soot during combustion and may result in formation of deposits in the engine.

In order to establish better control of fuel properties, the European standards organization, CEN, has published a standard (EN 14214) for FAME to be used as an automotive fuel. The standard establishes specifications for the FAME as a final fuel in engines designed or adapted for its use. The same standard also specifies the parameters for FAME to be used as the blend stock for conventional diesel fuel.

Thermal stability is expressed by the so called Iodine number of the FAME. Europe's EN14214 specification allows a maximum of 120 for the Iodine number, Germany's DIN 51606 tops out at 115. In practice only rapeseed methyl ester (97) or rapeseed ethyl ester (100) can meet this criterion. As a consequence FAME has to contain at least approximately 60% rapeseed methyl ester to meet these criteria.

A2.2 HVO as diesel replacer

Hydro-treated Vegetable Oils (HVO) such as vegetable oils may be processed by variations of petroleum refining processes including hydro-treatment. These refining methods can produce hydrocarbons with closely controlled and desirable fuel properties such as low aromatic levels and a very narrow distillation range. HVO production utilizes the same types of fats used for production of FAME. In addition, fatty acids isolated from tall oil are utilized in Scandinavia. Tall oil is a by-product of sulphate pulping of wood for pulp production and contains up to 40% fatty acids.

In HVO production these refined vegetable or animal oils and fats are treated with hydrogen (hydrogenated) and subsequently isomerized.[110] During hydrogenation oxygen, sulphur and

[108] Source: (Kampman et al, 2011) (Bacovsky et al, 2013), Croezen, 2008

[109] Refining of fats concerns removal of components which may have negative effects on taste, stability, appearance or nutritional value.

[110] **Isomerisation** refers to a process by which a hydrocarbon molecule is transformed into another molecule which has exactly the same atoms, but the atoms have a different arrangement. In case of isomerization of fatty acids the straight hydrocarbon molecules produced during hydro deoxygenation are converted into branched molecules. This has the effect that the melting point of the molecules and hence the cloud point of HVO is lowered.

nitrogen are removed as water, H_2S and NH3 and unsaturated bonds are saturated. The glycol present in the vegetable oil is hydrogenated into propane.

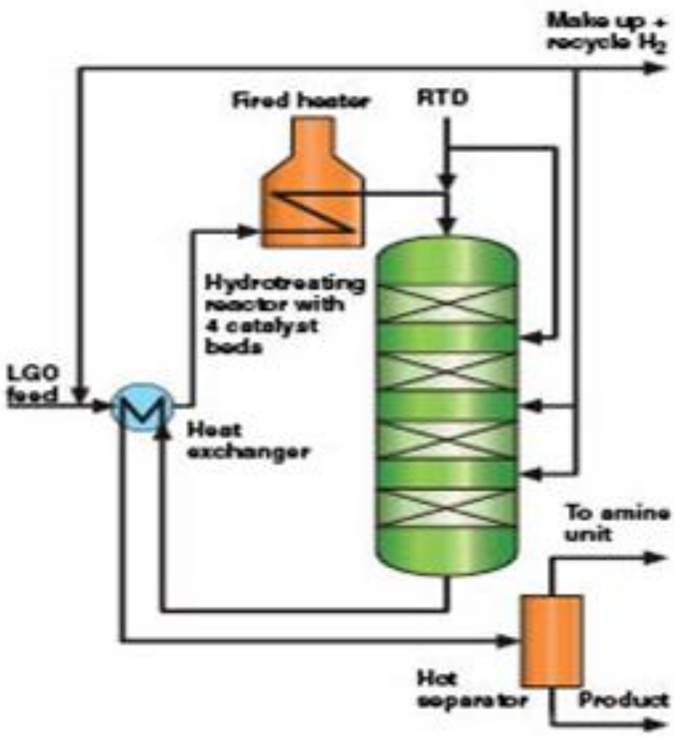
Products assay is a function of feedstock composition and operational conditions and may range as indicated below:

- Propane (2-4% weight)
- Naphta (1-10% weight)
- Diesel (88-98% weight)

Unlike FAME, refining vegetable oils usually yields paraffinic middle distillate fuel oils that can be indistinguishable from conventional fuel components derived from petroleum, but the average density is slightly lower than that of conventional diesel fuel. Therefore, it can be blended with conventional diesel fuel with very few issues up to B30 blends, beyond which the blend density would be below the diesel specification requirement (EN590). Consequently, engine and vehicle manufacturers widely support the development of hydro-treated renewable fuels. However, according to VW and Renault, Neste in Finland is the only major supplier of HVO at present and its penetration in the EU is not high (i.e., <5% of all bio-diesel sold in the EU in 2014).

The cetane number of HVO is higher in comparison to diesel, which result in some advantages, such as easier ignition, more efficient combustion and less NOx emissions. As HVO contains virtually no sulphur and aromatics, it can be considered a premium fuel. A disadvantage is the lubricity of HVO, which is not as good as the lubricity of diesel.

Figure A2.1 Hydrotreating of vegetable oils as implemented by PREEMs Gothenburg refinery



Source: http://www.topsoe.com/sites/default/files/novel_hydrotreating_technology_for_production_of_green_diesel.ashx_.pdf

LGO = Light Gas Oil, RTD = Raw Tall-oil Diesel. The RTD is injected at four points in the hydrotreater, between the individual catalysts beds.

HVO is primarily produced with dedicated installations such as realised in Rotterdam and Porvoo. As an alternative tall oil can be co-processed with conventional diesel in a retrofitted diesel hydrotreater, as e.g. has been implemented at PREEM's Gothenburg refinery, where a 85%/15% blend of conventional and tall oil based diesel is processed. Higher percentages may not meet cloud point specifications, because of the high molecular weight of the tall oil acids.

A2.3 Diesel and bio-diesel properties

Table A2.1 Properties of Diesel and Bio-diesel

	HVO	EN590 (summer grade)	FAME (from rape seed oil)
Density at 15 ºC (kg/m^3)	775 … 785	≈ 835	≈ 885
Viscosity at 40 ºC	2.5 … 3.5	≈ 3.5	≈ 4.5
Cetane number	≈ 80 … 99	≈ 53	≈ 51
Distillation rangeºC	≈ 180 … 320	≈ 180 … 360	≈ 350 … 370
Cloud pointºC	-5 … -25	≈ -5	≈ -5
Heating value, lower (MJ/kg)	≈ 44.0	≈ 42.7	≈ 37.5
Heating value, lower (MJ/l)	≈ 34.4	≈ 35.7	≈ 33.2
Total aromatics (wt-%)	0	≈ 30	0
Polyaromatics (wt-%)[1]	0	≈ 4	0
Oxygen content (wt-%)	0	0	≈ 11
Sulfur content (mg/kg)	<10	<10	<10
Lubricity HFRR at 60º (µm)	<460[2]	<460[2]	<460
Storage stability	Good	Good	Very challenging

(1) European definition including di- and tri+ -aromatics

(2) With lubricity additive

Source: Environmental Protection Agency, 2002

Table A2.1 provides a summary of the important characteristics of bio-diesel types contrasted to pure diesel fuel meeting the European EN590 specification. The data shows that FAME has a volumetric energy content 8% lower than that of diesel while the energy of HVO is about 4% lower than that of diesel.

A2.4 Ethanol as petrol replacer

Ethanol is the only bio-fuel considered for blending with petrol. While other components derived from bio-ethanol and bio-methanol have been considered, ETBE is the only other fuel that has any commercial scale production in the EU and is used with petrol, or ethanol and petrol.

A2.4.1 Feedstocks used

Typical feedstocks include sugar crops (sugar cane, sugar beet, sweet sorghum) and starch containing commodities (grains - corn (maize), wheat, barley – and tuber crops, e.g., potato, cassava).

Technological innovation aims at utilization of cellulose as is present in ligno-cellulosic feedstocks such as wood, fast-growing grasses (e.g., giant cane) and crop residues such as straw. In practice, wood proves to be a difficult feedstock that is more suitable for thermochemical production.

A2.4.2 Biochemical production route

Ethanol is produced biochemically by fermentation of C6 sugars (glucose and fructose), as present in starch and saccharose, by yeast. Sugar is used in yeast metabolism and growth and is converted into 50 weight% CO2 and 50 weight% ethanol.

Fermentation of disaccharides requires no pre-treatment. Starch and cellulose need to be hydrolysed by cooking in boiling water into disaccharides and monosaccharides. Hydrolysis of cellulose must be promoted by microorganisms (cellulase), hydrolysis of starch has a sufficiently high reaction rate by itself. An alternative approach has been implemented in the USA for wood processing: the wood is gasified and the produced CO is fermented into ethanol.

Fermentation of C5 sugars, part of the sugars in hemicelluloses, is still under development and requires genetic modification of yeast.

Fermentation typically takes place in warm water as a reaction medium, in part to avoid intoxication of the yeast at elevated ethanol concentrations. As a consequence, the produced ethanol has to be isolated by distillation. Sugar syrup or low grade exhausted molasses from the sugar process are used to feed the bioethanol plant

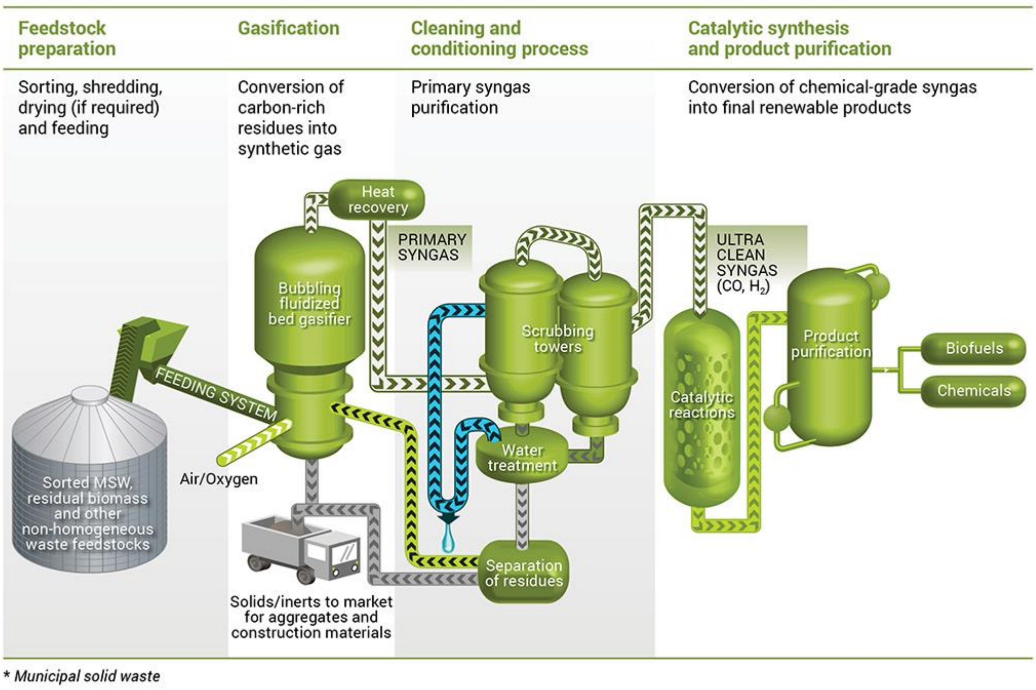
A2.4.3 Thermochemical production

An alternative production route for ethanol concerns catalysed synthesis from CO and H2, produced by biomass gasification. This route is especially suitable for woody biomass with low ash content. Produced CO and H2 are next converted with a catalysed process into ethanol.

The thermochemical production route has been developed into a commercial scale technology by Enerkem. The Enerkem technology platform involves a fluidized bubbling bed gasifier. Clean syngas is catalytically converted to mixed alcohols. A first commercial, MSW processing plant with an ethanol production capacity of 38 million litres per year was inaugurated in Edmonton, Canada on June 4th 2014.

Enerkem partners with AkzoNobel to jointly explore development of waste-to-chemicals facilities in Europe, aimed at production of bio-based methanol and acetic acid.

Figure A2.2 Enerkem production process flow sheet



Source: Bacovsky et al, 2013

A2.4.4 Bio-ethanol utilization

Bio-ethanol is typically used in passenger cars, as low blends of around 5-10% bio-ethanol can be used in unmodified petrol engines. Higher blends require adapted engines. In colder climates E85, a mix of 85% bio-ethanol and 15% petrol, should be used to avoid cold start problems in view of the reduced vapour pressure of ethanol. In warmer climates pure bio-ethanol (E100) can be used in adapted petrol engines. Petrol vehicles with adapted engines are so-called flex-fuel vehicles (FFVs), which run either on petrol or on an ethanol blend up to 85 vol%. Like FAME, E85 reacts differently with certain materials (plastic and rubber) compared to regular petrol. Therefore some materials in the existing infrastructure and engines need to be replaced to avoid technical problems.

Ethanol can also be applied in heavy duty vehicles as ED95, a blend containing up to 95% ethanol and as so-called E-diesel, an ethanol-diesel blend containing up to 10-15% ethanol[111]. While ethanol does not readily mix with diesel, it is possible to provide a semi-stable blend with the use of dispersants. E-diesel fuel lowers the blend flashpoint, which is well below the minimum limit set by diesel fuel standards. Such flashpoint levels basically can result in fuel handling related fire safety issues comparable to those for neat ethanol or petrol. E-diesel advocates believe that safety risks can be mitigated by adopting the storage and refuelling methods commonly used by methanol producers, for example. Equipping all storage tank vents and the vehicle tank vent and fill openings with flame arresters can eliminate some of these concerns (Waterland, Venkateshand Unnasch, 2003). In addition to the refuelling infrastructure concerns, vehicle manufacturers have reported (ACEA, et al., 2013) that e-diesel may damage vehicle parts, especially fuel injectors, and cause other types of vehicle failure due to low lubricity. In addition, ethanol separates from diesel during injection into the engine and the combustion process is affected. For these reasons, e-diesel has no support at all with auto-manufacturers.

The energy content of bio-ethanol is around 35% - 40% lower compared to petrol diesel. This means that (much) more ethanol is needed to cover the same distance. On the contrary the octane number of ethanol is higher resulting in a higher energy efficiency, because a higher compression rate can be used.

A2.5 Potential future biofuels under development

Alternative advanced production routes applied at limited scale or being on the brink of demonstration on commercial scale include:

- **Production of methanol** via gasification of glycerol by Bio MCN in The Netherlands; The glycerol used by Bio MCN is a by-product of biodiesel production and the production process is hence directly linked to biodiesel production.
- **Synthetic Fuels from Bio-mass** can be created using processes such as Fischer-Tropsch, which has been around for almost 100 years. Similar processes are used today and their aim is to convert feedstock of biomass, as well as methane (captured from agricultural wastes) into fuels, including diesel. The processes are commonly referred to as BTL (Biomass-To-Liquids) or GTL (Gas-To-Liquids). Regardless of the feedstock, these processes involve a gasification step (synthetic gas production) and a second step of gas synthesis to various liquid hydrocarbons.The synthetic diesel fuel can be tailored to be used as a “drop-in” (or interchangeable) fuel with conventional diesel. Due to parafinnic nature of this fuel, there could be an issue with lubricity although traditionally it can be overcome with appropriate additives (Neste Oil, 2006). However, there are no commercial scale BTL facilities operating in the EU today although there is pilot production in the Netherlands.
- **The bioforming process:** a two-step catalytic process in which sugars and cellulosic biomass are first converted in a reaction at elevated pressure and water into low oxygen

[111]Pure Energy Corporation, Website http://www.oxydiesel.com/oxyindex.html, Accessed August 4, 2014.

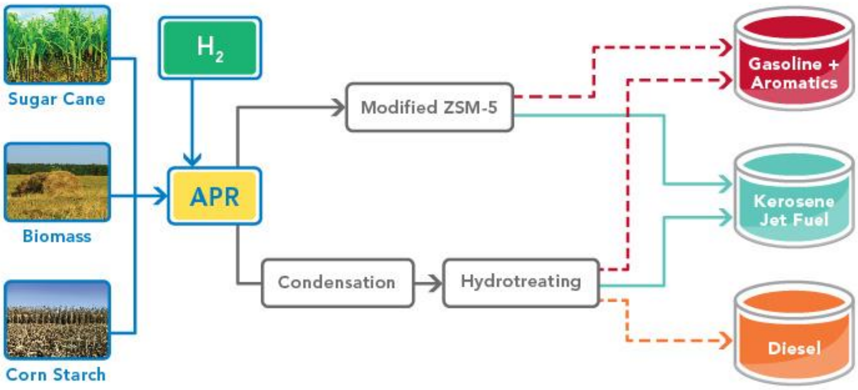
content hydrocarbons[112], which can next be converted into fuels and chemicals utilizing standard petrochemical processes (see Figure A2.3).

- **Hydropyrolysis:** fast pyrolysis of biomass in a hydrogen atmosphere.

The last two processes have been adopted by Shell, which is sponsoring further development by respectively Virent and subsidiary CRI. Shell expects to be producing advanced biofuels at scale, in US, by end of decade with both technologies.

With Virent, Shell has developed a petrol made from sugars that has this year been registered by EPA for blending in petrol at up to 40% and a jet product that can be blended at 15%. The jet fuel product is currently going through the certification process.

Figure A2.3 Bioforming process flow sheet



Source: Bacovsky et al, 2013

[112] The aqueous phase reforming step utilizes heterogeneous catalysts at moderate temperatures and pressures to reduce the oxygen content of the carbohydrate feedstock. Some of the reactions in the APR step include: (1) reforming to generate hydrogen; (2) dehydrogenation of alcohols/hydrogenation of carbonyls; (3) deoxygenation reactions; (4) hydrogenolysis; and (5) cyclization.

Annex 3 A first-order assessment of future availability of biofuels from sustainable, non-food biomass

In this Annex a broad analysis is presented evaluating availability of sustainable feedstocks in the EU that can be used above the 7% cap, based on existing literature. The recent ILUC decision and relevant EU directives imply that the future biofuels marketed have to meet the following criteria:

- Not produced from cultivated feedstock
- ILUC-free or low-ILUC
- Retaining soil fertility, SOC-levels
- Retaining surface and ground water quality
- Matching the no net biodiversity loss target

This leads to the following possible route for feedstock provision:

- utilization of by-products and residues from various economic sectors that do not have other useful applications
- utilization of biomass from landscape management

As discussed in the previous Annex, the technology to use these feedstocks to produce bioethanol is currently the most advanced, but efforts are ongoing to develop a number of alternative conversion processes that could produce both petrol and diesel replacements from these feedstocks.

Note that the potential availability of these types of low-ILUC feedstocks is one of the key drivers for these R&D efforts: if the share of sustainable biofuels in transport fuels is to be increased significantly in the future, both the fuels suppliers and the biofuels industry needs to be able to rely on routes with sufficient and reliable sustainable biomass supply (source: interviews with these stakeholders, and literature).

The ILUC decision does, however, leave an option to also include ILUC-free or low-ILUC, cultivated biomass as a possible feedstock which does not fall under the cap, at a later stage. As this may be an interesting option to expand the feedstock base for biofuels in the EU, the is also included in this analysis. This could concern cultivation of more productive crops on land already utilized previously for biofuels feedstock cultivation, without intensification of cultivation, and intensified cultivation of cover crops may also have significant potential for low-ILUC. However, the definition of low-ILUC cultivated biomass is difficult to implement and monitor.

There are two important issues to consider when interpreting the data presented in this Annex:

- As noted in the remarks Section of the table and mentioned above, many of these feedstocks can also be used for other applications. The waste and residues can typically also be used for electricity and heat production, and as renewable feedstock for the chemical industry. The cultivated low-ILUC biofuels can also be used for food and feed. To derive a realistic estimate of potential availability for the biofuels sector thus requires a much more extensive and complex assessment of future availability and demand from all sectors involved. This competition is also realised in the ILUC decision recently adopted in by the European Parliament, which included the provision to the RED that support schemes that promote the use of renewable energy shall not distort the markets in raw materials of other manufacturing sectors in which the same raw materials are traditionally used.
- As mentioned before, the uncertainties regarding future success of the R&D efforts in the various advanced biofuels routes are still significant. Especially the advanced biodiesel processes still seem to be relatively far away from commercial application

The criteria possibly exclude production of biofuels feedstock by intensification of cultivation, as recently explored by Ecofys. In Ecofys, 2015 several case studies are analyzed for 'low ILUC' biofuels produced from agro commodities cultivated using highly intensive cultivation practices, compared with reference cultivation systems. The idea behind this approach is that intensification and yield increases per hectare will reduce land requirements for food and feed production and will hence make arable land available for cultivation of biofuels feedstocks. As intensification of crop cultivation will very likely result in biodiversity decrease, as illustrated by the low level of biodiversity on arable land in the Netherlands, compared with e.g. low input or subsistence arable land in Eastern Europe. This loss in biodiversity is in itself not contradictory to the RED sustainability criteria, but is at odds with the EU's no net loss principle as defined in the EU Biodiversity Strategy to 2020.

Next to biodiversity loss, a number of other sustainability issues may be relevant in case of intensification, such as

- loss of soil carbon and nutrients,
- increased leaching of nutrients and associated impacts on surface and ground water quality.

In all, 'ILUC free' or 'low ILUC' biofuels from more intensively cultivated arable land seem to be less desirable and have hence been ignored.

A3.1 Biofuels from cultivated raw materials

A3.1.1 Increased utilization of crops with higher biofuels yields per hectare on current biofuels feedstock cultivation area

For current production of biofuels in the EU a total area of 8 - 9 Mha of arable land is utilized (EC, 2014f):

- approximately 6.0 - 6.5 Mha for cultivation of rape seed and smaller volumes of sunflower utilized in biodiesel production;
- approximately 2.0 - 2.5 Mha for cultivation of sugar beets and cereals utilized in bio-ethanol production.

This area is spread out over the entire EU land area.

Feedstock availability for biofuels production may be increased without or with only limited indirect land use change by cultivating crops that allow higher biofuel yields per hectare.

The most easily implementable type of crop that gives increased feedstock yields while it can also be grown almost anywhere in the EU is the sugar beet. This crop yields 5.5 tonnes of ethanol per hectare on average in the EU (CEFS, 2013). This is in terms of biofuel energy content approximately 3 times more (EC, 2014f) than rape seed (1.2 tonnes/ha of vegetable oil) or cereals (1.7 tonnes/ha of ethanol)[113].

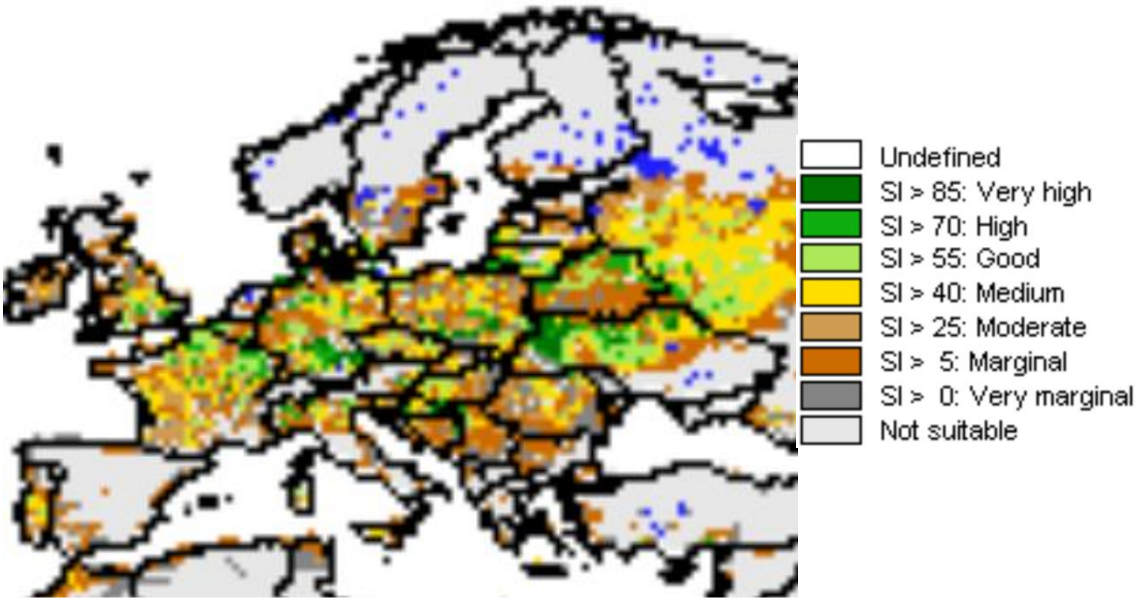
Total amount of bio-ethanol that could be produced on the currently utilized 8 – 9 Mha is estimated at 45 – 50 Mtonnes/year or 28 – 30 Mtoe/year assuming:

- all arable land currently utilized for cultivation of biofuels feedstock is suited for sugar beet cultivation
- sugar beets can be integrated in the rotations currently producing cereals and rape seed for biofuels production

This is approximately twice the amount of bio-ethanol required for meeting total petrol demand in the EU in 2024 with E20.

[113] Lower heating value of ethanol amounts to approximately 26.8 GJ/tonne, the LHV of vegetable oil to approximately 37 GJ/tonne.

Figure A3.1 Suitability of soil and climate for sugar beet cultivation in the EU



Source: GAEZ, 2002

The disadvantage of utilization of sugar beets is that beets cannot be stored as the sugar content rapidly declines during storage. Hence processing has to take place during the harvesting campaign. A second potential disadvantage is that production costs for sugar beet ethanol seem to be somewhat higher than production costs for cereals based ethanol.

On the other hand sugar beets produce less impact per unit of product, compared with cereals require beets less water and nutrients per unit of ethanol.

Alternative feedstocks for sugar beet might be fodder beet, chicory or Jerusalem artichoke or another crop with high sugar production per hectare that can be cultivated within the EU. A more in-depth analysis taking into account climatic aspects, soil characteristics and farm management aspects to determine the best suited crops per region is recommended.

Sugar isolated from sugar beets may also be utilized for production of chemicals. Whether this happens will depend on renewable fuel policy and other relevant policies.

A3.1.2 Cover crops cultivation during autumn and winter

A second option for supply of ILUC free or low ILUC feedstock may be increased cultivation of cover crops and green manure during autumn and winter, seasons during which food and feed crops are normally not grown.

This option will however probably only allow cultivation of fresh biomass such as leaves and stems as crops normally do not produce oil seeds or grains in autumn and winter.

That in turn means cover crops are only suitable as a feedstock for 2^{nd} generation biofuels production or require biomass refining – e.g. for isolation of fermentable sugars from the fresh biomass. Refining technologies are currently under development and are being demonstrated at commercial scale in e.g. the Grassa grass refining initiative in The Netherlands. The Grassa initiative is based on mobile refineries in which biomass is separated by milling, pressing and sieving into juices with dissolved sugars and proteins and fibres. The dissolved sugars could be utilized in conventional ethanol production utilizing sugar fermentation.

A first order potential of 30 – 60 Mtonnes/year of ethanol was estimated on the basis of following basic assumptions:

- Fresh stem and leave yields for cover crops amount to 2 – 4 tonnes d.m./ha/year.

- The ethanol / feedstock ratio is assumed similar with the ratio for straw (1 / 4 – JEC, 2014). Yield would amount to 0.5 – 1.0 tonne of ethanol per hectare.
- Cover crops may be cultivated in combination with crops harvested before mid-September – early October, such as corn maize, maize silage, winter wheat. Total area of cereals and silages cultivated in the EU amounts to approximately 60 Mha (EC, 2014f).

The estimate is a first rough estimate.

- It is based on one cover crop, while for The Netherlands alone there are 15 – 20 relevant cover crops (Timmer, 2004). Some of these can potentially produce significantly more biomass per hectare than winter rye. But possibilities for application of these crops may be limited by e.g. promotion of pests and diseases by certain cover crops for value crops or by the period of the year in which they can be grown. Winter rye is a known cover crop for land cover after a maize silage cultivation and has the advantage that it can sequester nitrogen.
- Yields for the considered cover crop have been based on experiences in The Netherlands (Timmer, 2004). The assumed yield is comparable with yields obtained during trials in Flanders[114]. But in different climate zones yields may differ.

Isolation of sugars by crop refining would make cover crops multi-applicable in the sense that fibres and proteins could be utilized for livestock feeding. Production of solid board from grass fibres has been demonstrated in The Netherlands[115].

A3.2 Biofuels from by-products and residues

A3.2.1 Residual fats and fatty acids

Residual fats and fatty acids are often considered as being low ILUC feedstocks for biodiesel and HVO. This is however questionable for some categories of fats. Residual fats and fatty acids include:

- Used cooking oil;
- Fats from meat processing and animal waste processing;
- Tall oil fatty acids

Based on the information collected during the project following characteristics were composed for the different by-products.

Table A3.1 Estimated availability and pricing of residual oils in the EU

	TOFA from chemical paper pulp	Waste fats from meat processing industries	Waste fats from consumers and catering
Price, €/tonne	900 - 1,000	450 - 550	900 - 1,000
Potential volume, kilotonnes	600 (EU)	650 (EU)	650 (EU)
Current application	Chemicals, fuel, biodiesel	biodiesel, co-combustion	biodiesel
Added value when processed into naphtha	modest to significant	significant	significant

[114] See: http://lib.ugent.be/fulltxt/RUG01/001/789/777/RUG01-001789777_2012_0001_AC.pdf

[115] See: http://grassa.nl/

	TOFA from chemical paper pulp	Waste fats from meat processing industries	Waste fats from consumers and catering
Required effort to contract	low	low	high
Type of contract required	medium term	medium term	long term

Source: Ecofys, 2013a, Ecofys, 2013b, Pelkmans, 2014, Baumassy, 2014

The total of these categories is somewhat less than the amount of residual vegetable and animal oils projected by the EU to be utilized for biofuels production in 2024. According to the EU publication “Prospects for EU agricultural markets and income 2014-2024” the amount of residual oils utilized in 2024 will amount to approximately 3.5 Mtonnes/year, approximately 1 Mtonne/year more than the estimated size of the three categories described below. The EU projection may include e.g. fatty acid distillate, technical corn oil, and spent bleaching oil.

Animal fats are fats from slaughtered animals that are rendered into a variety of products, which can be classified by their degree of quality, from high to low:

- Animal fats intended for human consumption.
- Category 3: fats that can be used for animal feed and cosmetics. For example parts of slaughtered animals, which are fit for human consumption in accordance with EU legislation, but are not intended for human consumption for commercial reasons.
- Category 2: fats that can be used for soil enhancement and for technical purposes, such as oleochemical products and special chemicals[116].
- Category 1: fats that have a high risk for human health, for example animals suspected of being infected by a TSE[2] or in which the presence of a TSE has been officially confirmed; specified risk material. category can be used for energy purposes or biodiesel production and are not allowed to enter the human or animal food chains.

Table A3.2 Waste fats production from meat processing

	2010	2009	2008	2007	2006
Germany	689	669	652	637	600
Spain	381	371	396	402	376
France	333	323	345	345	346
Poland	279	258	300	328	325
Italy	290	283	287	289	282
Netherlands	224	215	208	206	210
UK	155	147	151	152	147
Denmark	144	139	147	154	151
Belgium + Lux	132	126	125	126	120
Austria	109	108	108	108	107
Romania	89	86	84	92	86
Ireland	73	67	70	75	75

[116] Examples of this category ABPs include manure and digestive tract content, (parts of) animals that have died from other causes than by being slaughtered for human consumption, including animals killed to eradicate an epizootic disease

	2010	2009	2008	2007	2006
Hungary	45	41	46	50	48
Other	224	222	244	247	228
Total	**3167**	**3055**	**3163**	**3211**	**3101**

Source: Ecofys, 2013b

Fats categorized as being of quality 3 to 1 are produced by rendering companies, such as:

- Rendac in the Netherlands and Belgium
- Saria Group in Germany, France, Spain, Poalnd and Austria

Both companies own biodiesel producing facilities, both for C3 fats as for C1 fats.

Total EU production of fats amounts to 3,100 - 3,200 ktpy of which approximately 650 ktpy of C1 and C2 waste fats[117].

The produced fats are primarily applied for:

- Co-combustion (520 ktpy) and biodiesel production (410 ktpy);
- Feed (730 ktpy) and pet food (360 ktpy);
- Oleochemical feedstock (600 ktpy).

In theory the total volume of residual fats could be utilized for biodiesel (or HVO) production. As large amounts already have an application, utilization for biodiesel production would lead to market disturbances and possibly ILUC due to the requirement of cultivating primary crops for production of the feedstocks required in the competing industries.

A3.2.2 Straw

According to a JRC analysis (see Alterra, 2012), a total of 45 – 50 Mtoe[118] of straw could be utilized for biofuels production annually without sustainability issues such as deterioration of soil quality. Associated costs are estimated at €40/tonne straw.

The estimation includes straw from a wide range of crops delivering straw including all cereals, rice, and maize, sunflower and oil seed rape. the amount of straw that should be left on the land for conservation of soil quality were estimated to be 40% for wheat, rye, oats and barley and at 50% for the other 4 crops. Estimated demands for straw for competitive uses such as bedding in specific livestock systems (including horses) and for mushroom production have also been subtracted from the bioenergy potential.

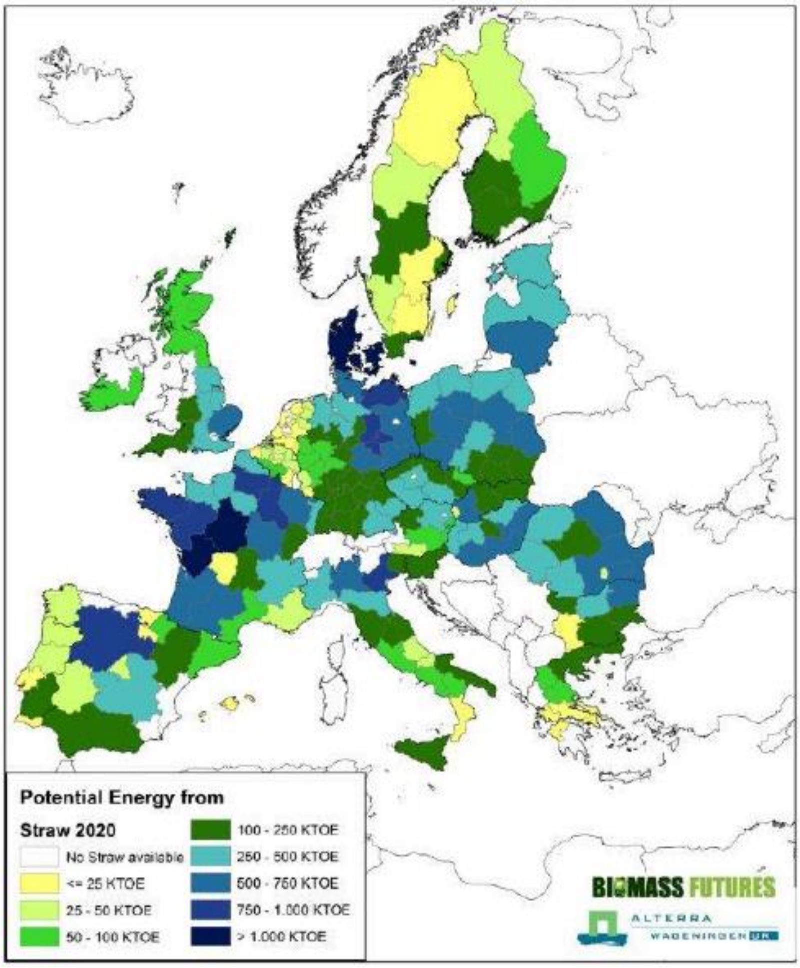
A more detailed disquisition of the analysis conducted by JRC can be found in (Alterra, 2012).

In this study the potential of straw has been recalculated into a potential production volume of bio-ethanol assuming the ethanol / dry straw ratio of 1 / 4 assumed in JEC, 2014.

[117] Mail exchange with Ralph Brands, Sales Manager Energy at Ecoson / Rendac / Vion Ingredients

[118] A toe = ton oil equivalent = 41.86 GJ/tonne LHV. Straw has a LHV of approximately 14 MJ/kg.

Figure A3.2 Geographical sustainable availability of straw in the EU



Source: Alterra, 2012

A3.3 Other residues from agricultural land utilization

According to Alterra, 2012 pruning's and cuttings in permanent crops plantations with soft fruit, citrus, olives but also vineyards can supply up to 10 Mtoe of biomass.

Utilization for biofuels production in practice competes with utilization for heat and/or power generation.

A3.3.1 Woody biomass from forests, other wooded land and from industry and consumers

According to the EU Wood study (EU Wood, 2010) intensification of wood mobilization in European forests could sustainably produce a total amount of 36 Mtoe of round wood (thinning) and 19 Mtoe of forests residues (branches and tops). The estimate refers to a scenario in which forests with high biodiversity are excluded from harvesting and more measures are taken to prevent loss of site productivity and soil erosion.

In addition landscape care may an additional 11 – 11.4 Mtoe, while increased mobilization of forest wood and residues may yield another 10 Mtoe of woody biomass, compared with current production and utilization. The considered residues include black liquor, saw dust and other sawmill residues, other industrial residues and consumer waste wood.

Utilization for biofuels production in practice competes with utilization for heat and/or power generation.

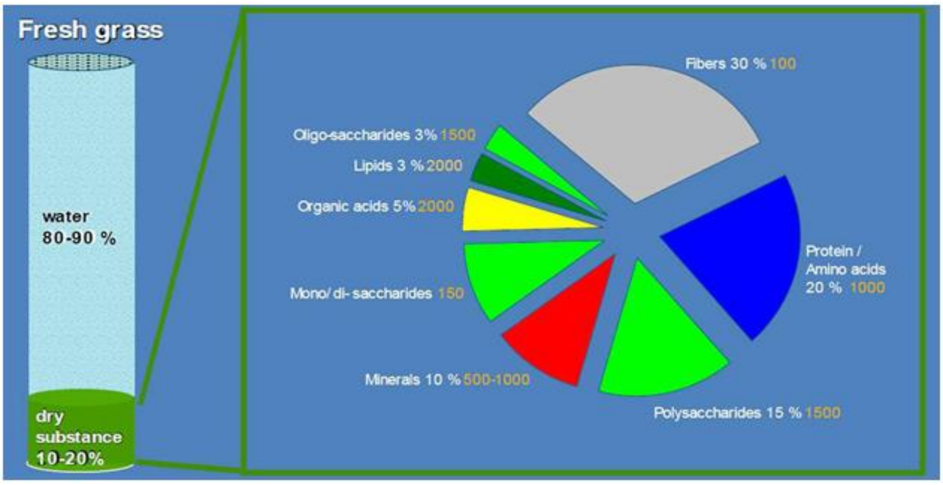
A3.3.2 Grass

In regions with intensive dairy cattle and other bovine husbandry part of the grass cultivated for feeding these animals is lost because it is too wet. Especially in spring and wet summers a lot of grass can be lost. Availability of surplus grass in the EU is estimated at 15 Mton dry matter per year from fertilized grasslands.

Next to this an indicated amount of 15-20 Mton dry matter per year from natural sources and unfertilized lands (Van Zijderveld, 2012).

Grass can be separated into different components, a wet component which can be used as feed, and fibres which can be used to produce e.g. graphic board component or paper, fertilizer and a residue which can be processed into biogas through anaerobic digestion (Courage2025).

Figure A3.3 Average composition of grass from fertilized grasslands



Source: see footnote[119].

The technology has meanwhile been demonstrated at industrial scale with a mobile installation, allowing surplus grass processing at the point where it is released.

Assuming an availability of 30 Mton (dry matter) of surplus grass in the EU per year, grass refinery could potentially produce 6 Mton protein, 9 Mton fibre, 1 Mton fat, 14 Mton sugars (Van Zijderveld, 2012). The high-protein concentrate can substitute soy as animal feed. The sugars and fat can be utilized as biofuels feedstock. The fibres may also be used for (2nd generation) biofuels production or as fuel in coal fired power plants.

As the grass is very wet, storage by means of silaging is impossible by definition (otherwise the grass would be utilized as silage for cattle) and utilization for anaerobic digestion and other production routes for heat and/or power are secluded.

A3.3.3 Biodegradable consumer waste

Around 50 Mton of bio-municipal solid waste (MSW) is landfilled in the EU-27 every year (based on EC, 2012). Incineration with energy recovery, as electricity and heat, provides a useful alternative for what would otherwise be waste. Composting also is a valuable application of bio-waste, a little over 60 Mton of bio-waste is already recovered (in another way than energy recovery; EC, 2012).

[119]See: http://www.biorefinery.nl/fileadmin/biorefinery/docs/bioref/Presentatie__7__Grasraffinage_Courage_WS_061207.pdf and http://www.kcpk.nl/kees-van-zijderveld

A3.3.4 Palm oil from degraded soils

WWF has analyzed the possibilities of oil palm cultivation on degraded soils, such as Alang-Alang grasslands on Kalimantan (WWF, 2009). The reason for WWF to study such a possibility is twofold:

- Production of additional palm oil for food applications and indirect avoidance of land use
- Land restoration by removal of the grass

Such a cultivation scheme may be considered to be ILUC free and sustainable as the land aimed at has already been degraded due to previous economic activities (e.g. timber fellings) (WWF, 2009).

For oil palms cultivated on grass land the reference is limited to unutilized grasslands with limited carbon stocks in vegetation (± 10 metric tons of carbon per hectare) and soils (45 – 60 metric tons of carbon per hectare).

Planting and cultivating oil palms on such lands results in additional sequestration of carbon in both the growing oil palms and the soils. Sequestration in soils occurs because the oil palms give more biomass to the soils as leafs, twigs and fruit residues than the original grass vegetation, resulting in built up of additional humus.

The net effect is an increase in sequestered carbon of approximately 14 metric tons of CO_2/ha/year (WWF, 2009).

Annex 4 Modelling methodology to estimate vehicle emissions

A4.1 Introduction

For the hypothetical scenarios described in Chapter 1, Section 1.7.3 for increasing the limits of the bio-content of petrol and diesel fuels, a calculation model was developed with which the biofuel market uptake could be calculated, and the associated impact on vehicle pollutant (oxides of nitrogen (NOX), total hydrocarbons (THC), non-methane hydrocarbons (NMHC) (for petrol vehicles only), carbon monoxide (CO), and particulate matter (PM)) and carbon dioxide (CO2) emissions in 2020 and 2030.

The following describes the methodology used for these calculations.

A4.2 Methodology

The following overall approach was used to calculate emissions. Each of these steps is described in greater detail below.

Step 1. Establish base case emissions and base case emission factors

Step 2. Calculate the percent reduction in emission factors for each pollutant and fuel type using base case emission factors calculated in step 1 and vehicle test results for each type of fuel.

Step 3. Determine the vehicle populations using each fuel under each scenario and analysis year

Step 4. Determine total activity levels by vehicle type, fuel type, and year

Step 5. Determine total emissions for each vehicle type, fuel type, and year for each scenario.

A4.2.1 Step 1: Base case Emissions and Emission Factors

Under this step, base case emissions for each year and base case emission factors (for the base case fuel types) were established. This allows comparison to emissions for the fuel blend scenarios. The following approach, along with key assumptions, was used.

1. Determine base case emissions:
   a. Outputs from the TREMOVES model (version 3.3.2)[120] were used to determine total base case emissions for 2010, 2020, and 2030 for light duty vehicles (LDVs) and heavy duty vehicles (HDVs).
   b. Emissions for 2013 were determined by linearly interpolating values from 2010 to 2020 (TREMOVES does not have year 2013 data).
   c. For non-methane volatile organic compounds (NMVOC), as reported in TREMOVES, was converted to NMHC and THC using conversion factors from the Environmental Protection Agency, assuming that NMVOC is equivalent to VOC (US EPA, 2010).
   d. For CO_2, Regulation (EC) No 443/2009 requires that only the fleet average is regulated; as such, it was assumed that EC mandatory 2020 emission reduction targets for new passenger cars and vans would be met[121]. As such, base case CO_2 emissions in 2020 were assumed to decrease in line with these targets. Since no CO_2 targets have been set for 2030, it was assumed that 2020 targets would remain constant through 2030.

[120] http://www.tmleuven.com/methode/tremove/home.htm

[121] http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm

2. Determine base case emission factors for petrol vehicles:
    a. Pollutant emission factors for E5 and E10 were obtained from *Impact of ethanol containing gasoline blends on emissions from a flex-fuel vehicle tested over the Worldwide Harmonized Light duty Test Cycle (WLTC)* (Suarez-Bertoa et al. 2015). These data are the basis for data provided graphically in Chapter 2, Figure 2.3 and Figure 2.3Figure 2.4. Emission factors for the WLTC and hydrous fuels (e.g. HE10) have been used. WLTC data has been used since vehicle emissions tests described in Chapter 2 and Annex 55 were also based on the WLTC test, and WLTC will become the EU type-approval procedure for fuel consumption and CO_2 in 2017.
    b. Emission factors for E5 and E10 for PM were estimated from Chapter 2, Figure 2.6. Emission factors represent the Peugeot - WLTC.
    c. The base case petrol fuel is E5 (5% v/v ethanol), equivalent to 3.4% energy from Chapter 1, Table 1.8.
3. Determine base case emission factors for diesel vehicles:
    a. The percent reductions for B7 and B10 fuels compared to B0 were obtained from Chapter 2, Table 2.6 (LDVs) and Table 2.7 (HDVs). Where ranges in percent reductions were presented, the mid-range values were used.
    b. Assumed all vehicles comply with Euro 5 or Euro 6 standards (reduction percentages for NO_X and PM vary based on Euro standard compliance). This assumption is supported by TREMOVES data: 70% of vehicles comply with Euro 5 or 6 standards in 2020 and 100% comply with Euro 5 or 6 standards in 2030.
    c. Assumed all HDVs have oxidation catalysts (reduction percentages for THC and CO vary based on the presence of oxidation catalysts).
    d. The base case diesel fuel is B5.7 (5.7% v/v biodiesel), equivalent to 5.4% energy from Chapter 1, Table 1.7.
    e. Emission factors for B5.7 fuel were determined by linearly extrapolating emission factors for B7 to B10 fuels based on their biodiesel content (7% and 10% v/v, respectively). This assumes that emissions are directly proportional to the biodiesel content of the fuel.
    f. The change in emission factors from B7 to B5.7 was applied to emission factors for B7 determined by (Suarez-Bertoa et al. 2015) to estimate the base case emission factors.

Emission factors are presented in Table A4.1 below.

Table A4.1 Emission Factors

Vehicle/ Fuel / Pollutant	Emission Factors[a]			
Petrol - LDV	**E5[b]**	**E10[c]**	**E20[c]**	**E25**
CO_2	151.00	151.00	148.74	147.98
NOx	62.00	62.62	63.24	63.24
THC	93.00	93.00	89.28	89.28
NMHC	82.00	82.00	78.72	78.72
CO	394.00	374.30	334.90	334.90
PM	0.00110	0.00102	0.00091	0.00091
PN	5.00E+11	1.33E+12	1.28E+12	1.28E+12
Diesel – LDV	**B5.7[b]**	**B7[c]**	**B10[c]**	**B30[c]**
CO_2	152.40	152.40	152.40	152.40
NOx	570.88	576.59	582.36	582.36
THC	6.33	6.08	5.78	4.91

Vehicle/ Fuel / Pollutant	Emission Factors[a]			
CO	80.12	76.92	73.07	62.11
PM	1.10	1.03	0.95	0.78
PN	8.60E+09	8.58E+09	2.59E+10	7.93E+10
Diesel – HDV	**B5.7[b]**	**B7[c]**	**B10[c]**	**B30[c]**
CO_2	152.40	152.40	152.40	152.40
NOx	570.88	576.59	582.36	582.36
THC	6.31	6.18	6.06	5.30
CO	79.81	78.21	76.65	70.90
PM	1.10	1.03	0.95	0.71
PN	8.60E+09	8.58E+09	2.59E+10	7.93E+10

Notes:
Units are milligrams per vehicle-kilometer (mg/km) for all pollutants except PM, where units are grams per vehicle-kilometer (g/km), and PN, where units are number of particles per vehicle-kilometer (g/km)
Base case fuels

A4.2.2 Step 2: Percent Reduction in Emissions

Using the base case emission factors estimated under Step 1, the percent reduction in emission factors for each pollutant and fuel type compared to the base case fuels was estimated. The following approach, along with key assumptions, was used.

1. The base case emission factors for each pollutant and fuel as calculated under Step 1 were compared with data presented in Chapter 2, Table 2.5, Table 2.6 and Table 2.7.
2. The percent reductions for petrol and diesel-based biofuels described in Chapter 2, Table 2.5, Table 2.6 and Table 2.7 were applied to the base case emission factors to calculate emission factors for the higher biofuel blends for LDV and HDV.

A4.2.3 Step 3: Vehicle Populations by Scenario

Vehicle populations using each fuel type under each analysis scenario were estimated using the following approach.

1. Scenarios analysed are based on the Chapter 1, 1.7.3.
2. For Scenario C, it was assumed that vehicles compatible with E20 are also compatible with E25 and vehicles compatible with B10 are also compatible with B30 (Chapter 2).
3. Vehicle populations by model year, calendar year, and fuel compatibility were obtained from TREMOVES model outputs.
4. To determine the number of LDV vehicles using petrol versus diesel, vehicle activity (kilometers traveled) from TREMOVES by vehicle type and fuel type were used.
5. Based on TREMOVES outputs, a small percentage of LDVs and HDVs use natural gas; these vehicles were not included in the analysis.

Vehicle populations by scenario are presented in Table A4.2 below.

Table A4.2 Vehicle Populations by Scenario (Thousands)

Vehicle / Fuel Type	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
LDVs						
E10	10,791	10,791	10,791	11,865	7,208	7,208
E20	0	0	0	0	4,657	0
E25	0	0	0	0	0	4,657
B7	17,076	17,076	17,076	18,817	11,431	11,431
B10	0	0	0	0	7,386	5,540

Vehicle / Fuel Type	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
B30	0	0	0	0	0	1,847
HDVs						
B7	10,921	10,921	10,921	12,343	7,849	7,849
B10	0	0	0	0	4,495	3,371
B30	0	0	0	0	0	1,124

A4.2.4 Step 4: Vehicle Activity by Scenario

Total activity levels by vehicle type, fuel type, and analysis year were calculated as follows.

1. The vehicle populations by scenario and fuel type as calculated under Step 3 above was used to determine the percentage of total vehicle activity (kilometers traveled).
2. It was assumed that vehicle population equals activity (kilometers traveled), and therefore also equals emissions.

The percent vehicle activity by scenario are presented in Table A4.3 below.

Table A4.3 Percent Vehicle Activity by Scenario

Vehicle / Fuel Type	2020			2030		
	Scenario A	Scenario B	Scenario C	Scenario A	Scenario B	Scenario C
LDVs						
E10	39%	39%	39%	39%	23%	23%
E20	0%	0%	0%	0%	15%	0%
E25	0%	0%	0%	0%	0%	15%
B7	61%	61%	61%	61%	37%	37%
B10	0%	0%	0%	0%	24%	18%
B30	0%	0%	0%	0%	0%	6%
All Fuels	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*
HDVs						
B7	100%	100%	100%	100%	64%	64%
B10	0%	0%	0%	0%	36%	27%
B30	0%	0%	0%	0%	0%	9%
All Fuels	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*

A4.2.5 Step 5: Emissions by Scenario

Total emissions for each vehicle type, fuel type, and year for each scenario were calculated as follows.

1. For each pollutant, year, vehicle type, and fuel type, total base case emissions from Step 1 were multiplied by the percent reductions from Step 2 and the vehicle activity percentages from Step 4 to determine emissions for each scenario.
2. Emission reductions were calculated by comparing emissions for each scenario to the base case emissions determined in Step 1.

Annex 5 Millbrook Vehicle Test Report

Test Report

MILLBROOK

Customer	**ICF International**
Vehicle	**Euro 6 Diesel and Gasoline vehicles**
Test	**Evaluation of Bio Fuels on Emissions and Fuel**
Millbrook Report No.	**MBK15/0621**
Millbrook Project No.	**PT0270-001-01**

Author: A. Shepherd, Senior Engineer - Powertrain

Approved for Issue: P. Stones, Head of Emissions & Fuel Economy

Date: 06 August 2015

Test Report

Executive Summary

The project detailed in this report was conducted to produce emission data for test fuels with varying levels of Bio-content to allow further analysis to be conducted which is not covered in this report. The following Diesel and Gasoline fuels were considered

- Diesel Reference B7
- Diesel B10
- Diesel B30
- Gasoline Reference E10
- Gasoline E20

Tests were conducted on Euro 6 compliant vehicles running on a chassis dynamometer (Dyno) with emissions sampled using a Constant Volume Sampler (CVS) system, Peugeot 508 (2.0L Diesel) and Peugeot 308 (1.2L Gasoline).

Testing was completed successfully with a full set of results obtained.

Distribution

Organisation	Recipient	Format	Qty
ICF International Watling House, 33 Cannon Street, London, EC4M 5SB	Mr Ravi Kantamaneni	PDF	1
Millbrook Proving Ground Ltd Millbrook Bedford MK45 2JQ	Contract file Andrew Shepherd	PDF Paper	1 1

Report Revision History

Rev.	Revision Description	Date	Author	Approver	Pages
0	Preliminary release	06 August 2015	A.Shepherd	-.-	All

Contents

Section	Page Nos.

Appendices

List of Figures

Objectives

1. Conduct emission tests on two vehicles, 1 gasoline and 1 diesel, to the World Harmonized Light Vehicles Test Cycle (WLTC) in a repeatable manner.
2. Present the differences in fuel consumption and emissions results from the different fuels being tested containing various levels of bio-content. For the gasoline vehicle two fuels were examined, E10 and E20. Three fuels were evaluated using the diesel vehicle, those being B7, B10 and B30.

Conclusions

1. Two vehicles were successfully run in a repeatable manner to the WLTC cycle resulting in Coefficients of Variance (CoV) below 0.35% for all test fuels.
2. Emissions results for test fuels with varying levels of bio content were produced for further analysis along with modal data.

Test Facility and Date

The WLTC tests on two test vehicles were performed between the 24th June 2015 and 12th July 2015 in the Vehicle Emissions Laboratory (VEL) facility at Millbrook Proving Ground Ltd.

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Millbrook
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MK45 2JQ
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Contact: Mr. Andrew Shepherd - Powertrain Engineer.
Telephone: 01525 408423
Fax: 01525 408312
Email: andy.shepherd@millbrook.co.uk

Test Material/Vehicle

Item	Identification
Test Vehicle 1 - Peugeot 308sw	
Registration Number	*LP64AEW*
Chassis OEM	*Peugeot 308sw*
Engine OEM & Model	*1.2L PureTech e-THP 130*
Power Rating	*96 kW @ 5500 rpm*
Torque Rating	*230 Nm @ 1750 rpm*
Engine Size	*1199 cc*
Euro Standard	*Euro 6*
Transmission OEM	*6 Speed Manual*
Fuel type & Spec	*Gasoline*
Odometer at start of test	*3,606 miles*
Test Vehicle 2 - Peugeot 508	
Registration Number	*LT64OVG*
Chassis OEM	*Peugeot 508*
Engine OEM & Model	*2.0L BlueHDi 150 S&S*
Power Rating	*110 kW @ 4000 rpm*
Torque Rating	*370 Nm @ 2000 rpm*
Engine Size	*1999 cc*
Euro Standard	*Euro 6*
Transmission OEM	*6 Speed Manual*
Fuel type & Spec	*Diesel*
Odometer at start of test	*10,212 miles*
2 x 50L barrels of E20 fuel (Millbrook supplied)	“E20 Gasoline”, CAF-W15/438
2 x 50L barrels of B10 fuel (Millbrook supplied)	“B10 Diesel”, CAF-G15/313
2 x 50L barrels of B20 fuel (Millbrook supplied)	“B20 Diesel”, CAF-G15/314

Full vehicle details are documented in Appendix B.

Dynamometer Settings

	Vehicle 1 (Peugeot 308sw)	Vehicle 2 (Peugeot 508)
Mass (kg)	1,360	1,700
F0 (N)	7.10	7.9
F1 (N/kmh)	0	0
F2 (N/kmh^2)	0.04810	0.05360
F3 (N/kmh^3)	0	0

The parameters above were used in the dynamometer settings to take into account vehicle inertia, rolling resistance, frictional and aerodynamic resistance. These have been taken from UNECE Regulation 83 for the applicable vehicle mass.

Test Procedure

Gear shift schedule

A gear shift schedule was constructed for each vehicle during start of the test program as detailed by the procedure set out in the WLTP regulation. The vehicles were driven to these shift schedules on each test to ensure repeatability.

Test Steps

For each test the vehicle's stop-start function for engine control was disabled to ensure each test was as repeatable as possible. The study is concerned about test repeatability to highlight any measurable differences in vehicle emission data due to varying levels of bio-content and not the overall emission levels produced by the test vehicles in relation to legislative limits.

The main procedural steps of the test programme were carried out in the below order:

Gasoline vehicle – Peugeot 308sw

- Fuel flush to E10 Reference fuel
- Run 3xWLTC emissions tests

- Fuel flush to E20 Gasoline fuel
- Run 3xWLTC emissions tests

Diesel vehicle – Peugeot 508

- Fuel flush to B7 Reference fuel
- Run 3xWLTC emissions tests

- Fuel flush to B10 Diesel fuel
- Run 3xWLTC emissions tests

- Fuel flush to B30 Diesel fuel
- Run 3xWLTC emissions tests

Fuel flush procedure

The vehicles were flushed onto each fuel using the following procedure:

- Drain existing fuel from the tank
- Fill with 15L of the test fuel
- Drive for 15 minutes
- Drain remaining fuel from the tank
- Fill with 45L of test fuel (Retain a 5L sample of the test fuel)
- Vehicle driven for 250 miles to a Public Road Simulation (PRS) schedule of 1/3 urban, 1/3 rural and 1/3 motorway on Millbrook's tracks.

Before each emissions test, the vehicle was prepared using the following procedure:

- Tyre pressure check/adjustment
- Exhaust leak check
- Pre-conditioning drive cycle on chassis dynamometer:
    - Gasoline (1xECE followed by 2xEUDC drive cycles)
    - Diesel (3xEUDC drive cycles)
- Vehicle soak with battery on charge inside laboratory (23°C ± 2°C for 6 hour minimum)

To ensure repeatability, each vehicle had a dedicated driver that completed all tests on that vehicle. A set of emissions tests for each fuel consisted of:

- Three cold-start WLTC emissions tests with 1Hz Modal Analysis

The laboratory was conditioned to a constant 23°C ± 2°C throughout the test period.

Descriptions of the pre-conditioning cycle and WLTC test cycle can be found in Appendix D.

Fuel consumption was calculated using the Carbon Balance Method detailed in Appendix E.

Instrumentation

Pollutant		Measurement technique	Frequency	Analysis technique
Regulated	Total hydrocarbons (HC)	Bag	Per phase	Flame ionisation
	Carbon monoxide (CO)	Bag	Per phase	Non-dispersive IR
	Nitrogen oxides (NO_x)	Bag	Per phase	Chemiluminescence
Unregulated	Carbon dioxide (CO_2)	Bag	Per phase	Non-dispersive IR
	Total hydrocarbons (HC)	Continuous modal tailpipe and engine	1 Hz	Flame Ionization
	Carbon monoxide (CO)	Continuous modal tailpipe and engine	1 Hz	Non-dispersive IR
	Nitrogen oxides (NO_x)	Continuous modal tailpipe and engine	1 Hz	Chemiluminescence
	Carbon dioxide (CO_2)	Continuous modal tailpipe and engine	1 Hz	Non-dispersive IR

Item	Ser. No.	Calibration due date
Vehicle Weigh scales	4-9820-46	18 Feb 2016

Test Results and Discussion

Test Repeatability

Test result repeatability was very good throughout the test project.

For comparisons to be valid, the driven cycle and force on the dynamometer should be comparable. Figure 1 shows an overlay of dynamometer roller speed from all cold WLTC tests carried out on the Diesel vehicle in the programme. Figure 2 shows the same parameters for the Gasoline vehicle.

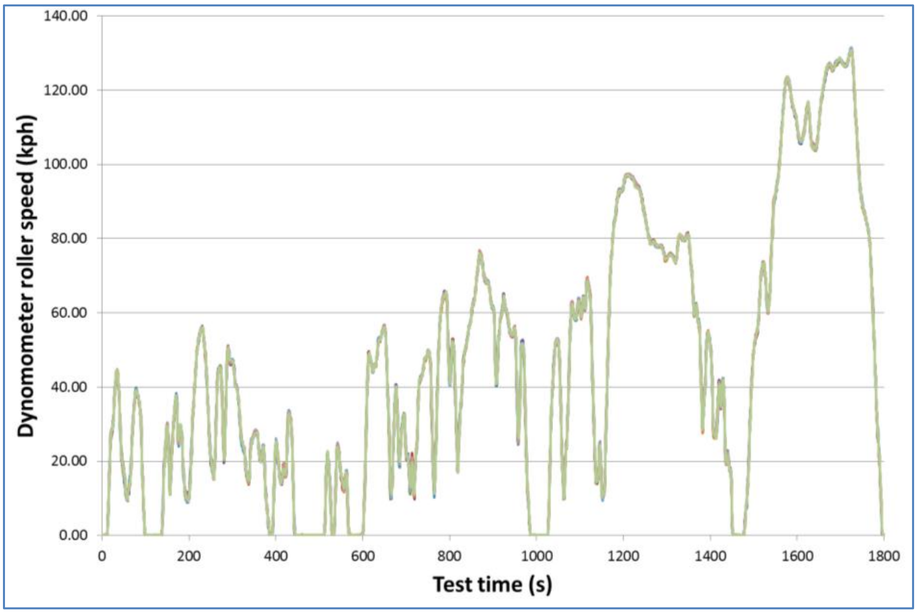


Figure 1. Graph showing Dyno roller speed over all WLTC cycles - Diesel

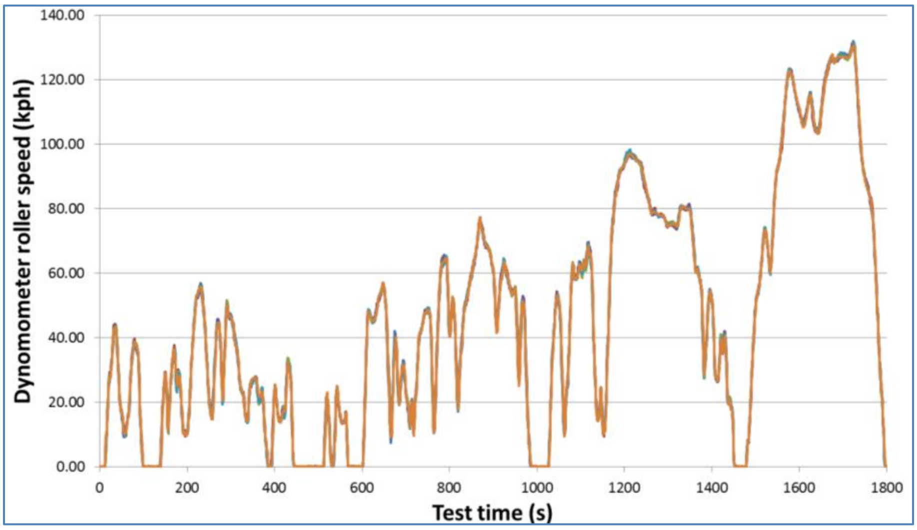


Figure 2. Graph showing Dyno roller speed over all WLTC cycles - Gasoline

All of the tests conducted were driven according to the drive trace in a repeatable manner. The drive trace specifies a tolerance of ±2km/h and ±1 second from the required speed before highlighting a driver violation.

Figure 3 shows an overlay of dynamometer force from all WLTC tests carried out in the programme on the Diesel vehicle. Dynamometer force applied to the vehicle over the WLTC cycles was observed to be very repeatable.

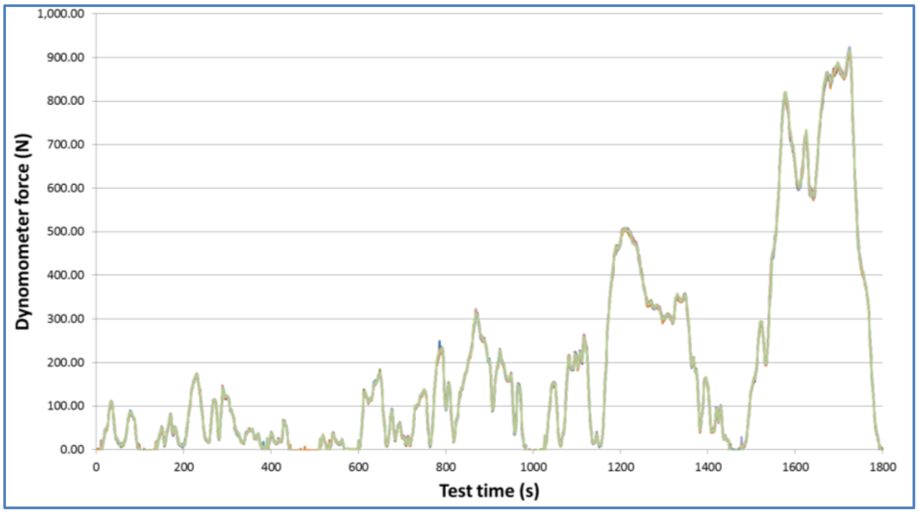


Figure 3. Graph showing Dyno force over all WLTC cycles – Diesel

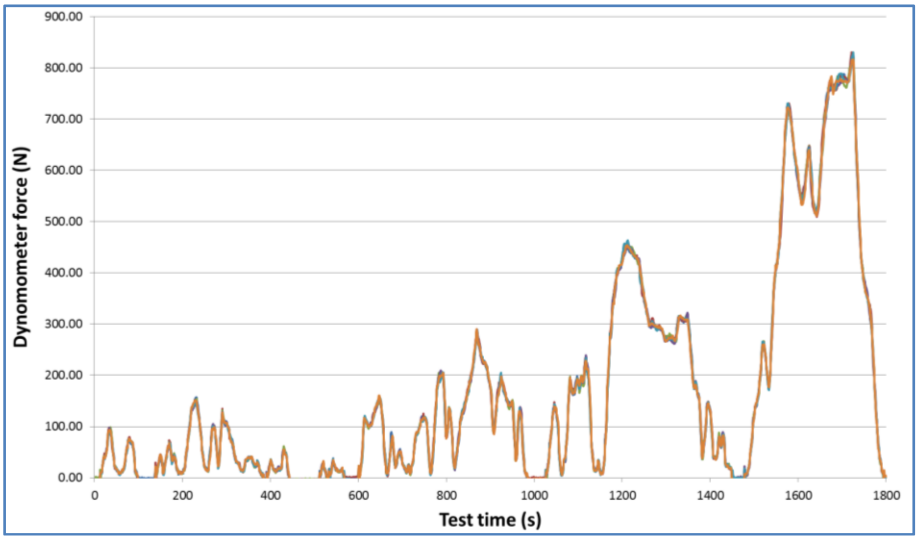


Figure 4. Graph showing Dyno force over all WLTC cycles – Gasoline

Repeatability of emissions results was very good throughout the programme, evidenced by low Coefficients of Variance (CoV) in fuel consumption over the WLTC cycles shown in Table 1.

Test Fuel	Diesel B7	Diesel B10	Diesel B30	Gasoline E10	Gasoline E20
Coefficient of Variance	0.34%	0.14%	0.16%	0.29%	0.33%

Table 1. Coefficient of Variance of fuel consumption over WLTC cycles

Emission results

Tables 2 and 3 show the average recorded figures for each test fuel. Each figure is an average of three test results on that fuel. The full set of emissions test results can be found in Appendix A.

Test Fuel	NO_2 (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)	Fuel Cons (L/100km)
B7	219	6	80	572	152	1	8.60E+09	5.81
B10	217	10	89	557	151	1	2.60E+10	5.72
B30	259	9	89	609	151	1	2.64E+10	5.75

Table 2. Emission summary averages over WLTC cycles – Diesel

Test Fuel	NMHC (mg/km)	THC (mg/km)	CO (mg/km)	NO_x (mg/km)	CO_2 (g/km)	PM (mg/km)	PN (Nb/km)	Fuel Cons (L/100km)
E10	18	20	287	49	142.4	2	1.33E+12	6.25
E20	17	20	458	32	139.9	1	1.28E+12	6.57

Table 3. Emission summary averages over WLTC cycles – Gasoline

Fuel consumption was calculated using the carbon balance method outlined in Appendix E, the carbon weight fraction and specific gravity of each fuel is given in Table 4.

Test Fuel	Carbon Weight Fraction (CWF)	Specific Gravity
B7	0.860	0.833
B10	0.859	0.841
B30	0.843	0.851
E10	0.833	0.749
E20	0.789	0.741

Table 4. CWF and SG of test fuels

Emission Results Discussion - Gasoline

Whilst the CoV of CO_2 and Fuel Consumption figures of the test conducted on the gasoline vehicle were low, in the region of 0.3% (CO_2 being the main contributor to fuel consumption figures), it was identified that several other gases saw much higher CoV values. Tests on both E10 and E20 fuels returned CoV figures for NO_x of 45.6 and 39.3 respectively. Due to low overall values of NOx produced (averages of 49 and 32 mg/km) a small change in mass greatly affects the CoV values. Checking modal data from each test it can be seen that there was a large amount of NO_x produced during one acceleration on test ML01014616 at 1564 seconds. The trace of tailpipe CO_2 mass shows that the acceleration during test ML01014616 might have been more aggressive, however, no driver violations were recorded with the drive trace being within legislative limits. A similar observation was made for NO_x values when the modal data was checked for the E20 test fuel, although the level of deviation was not to the same extent.

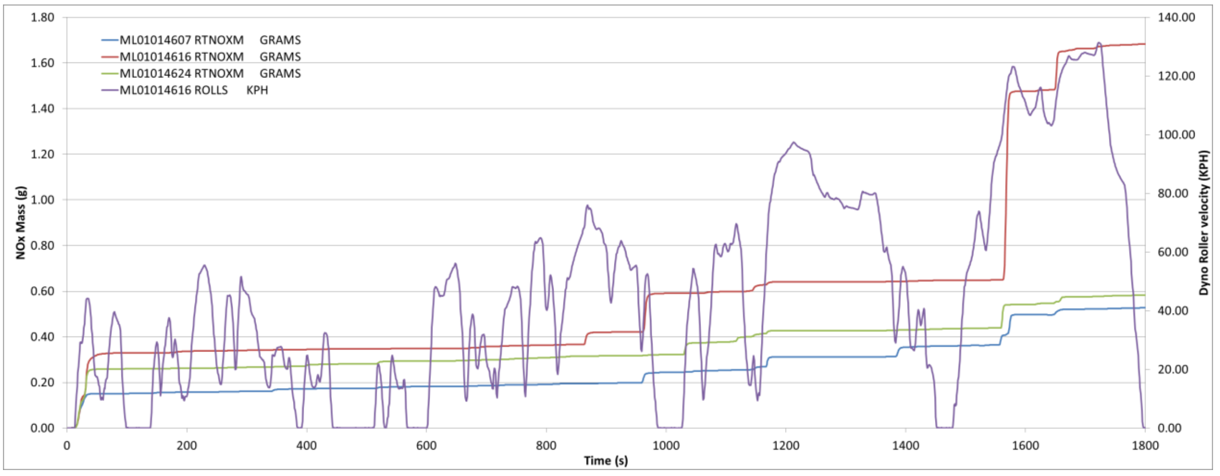


Figure 5. Graph of cumulative NOx mass (g) modal data – E10 Gasoline

In the same set of tests for the E10 fuel a high CoV (24.67) was noted in the CO results. The majority or the discrepancy was observed to be in phase 1; this can be seen in the modal data referenced in Figure 6. Whilst traces diverge slightly over the test period, it is during the acceleration of the first hill where the main deviation occurs. No other significant deviations in vehicle or driver traces were observed during this time period.

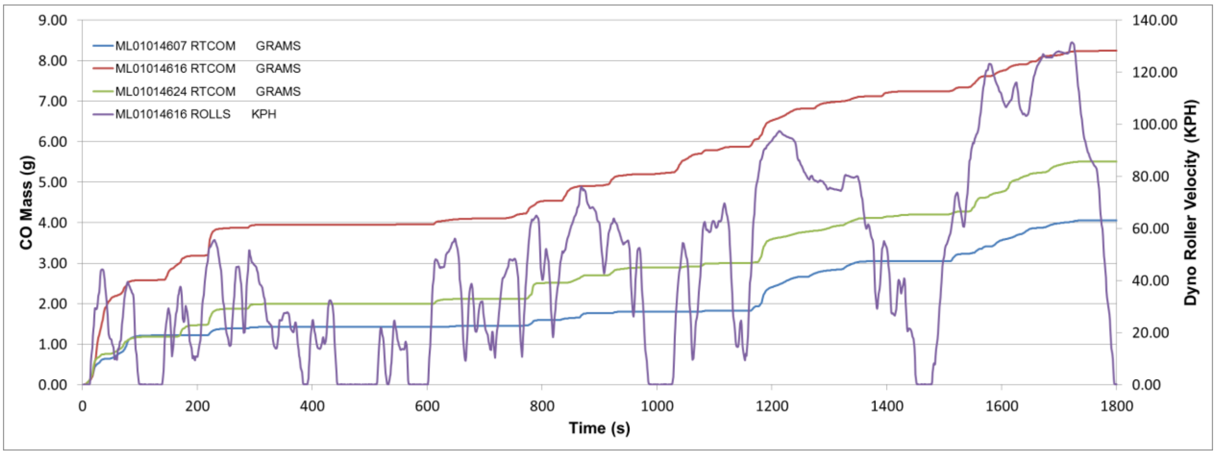


Figure 6. Graph of cumulative CO mass (g) modal data – E10 Gasoline

Emission Results Discussion - Diesel

It is noted that the NO_x results on the diesel vehicles are very high compared to the Euro 6b M_1 limit of 80mg/km. Average NO_x results were seen at 573mg/km for B7, 557mg/km for B10 and 607mg/km for B30, which range from 716% to 759% of the Euro 6b limits. However, the Euro 6b limits refer to a vehicle run over the NEDC cycle, for this project the WLTP cycle was used. The Peugeot 508 2.0L BlueHDI diesel test vehicle achieved a NO_x level of 57mg/km during type approval test work (data obtained from http://carfueldata.direct.gov.uk). Whilst the test vehicle only achieved NO_x levels in magnitudes higher than the type approval limit, it is behaviour attributed to diesel vehicles that is widely recognised in the industry when running cycles other than the NEDC.

As a precaution, the vehicle was checked for any trouble codes (none were present), the Selective Catalytic Reduction (SCR) system was checked for distance remaining until refill of the AdBlue tank was required and found the level to be greater than required for project completion. The vehicle literature was also checked which confirmed that it’s AdBlue system warns when low levels are present and prevents the vehicle engine from starting if the SCR system is deemed not to be working (empty/faulty). No concerns were raised during the checks and the vehicle was considered to be running correctly.

Appendices

Appendix A. Emission Results

DIESEL WLTC
EMISSIONS TEST SUMMARY SHEET

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**

Vehicle No:	***LT64OVG***	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	***Peugeot 508***	Deterioration Factors		INERTIA	1700 kg
Engine:	***2.0L Diesel BlueHDI***	CO	N/A	F°	7.90 N
Transmission:	***6-Spd Manual***	THC+Nox	N/A	F_1	0.0000 N/kmh
Fuel Type:	***Euro 6 B7 Reference Diesel***	NOx	N/A	F_2	0.05360 N/kmh^2
Fuel Batch No:	***CAF-G14/580***	PM / PN	N/A	F_3	0.00000 N/kmh^3
Millbrook Project No:	***PT0270-001-01***				

Test No: ***ML01014594***	***24-Jun-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **10714**	UNITS								
Phase 1 *Low*	mg/km	64.504	32.349	508.133	295.722	182.6	NA	4.91E+10	6.99
Phase 2 *Medium*	mg/km	122.068	4.467	4.620	264.735	141.7	NA	7.71E+09	5.40
Phase 3 *High*	mg/km	47.338	1.515	27.081	105.443	128.8	NA	5.59E+09	4.91
Phase 4 *Extra High*	mg/km	504.495	1.622	8.509	1221.253	169.1		3.41E+09	6.45
Combined result	**mg/km**	**227.769**	**6.288**	**80.258**	**561.308**	**153.0**	**1.06**	**1.11E+10**	litres/100km
									5.84

Test No: ***ML01014600***	***25-Jun-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **10748**	UNITS								
Phase 1 *Low*	mg/km	54.316	29.828	532.428	324.970	170.3	NA	5.75E+10	6.53
Phase 2 *Medium*	mg/km	100.976	3.316	30.548	331.476	137.3	NA	4.04E+09	5.23
Phase 3 *High*	mg/km	34.424	3.100	16.133	111.700	130.6	NA	2.38E+09	4.98
Phase 4 *Extra High*	mg/km	489.070	1.663	10.947	1178.917	171.1		1.28E+09	6.52
Combined result	**mg/km**	**212.688**	**6.207**	**86.218**	**565.813**	**151.8**	**1.15**	**9.67E+09**	litres/100km
									5.79

Test No: ***ML01014610***	***26-Jun-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **10779**	UNITS								
Phase 1 *Low*	mg/km	45.112	29.504	469.216	351.722	169.2	NA	1.31E+10	6.48
Phase 2 *Medium*	mg/km	102.874	5.224	15.338	326.037	137.9	NA	6.23E+09	5.26
Phase 3 *High*	mg/km	40.344	2.481	7.674	136.167	131.5	NA	4.05E+09	5.01
Phase 4 *Extra High*	mg/km	498.343	1.638	10.836	1215.251	171.8		2.22E+09	6.55
Combined result	**mg/km**	**216.959**	**6.357**	**72.052**	**588.685**	**152.3**	**1.05**	**5.06E+09**	litres/100km
									5.81

Average of Combined Tests (mg/km)	219.139	6.284	79.509	571.935	152.4	1.087	8.60E+09	5.81
Standard Deviation/Mean x100	2.90	0.98	7.30	2.10	0.34	4.14	29.83	0.34

Comments:
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.860 and a Specific Gravity (SG) of 0.833
Phase 3 and 4 Emissions split by mass from single bag using modal analysis.

Compiling Engineer	Date: 29/06/2015	Approving Engineer:	Date: 29/06/2015

Issue No.	Effective Date:	POF003
4	07-Jan-13	Page 1 of 1

Test Report

DIESEL WLTC
EMISSIONS TEST SUMMARY SHEET

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**
Vehicle No:	***LT64OVG***
Vehicle Type:	***Peugeot 508***
Engine:	***2.0L Diesel BlueHDI***
Transmission:	***6-Spd Manual***
Fuel Type:	***B10 Diesel Fuel***
Fuel Batch No:	***CAF G15/313***
Millbrook Project No:	***PT0270-001-01***

Site No.	1	DYNAMOMETER SETTINGS	
Deterioration Factors		INERTIA	1700 kg
CO	N/A	F°	7.90 N
THC+Nox	N/A	F₁	0.0000 N/kmh
NOx	N/A	F₂	0.05360 N/kmh ²
PM / PN	N/A	F₃	0.00000 N/kmh ³

Test No: ***ML01014628***	***01-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **11090**	UNITS								
Phase 1 *Low*	mg/km	12.850	41.239	437.821	228.031	170.8	NA	2.54E+11	6.48
Phase 2 *Medium*	mg/km	4.749	9.124	39.959	82.972	139.3	NA	1.32E+10	5.26
Phase 3 *High*	mg/km	82.679	5.748	23.523	176.127	128.9	NA	8.71E+09	4.87
Phase 4 *Extra High*	mg/km	462.842	2.457	12.463	1095.659	170.7		4.72E+09	6.45
Combined result	**mg/km**	**192.742**	**9.998**	**78.109**	**491.946**	**151.6**	**0.89**	**4.09E+10**	litres/100km
									5.73

Test No: ***ML01014636***	***02-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **11121**	UNITS								
Phase 1 *Low*	mg/km	62.379	50.177	515.692	368.278	173.0	NA	1.62E+11	6.57
Phase 2 *Medium*	mg/km	114.127	9.766	48.578	300.785	139.6	NA	6.11E+09	5.28
Phase 3 *High*	mg/km	103.765	5.583	17.537	242.358	128.2	NA	4.17E+09	4.84
Phase 4 *Extra High*	mg/km	507.477	4.809	6.877	1241.587	169.8		2.21E+09	6.41
Combined result	**mg/km**	**244.189**	**12.125**	**86.636**	**627.659**	**151.4**	**1.19**	**2.49E+10**	litres/100km
									5.72

Test No: ***ML01014645***	***03-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **11153**	UNITS								
Phase 1 *Low*	mg/km	48.032	28.687	539.853	302.047	171.0	NA	7.06E+10	6.49
Phase 2 *Medium*	mg/km	99.283	3.867	68.934	288.341	137.7	NA	5.00E+09	5.20
Phase 3 *High*	mg/km	57.827	2.894	28.265	124.482	128.8	NA	3.42E+09	4.87
Phase 4 *Extra High*	mg/km	478.051	2.660	16.435	1157.981	170.0		1.93E+09	6.42
Combined result	**mg/km**	**214.645**	**6.469**	**100.903**	**550.523**	**151.1**	**1.42**	**1.22E+10**	litres/100km
									5.71

Average of Combined Tests (mg/km)	217.192	9.531	88.549	556.709	151.4	1.167	2.60E+10	5.72
Standard Deviation/Mean x100	9.71	24.48	10.62	9.98	0.15	18.60	45.11	0.14

Comments:
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.859 and a Specific Gravity (SG) of 0.841
Phase 3 and 4 Emissions split by mass from single bag using modal analysis.

Compiling Enginee	Date: 03/07/2015	Approving Engineer:	Date: 10/07/2015

Issue No. 4 | Effective Date: 07-Jan-13 | POF003 Page 1 of 1

Test Report

DIESEL WLTC

EMISSIONS TEST SUMMARY SHEET

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**

Vehicle No:	***LT64OVG***	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	***Peugeot 508***	Deterioration Factors		INERTIA	1700 kg
Engine:	***2.0L Diesel BlueHDI***	CO	N/A	F°	7.90 N
Transmission:	***6-Spd Manual***	THC+Nox	N/A	F_1	0.0000 N/kmh
Fuel Type:	***B30 Diesel Fuel***	NOx	N/A	F_2	0.05360 N/kmh ^{2}
Fuel Batch No:	***CAF G15/314***	PM / PN	N/A	F_3	0.00000 N/kmh ^{3}
Millbrook Project No:	***PT0270-001-01***				

Test No: ***ML01014659***	***08-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN Nb / km	Fuel Cons (Carb Bal)
Odo at SOT: **11453**	UNITS								
Phase 1 *Low*	mg/km	63.268	44.274	553.775	322.475	170.5	NA	2.89E+11	6.53
Phase 2 *Medium*	mg/km	121.746	5.955	18.463	314.013	138.3	NA	1.08E+10	5.27
Phase 3 *High*	mg/km	125.142	4.539	4.988	284.631	127.4	NA	2.99E+09	4.85
Phase 4 *Extra High*	mg/km	548.837	3.753	6.102	1245.497	170.9		1.63E+09	6.51
Combined result	**mg/km**	**267.032**	**9.882**	**81.713**	**638.931**	**151.1**	**1.29**	**4.24E+10**	litres/100km
									5.76

Test No: ***ML01014666***	***09-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN Nb / km	Fuel Cons (Carb Bal)
Odo at SOT: **11484**	UNITS								
Phase 1 *Low*	mg/km	75.315	29.601	526.790	362.720	171.3	NA	1.44E+11	6.55
Phase 2 *Medium*	mg/km	126.193	4.910	39.352	323.606	136.7	NA	6.85E+09	5.21
Phase 3 *High*	mg/km	130.152	2.396	16.162	253.287	128.4	NA	4.34E+09	4.89
Phase 4 *Extra High*	mg/km	521.035	1.413	7.243	1166.809	169.0		2.46E+09	6.43
Combined result	**mg/km**	**261.359**	**6.199**	**85.962**	**608.921**	**150.5**	**1.77**	**2.29E+10**	litres/100km
									5.73

Test No: ***ML01014676***	***12-Jul-15***	NO_2	THC	CO	NO_x	CO_2 (g/km)	PM	PN Nb / km	Fuel Cons (Carb Bal)
Odo at SOT: **11545**	UNITS								
Phase 1 *Low*	mg/km	45.521	43.391	599.972	282.825	169.7	NA	9.33E+10	6.50
Phase 2 *Medium*	mg/km	113.226	7.333	78.504	313.847	137.9	NA	3.30E+09	5.25
Phase 3 *High*	mg/km	102.578	4.223	5.191	222.787	127.5	NA	1.53E+09	4.85
Phase 4 *Extra High*	mg/km	525.951	2.735	7.748	1148.842	170.7		9.44E+08	6.50
Combined result	**mg/km**	**248.035**	**9.564**	**100.528**	**580.422**	**150.8**	**0.70**	**1.39E+10**	litres/100km
									5.75

Average of Combined Tests (mg/km)	258.809	8.549	89.401	609.425	150.8	1.253	2.64E+10	5.75
Standard Deviation/Mean x100	3.08	19.49	9.01	3.92	0.15	34.91	45.04	0.16

Comments:
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.843 and a Specific Gravity (SG) of 0.851
Phase 3 and 4 Emissions split by mass from single bag using modal analysis.

Compiling Enginee	Date: 13/07/2015	Approving Engineer:	Date: 13/07/2015

Test Report

PETROL WLTC
EMISSIONS TEST SUMMARY SHEET

Customer:	**ICF Consulting Services**				
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**				
Test Purpose:	**Bio components level study for transport fuels**				
Vehicle No:	***LP64AEW***	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	***Peugeot 308sw***	Deterioration Factors		INERTIA	1360 kg
Engine:	***1.2L Petrol PureTECH***	CO	N/A	F_0	7.10 N
Transmission:	***6-Spd Manual***	THC / NMHC	N/A	F_1	0.0000 N/kmh
Fuel Type:	***Euro 6 E10 Reference Fuel***	NOx	N/A	F_2	0.04810 N/kmh ²
Fuel Batch No:	***CAF W14/395***	PM / PN	N/A	F_3	0.00000 N/kmh ³
Millbrook Project No:	***PT0241-002-01***				

Test No: ***ML01014607***	***26-Jun-15***	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **2533**	UNITS								
Phase 1 *Low*	mg/km	110.010	122.519	712.986	85.854	172.033	N/A	5.64E+12	7.59
Phase 2 *Medium*	mg/km	1.685	2.408	73.958	30.075	124.372	N/A	8.28E+11	5.45
Phase 3 *High*	mg/km	0.559	1.074	180.780	20.430	118.816	N/A	6.14E+11	5.21
Phase 4 *Extra High*	mg/km	1.048	2.014	125.807	25.294	163.570	N/A	9.30E+11	7.17
Combined result	**mg/km**	**15.743**	**17.792**	**209.886**	**32.831**	**143.061**	**2.51**	**1.44E+12**	litres/100km
									6.28

Test No: ***ML01014616***	***27-Jun-15***	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **2550**	UNITS								
Phase 1 *Low*	mg/km	135.649	156.310	1489.371	131.710	168.081	N/A	5.05E+12	7.48
Phase 2 *Medium*	mg/km	2.996	4.158	268.555	52.494	126.728	N/A	7.05E+11	5.57
Phase 3 *High*	mg/km	0.968	1.379	281.502	8.669	119.355	N/A	5.08E+11	5.24
Phase 4 *Extra High*	mg/km	2.183	3.111	120.655	137.256	160.564	N/A	7.50E+11	7.04
Combined result	**mg/km**	**20.005**	**23.043**	**381.111**	**79.860**	**142.072**	**2.25**	**1.23E+12**	litres/100km
									6.25

Test No: ***ML01014624***	***30-Jun-15***	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons (Carb Bal)
Odo at SOT: **2772**	UNITS								
Phase 1 *Low*	mg/km	122.5934	138.746	921.233	136.946	174.864	N/A	5.63E+12	7.74
Phase 2 *Medium*	mg/km	0.4681	1.172	162.666	7.427	125.117	N/A	6.77E+11	5.49
Phase 3 *High*	mg/km	0.4277	1.093	189.027	18.875	117.141	N/A	5.28E+11	5.14
Phase 4 *Extra High*	mg/km	1.3663	3.493	162.401	21.189	160.466	N/A	7.86E+11	7.03
Combined result	**mg/km**	**17.255**	**20.129**	**270.797**	**32.942**	**141.960**	**2.10**	**1.33E+12**	litres/100km
									6.23

Average of Combined Tests (mg/km)	17.668	20.321	287.265	48.545	142.4	2.29	1.33E+12	6.25
Standard Deviation/Mean x100	9.98	10.57	24.67	45.62	0.35	7.41	6.21	0.29

Comments:

* NO_2 values below measurable range.

Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.833 and a Specific Gravity (SG) of 0.749

Phase 3 and 4 emissions split by mass from single bag using modal analysis. CH4 split using phase 3 to 4 THC mass ratio.

Compiling Engineer	Date: 01/07/2015	Approving Engineer:	Date: 01/07/2015

Issue No.	Effective Date:	POF003
4	07-Jan-13	Page 1 of 1

Test Report

MILLBROOK

PETROL WLTC
EMISSIONS TEST SUMMARY SHEET

MILLBROOK

Customer:	ICF Consulting Services				
Customer Address:	Watling House, 33 Cannon Street, London, EC4M 5SB				
Test Purpose:	Bio components level study for transport fuels				
Vehicle No:	***LP64AEW***	Site No.	1	DYNAMOMETER SETTINGS	
Vehicle Type:	***Peugeot 308sw***	Deterioration Factors		INERTIA	1360 kg
Engine:	***1.2L Petrol PureTECH***	CO	N/A	F_0	7.10 N
Transmission:	***6-Spd Manual***	THC / NMHC	N/A	F_1	0.0000 N/kmh
Fuel Type:	***E20 Gasoline***	NOx	N/A	F_2	0.04810 N/kmh ^{2}
Fuel Batch No:	***CAF W15/438***	PM / PN	N/A	F_3	0.00000 N/kmh ^{3}
Millbrook Project No:	***PT0270-001-01***				

Test No: ***ML01014655***	***07-Jul-15***	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons
Odo at SOT: 2769	UNITS								(Carb Bal)
Phase 1 *Low*	mg/km	113.156	134.069	2111.38	98.504	170.049	N/A	4.37E+12	8.12
Phase 2 *Medium*	mg/km	3.452	4.602	432.235	7.947	124.166	N/A	7.00E+11	5.83
Phase 3 *High*	mg/km	0.966	1.798	244.664	7.416	117.118	N/A	4.25E+11	5.49
Phase 4 *Extra High*	mg/km	3.910	7.276	166.429	42.481	157.073	N/A	8.36E+11	7.35
Combined result	**mg/km**	**17.976**	**21.802**	**501.809**	**32.125**	**140.014**	**1.270**	**1.15E+12**	litres/100km
									6.58

Test No: ***ML01014658***	***08-Jul-15***	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons
Odo at SOT: 2788	UNITS								(Carb Bal)
Phase 1 *Low*	mg/km	100.127	117.827	1513.55	83.669	169.909	N/A	4.29E+12	8.06
Phase 2 *Medium*	mg/km	3.320	4.495	429.476	8.252	124.328	N/A	7.01E+11	5.84
Phase 3 *High*	mg/km	0.713	1.291	323.682	2.923	116.463	N/A	5.18E+11	5.46
Phase 4 *Extra High*	mg/km	2.629	4.759	160.276	9.089	158.639	N/A	1.00E+12	7.42
Combined result	**mg/km**	**15.508**	**18.520**	**443.524**	**16.850**	**140.365**	**1.030**	**1.23E+12**	litres/100km
									6.59

Test No: ***ML01014663***	***09-Jul-15***	NMHC	THC	CO	NO_x	CO_2 (g/km)	PM	PN (Nb/km)	Fuel Cons
Odo at SOT: 2807	UNITS								(Carb Bal)
Phase 1 *Low*	mg/km	116.299	135.980	1847.88	91.210	167.576	N/A	4.43E+12	7.98
Phase 2 *Medium*	mg/km	3.1704	4.454	242.460	21.479	125.771	N/A	1.18E+12	5.89
Phase 3 *High*	mg/km	0.6055	1.138	309.691	4.299	114.000	N/A	6.40E+11	5.35
Phase 4 *Extra High*	mg/km	1.9550	3.675	108.954	84.194	157.803	N/A	1.25E+12	7.38
Combined result	**mg/km**	**17.404**	**20.528**	**427.392**	**47.908**	**139.287**	**1.520**	**1.47E+12**	litres/100km
									6.54

Average of Combined Tests (mg/km)	16.963	20.284	457.575	32.294	139.9	1.273	1.28E+12	6.57
Standard Deviation/Mean x100	6.22	6.66	6.99	39.26	0.32	15.71	10.67	0.33

Comments:
* NO_2 values below measurable range.
Fuel consumption calculated using the carbon balance method with a carbon weight fraction of 0.789 and a Specific Gravity (SG) of 0.741
Phase 3 and 4 emissions split by mass from single bag using modal analysis. CH4 split using phase 3 to 4 THC mass ratio.

Compiling Engineer	Date: 13/07/2015	Approving Engineer:	Date: 13/07/2015

Issue No. 4 | Effective Date: 07-Jan-13 | POF003 Page 1 of 1

Appendix B. Vehicle details

MILLBROOK VEHICLE EMISSIONS LABORATORY

Vehicle Details Sheet

Customer:	ICF Consulting Services
Customer Address:	Watling House, 33 Cannon Street, London, EC4M 5SB
Test Purpose:	Bio components level study for transport fuels
Test Vehicle	Passanger Car Emissions - Euro 6

Vehicle Information	Vehicle Registration No.	LT64OVG
	VIN	VF38DAHXMEL030599
	Year of Registration	2014
	Make & Model	Peugeot 508
	Model Varient	2.0 BlueHDi 150
	Body Type	Saloon
	Tyre Make/Size	Michelin Primacy HP - 235/45 R18
	Mileage	10212
Technical Specification	Fuel	Diesel
	Transmission	6-Spd Manual
	Engine Type/Code	2.0 BlueHDi 150
	Engine Size	1997 cc
	Number of Cylinders	4
	Fuel System Type	2.0L Diesel with CAT, SCR and DPF
	Aspiration	Turbocharged
	Euro Level	6
	Maximum Power@rpm	110 Kw @ 4000 rpm
	Maximum Torque@rpm	370 Nm @ 2000 rpm

Type Approval Information	Euro Level	HC+Nox mg/km	CO mg/km	NOx mg/km	CO2 g/km	PM mg/km	Fuel Cons l/100km
	EC Stage VI	67	157	57	109	0.1	4.20

Photographic

Comments: Emissions and Fuel Consumption data taken from www.carfueldata.direct.gov.uk/

Compiling Engineer:	DATE:	Approving Engineer:	DATE:

MILLBROOK VEHICLE EMISSIONS LABORATORY

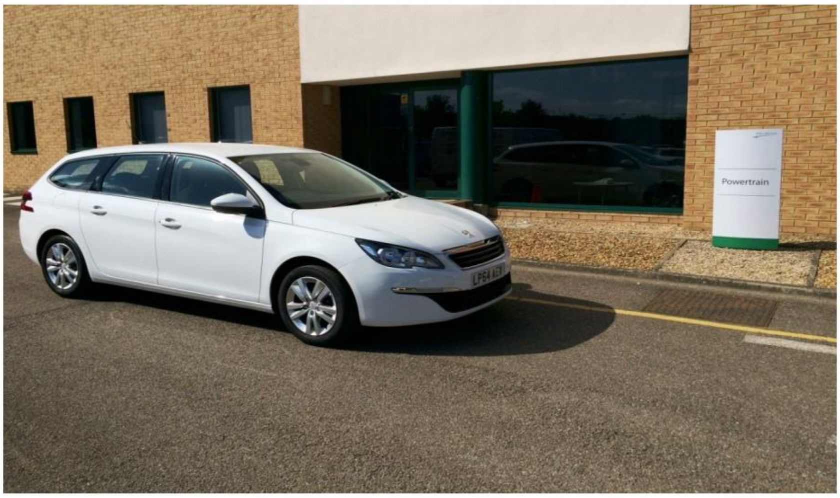
Vehicle Details Sheet

Customer:	**ICF Consulting Services**
Customer Address:	**Watling House, 33 Cannon Street, London, EC4M 5SB**
Test Purpose:	**Bio components level study for transport fuels**
Test Vehicle	**Passanger Car Emissions - Euro 6**

Vehicle Information	**Vehicle Registration No.**	**LP64AEW**
	VIN	**VF3LRHNYHES182421**
	Year of Registration	**2014**
	Make & Model	**Peugeot 308sw**
	Model Varient	**PureTech 1.2 130 S&S**
	Body Type	**Estate**
	Tyre Make/Size	**Michelin Energy Saver - 205/55 R16**
	Mileage	**3603**
Technical Specification	**Fuel**	**Gasoline**
	Transmission	**6-Spd Manual**
	Engine Type/Code	**PureTech 1.2 130 S&S**
	Engine Size	**1199 cc**
	Number of Cylinders	
	Fuel System Type	
	Aspiration	**Turbocharged**
	Euro Level	**6**
	Maximum Power@rpm	**96 Kw @ 5500 rpm**
	Maximum Torque@rpm	**230 Nm @ 1750 rpm**

Type Approval Information	Euro Level	HC+Nox mg/km	CO mg/km	NOx mg/km	CO2 g/km	PM mg/km	Fuel Cons l/100km
	EC Stage VI	N/A	196	23	109	N/A	4.70

Photographic



Comments: Emissions and Fuel Consumption data taken from www.carfueldata.direct.gov.uk/

Compiling Engineer:	DATE:	Approving Engineer:	DATE:

Test Report

Appendix C. Fuel Certificate of Analysis

Euro 6 Gasoline – E10

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-W14/395	**Contact:**	Andy Inskip
Fuel Type:	Euro 6 Gasoline	**Order No:**	PO3054146
Customer:	Millbrook	**Date:**	05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
Appearance @ -7°C	Visual		Report		C&B
RON	EN ISO 5164		95.0	98.0	96.6
MON	EN ISO 5163		85.0	89.0	86.2
Density @ 15°C	EN ISO 12185	kg/L	0.7430	0.7560	0.7488
DVPE @ 37.8°C	EN 13016-1	kPa	56.0	60.0	58.2
Sulfur	EN ISO 20846	mg/kg	-	10.0	1.0
Water Content	EN ISO 12937	% v/v	-	0.050	0.029
Aromatics	ASTM D1319	% v/v	Report		28.8
Olefins	ASTM D1319	% v/v	Report		10.2
Saturates	ASTM D1319	% v/v	Report		51.8
PIONA			Report		
Paraffins	ASTM D6730 mod	% v/v	Report		10.0
Isoparaffins	ASTM D6730 mod	% v/v	Report		33.1
Olefins	ASTM D6730 mod	% v/v	6.0	13.0	9.8
Naphthenes	ASTM D6730 mod	% v/v	Report		6.8
Aromatics	ASTM D6730 mod	% v/v	25.0	32.0	29.8
Benzene	ASTM D6730 mod	% v/v	-	1.0	<0.1
Oxygenates			Report		
Methanol	ASTM D6730 mod	% v/v	Report		<0.1
Ethanol	ASTM D6730 mod	% v/v	9.0	10.0	9.3
MTBE	ASTM D6730 mod	% v/v	Report		<0.1
ETBE	ASTM D6730 mod	% v/v	Report		<0.1
Oxidation Stability	EN ISO 7536	min	480	-	>480
Copper Corrosion (3h at 50ºC)	EN ISO 2160	Rating	Class 1	-	1A
Existent Gum - Washed	EN ISO 6246	mg/100mL	-	4	<1
Lead	EN 237	mg/L	-	5.0	<2.5
Phosphorus	ASTM D3231	mg/L	-	1.30	<0.20
Carbon	ASTM D6370 mod	% m/m	Report		83.30
Hydrogen	ASTM D6370 mod	% m/m	Report		13.30
Oxygen	ASTM D6730 mod	% m/m	3.30	3.70	3.40
C/H Ratio	Calculation		Report		0.526
C/O Ratio	Calculation		Report		32.635

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Test Report

MILLBROOK

CORYTON
advanced fuels

Certificate of Analysis

Fuel Blend No:	CAF-W14/395	**Contact:**	Andy Inskip
Fuel Type:	Euro 6 Gasoline	**Order No:**	PO3054146
Customer:	Millbrook	**Date:**	05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Distillation (Evaporated)			Report		
E70	EN ISO 3405	% v/v	34.0	46.0	42.6
E100	EN ISO 3405	% v/v	54.0	62.0	59.9
E150	EN ISO 3405	% v/v	86.0	94.0	90.4
IBP	EN ISO 3405	°C	Report		35.1
10% Volume Evaporated	EN ISO 3405	°C	Report		56.9
20% Volume Evaporated	EN ISO 3405	°C	Report		61.0
30% Volume Evaporated	EN ISO 3405	°C	Report		63.4
40% Volume Evaporated	EN ISO 3405	°C	Report		66.3
50% Volume Evaporated	EN ISO 3405	°C	Report		86.0
60% Volume Evaporated	EN ISO 3405	°C	Report		100.1
70% Volume Evaporated	EN ISO 3405	°C	Report		114.6
80% Volume Evaporated	EN ISO 3405	°C	Report		130.2
90% Volume Evaporated	EN ISO 3405	°C	Report		149.0
95% Volume Evaporated	EN ISO 3405	°C	Report		164.9
FBP	EN ISO 3405	°C	170.0	195.0	189.4
Residue	EN ISO 3405	% v/v	-	2.0	1.0
Recovery	EN ISO 3405	% v/v	Report		99.0

Notes:

Date:	05/03/2015
Authorised by: C L Goodfellow *Operations Director*	

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Registered in England & Wales
Registered Company No. 7232065
Registered Office Address: The Manorway, Stanford-le-Hope, Essex. SS17 9LN

Test Report

Gasoline – E20

Certificate of Analysis

Fuel Blend No:	CAF-W15/438	**Contact:**	Andy Shepherd
Fuel Type:	E20 Gasoline	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	10/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Appearance	Visual		Report		C&B
RON	EN ISO 5164		Report		101.8
MON	EN ISO 5163		Report		87.6
Density @ 15°C	EN ISO 12185	kg/L	Report		0.7411
DVPE @ 37.8°C	EN 13016-1	kPa	Report		86.8
Sulfur	EN ISO 20846	mg/kg	Report		4.2
VLI	Calculation		Report		1199
Aromatics	ASTM D1319	% v/v	Report		21.4
Olefins	ASTM D1319	% v/v	Report		12.8
Saturates	ASTM D1319	% v/v	Report		45.1
Benzene	ASTM D6730 mod	% v/v	Report		0.77
Oxygenates					
Methanol	ASTM D6730 mod	% v/v	Report		<0.1
Ethanol	ASTM D6730 mod	% v/v	Report		20.7
i-Propanol	ASTM D6730 mod	% v/v	Report		<0.1
i-Butanol	ASTM D6730 mod	% v/v	Report		<0.1
t-Butanol	ASTM D6730 mod	% v/v	Report		<0.1
MTBE	ASTM D6730 mod	% v/v	Report		<0.1
ETBE	ASTM D6730 mod	% v/v	Report		<0.1
Ethers (5 or more C atoms)	ASTM D6730 mod	% v/v	Report		<0.1
Oxygenates - Total	ASTM D6730 mod	% v/v	Report		20.7
Oxidation Stability	EN ISO 7536	min	Report		>360
Copper Corrosion (3h at 50°C)	EN ISO 2160	Rating	Report		1A
Existent Gum - Washed	EN ISO 6246	mg/100mL	Report		<1
Lead	EN 237	g/L	Report		<0.0025
Carbon	ASTM D6730 mod	% m/m	Report		78.87
Hydrogen	ASTM D6730 mod	% m/m	Report		13.42
Oxygen	ASTM D6730 mod	% m/m	Report		7.70
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		45.99
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		43.08

Test Report

Certificate of Analysis

Fuel Blend No:	CAF-W15/438	**Contact:**	Andy Shepherd
Fuel Type:	E20 Gasoline	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	10/06/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Distillation (Evaporated)			Report		
E70	EN ISO 3405	% v/v	Report		47.3
E100	EN ISO 3405	% v/v	Report		71.9
E150	EN ISO 3405	% v/v	Report		93.8
E180	EN ISO 3405	% v/v	Report		99.9
IBP	EN ISO 3405	°C	Report		27.3
10% Volume Evaporated	EN ISO 3405	°C	Report		46.3
20% Volume Evaporated	EN ISO 3405	°C	Report		54.4
30% Volume Evaporated	EN ISO 3405	°C	Report		61.5
40% Volume Evaporated	EN ISO 3405	°C	Report		67.1
50% Volume Evaporated	EN ISO 3405	°C	Report		71.1
60% Volume Evaporated	EN ISO 3405	°C	Report		74.2
70% Volume Evaporated	EN ISO 3405	°C	Report		78.2
80% Volume Evaporated	EN ISO 3405	°C	Report		121.4
90% Volume Evaporated	EN ISO 3405	°C	Report		140.2
95% Volume Evaporated	EN ISO 3405	°C	Report		156.1
FBP	EN ISO 3405	°C	Report		172.8
Residue	EN ISO 3405	% v/v	Report		1.0

Sample Received Condition: Good (No Seal)
Date Sample Received: 03/06/2015

Notes:

Date:	10/06/2015
Authorised by: M Rodriguez *Blend Formulator*	

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Test Report

Euro 6 Diesel – B7

CORYTON advanced fuels

Certificate of Analysis

Fuel Blend No: CAF-G14/580 **Contact:** Andy Inskip
Fuel Type: Euro 6 Diesel **Order No:** PO3054146
Customer: Millbrook **Date:** 05/03/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
Cetane Number	EN ISO 5165		52.0	56.0	53.4
Cetane Index	EN ISO 4264		46.0	-	54.5
Density @ 15°C	EN ISO 12185	kg/L	0.8330	0.8370	0.8332
Cloud Point	EN ISO 23015	°C	-	-10	-13
Carbon Residue (10% Dis. Res)	EN ISO 10370	% m/m	-	0.20	0.01
Flash Point	EN ISO 2719	ºC	55.0	-	64.0
Lubricity, corrected wear scar diameter (wsd 1.4) @ 60ºC	EN ISO 12156-1	µm	-	400	165
Sulfur	EN ISO 20846	mg/kg	-	10.0	5.0
Strong Acid Number	ISO 6618	mgKOH/g	-	0.10	0
Viscosity at 40ºC	EN ISO 3104	mm²/s	2.300	3.300	2.711
Water Content	EN ISO 12937	mg/kg	-	200	170
FAME Content	EN 14078	% v/v	6.0	7.0	6.5
Mono Aromatics Content	EN 12916 mod	% m/m	Report		21.5
Di Aromatics Content	EN 12916 mod	% m/m	Report		3.3
Tri+ Aromatics Content	EN 12916 mod	% m/m	Report		0.2
Polycyclic Aromatics Content	EN 12916 mod	% m/m	2.0	4.0	3.5
Total Aromatics	EN 12916 mod	% m/m	Report		25.0
Oxidation Stability	EN 15751	h	20.0	-	>20.0
Ash Content	EN ISO 6245	% m/m	-	0.010	<0.010
Copper Corrosion (3h at 50ºC)	EN ISO 2160	Rating	1	-	1A
Total Contamination	EN 12662	mg/kg	-	24	15
Carbon	ASTM D3343 mod	% m/m	Report		85.96
Hydrogen	ASTM D3343 mod	% m/m	Report		13.33
Oxygen	EN 14078	% m/m	Report		0.70
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		45.62
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		42.79

Test Report

Certificate of Analysis

Fuel Blend No:	CAF-G14/580	**Contact:**	Andy Inskip
Fuel Type:	Euro 6 Diesel	**Order No:**	PO3054146
Customer:	Millbrook	**Date:**	05/03/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Distillation (Evaporated)					
E250	EN ISO 3405	% v/v	Report		33.4
E350	EN ISO 3405	% v/v	Report		96.0
IBP	EN ISO 3405	ºC	Report		171.9
10% Volume Evaporated	EN ISO 3405	ºC	Report		209.6
20% Volume Evaporated	EN ISO 3405	ºC	Report		227.8
30% Volume Evaporated	EN ISO 3405	ºC	Report		244.5
40% Volume Evaporated	EN ISO 3405	ºC	Report		260.0
50% Volume Evaporated	EN ISO 3405	ºC	245.0	-	274.7
60% Volume Evaporated	EN ISO 3405	ºC	Report		289.4
70% Volume Evaporated	EN ISO 3405	ºC	Report		303.7
80% Volume Evaporated	EN ISO 3405	ºC	Report		318.5
90% Volume Evaporated	EN ISO 3405	ºC	Report		334.6
95% Volume Evaporated	EN ISO 3405	ºC	345.0	360.0	346.5
FBP	EN ISO 3405	ºC	-	370.0	355.9
Loss	EN ISO 3405	% v/v	Report		0.0
Residue	EN ISO 3405	% v/v	Report		1.4

Sample Received Condition: Good (No Seal)
Date Sample Received: 22/10/2014

Notes:

Date:	05/03/2015
Authorised by: C L Goodfellow *Operations Director*	

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Test Report

Diesel – B10

Certificate of Analysis

Fuel Blend No:	CAF-G15/313	**Contact:**	Andy Shepherd
Fuel Type:	B10 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Appearance	Visual		Report		C&B
Cetane Number	EN ISO 5165		Report		52.3
Cetane Index	EN ISO 4264		Report		50.7
Density @ 15°C	EN ISO 12185	kg/L	Report		0.8414
CFPP	EN 116	°C	Report		-22
Flash Point	EN ISO 2719	°C	Report		62.0
Lubricity, corrected wear scar diameter (wsd 1.4) @ 60°C	EN ISO 12156-1	µm	Report		163
Sulfur	EN ISO 20846	mg/kg	Report		9.2
Viscosity at 40°C	EN ISO 3104	mm²/s	Report		2.667
Water Content	EN ISO 12937	mg/kg	Report		140
FAME Content	EN 14078	% m/m	Report		9.7
Mono Aromatics Content	IP 391 mod	% m/m	Report		24.9
Di Aromatics Content	IP 391 mod	% m/m	Report		4.0
Tri+ Aromatics Content	IP 391 mod	% m/m	Report		0.4
Polycyclic Aromatics Content	IP 391 mod	% m/m	Report		4.4
Total Aromatics	IP 391 mod	% m/m	Report		29.3
Oxidation Stability (16h)	EN ISO 12205	g/m³	Report		<1
Ash Content	EN ISO 6245	% m/m	Report		<0.001
Carbon Residue (10% Dis. Res)	EN ISO 10370	% m/m	Report		0.06
Copper Corrosion (3h at 50°C)	EN ISO 2160	Rating	Report		1A
Total Contamination	EN 12662	mg/kg	Report		7
Carbon	ASTM D3343 mod	% m/m	Report		85.92
Hydrogen	ASTM D3343	% m/m	Report		13.03
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		45.24
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		42.48

Test Report

Certificate of Analysis

Fuel Blend No:	CAF-G15/313	**Contact:**	Andy Shepherd
Fuel Type:	B10 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Distillation (Evaporated)					
E250	EN ISO 3405	% v/v	Report		36.6
E350	EN ISO 3405	% v/v	Report		95.4
IBP	EN ISO 3405	ºC	Report		166.0
10% Volume Evaporated	EN ISO 3405	ºC	Report		196.1
20% Volume Evaporated	EN ISO 3405	ºC	Report		215.2
30% Volume Evaporated	EN ISO 3405	ºC	Report		235.0
40% Volume Evaporated	EN ISO 3405	ºC	Report		257.5
50% Volume Evaporated	EN ISO 3405	ºC	Report		278.8
60% Volume Evaporated	EN ISO 3405	ºC	Report		297.8
70% Volume Evaporated	EN ISO 3405	ºC	Report		313.5
80% Volume Evaporated	EN ISO 3405	ºC	Report		326.4
90% Volume Evaporated	EN ISO 3405	ºC	Report		338.6
95% Volume Evaporated	EN ISO 3405	ºC	Report		349.0
FBP	EN ISO 3405	ºC	Report		357.6
Residue	EN ISO 3405	% v/v	Report		1.2

Sample Received Condition: Good (No Seal)
Date Sample Received: 26/05/2015

Notes:

Date:	08/06/2015
Authorised by: M Rodriguez *Blend Formulator*	

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Test Report

Diesel – B30

Certificate of Analysis

Fuel Blend No:	CAF-G15/314	**Contact:**	Andy Shepherd
Fuel Type:	B30 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit Min	Limit Max	Result
Appearance	Visual		Report		C&B
Cetane Number	EN ISO 5165		Report		51.7
Cetane Index	EN ISO 4264		Report		51.2
Density @ 15°C	EN ISO 12185	kg/L	Report		0.8505
CFPP	EN 116	ºC	Report		-23
Flash Point	EN ISO 2719	ºC	Report		66.0
Lubricity, corrected wear scar diameter (wsd 1.4) @ 60ºC	EN ISO 12156-1	µm	Report		314
Sulfur	EN ISO 20846	mg/kg	Report		8.0
Viscosity at 40ºC	EN ISO 3104	mm²/s	Report		2.986
Water Content	EN ISO 12937	mg/kg	Report		190
FAME Content	EN 14078	% m/m	Report		29.5
Mono Aromatics Content	IP 391 mod	% m/m	Report		19.3
Di Aromatics Content	IP 391 mod	% m/m	Report		3.0
Tri+ Aromatics Content	IP 391 mod	% m/m	Report		0.3
Polycyclic Aromatics Content	IP 391 mod	% m/m	Report		3.3
Total Aromatics	IP 391 mod	% m/m	Report		22.6
Oxidation Stability (16h)	EN ISO 12205	g/m³	Report		5
Ash Content	EN ISO 6245	% m/m	Report		0.002
Carbon Residue (10% Dis. Res)	EN ISO 10370	% m/m	Report		0.11
Copper Corrosion (3h at 50ºC)	EN ISO 2160	Rating	Report		1A
Total Contamination	EN 12662	mg/kg	Report		12
Carbon	ASTM D3343 mod	% m/m	Report		84.34
Hydrogen	ASTM D3343	% m/m	Report		12.48
Gross Calorific Value	ASTM D3338 mod	MJ/kg	Report		44.02
Net Calorific Value	ASTM D3338 mod	MJ/kg	Report		41.38

Test Report

MILLBROOK

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Certificate of Analysis

Fuel Blend No:	CAF-G15/314	**Contact:**	Andy Shepherd
Fuel Type:	B30 Diesel	**Order No:**	PO3056199-1
Customer:	Millbrook	**Date:**	08/06/2015

Test	Method	Unit	Limit		Result
			Min	Max	
Distillation (Evaporated)					
E250	EN ISO 3405	% v/v	Report		26.7
E350	EN ISO 3405	% v/v	Report		95.2
IBP	EN ISO 3405	°C	Report		171.2
10% Volume Evaporated	EN ISO 3405	°C	Report		202.7
20% Volume Evaporated	EN ISO 3405	°C	Report		229.6
30% Volume Evaporated	EN ISO 3405	°C	Report		259.3
40% Volume Evaporated	EN ISO 3405	°C	Report		286.6
50% Volume Evaporated	EN ISO 3405	°C	Report		306.3
60% Volume Evaporated	EN ISO 3405	°C	Report		319.6
70% Volume Evaporated	EN ISO 3405	°C	Report		328.2
80% Volume Evaporated	EN ISO 3405	°C	Report		334.5
90% Volume Evaporated	EN ISO 3405	°C	Report		340.8
95% Volume Evaporated	EN ISO 3405	°C	Report		349.2
FBP	EN ISO 3405	°C	Report		355.2
Residue	EN ISO 3405	% v/v	Report		0.9

Sample Received Condition: Good (No Seal)
Date Sample Received: 26/05/2015

Notes:

Date:	08/06/2015
Authorised by: M Rodriguez *Blend Formulator*	

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Appendix D. Description of test cycles

Preconditioning cycle - NEDC (New European Drive Cycle)

Phases of the New European Drive Cycle (NEDC) were used for vehicle preconditioning prior to each test. The NEDC consists of two phases; Urban (ECE) and Extra-Urban (EUDC) and is performed on a chassis dynamometer.
The preconditioning cycles were made up as follows:

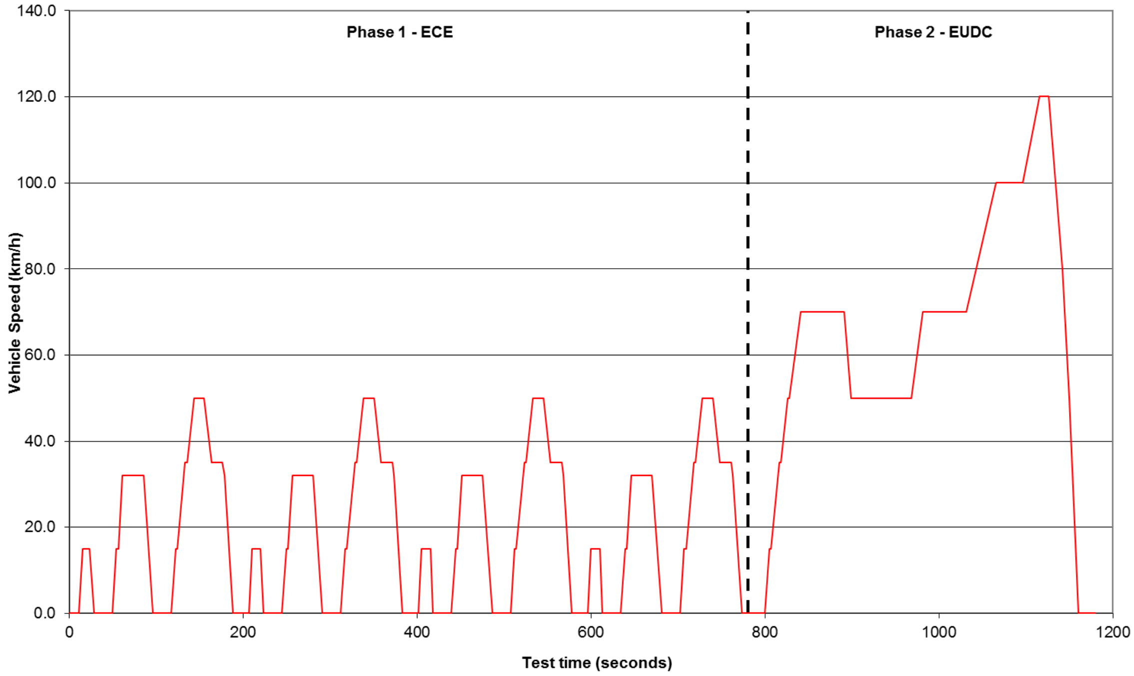
- Diesel vehicle; 3 x EUDC
- Gasoline vehicle; 1 x ECE, 2 x EUDC

Urban Cycle

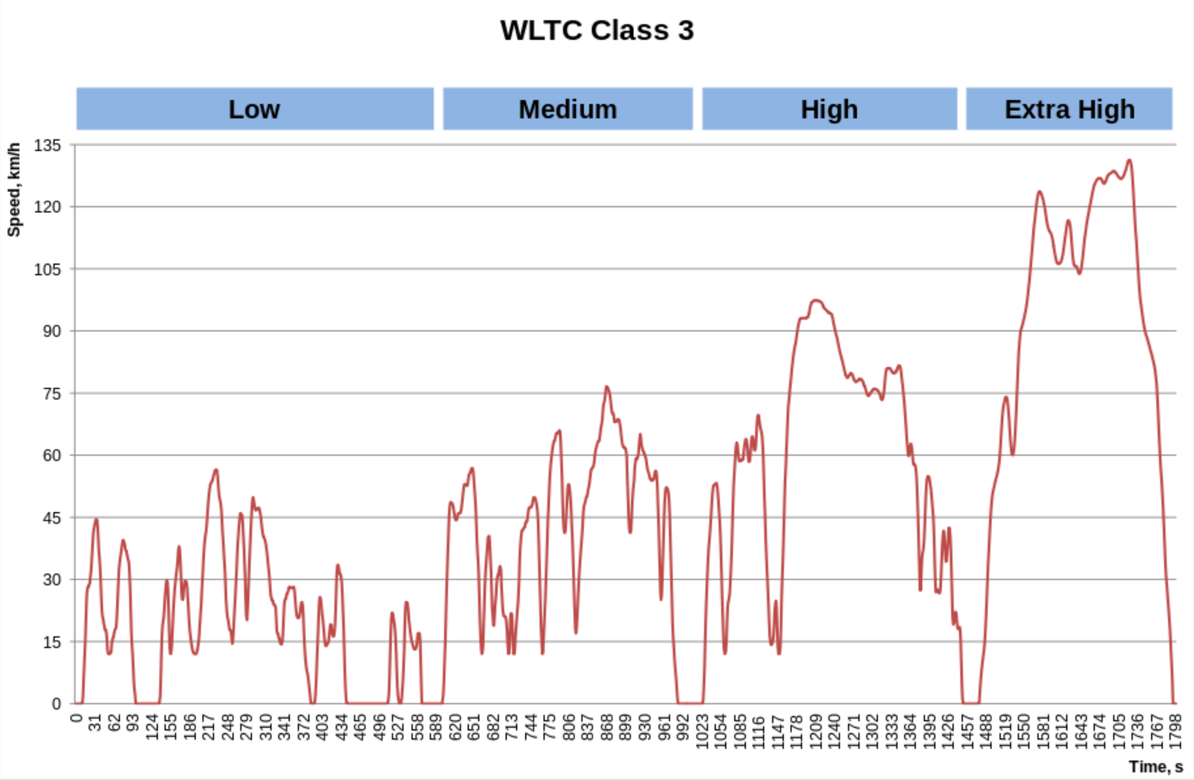
The Urban test cycle is carried out in a laboratory at an ambient temperature of 20° to 30°C on a rolling road from a cold start i.e. the engine has not run for several hours. The cycle consists of a series of accelerations, steady speeds, decelerations and idling. Maximum speed is 31 mph (50 km/h), average speed 12 mph (19 km/h) and the distance covered is 2.5 miles (4 km). The cycle is shown as Phase 1 in the diagram below.

Extra-Urban Cycle

This cycle is conducted immediately following the Urban cycle and consists of roughly half-steady speed driving and the remainder accelerations, decelerations and some idling. Maximum speed is 75 mph (120 km/h), average speed is 39 mph (63 km/h) and the distance covered is 4.3 miles (7 km). The cycle is shown as Phase 2 in the diagram below.



The graph below shows the WLTP drive cycle used in this project during which time the vehicle emissions were sampled.



The table below describes the makeup of the WLTC cycle.

WLTC Class 3 test cycle					
	Low	Medium	High	Extra High	Total
Duration, s	589	433	455	323	1800
Stop duration, s	156	48	31	7	242
Distance, m	3095	4756	7158	8254	23262
% of stops	26.5%	11.1%	6.8%	2.2%	13.4%
Maximum speed, km/h	56.5	76.6	97.4	131.3	
Average speed without stops, km/h	25.7	44.5	60.8	94.0	53.8
Average speed with stops, km/h	18.9	39.5	56.6	92.0	46.5
Minimum acceleration, m/s^2	-1.5	-1.5	-1.5	-1.2	
Maximum acceleration, m/s^2	1.5	1.6	1.6	1.0	

Appendix E. Carbon Balance Method

The fuel consumption of a hydrocarbon fuel can be calculated by measuring the carbon compounds present in the engine exhaust.

Fuel consumption is a measure of the amount of fuel used by an engine or a vehicle when operated for a specified time or over a specified distance.

The fuel consumption can be reported as an integrated result for a vehicle operated over a specified drive cycle or as instantaneous values at one second intervals. When the vehicle is operated over a drive cycle the results are usually reported as litres per 100 kilometres for EC tests and miles per US gallons for US Federal tests.

Fundamentals

1 Fuel consists primarily of carbon. The percentage mass of carbon contained in a fuel is given by the carbon mass fraction (sometimes called carbon weight fraction).

2 During combustion, the majority of the carbon in the fuel reacts with air to form carbon dioxide and carbon monoxide.

3 The mass flow rate of carbon entering the engine is identical to the mass flow rate of carbon leaving the engine.

4 A small proportion of the fuel passes through the engine and is present in the exhaust as un-burnt hydrocarbons.

The carbon balance equations used was:

$$FC_{Gasoline} = \frac{0.1}{D \cdot CWF} \cdot [(CWF \cdot HC) + (0.429 \cdot CO) + (0.273 \cdot CO_2)]$$

In these formulae:

FC = the fuel consumption in litre per 100 km
D = the density of the test fuel
CWF = the Carbon Weight Fraction of the test fuel
HC = the measured emission of hydrocarbons in g/km
CO = the measured emission of carbon monoxide in g/km
CO_2 = the measured emission of carbon dioxide in g/km

Test Report

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ML-02-17-580-EN-N

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doi:10.2834/153655