Wood Mackenzie

European Commission

Impact of the use of biofuels on oil refining and fuels specifications

Final Report – October 2010

Wood Mackenzie

RICARDO

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Glossary

ASTM	ASTM International, originally known as the American Society for Testing and Materials
Bbl	barrel (defined as 42 US gallons)
Bpd	barrels per day
B100	Biodiesel with 100% FAME
C&EE	Central and Eastern Europe
CAFE	Corporate Average Fuel Economy
CAI	Controlled Auto Ignition
CDU	Crude distillation capacity
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPS	Cam Profile Switching
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
EC	European Community
EGR	Exhaust Gas Recirculation
EISA	Energy Independence and Security Act
ETBE	Ethyl tert-butyl ether
ETS	Emissions Trading Scheme
EU	European Union
EV	Electric vehicle
E85	Gasoline type fuel with up to 85%vol ethanol
FAME	Fatty Acid Methyl Ester
FETSA	Federation of European Tank Storage Associations
FFC	Fluid Catalytic Cracking
FIE	Fuel Injection Equipment
FQD	Fuel Quality Directive
FSU	Former Soviet Union
FWC	Four Way Catalyst
GDI	Gasoline Direct Injection
GDP	Gross Domestic Product
GPF	Gasoline Particulate Filter
Greater Europe	Greater Europe consists of three territories – North West Europe, Central & Eastern Europe and the Mediterranean
GTL	Gas to Liquids
g/km	Gramme per kilometer
HC	Hydrocarbon emissions

HCCI	Homogeneous Charge Compression Ignition
HP	High Pressure
HSFO	High Sulphur Fuel Oil
HVO	Hydrogenated Vegetable Oil
IATA	International Airline Transport Association
IMO	International Maritime Organisation
IPA	Institut für Physik der Atmosphere
kb/d	Thousand barrels per day
kbcd	Thousand barrels per calendar day
LHS	Left hand side
LLS	Louisiana Light Sweet
LNG	Liquid Natural Gas
LNT	Lean NOx Trap
LPG	Liquid Petroleum Gas
LSFO	Low Sulphur Fuel Oil
Mb/d	Million barrels per day
Mbcd	Million barrels per calendar day
Med	Mediterranean
Mt	Million (metric) tonnes
MTBE	Methyl tert-butyl ether
NCM	Net Cash Margin
NGL	Natural gas liquid
NOC	National Oil Company
NOx	Nitrogen Oxides emissions
NWE	North West Europe is made up of Austria, Belgium, Denmark, Finland, Northern France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland, United Kingdom
OPEC	Organization of the Petroleum Exporting Countries
PM	Particulate emissions
Pmax	Maximum cylinder pressure
PMC	Particulate Matter Catalyst
pa	per annum
ppm	parts per million
RED	Renewable Energy Directive
RHS	Right hand side
SCR	Selective Catalytic Reduction
SECA	Special Emission Control Area
SOx	Sulphur Oxides emissions

T/C	Turbocharger
te	(metric) tonne
TWC	Three Way Catalyst
ULSD	Ultra Low Sulphur Diesel
USGC	US Gulf Coast
VGT	Variable Geometry Turbocharger
VVA	Variable Valve Actuation
WOT	Wide Open Throttle
WTI	West Texas Intermediate
Wt%	Weight percent
ytd	Year to date
$/bbl	US dollar per barrel
$/te	US dollar per tonne

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1 Executive Summary

The EU has agreed on achieving a 20% reduction in greenhouse gas emissions and an increase to 20% in the share of renewables in its energy mix by 2020. For the transport sector, a 10% target for the use of renewable energy including biofuels was also agreed, tied to a set of sustainability criteria. A substantial increase in biofuels consumption, from the level of 2.6% of EU road transport fuels in 2007, is therefore needed to meet the 10% EU target. This may have an impact on fuel specifications within as well as outside the EU.

Increasing biofuel supply implies reduced oil refinery processing, potentially leading to reduction of existing refining capacity and affecting the entire oil industry supply chain both in the EU and third countries.

The study will therefore assess:

- The impact of increased consumption of biofuels on the oil refining process, refining economics and fuel specifications.
- Scenarios for supply of gasoline- and diesel-replacers and use of high and low blends with conventional oils.
- Prospects for biofuels in bunkering and aviation fuel markets.
- Impact on refinery energy use, refinery greenhouse gas emissions, impact on prices of oil, oil products and their differentials; for example, prospects for simultaneous biofuels expansion outside and within the EU affecting gasoline market balances in the Atlantic Basin with potentially global implications.
- Implications for security of oil supply in the EU and options for management of the downstream sector in case of disruption of biofuel supply.
- Experience in leading biofuel markets such as Brazil, the USA and parts of Asia, to be integrated into the above considerations.

The study is intended to be used by the European Commission to provide input to the EU-OPEC Energy Dialogue.

1.1 European Refining Environment

1.1.1 European Demand For Refined Products

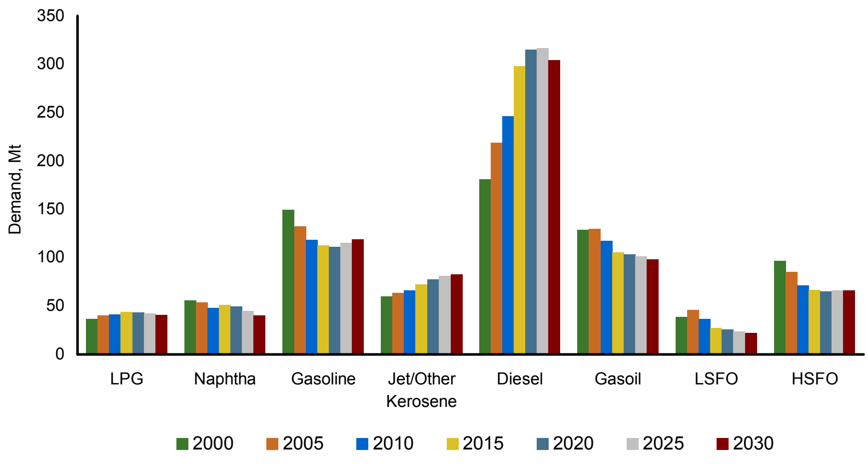
We define an area we call Greater Europe consisting of three territories – North West Europe, Central & Eastern Europe (including non EU countries such as Turkey) and the Mediterranean (including North Africa and the Levant). Greater Europe currently accounts for 22% of global demand (for comparison, Asia Pacific accounts for 30% and North America 27%). Total demand is forecast to grow from 856 Mt (18.0 Mb/d) in 2009 to 914 Mt (19.2 Mb/d) by 2025 – an increase of 57 Mt (1.2 Mb/d), or 6.7%.

Greater Europe has the slowest growth rate of all of our defined seven regions in the world and, as a result, Greater Europe's share of global demand falls to 18% by 2025 (Asia Pacific grows to 36%, while North America declines to 22%).

Greater Europe demand is currently dominated by North West Europe (NWE) which accounted for 48% of the region's total demand in 2009. By 2025 the Mediterranean (Med) is expected to become the largest region in terms of oil demand – this is due to both continued demand growth in the Med over the forecast period while demand in NWE starts to fall around 2015. Central and Eastern Europe (C&EE) has the fastest demand growth rate within Greater Europe, at around 1.0% per annum, although in absolute terms the region remains small and accounts for less than 10% of Greater Europe's demand.

Diesel is expected to make the largest contribution to demand growth in Greater Europe, as dieselisation of the car fleet continues in the short term, commercial transport demand expands and EU legislation aligns non-road fuel quality requirements with the on-road sector. Jet fuel demand growth is also expected to be robust, as the expansion of air travel continues. Demand for gasoline is forecast to decline substantially out to 2020 - largely due to the dieselisation trend - before staging a slight recovery through to 2025. Gasoil and fuel oil face competition from other energy products.

Figure 1: Greater European Demand by Product, 2000-2030



Source: Wood Mackenzie

1.1.2 European Supply of Oil Products

Refinery investments still outpace closures. We anticipate that 380 kb/d of crude capacity – the equivalent of nearly two world-scale refineries - will come on stream in Greater Europe between 2010 and 2015 on the basis of currently announced projects (excluding capacity closures). All the additional capacity is from the expansion of existing refineries. The closure of the Dunkirk refinery in France together with a reduction in CDU capacity in France will reduce capacity by 240 kb/d. The net effect of announced closures and capacity expansion is an addition of 143 kb/d between 2010 and 2015.

The majority of the additional capacity is forecast to come on stream in the Med driven by strong demand growth in the North African Med countries.

In addition to the investment in crude capacity, there is significant investment in both hydrocracking and coking capacity. Again the majority of this investment is taking place within the Med region.

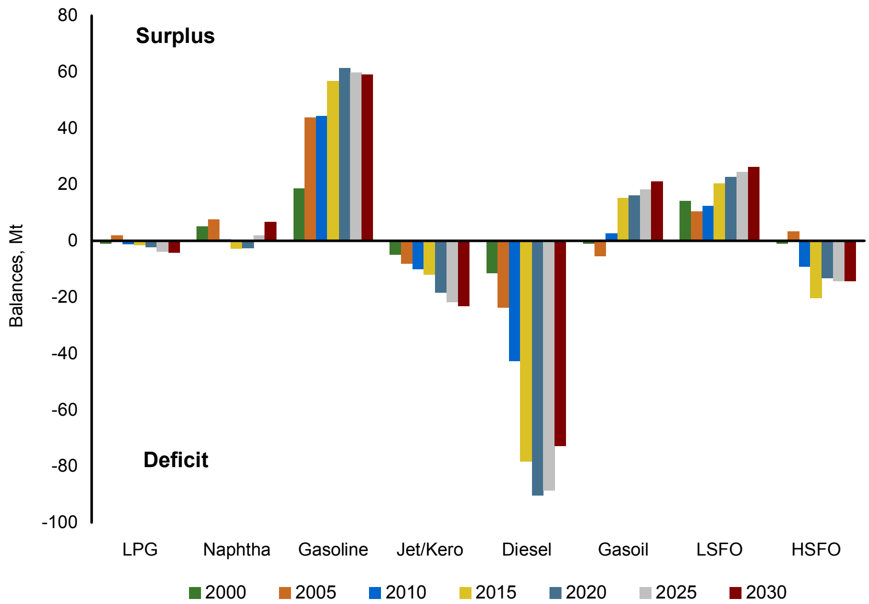
The total crude distillation capacity in Greater Europe was 18.6 Mbcd at the end of 2009, from 136 main fuels refineries. The average refinery size is 136 kbcd, with an average Wood Mackenzie complexity of 6.1. North West Europe (NWE) accounts for 48% of the region's refining capacity, followed by the Med with 44%. Central and Eastern Europe (C&EE) has only 9% of the region's capacity.

1.1.3 European Oil Product Balance

The gasoline surplus grows substantially. The all supply surplus increases from 43 Mt (990 kb/d) in 2009 to almost 60 Mt (1.4 Mb/d) by 2025. Demand is forecast to decline out to 2020 due to rising efficiency and continued dieselisation of the car fleet, and this decline more than offsets lower refinery production due to reduced utilisation. Post 2015, the surplus grows at a slower rate.

The diesel deficit increases due to higher demand. The diesel all supply deficit is expected to grow from 43 Mt (890 kb/d) in 2009 to around 78 Mt (1.6 Mb/d) by 2015, due to strong growth in demand for road diesel, as well as the expected switch in quality from non-road gasoil to diesel quality. By 2025, we forecast an all supply deficit of 89 Mt (1.8 Mb/d). The gasoil surplus is expected to increase as demand falls.

Figure 2: Greater European All Supply Product Balances, 2000-2030



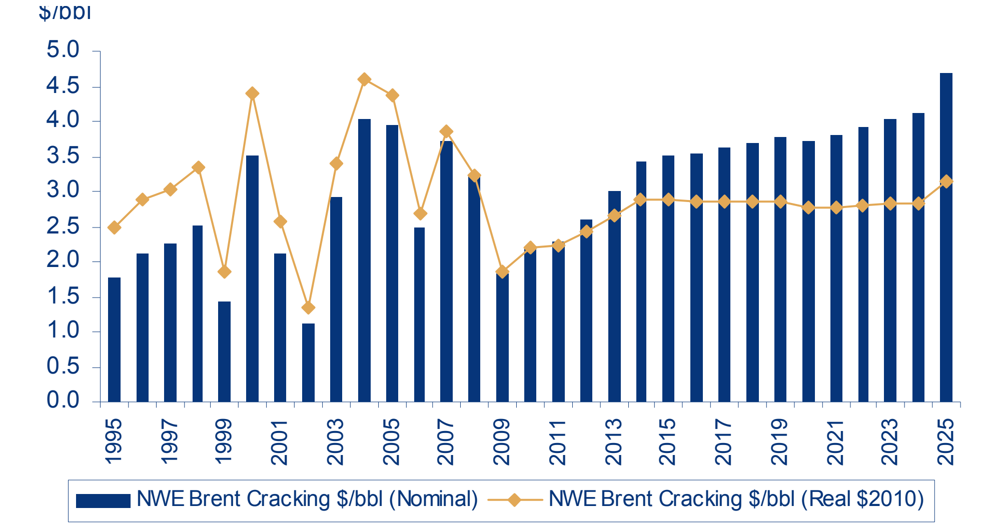
Source: Wood Mackenzie

The fuel oil surplus disappears in the short-term, but grows again longer-term. The current fuel oil surplus of around 6 Mt (100 kb/d) is forecast to disappear soon after 2010. Supply reduces due to significant investment in upgrading units and lower crude runs. Demand for fuel oil declines due to falling inland demand caused by gas substitution. The LSFO surplus grows by 2015 due to the shift of some bunker demand from LSFO to gasoil. The HSFO deficit grows significantly in the short-term as supply falls and demand for high sulphur bunkers continues to grow, but falls in the longer-term as refinery utilisation rises slightly.

1.1.4 Outlook For European Refining

A surplus of refining capacity will keep European refining margins at low levels, relative to those seen in the middle of the last decade, for the next few years. In the medium term, we forecast a slight recovery due to strength in diesel crack spreads but even by 2015, refining margins are below the historic long-term average. This illustrates our view that the refining business in Europe will operate in a low-margin environment for several years and that surplus global refining capacity is likely to prevent another ‘golden age’ for European refiners.

Figure 3: Gross NWE margin outlook for FCC cracking Brent



Source: Wood Mackenzie

The current low margin refining environment combined with a long term declining demand for oil products in many parts of Europe means that companies are evaluating their refining assets and several have been put up for sale by their owners.

1.2 European Biofuels Environment

1.2.1 European Biofuel Mandates

The Renewable Energy Directive (RED) requires Member States to 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 road transport in that Member State. We expect that biofuels will be the main contributor to that target.

Renewable fuels counting towards the target must meet minimum standards for life-cycle carbon emissions

- 35% from 2013
- 50% from 2017 for existing production plants and 60% for new production

Renewable fuels counting towards the target must meet sustainability standards, including the requirement that biofuels are not made from raw materials obtained from land with a high biodiversity, wetlands and continuously forested areas, or areas that were once woodlands.

The contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material (second generation sources) shall be considered to be twice that made by other biofuels.

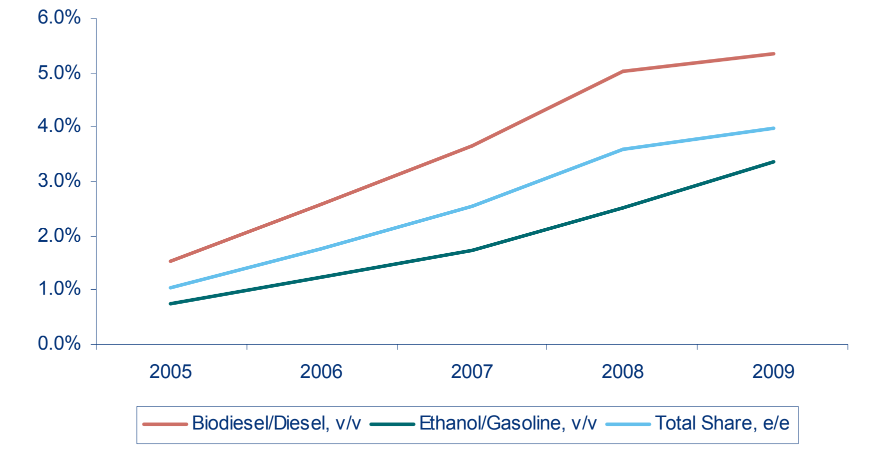
The Fuels Quality Directive (FQD) requires suppliers of road transport fuels to reduce the life-cycle greenhouse gas emissions per unit of energy from fuel and energy supplied by up to 10% by the 31st December 2020. This consists of a 6% reduction (compared to the 2010 level) obtained through the use of biofuels, alternative fuels and reductions in flaring and venting at production sites.

Subject to review, a further 2% reduction should be obtained through the use of environmentally friendly carbon capture and storage technologies and electric vehicles and an additional 2% reduction through the purchase of credits through the Clean Development Mechanism of the Kyoto Protocol.

1.2.2 European Biofuel Demand

Biodiesel accounted for an estimated 5.4% of the approximately 230 billion litre EU road diesel market on a volume basis in 2009 whilst ethanol accounted for an estimated 3.4% of the approximately 130 billion litre gasoline market. Overall, biofuels accounted for 4% of energy use in road transport; up from 1% in 2005. Directive 2003/30/EC – the Biofuels Directive – required biofuels to account for 2% of road transport energy demand by 2005, rising to 5.75% by 2010. The 2005 target was missed and it seems highly unlikely that the 2010 target will be hit, but nevertheless, much progress has been made towards the aims of that Directive and we estimate that biofuels could contribute just over 5% of road transport energy demand in 2010.

Figure 4: Biofuels Share of EU Road Transport Fuels Markets



Source: Wood Mackenzie

1.2.3 Technical Constraints On Biofuels

There are a number of well documented technical constraints associated with the use of biofuels that limit the acceptable biofuel content in fuel for current vehicles. These constraints need to be addressed if biofuel blend volumes are to be increased. They include the effect of biofuels on the combustion system, lubrication, exhaust gas recirculation (EGR), engine-out emissions, after-treatment systems and material compatibility. The issues are distinct with relation to biodiesel products, especially FAME, in diesel engines and biogasoline in gasoline engines.

For vehicle technology, the challenge for industry is to ensure the co-development of future engine systems to utilise biofuels in an efficient and uncompromising manner. This will mean minimising the impact of negative features, such as reduced heating value, active chemistry and reduced operability, whilst seeking to benefit from the characteristic advantages, such as high octane or cetane number.

1.2.4 Future Biofuel Scenarios For Europe

The aim of this study is to investigate the potential impact of biofuels on the refining industry and fuel specifications. That impact will be different depending on the following:

- The overall volume of biofuels incorporated into the EU transport fuels market
- The mix of each type of biofuel within that overall volume
- The properties of those biofuels

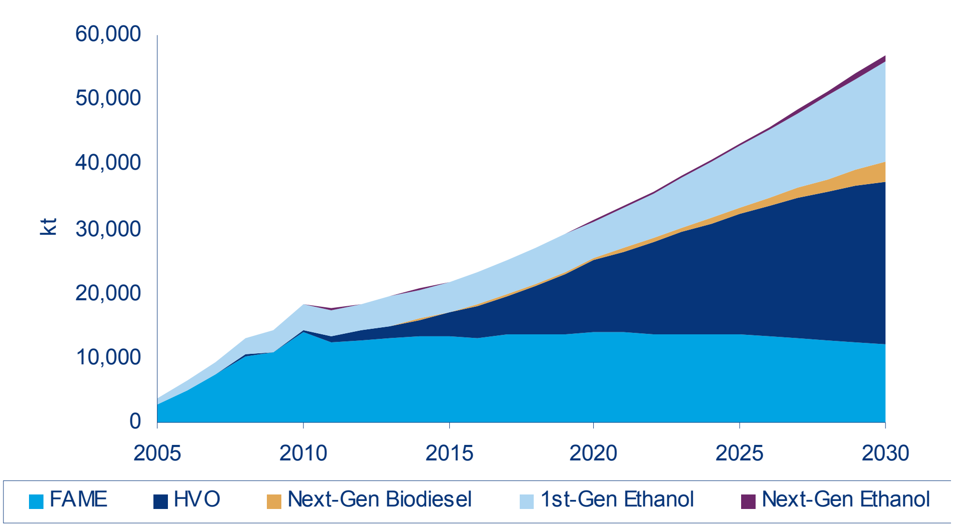
There is considerable uncertainty surrounding each of these factors. We have therefore developed three potential scenarios for the level of future biofuels consumption and the mix of biofuels, with the aim of exploring a wide range of possible impacts on the refining sector and on fuel specifications.

Scenario 1

Scenario 1 assumes that the Renewable Energy and Fuel Quality Directives are met with a relatively high share of biodiesels and a relatively low ethanol share. This pattern then extends through to 2030.

In this scenario, the majority of the biofuels are from first-generation sources, even in 2030. There is limited contribution from next-generation biofuels, as their commercialisation continues to be delayed for economic and technological reasons. Their share does grow slowly over time, as some production plants are built, but these mainly rely on substantial government support.

Figure 5: Scenario 1 – Biofuel consumption, 2005 – 2030



Source: Wood Mackenzie

The uptake of plug-in electric vehicles is low, with EVs representing less than 1% of market share in 2020 and less than 6% in 2030. Therefore the contribution from renewable electricity is low.

Figure 5 shows how the consumption of biofuels grows over time in Scenario 1. Total biodiesel demand grows from around 3 Mt in 2005 to 26 Mt by 2020 and 41 Mt by 2030. Of this total the majority is produced using currently commercial technologies, with next-generation biodiesel consumption being less than 0.5 Mt in 2020 and 3 Mt in 2030. Fuel ethanol consumption rises from 0.8 Mt in 2005 to 6 Mt in 2020 and 17 Mt in 2030. Of this total, next-generation ethanol accounts for less than 1 Mt by 2030.

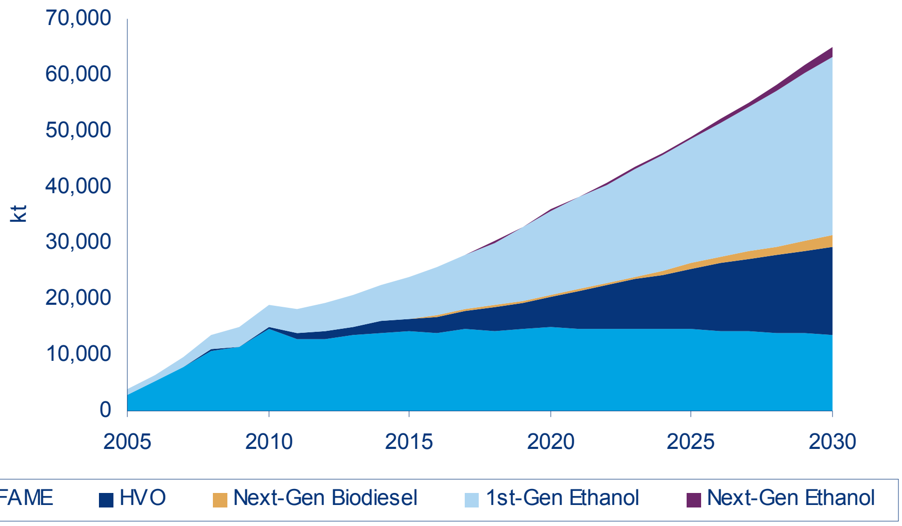
Scenario 2

Scenario 2 assumes that the Renewable Energy and Fuel Quality Directives are met with a relatively high share of ethanol and a relatively low biodiesel share. This pattern then extends through to 2030.

As for Scenario 1, the majority of the biofuels are from first-generation sources, even in 2030. Similarly, the uptake of plug-in electric vehicles is low, with EVs representing less than 1% of market share in 2020 and less than 6% in 2030. Therefore the contribution from renewable electricity is low.

Figure 6 shows how the consumption of biofuels grows over time in Scenario 2. Total biodiesel demand grows from around 3 Mt in 2005 to 21 Mt by 2020 and 31 Mt by 2030. Of this total the majority is produced using currently commercial technologies, with next-generation biodiesel consumption being less than 0.5 Mt in 2020 and 2 Mt in 2030. Fuel ethanol consumption rises from 0.8 Mt in 2005 to 15 Mt in 2020 and 34 Mt in 2030. Of this total, next-generation ethanol accounts for less than 2 Mt by 2030.

Figure 6: Scenario 2 – Biofuel consumption, 2005 – 2030



Source: Wood Mackenzie

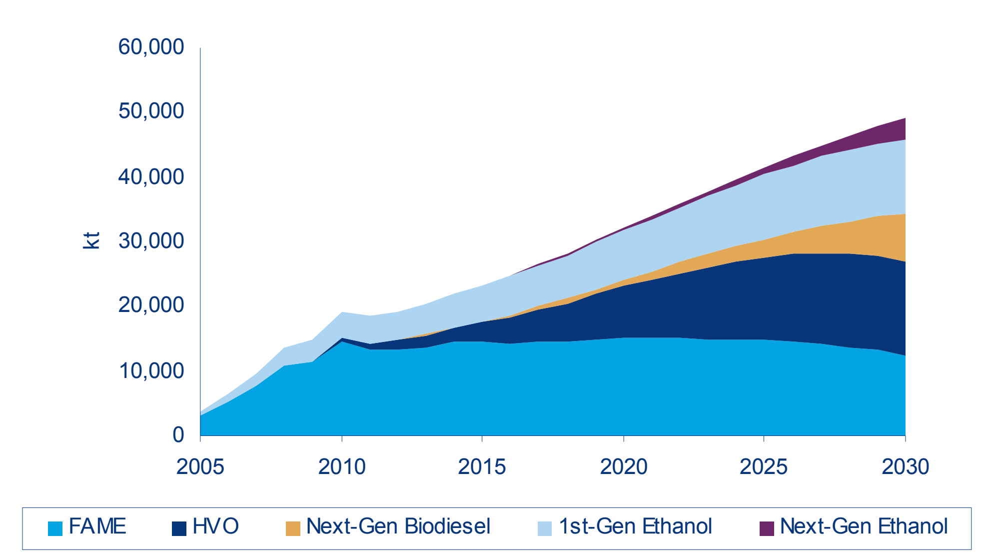
Scenario 3

Scenario 3 assumes that the Renewable Energy and Fuel Quality Directives are met with a high share of next generation biofuels and renewable electricity. This pattern extends through to 2030. Next generation biofuel production technologies reach commercialisation and make a significant contribution towards the EU's renewable transport fuels targets, especially by 2030.

The uptake of plug-in electric vehicles is higher in this scenario, with EVs representing 10% of market share in 2020 and 22% in 2030. Even, so the contribution from renewable electricity remains relatively low.

Figure 7 shows how the consumption of biofuels grows over time in Scenario 3. Total biodiesel demand grows from around 3 Mt in 2005 to 24 Mt by 2020 and 34 Mt by 2030. Of this total the majority is still produced using currently commercial technologies, but next-generation biodiesel consumption grows rapidly after 2020 to reach over 7 Mt by 2030. Fuel ethanol consumption rises from 0.8 Mt in 2005 to 8 Mt in 2020 and 15 Mt in 2030. Of this total, next-generation ethanol accounts for over 3 Mt by 2030.

Figure 7: Scenario 3 – Biofuel consumption, 2005 – 2030



Source: Wood Mackenzie

1.3 Implications for European Refining

This report has isolated and compared how three different biofuel scenarios impact three key criteria of the downstream sector:

- Carbon Emissions
- Refining Economics
- Crude Demand

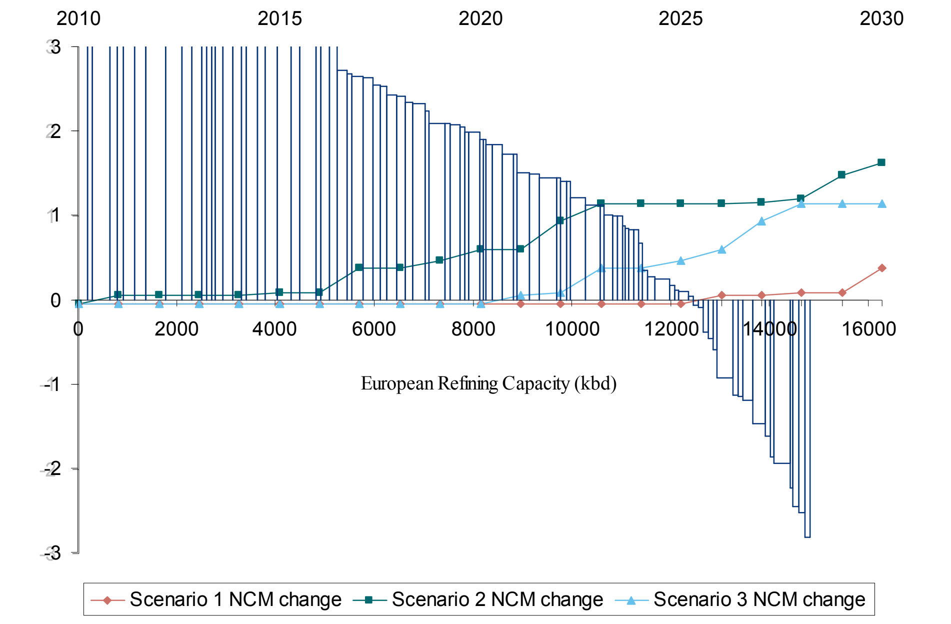
Scenario 1 which has the highest increase in the volumes of biodiesel in the diesel pool has been shown to have a limited affect on each of the downstream criteria identified above due to the large European diesel deficits. Only once the biodiesel volumes close these deficits sufficiently to narrow the European diesel import parity pricing environment will refining carbon emissions, refining economics and European crude demand be affected.

Scenario 2 which has the highest increase of biogasoline into the gasoline pool has the greatest effect on the downstream criteria due to the large European gasoline surplus. For every barrel of biogasoline which enters the gasoline pool European gasoline prices will move downwards and so reduce the net cash margin for European refiners. European refiners can be expected to respond to these price signals by reducing their supply. As refineries reduce their production their carbon emissions will fall in line with the reduction in crude demand.

Scenario 3 where an increase in biofuels is complemented by a large rise in electric vehicle registrations sits between the two other scenarios. A large rise in electric vehicle registrations takes time to filter through and start reducing gasoline demand due to the large existing gasoline vehicle parc. However a rise in electric vehicle registrations combined with the increasing biogasoline content in the gasoline pool results in gasoline prices moving downwards with similar impacts on the downstream criteria as seen in Scenario 2.

For every barrel of biogasoline entering the gasoline pool European gasoline prices are expected to move downwards and so reduce the net cash margin for European refiners. European refiners can be expected to respond to these price signals by reducing their supply. As refineries reduce their production their carbon emissions will fall in line with the reduction in crude demand. However for biodiesel, only once the biodiesel volumes close the large European diesel deficit sufficiently to narrow the European diesel import parity pricing environment will refining economics, carbon emissions and crude demand alter. Whilst electric vehicles are expected to reduce gasoline demand the time it takes for them to do so initially reduces the impact on European refineries.

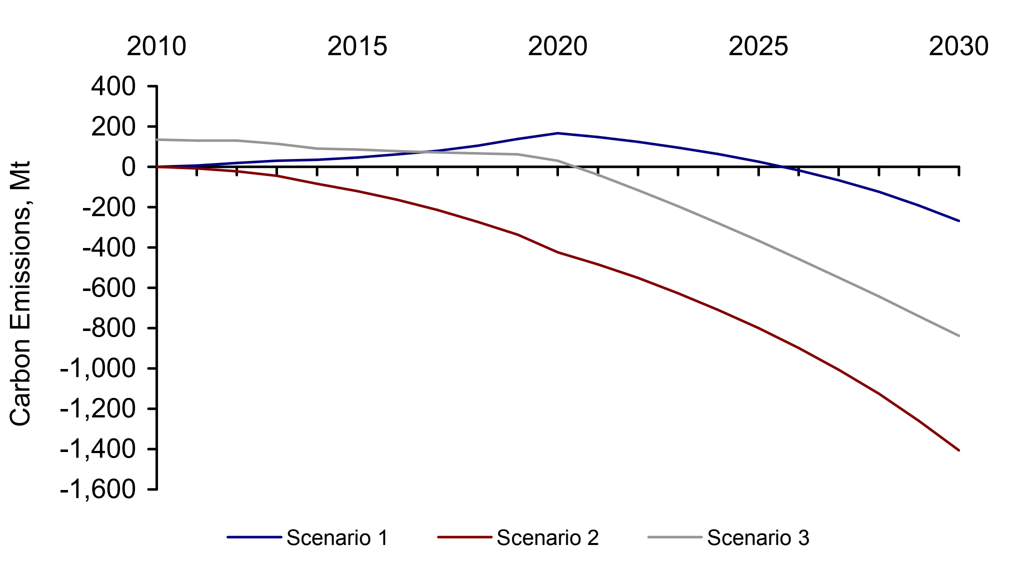
Figure 8: Scenario Comparison On NCM Changes

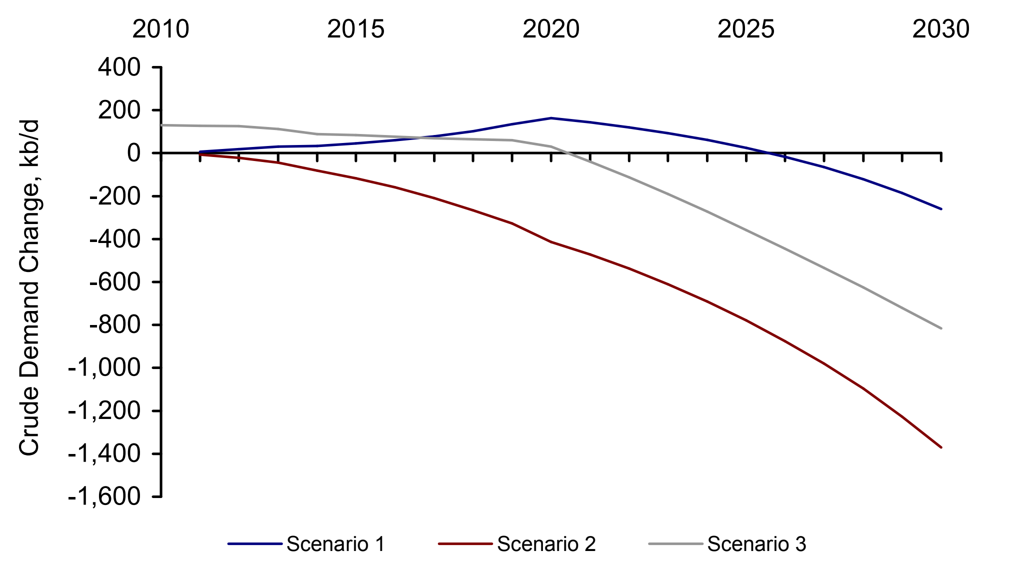


Source: Wood Mackenzie

N.B. Each Scenario line shows what will form the new point at which NCM's are equal to zero (2010-2030)

Figure 9: Scenario Comparison On Carbon Emission & Crude Demand Changes





Source: Wood Mackenzie

1.3.1 Security of Supply Considerations for the EU

It is apparent that increase in consumption of biodiesel, up to 2020 Target levels and beyond such as portrayed in our Scenario 1, are unlikely to have a particularly negative implication for EU security of oil supply in that this merely contributes to the regional deficit in diesel supply vs demand and reduces the need for imports of conventional diesel from regions such as the FSU, the Indian Ocean Rim and the Americas. To the extent that biodiesel originates from EU domestic sources there is an overall reduction in import dependency; to the extent that the biodiesel source is external there is still likely to be a benefit in respect of supply diversity. Increasing use of biodiesel is not expected to result in significant worsening of EU refinery margins during the next decade and thus in incremental closures.

On the other hand, in outcomes such as our Scenario 2 in which biofuel targets for 2020 and beyond are satisfied largely by first generation ethanol, the EU gasoline surplus is exacerbated and refinery runs must be adjusted downwards to avoid oversupply. In this case, security of EU oil supply is likely to be negatively effected. The ethanol would penetrate the market on the basis of its low price and this is more likely to arise from non EU sources. Bioethanol supply is not well diversified at present, with Brazil and a few other suppliers predominant. Thus there is a risk of a high degree of reliance on few sources of ethanol supply. With lower EU refining runs, imports of diesel and jet fuel would need to increase, further increasing dependence on export refiners. A significant number of refineries would be likely to close with progressive increases in ethanol penetration.

Parallel increases in penetration of both biodiesel and bioethanol with higher proportions of second generation supply, as exemplified by our Scenario 3, would still be likely to result in a greater reduction in EU security of oil supply than Scenario 1, with significant incremental refinery closures implied after 2020

2 Introduction

2.1 Wood Mackenzie and Ricardo's roles

The EU has agreed on achieving a 20% reduction in greenhouse gas emissions and an increase to 20% in the share of renewables in its energy mix by 2020. For the transport sector, a 10% target for the use of renewable energy including biofuels has also been agreed, tied to a set of sustainability criteria. A substantial increase in biofuels consumption, from the level of 2.6% of EU road transport fuels in 2007, is therefore required to meet the 10% EU target. This may have an impact on fuel specifications within, as well as outside, the EU.

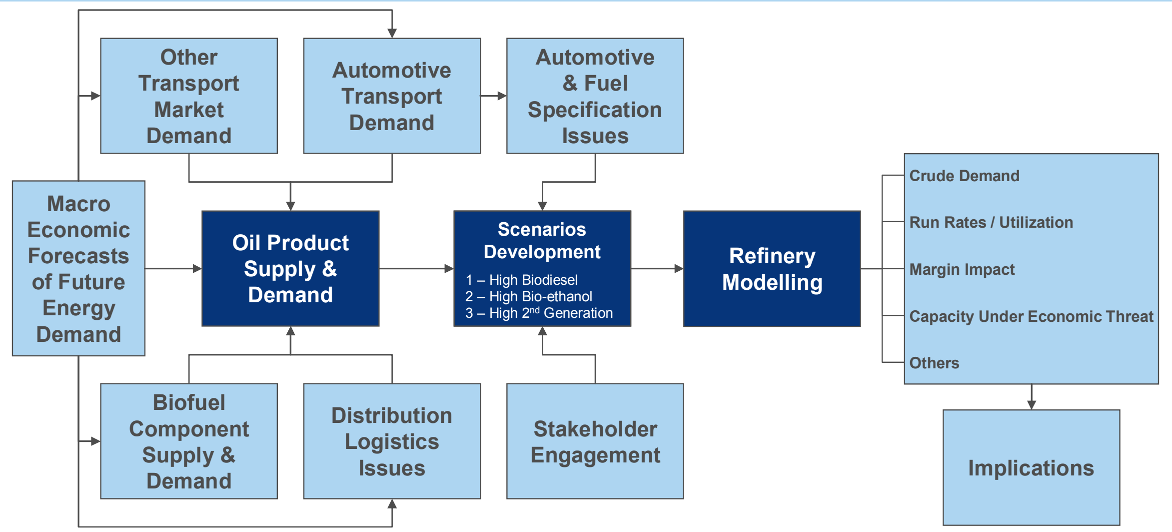
Increasing biofuel supply implies reduced oil refinery processing, potentially leading to reduction of existing refining capacity and affecting the entire oil industry supply chain both in the EU and third countries. The European Commission, DG TREN (now DG Energy) ('Client') has engaged Wood Mackenzie and Ricardo to consider the impact of biofuels on refining in the EU. This study will assess:

- The impact of increased consumption of biofuels on the oil refining process, refining economics and fuel specifications.
- Scenarios for supply of gasoline- and diesel-replacers and use of high and low blends with conventional oils.
- Prospects for biofuels in bunkering and aviation fuel markets.
- Impact on refinery energy use, refinery greenhouse gas emissions, impact on prices of oil, oil products and their differentials; for example, prospects for simultaneous biofuels expansion outside and within the EU affecting gasoline market balances in the Atlantic Basin with potentially global implications.
- Implications for security of oil supply in the EU and options for management of the downstream sector in case of disruption of biofuel supply.
- Experience in leading biofuel markets such as Brazil, the USA and parts of Asia, to be integrated into the above considerations.

The study is intended to be used by the European Commission to provide input to the EU-OPEC Energy Dialogue.

Wood Mackenzie and Ricardo have worked as partners to complete this study. Figure 10 below highlights the key consideration areas and their interrelationships that have been used during the study to establish implications for the European refining industry.

Figure 10: Key Considerations Informing Study Approach



Source: Wood Mackenzie

2.1.1 Use of this report

The intent of this report is to provide an independent outlook that assists the Client to understand the implications which the increased use of biofuels could have on the European refining sector. The key aspects addressed within this report include:

- Chapter 3 provides an understanding of the global refining environment
- Chapter 4 provides an overview of industry fundamentals in Europe to provide an understanding of the market influences on refining margins and the background as to why different biofuels are expected to have different impacts on refining
- Chapter 7 provides an assessment of Automotive and Specification issues which will need to be addressed for biofuel content to rise in the different transportation fuels
- Chapter 10 provides an overview of the distribution and logistical needs for biofuels
- Chapter 12 establishes three future scenarios for biofuels in the EU and assesses the potential implications of each on refiners

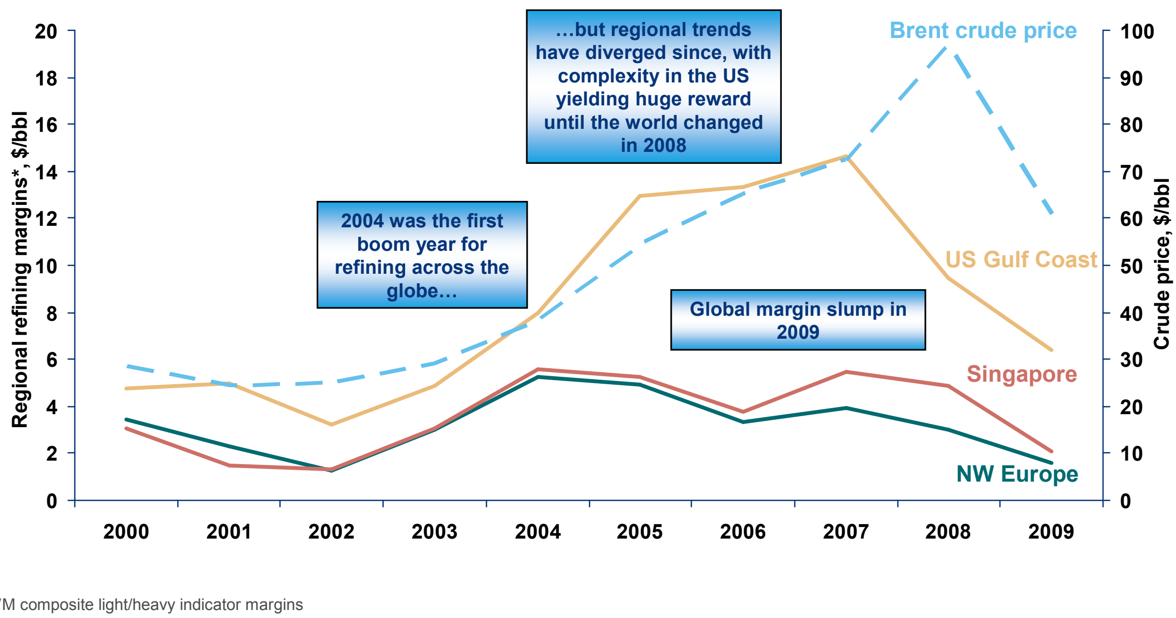
3 Global Refining Overview

3.1 Refining Environment

The refining industry experienced a sustained period of strong refining margins on a global basis until 2008. This refining margin performance reflected:

- Strong demand growth for oil products, particularly in Asia;
- Increasing crude oil price; and
- A series of separate events affecting the North American market, including the impact of hurricanes Rita and Katrina.

Figure 11: Regional Refining Margins



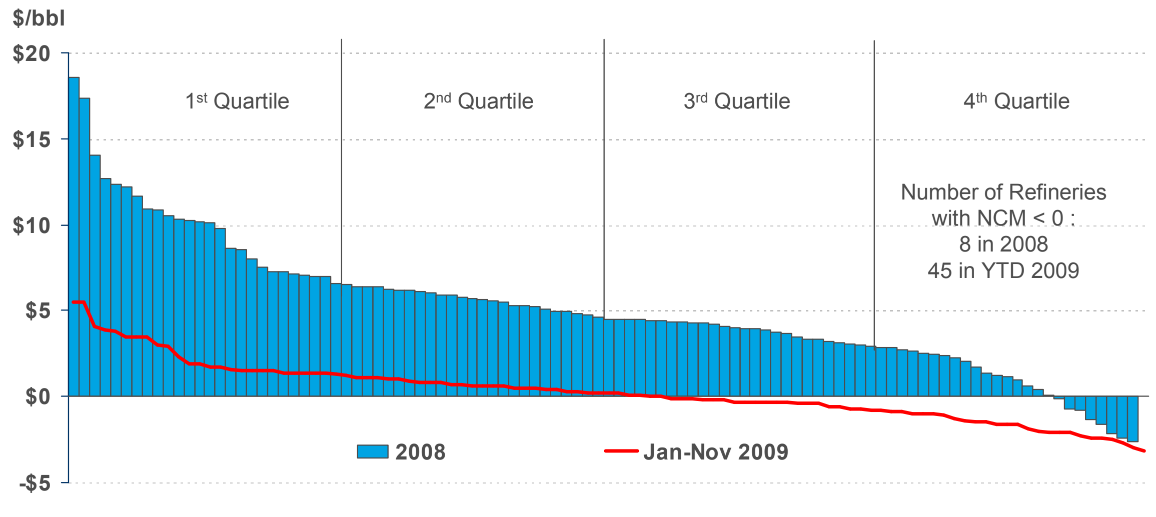
* WM composite light/heavy indicator margins

Source: Wood Mackenzie

Figure 11 presents the historic gross refining margins, aggregated to reflect the average refining configuration type in each key refining region.

In 2008 there was a dramatic change in fortunes for refiners with refining margins falling rapidly. As a result large numbers of refiners experienced negative cash margins in 2009 (see Figure 12).

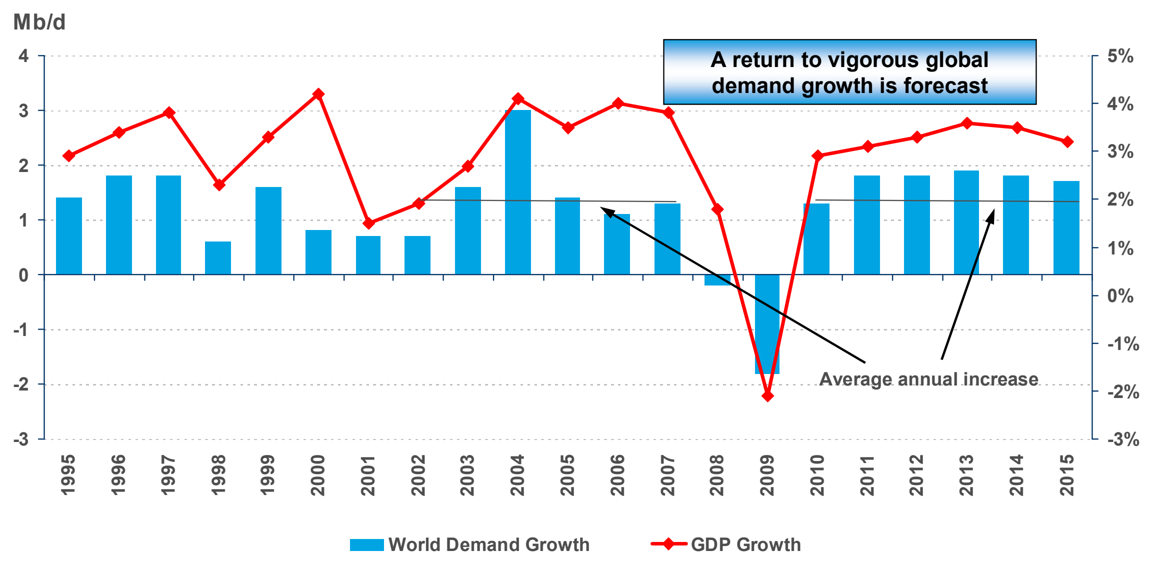
Figure 12: 2008-2009 Refinery Net Cash Margins



Source: Wood Mackenzie

This change was brought on by the global economic crisis. There is a strong correlation between GDP growth and demand for oil products. The global recession affected North America in 2008 with a large decline in the US economic output. North America accounted for 27% of global demand in 2008. The economic recession resulted in a large fall in demand for oil products. By 2009 the economic recession had spread to most regions of the world and world oil product demand fell by almost 2 Mb/d with declines occurring across all major products. Global oil product demand is expected to grow strongly as the global economy improves (see Figure 13).

Figure 13: World Oil Product Demand Growth and GDP

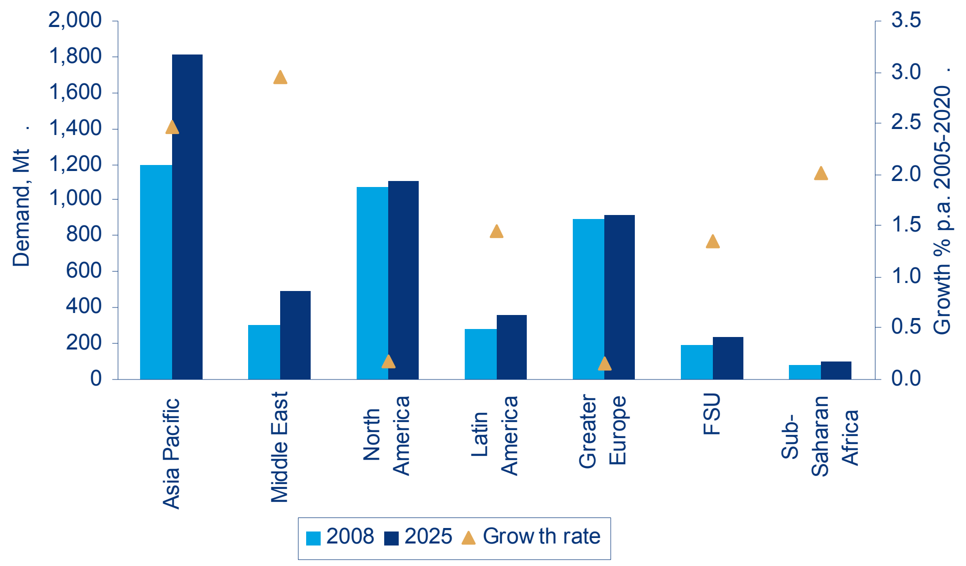


Source: Wood Mackenzie

Growth in demand for oil products is not expected to be even across all regions (see Figure 14). Demand growth will be dominated by the developing world. Asia Pacific and the Middle East account for over 70% of the forecast growth in demand between 2008 and 2015. In China, increasing personal incomes will result in higher car ownership which stands at a lowly 34 per thousand at the moment, but is growing rapidly. The rate of demand growth is expected to be strongest in the Middle-East, where rising oil prices should boost economic growth and their rapid pace of economic diversification - mainly through the development of large, energy-intensive industrial projects – should continue to underpin rapid oil demand growth.

Although there will be some growth in demand in Europe and North America in the short-term, as their economies recover, this growth is not expected to see them recover back to pre-crisis levels of oil demand. It is highly likely that demand in many developed countries, including the huge US market has now peaked. In Figure 14 North American demand growth from 2008 to 2025 is slightly misleading, as this is merely recovery from the sharp fall in demand between 2007 and 2008. In absolute terms, North American demand has peaked, as has demand in Western Europe and developed Asia. Increasingly stringent efficiency standards, such as the CAFE standard in the US (see Appendix A) and similar car fleet efficiency mandates in Europe, as well as continued increases in the use of gas and alternatives in stationary sectors will result in falling demand.

Figure 14: Regional Demand and Growth

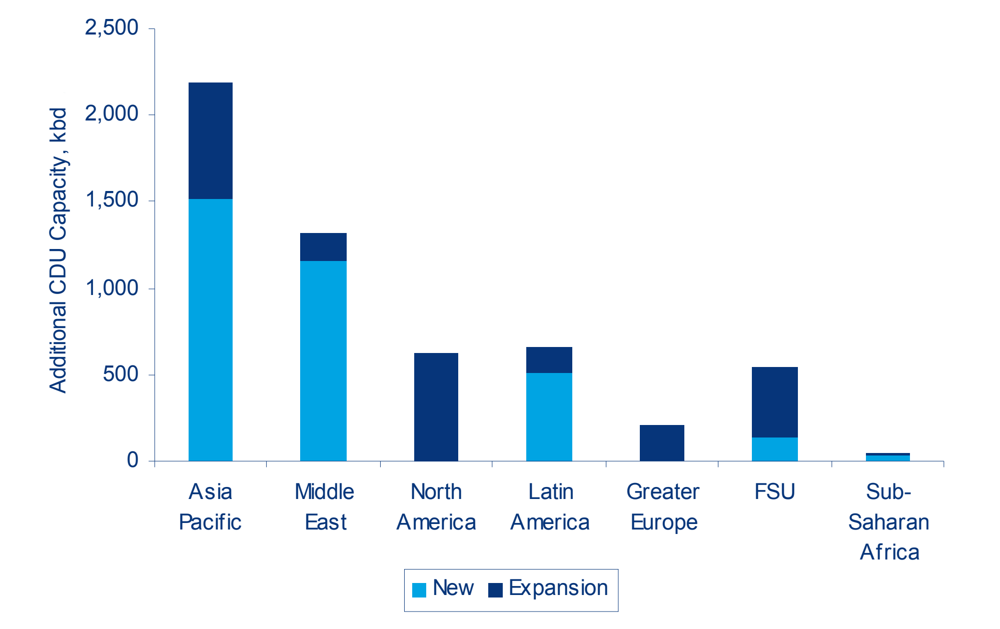


Source: Wood Mackenzie

There are 3.5 million barrels per day of crude distillation capacity coming onstream by the end of 2010. Most of this capacity, almost 2.4 million barrels per day, is in Asia. Between 2011 and 2015 a further 5.5 million barrels per day new capacity is expected to come on stream with half of this located in Asia (Figure 15). The capacity shown here represents only those projects which we rate as firm and which we think that they will go ahead.

In total, we believe that 9.0 million barrels per day of crude distillation capacity will be come on line by 2015. Nearly 3/4 of the additional refining capacity is being added in Asia and the Middle East. Most of this capacity will meet growing domestic demand but a there is a significant amount of export capacity within this which will be looking to supply the Atlantic Basin, or fast growing Asian markets.

Figure 15: Additional Refining Capacity (2011 – 2015)

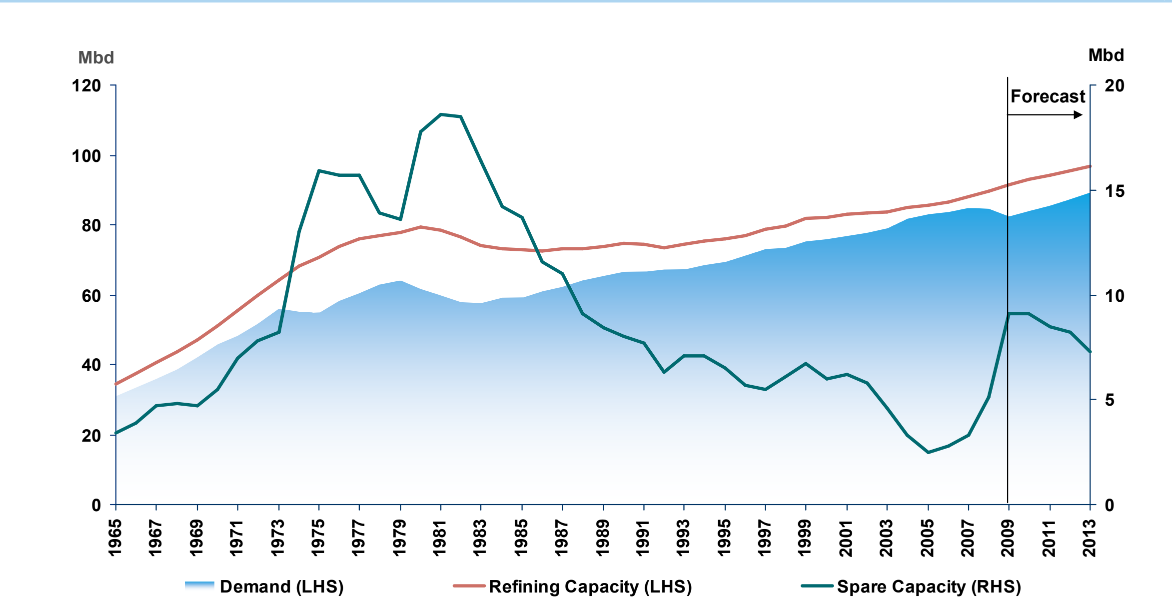


Source: Wood Mackenzie

We can also see that 1.0 million barrels per day of refining capacity is being added in North America and Greater Europe. With North American and Greater European demand falling the extra capacity is likely to increase problems of oversupply.

Large increases in world refining capacity at the same time as a drop in demand for oil products brought about by the economic recession has resulted in a weak refining environment (see Figure 16). Some refiners in mature markets are bowing to the inevitable and closing capacity in order to better align their portfolios with the new market reality.

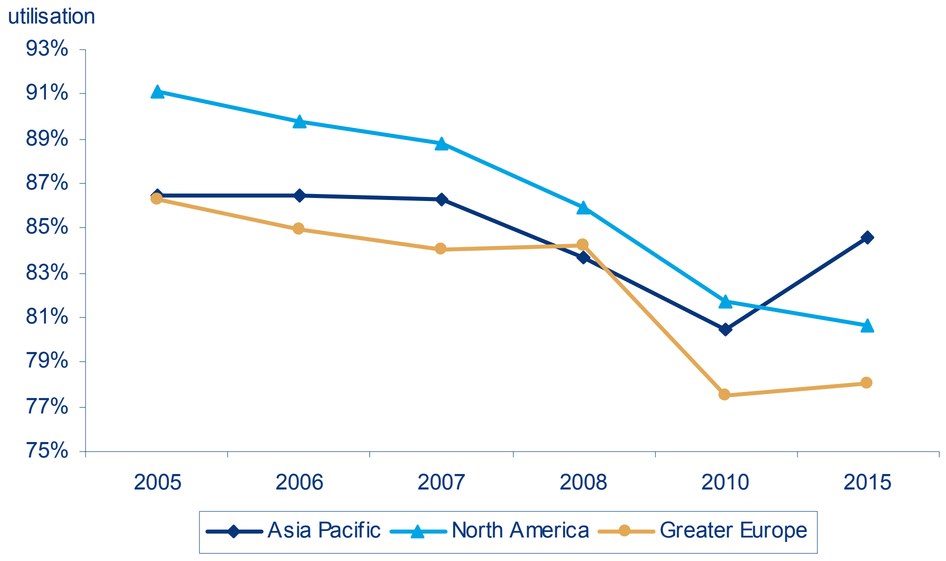
Figure 16: World Demand and World Refining Capacity



Source: Wood Mackenzie

There is presently over 3 Mb/d of refining capacity up for sale. We expect this number will rise as refineries in mature markets continue to consider their exit strategies. Eventually, some companies will inevitably be forced to re-asses their options and closure, or conversion to a terminal, if that refinery is coastal, will be among those options. However we do not believe that large numbers of refineries will close in the medium-term for the very simple fact that it is not an easy solution to close a refinery. Instead we expect to see continued reduction in average utilisation of refinery capacity (see Figure 17) and delays and cancellations to new refining projects and refinery expansion plans.

Figure 17: Regional Refinery Utilisation Rates



Source: Wood Mackenzie

3.2 Pricing Outlook

3.2.1 Crude Pricing Outlook

After the dramatic drop in oil prices during second half 2008, we saw a strong recovery in 2009. Thus far in 2010, the pattern has been surprisingly stable with prices trading in a range of $70 to $85 per barrel so far this year. OPEC continues to restrain its production, keeping it well below total capacity for the group, and the economy continues to show signs of recovery. These two trends stabilize prices and help keep them in the trading range.

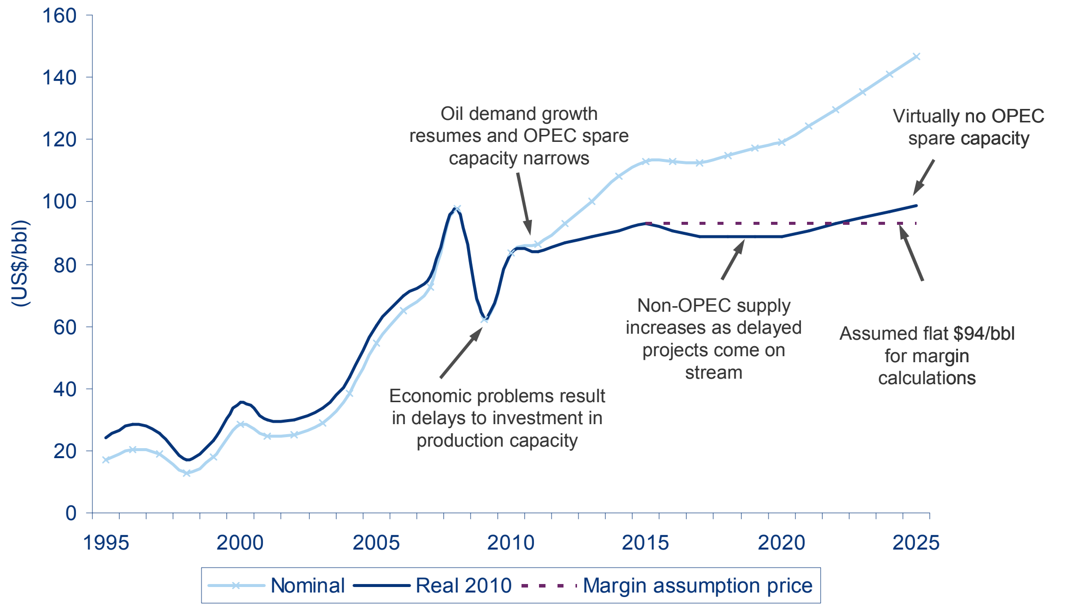
When the recovery shows signs of sputtering such as during the concerns about Greece's debt, then oil prices slide back down the range or when China's oil demand shows signs of strength, this can support prices toward the top end of the range. Production restraint by OPEC will continue to be needed in order to support prices within this range or near it. OPEC spare productive capacity remains relatively high at around 5.8 million b/d compared with 6.1 million b/d in 2009 on an annual average basis. With speculative interest in the oil market continuing in 2010, the day-to-day focus is more on the prospects for the world economy and US recovery. But, without the OPEC production restraint, there would be excess supply which would weigh on prices.

Prices are expected to rise from $81.80/bbl for physical Brent in 2010 to $92.90/bbl in 2015, in real terms, as spare capacity tightens due to strong demand growth. In 2011 OPEC spare productive capacity is expected to fall, averaging 4.9 million b/d for the year. By 2013, it averages 3.2 million b/d and in 2015, we expect only a 2.6 million b/d cushion.

From 2016 to 2020, prices are forecast to fall moderately and average $88.90/bbl in real terms due to increased non-OPEC supply. From 2016 to 2020 the delays in supply which we saw as a result of the tough conditions from the financial crisis are now causing an adjustment upward to the supply forecast from 2015 to 2020. Furthermore a cautious outlook for increased Iraqi production provides additional crude supply. The result is an increase in OPEC spare production capacity from 2016 to 2020, reaching 3.6 million b/d average for 2020.

Higher prices and increased efficiency are expected to lead to slower oil demand growth from 2020 to 2025, but supply growth is also much slower in this period. By 2025 OPEC spare productive capacity is expected to be low, at only 1.5 million b/d resulting in increased prices up to $99bbl in real terms and $146/bbl in nominal terms in 2025.

Figure 18: Crude Price Outlook



Source: Wood Mackenzie

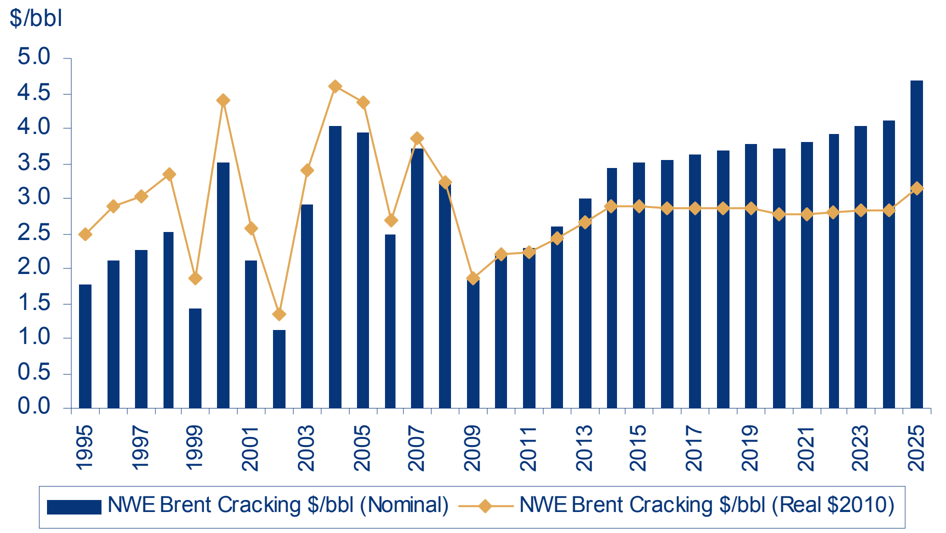
3.2.2 European Refining Margins

NWE margins remained depressed for much of the 1990s but improved dramatically in 2000 due to the introduction of new product specifications in both Europe and North America. Margins recovered from the unprecedented lows of 2002 during 2003 and rose strongly in 2004 due to strong global demand for refined products – in the US and China in particular, as detailed above.

In 2005 margins increased further due primarily to supply disruptions in the USGC following disruption from hurricanes Katrina and Rita and 2006 saw a correction from recent historical highs, with 2007 margins showing a marked improvement due to extensive refinery maintenance in both North America and Europe.

In 2008 margins were below 2007 levels due to the absence of one off effects and a return to market fundamentals in the Atlantic Basin. Margins weakened in 2009 due to reduced demand as a result of the global economic downturn and increased supply (both refining and renewables) which came on stream in Europe but more importantly the United States – which has been a significant source of support for European margins in recent years.

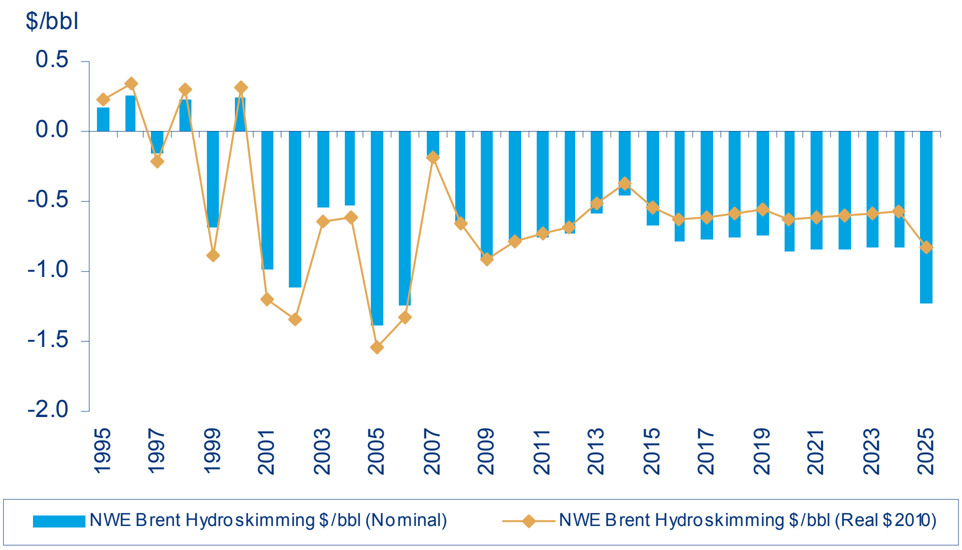
Figure 19: Gross NWE margin outlook for FCC cracking Brent



Source: Wood Mackenzie

Margins in 2010 have been supported by a cold winter that helped to draw down an overhang of middle distillate stocks. However, a surplus of refining capacity will keep refining margins at low levels for the next few years. In the medium term, we forecast a slight recovery due to strength in diesel crack spreads but even by 2015, refining margins are below the long-term average. This illustrates our view that the refining business in Europe will struggle for years to come and surplus global refining capacity will ensure that there will not be another 'golden age' for European refiners.

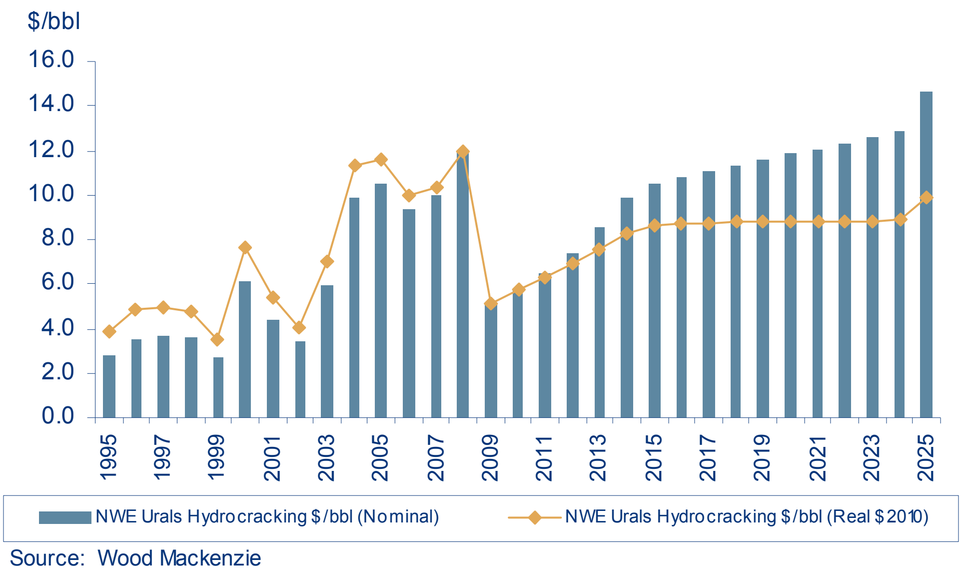
Figure 20: Gross NWE margin outlook for Hydroskimming Brent



Source: Wood Mackenzie

Forecast NWE hydroskimming margins remain deeply negative, as we do not expect hydroskimming of light crudes to be financially viable. In fact we believe that the marginal capacity will be catalytic cracking to at least 2015. Beyond 2015, there may be short periods when hydroskimming capacity may be profitable and other crudes may have better hydroskimming economics.

Figure 21: Gross NWE margin outlook for hydrocracking Urals



Source: Wood Mackenzie

The forecast NWE hydrocracking margin increases out to 2015 as the Urals discount widens and middle distillate crack spreads strengthen. However, the plateau from 2015 is significantly below the peak margins achieved between 2004 and 2008 as diesel crack spreads are not forecast to reach the extremes that occurred during that period.

3.3 European Refinery Capacity Closure Review

Our preferred approach for analysing competitive position considers the refinery Net Cash Margin (NCM). NCM captures most of the critical elements of a refinery's performance that define its competitive position in the short / medium term; it is defined as:

NCM ($/bbl) = Product Worth ($/bbl) - Cost of Crude ($/bbl) - Cash Operating Expenses ($/bbl)

NCM multiplied by annual crude throughput is effectively equivalent to EBITDA.

Wood Mackenzie's Refinery Evaluation Model provides a highly regarded industry tool for ranking net cash margins (i.e. earnings per unit capacity) for all refineries over 60 kb/d capacity. The constituent parts of the NCM, which represent the different activities having the greatest impact on the margin, are separately evaluated for each refinery to identify sources of sustainable competitive advantage:

- Cost of Crude Oil
- Crude Oil Delivery Costs
- Configuration/Value Added
- Efficiency
- Product Despatch Facilities
- Location/Environment

Crude oil costs and transportation - although the important feature is the delivered cost of crude to the refinery gate, for a full understanding it is important to differentiate between cost of crude at its source and the costs associated with transportation to the refinery. For example, a coastal and inland refinery may run the same crude slate but the cost of transportation of the crude could be much higher to the inland refinery depending on the supply route and associated crude delivery costs.

Configuration - in Europe and the US this is normally the most important parameter affecting net cash margin, however this is not the case in Asia Pacific. We model the output slate of each refinery in order to evaluate the added value due to refinery configuration. In this analysis we have assumed that the costs associated with a particular configuration are those which would be achieved by a top quartile cost performer. Deviations from top quartile cost performance are captured under efficiency.

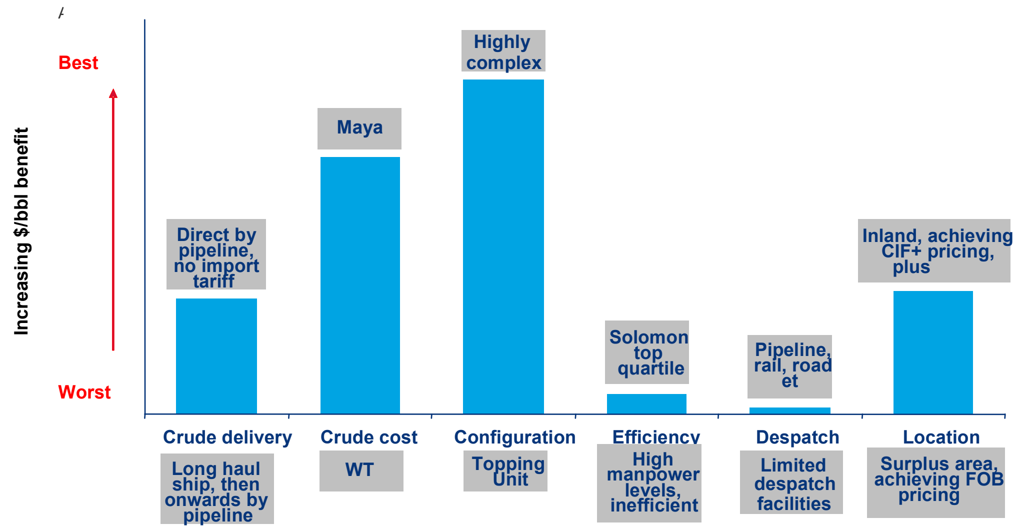
Efficiency - is defined as the deviation from the standards achieved by the best performer after allowing for the complexity of the refinery operation. It reflects how much of the potential added value is lost through less than ideal efficiency in a range of parameters such as cost performance, scale economies or the physical lay-out of the refinery.

Product dispatch facilities - refinery gate prices are influenced to an extent by product dispatch facilities. The ability to load product to various transport modes widens and lowers the cost of the refinery's supply envelope and hence impacts upon the netback price.

Location – this covers those factors not directly related to the assets themselves or the efficiency with which the assets are managed. Location covers aspects such as local pricing (e.g. inland versus coastal), remuneration levels, import tariffs, etc. Pricing is linked to each reference market.

In Figure 22 the deltas between the worst and best performing refineries for each of the constituent parts are illustrated for European refining in 2007.

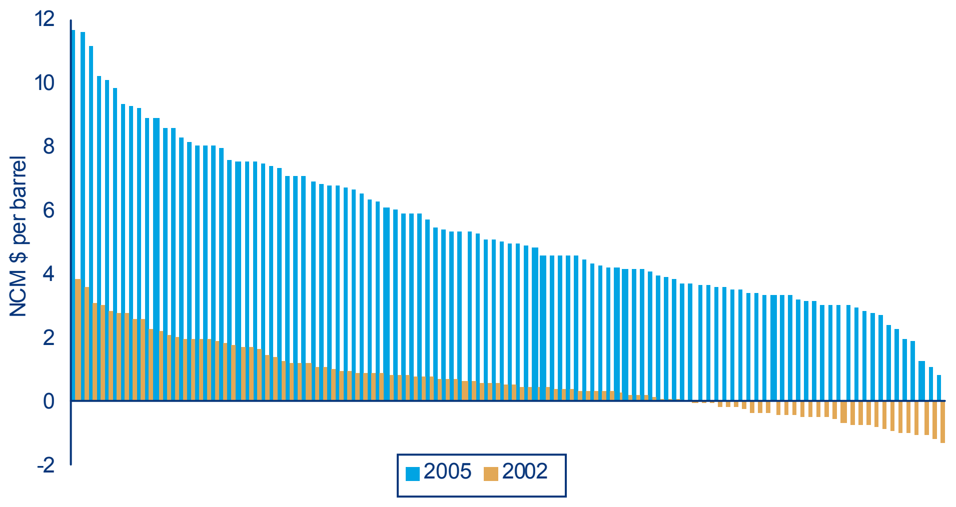
Figure 22: Components of European Net Cash Margin In 2007



Source: Wood Mackenzie

To illustrate the importance of competitive position, Figure 23 below shows the estimated Net Cash Margin for every conventional fuels refinery in Europe in. NCM's are shown for both 2005 (good economic environment for refining) and 2002 (poor economic environment). Each bar represents a single refinery, and they are ranked by NCM. Of the top fifteen performing refineries in 2002, twelve of these were also ranked in the top 15 in 2005. This analysis indicates that refineries with a top quartile NCM are likely to remain in the top quartile of performers whatever the prevailing market conditions. For this reason, top quartile performance is considered essential to provide comfort on cashflows.

Figure 23: European refining NCM in good and bad economic environments



Source: Wood Mackenzie

However the fact that a refinery has a negative NCM does not automatically mean that it will close. For example most of the refineries that had negative cash margins in 2002 are still operating today. Refinery closure decisions are based on more than the current economic reasons and would typically include an evaluation of:

- Asset strength – a refineries NCM relative to its peers
- High exit costs – the costs of cleaning up soil and groundwater contamination
- Owners attitude to the prospects for refining and their asset in particular
- Need for refinery upgrade/refit – Refineries requiring investments to satisfy new regulations will need to assess the viability of this
- Political context:
    - Security of supply concerns
    - Product exports support the balance of payments
    - Provides a local source of feedstock for the petrochemical sector
    - Higher value speciality products (lubricants, solvents, petroleum coke) that are not included in the “main fuels” analysis
    - Employment created by refineries
    - Sentiment

However the current low margin refining margin environment combined with a long term declining demand for oil products in many parts of Europe means that several refiners are evaluating their refining assets and large numbers have been put up for sale by their owners, see Figure 24.

Figure 24: European refineries for sale, idled and investing

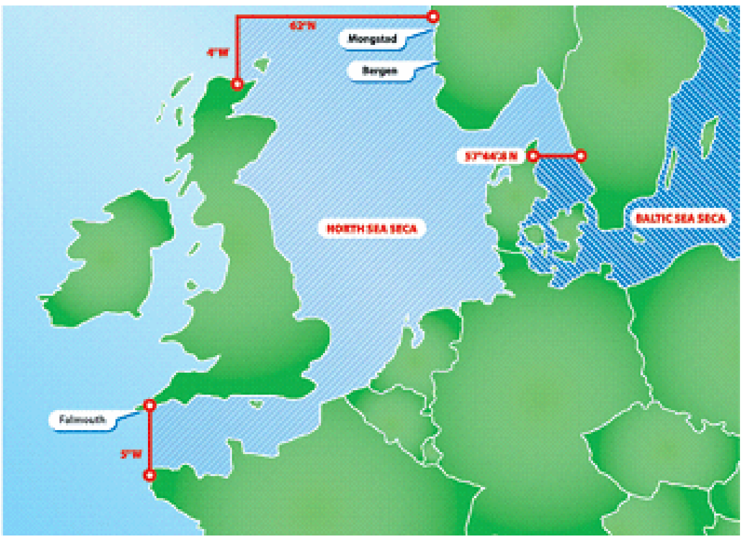
Refinery	Owner	Country	Capacity (kb/d)	Status
Antwerp Bit.	Petroplus	Belgium	20	Asset Sale
BRC	Petroplus	Belgium	105	Shutdown / Idle
Dunkirk	Total	France	135	Shutdown / Idle
Gonfreville	Total	France	100	Shutdown / Idle
Reichstett	Petroplus	France	81	Asset Sale
Berre l'Etang	Lyondell	France	100	Asset Sale
Harburg	Shell	Germany	104	Asset Sale
Heide	Shell	Germany	86	Asset Sale
Corinth	Motor Oil	Greece	60	CDU Investment
Thessaloniki	Hellenic	Greece	20	CDU Investment
Rome	Total	Italy	88	Asset Sale
Gdansk	Grupa Lotus	Poland	90	CDU Investment
Arpechim	OMV	Romania	66	Asset Sale
Puertollano	Repsol	Spain	60	Shutdown / Idle
Cartagena	Repsol	Spain	100	Shutdown / Idle
Puertollano	Repsol	Spain	28	CDU Investment
La Rabida	Repsol	Spain	90	CDU Investment
Gothenburg	Shell	Sweden	83	Asset Sale
Pembroke	CVX	UK	209	Asset Sale
Teeside	Petroplus	UK	111	Shutdown / Idle / Asset Sale
Stanlow	Shell	UK	282	Asset Sale
Lindsey	Total	UK	218	Asset Sale

Source: Wood Mackenzie

3.4 Bunker fuel switch from heavy fuel oil to gasoil

Sulphur emission control areas (SECA's) have been introduced in the Baltic Sea (from August 2006), the North Sea and English Channel (both from August 2007), and currently have a 1.5% limit on marine fuels used within them. Within the SECA's the shipping community is required to burn 1.0 wt% by mid-2010 and 0.1 wt% by 2015, versus 1.5 wt% sulphur as presently occurs. The change to 0.1% sulphur bunker fuel will require a switch to gasoil, away from fuel oil. By 2015, the switch away from fuel oil to gasoil in the bunker market is expected to be around 12Mt.

Figure 25: The North Sea and Baltic Sea SECAs



Source: Wood Mackenzie

The IMO has approved new amendments on bunker sulphur, which require the global shipping community to reduce from current limits of 4.5 wt% sulphur to 3.5 wt% sulphur by 2012 and then 0.5 wt% by 2020. In our opinion, the specification of 0.5% sulphur by 2020 is unachievable. There is a likely prospect of deferral of the 0.5% sulphur specification, through activation of a 'review' clause within the agreement in 2018. Alternatively it could be satisfied through ship-based scrubbers (exhaust gas cleaning system) which could allow higher sulphur fuel oil to continue to be used beyond 2020 - development of a approval standard for such systems is ongoing at the IMO. There also exists the possibility of using LNG as an alternative fuel source.

There are wide ranging concerns on abatement technology based on seawater scrubbing which could curtail their use:

- Annex VI states that port states may prohibit discharge of scrubber effluent overboard in ports within ECA's unless it can be documented that the effluent complies with criteria set by that port state. A mitigating measure is installation of filtration/treatment systems
- It has been indicated that conventional scrubber technology may be struggling to meet the emission criteria at high exhaust gas discharge flows
- Indications are there is a risk of blue-sheen originating from the scrubber overboard discharge. Although, not necessarily constituting an environmental hazard, the risk of such occurrences is to some operators unacceptable
- There are space considerations in the engine room and more specifically the funnel. Indications are the more advanced scrubber types can replace standard silencers, the associated piping systems may represent a challenge
- Pressure drop in scrubbers has also been indicated as a limitation, particular in way of main engines uptakes
- Tanker owners have had mixed experiences with corrosion of inert gas scrubbers and associated piping systems
- There are restrictions on allowing seawater scrubbing within ports due to fears about potential pollution and unless further research conclusively proves otherwise, we do not expect these restrictions to be lifted
- The EU has been reluctant to accept scrubbers. However, in the latest proposed amendments to the EU directive, they have opened for "trials of ship emission abatement technologies". Based on such trials they have indicated that they may accept abatement technology as an equivalent to low sulphur fuel. In such a case, they are also likely to develop criteria for resulting waste streams in their ports

The number of development projects related to new scrubber technology appears to be limited. However, some projects in the prototype phase show promising results in terms of overcoming the concerns highlighted above. Another factor which may affect scrubbing technology is that exhaust gas cleaning alternatives will reduce the emission of particulate matter (PM) which is considered to be the next focal point of IMO.

However seawater scrubbing does offer potential benefits. According to a report1 submitted to European Commission, all existing and new vessels are capable of installing equipment for seawater scrubbing. We expect that once the measure is approved by the EC, it will be widely adopted in the industry. Whilst various technology providers state seawater scrubbing can remove SO2 by approximately 98% the independent Cofala (J) et al. report suggests this number is likely to be closer to 75%% due to practical limitations such as the massive amounts of water required. This is not enough to meet the 0.1% S requirement for SECA areas by 2015.

Seawater scrubbing appears almost 50% cheaper than switching to low sulphur fuel[2]. If improved technologies in future enable seawater scrubbing to be equivalent to using 0.1% MD, then it is likely to be almost 5 times cheaper then fuel switching. This assumes that there is no increase in the price of 0.1% MD as a result of increased demand – in reality the differential is likely to be much higher due to higher demand.

LNG provides an alternative fuel source to meet the IMO legislation. There are two main marine engine LNG concepts. The dual fuel engine, which runs on both LNG and conventional fuel, is a flexible solution when the availability of LNG

[1] Cofala (J) et al. (2007) Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive", http://ec.europa.eu/environment/air/pdf/06107_final.pdf, Date accessed 13/9/10.

[2] Cofala (J) et al. (2007) Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive", http://ec.europa.eu/environment/air/pdf/06107_final.pdf, Date accessed 13/9/10.

fuel is uncertain. The lean burn mono fuel engine gives a simpler installation onboard and is a good choice when operating in regions with a developed grid of LNG bunkering stations or for ferry routes with dedicated ferries. In theory all commercial ships could eventually be fuelled by LNG. Initially however it is best suited to vessels serving regular sailing patterns, allowing for repeated bunkering at a limited number of locations. Norway provides one of the few examples of where LNG fuelled vessels are being used and whilst vessel numbers are low and vessel sizes are relatively small, there are further vessels on order.

LNG offers the lowest levels of emissions compared to low sulphur fuel and scrubber technology

- SOx and particulate emissions are reduced by almost 100%
- NOx emissions are reduced by 85-90%
- CO2 emissions are reduced by 20-25%

LNG faces a large infrastructure challenge if it is to become anything other than a niche shipping fuel. For LNG to be become more widely adopted there needs to be a LNG fuel supply infrastructure and a large fleet of LNG fuelled vessels. These two are mutually interdependent since ship-owners will not invest in LNG fuelled vessels until a LNG fuel supply infrastructure is in place and LNG fuel suppliers will not invest in infrastructure until there is a large fleet of LNG fuelled vessels.

A large fleet of LNG fuelled vessels is unlikely to appear imminently. The costs of converting an existing ship to be fuelled by LNG make it commercially unlikely. Therefore the fleet will only be slowly converted to LNG as old ships are replaced by new ship builds. However, even if all future new builds adopted LNG powered propulsion it would take 20-40 years for the entire fleet to be running on LNG.

We expect seawater scrubbing to be approved – at least for use on high seas – and most ship owners are likely to adopt it given the substantially lower costs as compared to fuel switching. This is sufficient for effectively bringing down sulphur content from 2.7% to close to 0.5% but not to 0.1%. We expect high sulphur fuel oil to continue to be widely used post-2020, regardless of the approval and adoption of sea water scrubber technologies.

4 Regional Supply & Demand Of Oil Products

The following section provides a view of the future supply-demand position by major product category on an inter-regional basis for Europe and for the other global regions, showing the contributions of biofuels and other non refinery supply in the balances. The focus of this report is Europe and we have included a detailed view of the North West Europe, Mediterranean Europe and Central & Eastern Europe in the main body of the report. Developments in other regions of the world have important implications for Europe, particularly on trade, and a more condensed review of other regions supply and demand for oil products is included in the Regional Review Of Supply and Demand for Oil Products (Appendix A). After summarising the regional supply and demand position the section then provides a view of oil product trade flows by main product category.

4.1 North West Europe

In this section we will review the North West Europe regional market which is in turn made up of Austria, Belgium, Denmark, Finland, Northern France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Sweden, Switzerland, United Kingdom (see Figure 26).

Figure 26: North West Europe Region

4.1.1 Demand

North West Europe (NWE) is a mature market in which oil demand is now in long-term decline; we expect that oil demand in the region peaked in 2006 at 445 Mt (9.45 Mb/d). By 2008 demand had already fallen to 439 Mt (9.25 Mb/d), but the sharp contraction in GDP during 2009 pushed demand down by more than 5% to 416 Mt (8.78 Mb/d), Although the economic outlook remains highly uncertain, at the moment the region looks to be on track for recovery, and with GDP growth in 2010 assumed to average just under 1.5%, oil demand is forecast to stabilise. GDP growth should gradually recover to average around 2.5% per annum by 2013/2014, before gradually weakening over the longer term to 2025 - between 2015-2025 GDP growth averages a little over 1.5 % per annum. On this basis oil demand is projected to recover to 431 Mt (9.10 Mb/d) in 2015, but then enter a long-term structural decline. By 2030 demand is projected to be just 396 Mt (8.3 Mb/d).

The outlook for oil demand in NWE is constrained by the combination of weak demographics (low growth and an aging population), relatively weak GDP growth, a maturing economic structure and approaching saturation levels in key areas like vehicle ownership. Governments throughout the region have also traditionally been keen to promote improved levels of energy efficiency. In recent years these trends have become greatly reinforced:

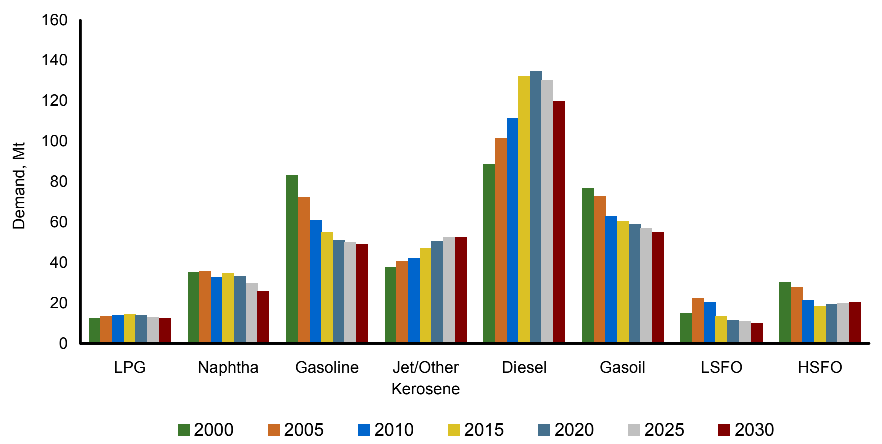
- High oil prices have reinforced government concerns over import dependency and oil cost, leading them to seek ways of reducing, or at least limiting, oil consumption

- Efforts to reduce oil consumption have also received a boost from the growing commitment throughout Europe to reduce carbon emissions, even to the extent of an active promotion of electric vehicle technology

And now the region has to deal with the fall out from the credit crunch and recession. Across the region governments are facing up to the need to limit and reduce budgetary deficits, which at a total European level is now around 6% of GDP. Several painful years of austerity now lie ahead as countries work to return to a more balanced and sustainable budgetary position, involving higher taxes for workers and consumers, reduced government investment and expenditure and higher unemployment. The net effect will be lower levels of expenditure by governments, corporations and consumers, which inevitably will have some knock-on effect on oil demand.

Against this backdrop it is hard to see demand staging anything but a brief recovery from the current low recession-led level of demand, before structural decline sets in once more. By 2025 demand is projected to be around the same as it was in 2009, but over 5% lower than the peak in 2006.

Figure 27: NWE Demand by Product, 2000-2030



Source: Wood Mackenzie

Indeed the key question seems to have become how steep the decline in demand could be. Apart from the economic outlook itself, there are several key parameters that will help define the pace of decline, the main assumptions are:

- **Passenger car efficiency** - vehicle manufacturers are expected to meet the requirement of a fleet average CO_2 emission target of 120g/km for new cars by 2015. However, although we expect conventional engine fuel efficiency to improve by around 10% between 2015 and 2025, we do not expect the target of 95g/km by 2020 to be achieved, as it would require fairly widespread take-up of electric vehicle technology and we cannot see battery technology being sufficiently advanced in this timeframe to allow for mass take-up by consumers

- **Carbon emissions in the aviation sector** - no specific impact of the EU cap-and-trade scheme on jet fuel demand trends is assumed, beyond a standard assumption of a steady improvement in fuel efficiency

- **Fuel Taxation** - we have assumed that taxes will continue to rise at the same rate as in recent years. Across the region as a whole taxes have increased at an average 2% per annum and this is assumed to continue. It is not assumed that governments will take direct action to harmonise diesel and gasoline taxes.

No change in the geographical spread of demand is expected, with Germany, the UK, Northern France, the Netherlands and Belgium continuing to dominate demand for oil products in NWE. At the product level, only kerosene (largely jet fuel) and diesel show any signs of growth, although in the case of diesel, this too is likely to be entering decline in the long-term.

Demand Trends By Product

LPG

LPG is used as an alternative petrochemical feedstock to naphtha, as a residential fuel, as an industrial fuel and as an automotive fuel. Since 2000 demand in industry has remained largely unchanged while demand has grown slightly in petrochemicals and the automotive sector. Residential demand has fallen steadily, as LPG has lost market share to gas and electricity.

Demand in the period to 2015 should hold up relatively well and remain close to current levels through to 2020, after which it declines through to 2030. Some small growth in automotive uses, together with continuing use in the petrochemical sector offsets further declines in residential demand and a weaker outlook in industry.

Naphtha

Naphtha is almost entirely used as a petrochemical feedstock. Future demand will depend on the general economic picture and increasingly the extent to which petrochemical rising production in the Middle East will compete with domestic production. Some growth to 2015 is expected as the economy recovers, but in the long-term, demand is forecast to fall steadily as competition from low-cost Middle East producers increases.

Gasoline

Despite a rise in the number of passenger cars, gasoline demand is forecast to continue to fall due to rising vehicle efficiency, lower vehicle distances travelled and an increase in the number of diesel cars in the passenger car fleet.

The NWE car parc has been growing at 1.5% per annum since 2000. Car numbers are forecast to continue to increase, although at an ever-slowing rate annually. Average car ownership per thousand capita in North West Europe is currently around 518 per thousand and is not expected to rise substantially by 2030.

There is also an increase in the level of dieselisation of the private car fleet. The proportion of diesel cars is forecast to increase to a peak of around 40% of the car parc by 2015, before progressively declining in the face of increasingly stringent diesel emissions controls, a gradual erosion of the pump price advantage of diesel over gasoline and the wider availability of new generation more fuel-efficient gasoline-engine cars. Alternative-fuelled cars remain negligible in comparison to the total car parc.

Jet/Kerosene

The long-term growth trend in jet/kerosene demand has been strong across NWE, reflecting the growth in air travel, in particular helped by the growing success of budget airlines. The growth story was interrupted between 2000 and 2005 as a result of 9/11 in 2001, the second Gulf war and the outbreak of SARS in early 2003, but these were transitory factors and growth picked up again between 2004 and 2006. More recently the trend has weakened significantly, in part due to the slowdown in the expansion of the budget airline industry, and the recession in 2009 saw demand drop by 5% compared to 2008.

As the regional economy revives so too will the volume of air traffic also pick up again. But several factors are expected to prevent jet fuel demand growth hitting the sort of levels seen in the past:

- The maturity of the budget airline business model in Europe
- Following many years of poor profitability, airlines are expected to be more focused on building and optimising load factors
- Fuel efficiency will improve steadily, especially now that the industry is being pushed to reduce carbon emissions
- A steady expansion in terminal and runway capacity can no longer be taken for granted, as the recent decisions to abandon expansion plans in the UK demonstrate – environmental pressures in this regard are likely to build

- Europe faces growing competition from the development of the Arab Gulf hub, based around Dubai and Abu Dhabi – potentially taking traffic away from the trans-Atlantic routes starting in Europe

Demand growth is projected through to 2030, but the rate of growth weakens considerably over time.

Aside from jet fuel, there is a small element of demand for standard grade kerosene used for heating purposes, mostly in the residential sector in the UK and Ireland. Demand is unlikely to change much from this level unless gas grids were to be expanded into less densely populated rural areas, which is unlikely.

Diesel/ Gas Oil

Diesel is the dominant road transport fuel in NWE, accounting for 64% of total fuel use in 2009 on a mass basis. In 2005 diesel represented 58% of the market, so diesel has been increasing its market share at over 1% each year.

In the forecast, road diesel demand is projected to increase through to 2015, but then to decline in the long-term. In the key commercial vehicle sector demand follows this trend - growing in response to a recovery in GDP and industrial production in the medium-term, but then starting to decline in the longer-term as energy efficiency improvements become more pronounced. It is clear that the EC is now gearing up to impose similar carbon reduction targets on commercial vehicles, as it has done on passenger vehicles, although as yet there are no clear mandates.

In the passenger sector, diesel demand grows steadily through the forecast period,. Growth is fastest in the period to 2015, a period in which the pace of dieselisation is still strong. The split between diesel and gasoline in new car registrations was around 50:50 in 2008, although it is clear that the dieselisation process has been and continues to slow – during 2009 it even reversed due to the impact of the various scrappage schemes around Europe. We expect diesel's share of the new car market to grow slightly in the short-term, but then to start to fall. Part of this fall is due to the growing role of electric vehicles, but we also expect a marginal recovery in consumer preference for gasoline for a number of reasons: -

- A shift in consumer preference towards vehicles with smaller capacities, likely on the back of government taxation policies, should favour gasoline over diesel

- Although the fuel efficiency of both diesel and gasoline engines will improve steadily, the absolute reduction in the case of gasoline is likely to be greater. Although diesel will always remain more fuel efficient, a narrowing of the gap in absolute efficiency may bring drivers back to gasoline

- Diesel prices are expected to rise more quickly than gasoline although not enough to eliminate the price differential at the pump in many countries unless governments change tax policy radically – which seems unlikely given the power of the commercial transport lobby in Europe and also the automotive and refining industries.

The impact of these developments will only be marginal and in the end, the automotive industry in Europe remains firmly focussed on diesel. However the forecast does reflect a small shift back towards gasoline although this is nowhere near enough to do anything more than marginally offset the structural decline in gasoline demand.

Demand for gasoil and off-road diesel is projected to increase through to 2015 and then fall back over the following ten years. The main developments are as follows:

- There are relatively large residential heating oil markets in Belgium, Northern France and, most of all, Germany, together accounting for over 80% of total residential/tertiary gasoil demand in NWE. On a year to year basis demand here fluctuates according to temperatures and consumer purchasing behaviour. But at a structural level heating oil has steadily been losing market share to natural gas. However it is becoming increasingly difficult for utilities to keep on expanding grids in a cost effective fashion as the areas left unconnected are increasingly those with difficult terrain and/or low population density. Some further decline in heating oil demand is expected, but it is likely to be marginal and have as much to do with improving fuel efficiency than competition with gas

- Gas also provides stiff competition in the commercial sector and gasoil demand here too is forecast to fall further

- In agriculture there are no real alternatives to diesel and gasoil in most uses, but demand will fall steadily as fuel efficiency improves

- Demand in industry is likely to remain relatively unchanged since again uses here tend to be in stand alone applications and in mechanical or driving applications for which there are no real alternatives

- Demand in inland waterways rises strongly due to efforts to find alternative ways of transporting freight

- There is a significant increase in use of gasoil in marine bunkers, stemming for the introduction of new IMO sulphur specifications for fuels in 2015

Thus the increasing use of distillates as marine bunkers largely offsets structural weakness in inland demand, where consumption is declining due to improving fuel efficiency and competition from other fuels.

New fuel specifications will have a major impact on the distribution of non-road demand between diesel and gasoil. The two relevant pieces of legislation are:

- EU Directive 2009/30/EC, which stipulates that from January 2011 all gas oil for use in non-road mobile machinery (currently 1000ppm suplhur) must contain no more than 10ppm sulphur - the same as current road diesel. Use by railways must switch to the lower specification no later than January 2012

- New IMO rules that limit the sulphur content of marine fuels consumed in SECAs to 1% from 2010 and 0.1% from 2015

In 2009 only around 8% of diesel/gasoil deliveries to non-road sectors were of diesel quality. Agriculture uses accounted for about 60% of this volume with industry making up a further 30%. Diesel demand in non-road sectors is forecast to increase through to 2015, as agricultural and industrial machinery switches to use diesel quality fuel. By 2030 this volume is projected to have risen slightly. By 2030 we estimate that diesel will account for 20-25% of non-road demand and some two-thirds of total diesel/gasoil demand.

In marine bunkers there is a sharp increase in gasoil demand once the new suplhur specifications become enforced in the SECAs, which include the Baltics, North Sea and English Channel. It is difficult to be precise about the volumes that may be involved, but we estimate that after 2015 about 11 Mt (225 kb/d) of low sulphur fuel oil demand switches to gasoil.

Fuel Oil

For the last fifteen years demand for fuel oil in NWE has been relatively static, annual demand fluctuating in the range 45-50 Mt (830-920 kb/d). In general during this period a structural decline in inland demand in industry and power generation has been offset by rising demand for marine bunkers. However recession in 2009 had a significant impact, reducing demand in both the inland markets and bunkers by a combined total of 13%.

In inland markets fuel oil has consistently lost market share to other fuels, especially since tighter sulphur emission standards have been introduced. Although to some extent it holds its own against competition from gas and coal when oil prices were low, indeed even taking back market share to a limited extent when gas prices were very strong around 2004/5. More recently a combination of high crude prices but low gas prices has left fuel oil highly uncompetitive, which helps explain some of the drop in demand seen in the last two years. Further market share will be lost in the coming years due to the combination of tightening environmental standards and high oil prices.

Today the fuel oil market in NWE is essentially a marine bunker market – total bunker sales in 2009 were double the level of inland demand and represented two-thirds of total NWE fuel oil demand. As the recovery in global GDP and trade gathers pace, so demand for bunkers will also increase. However the new IMO fuel specifications that come into force in 2015 will see 11-12 Mt of fuel oil demand switch into distillates and so despite higher marine bunker demand, fuel oil bunkers will fall through to 2015. After 2015, bunker demand is expected to grow again through to 2030.

Historically most bunker demand in NWE has been high sulphur (>1% sulphur). However, in the environmentally sensitive Scandinavian countries bordering the Baltic Sea, a market in low sulphur bunker fuel for ferries has developed over the past ten years. The IMO (International Maritime Organisation) and EU measures introduced a 1.5% sulphur limit on bunker fuel oil used in the Baltic Sea (designated as a SOx Emission Control Area or SECA) and in ferries on regular services between EU ports from May 2006. Subsequently, the creation of a second SECA made up of the North Sea and English Channel in November 2007 extended the use of 1.5% sulphur bunker fuel oil in NWE. In April 2008, the IMO published a number of proposals regarding the future sulphur content of bunker fuel oil. Under these proposals, the sulphur content of fuel oil used in the European SECAs is reduced to 1% in 2010. Thus, whereas LSFO accounted for around 30% of total bunker demand in 2005, in 2010 this will have risen to almost 45%. However after the further tightening in SECA specifications to a 0.1% sulphur limit from 2015, we assume that some LSFO volumes would be replaced gasoil. .

In the longer term a further radical change in bunker demand could occur were the IMO's proposal to reduce the global specification of bunker fuel oil to 0.5% sulphur content by 2020 be implemented. Potentially this would spell the death of the fuel oil bunker market with a further large scale switch to distillates. However at the moment there is sufficient uncertainty about the outcome of this proposal. Therefore we have assumed that these proposals are not implemented in their current form with the result that fuel oil bunker demand continues.

Tightening regulations for inland fuel oil quality have increased the percentage of low sulphur fuel oil in inland demand. While legislation required a limit of 1% sulphur in heavy fuel oil burnt inland from the beginning of 2003, it is still possible to burn fuel oil with sulphur content in excess of 1% in existing plants provided emissions do not exceed certain limits. In practice, this limits use to power stations fitted with flue gas desulphurisation or the few industries where the sulphur is absorbed in the final product, notably cement manufacture. In addition, EU countries that do not contribute to acidification can apply for a derogation to continue to use 3% fuel oil until 2013. In 2009 we estimate that two thirds of inland demand in NWE was low sulphur material, but this is likely to decline slightly in the future as the overall market for fuel oil in inland markets shrinks.

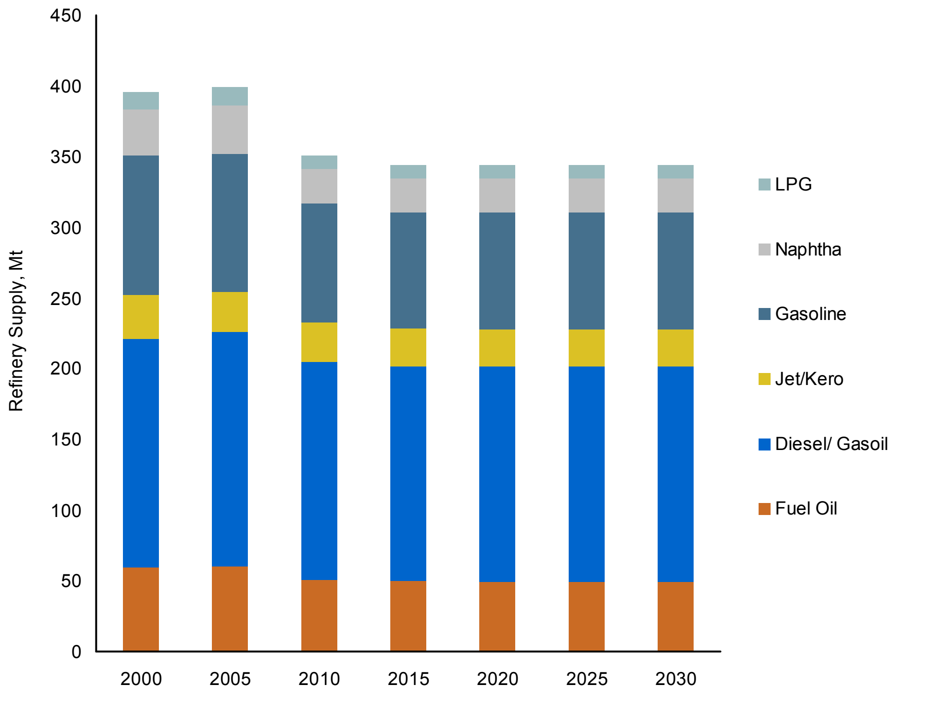
4.1.2 Supply

Refinery Supply

There are 51 main fuels refineries in NWE, with a total refining capacity of 8.9 Mbcd (approx. 445 Mt). 10 specialist refineries account for an additional 0.2 Mbcd (approx. 8 Mt). The average refinery size of the main fuels refineries is 174 kbcd.

There is little requirement for refiners to add new crude capacity due to the current surplus position and the large and growing gasoline surplus. In fact, refiners have already closed some capacity permanently whilst other capacity has been idled temporarily to prevent the build up of excess product stocks. The economic environment for refiners in NW Europe is forecast to be harsh and further closures are likely. Understandably there are few investments planned to expand refining capacity or upgrading.

Figure 28: NWE Forecast Refinery Supply, 2000-2030



Source: Wood Mackenzie

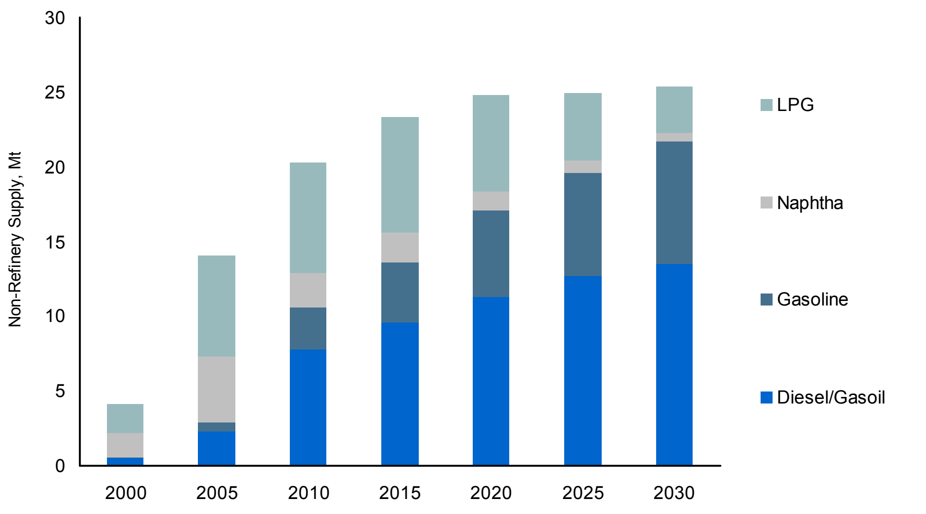
Some refiners are investing in diesel desulphurisation capacity. These investments are driven by tighter diesel specifications which reduced the amount of sulphur content to 10ppm for on-road diesel from 1st January 2009, and for most non-road diesel from 1st January 2011.

In 2009, NWE processed around 370 Mt (7.4 million b/d) of crude, achieving a utilisation rate of 81%. Our forecast is that refinery production will remain low throughout the period and utilisation rates will remain low unless there are additional refinery closures. We expect the growing gasoline surplus in NWE to be a limiting factor on refinery utilisation, resulting in rates never really recovering in the long-term. Utilisation rates at the level we have forecast are not sustainable in the long-term and indicate that further closures of refining capacity are necessary.

Non-Refinery Supply

Total non-refinery supply in North West Europe was estimated to be 20 Mt (485 kb/d) in 2009. We expect use of biofuels to grow in the future and the supply from NGLs to decrease. Total non-refinery supply grows to 26 Mt (0.6 Mb/d) per annum by 2030.

Figure 29: NWE Forecast Non-Refinery Supply, 2000-2030



Source: Wood Mackenzie

4.1.3 Balance

Refinery Supply Balance

In 2009, North West Europe (NWE) was deficit around 9 Mt (230 kb/d) of refined oil products supply versus domestic demand. Within this deficit, there is a large and growing surplus of gasoline as well as a surplus of low sulphur fuel oil. This serves to somewhat mask the significance of the large deficits of diesel and jet fuel. Post 2010, the total products deficit widens as demand starts to recover while utilisation remains low, but beyond 2015 demand falls due to the maturing economy and the deficit narrows.

- The deficit of LPG remains at a similar level to that in 2009.
- The naphtha deficit widens to 2015, but narrows in the long term
- We expect the gasoline surplus to continue to widen as demand falls
- The jet/kerosene deficit continues to grow during the forecast period.as demand grows, but refinery supply stays flat
- The NWE diesel deficit has been growing in recent years. Our forecast shows this deficit widening further out to 2030, as demand growth outpaces flat refinery supply
- We expect gasoil will remain balanced during the forecast period, mainly due to demand switching from gasoil to diesel (as a result of the off-road diesel specification change to 10ppm) being matched by the switch of bunker fuel demand in SECA's from fuel oil to gasoil.
- The surplus of low sulphur fuel oil is expected to grow significantly post-2010 as inland demand falls and low sulphur bunker fuel consumed in SECA's shifts to gasoil.
- HSFO moves from a small deficit to a small surplus over the forecast period as refinery supply remains flat while demand falls.

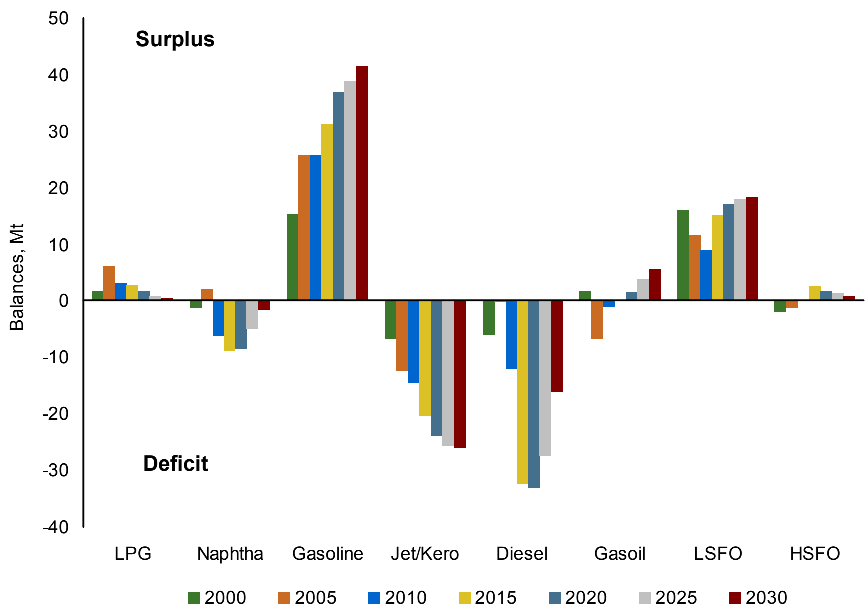
All Supply Balance

The addition of non-refinery supply to refinery output impacts upon the oil product balances by substantially increasing the overall surplus position. The chart below shows the all supply oil product balance forecast. This includes NGLs production and biofuels consumption.

In 2009, North West Europe was surplus 10 Mt (250 kb/d) all supply versus demand. This falls and becomes a small deficit by 2015 due to reduced refinery output. By 2025, the region is once again surplus as demand declines due to increased efficiency and a mature economy.

- The impact of non-refinery supply (from NGLs) moves LPG to a small surplus in the territory
- The effect of non-refinery supply on naphtha balances is less significant and they remain deficit throughout the forecast
- The addition of ethanol use to gasoline supply adds significantly to the surplus of gasoline
- The impact of growing biodiesel supply is to reduce the future diesel deficit.

Figure 30: NWE All Supply Product Balances, 2000-2030

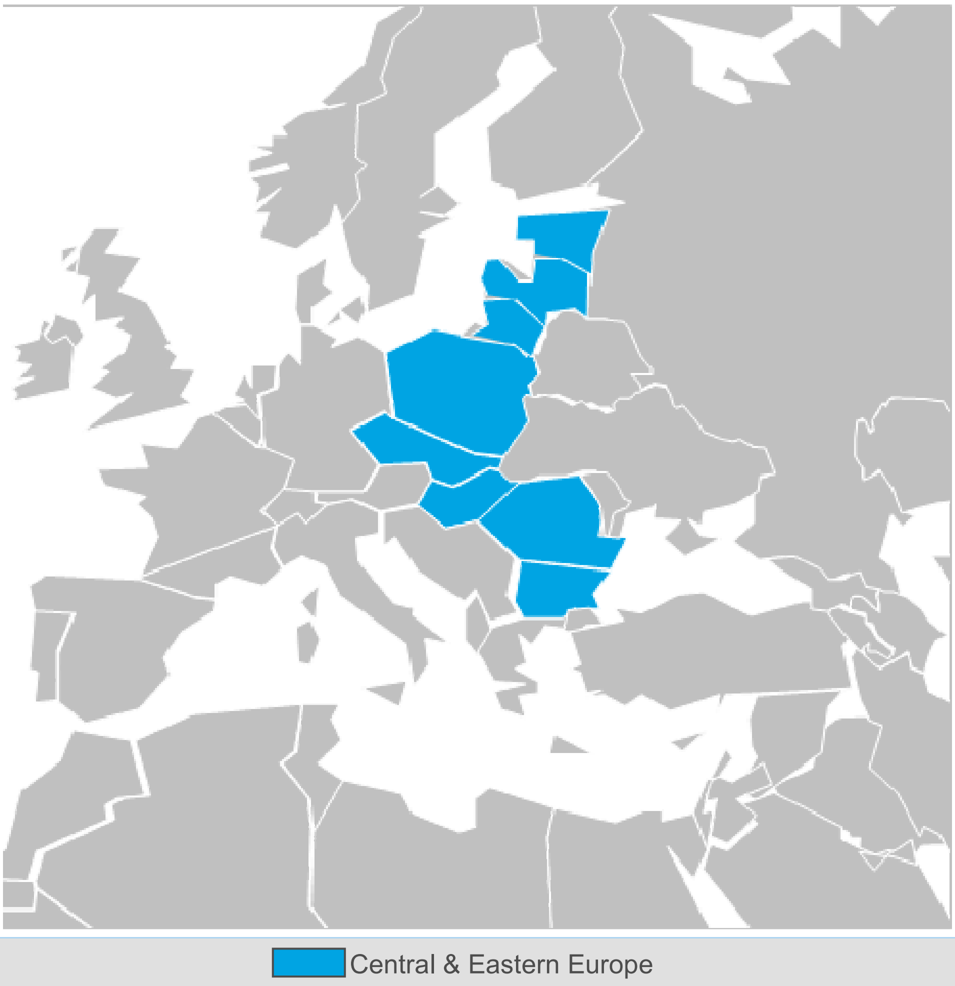


Source: Wood Mackenzie

4.2 Central & Eastern Europe

In this section we will review the Central & Eastern Europe regional market which is in turn made up of Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and the Slovak Republic (see Figure 31).

Figure 31: Central & Eastern Europe Region



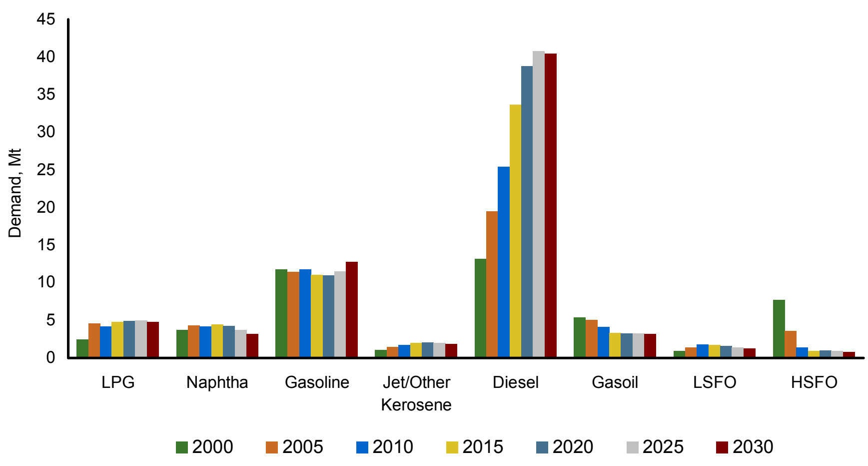
4.2.1 Demand

The countries of Central & Eastern Europe (C&EE) are quite different from their neighbours in NWE. In line with their lower levels of economic development during the years of Soviet domination, the markets for oil products are similarly under-developed. The region as a whole has received a significant economic boost with accession to the EU for most countries and with it there has been significant growth in oil demand. Between 2000-2008 demand increased by an average 2.5% per year, rising by 12 Mt (280 kb/d) in total. However in 2009 demand dropped by more than 3% as GDP contracted.

Demand will start to increase again once Europe as a whole starts to recover. Most of the countries in the region are heavily dependent on exporting to the rest of the EU – in recent years there has been a strong flow of direct investment by EU companies seeking to set up production in a part of the EU where costs are generally much lower. Once recovery in the core EU countries is underway the CEE region should start to feel the benefits of a revival in its main export markets. GDP growth is forecast to return to around 4% per annum in the period 2010-2015, weaker than in the years running up to the recent recession, but stronger than across the EU as a whole. Growth weakens in the long term but is still expected to average around 3% per annum. A significant rise in living standards is also expected as these countries catch up with the rest of their EU neighbours.

In line with this economic revival, growth in oil demand is projected to return to the pre-recession average of 2.5% per annum through to 2015, before weakening to 1.5% per annum to 2020 and 0.5% per annum after that. From the 2009 level of 66 Mt (1.4 Mb/d), total demand is forecast to rise to just over 80 Mt (1.7 Mb/d) in 2030. Although the CEE region will be subject to the same pressures as North West Europe (NWE) in terms of efforts to curb carbon emissions from road and air transport, stronger underlying economic and socio/demographic dynamics mean that the outlook for demand here is more robust.

Figure 32: CEE Demand by Product, 2000-2030



Source: Wood Mackenzie

Poland accounts for almost 40% of regional demand, followed by Romania, the Czech Republic, and Hungary – which together account for a further 41% of demand. The remaining five countries, which include the three Baltic states, represent less than a quarter of demand. The share of regional demand attributable to the different countries remains broadly stable going forwards, although the proportion of total demand accounted for by the smaller countries does increase slightly.

Demand Trends By Product

LPG

Demand for LPG has been growing rapidly. A significant automotive market has been developing in Poland, and demand here is expected to continue to grow in the future. Aside from automotive consumption, the bulk of regional LPG use is as a residential fuel and to a lesser extent, as petrochemical feedstock. Residential use will decline through the forecast period as increasing urbanisation and wider availability of gas and electricity erode sales.

Naphtha

Naphtha demand, roughly half of which stems from Poland and Hungary, is forecast to grow steadily throughout the forecast period as economic growth drives up demand for petrochemicals.

Gasoline

A relatively low level of car ownership at the moment means that there is potential for strong fleet growth once GDP growth recovers and as living standards rise further. At the moment car ownership stands at just over 350 cars per 1000 people, which is about 70% of the level in NWE. The forecast assumes that by 2030 car ownership levels will be approaching the same level as projected for NWE.

Compared to the rest of Europe, the pace of dieselisation in these countries had been relatively slow until recent years and diesel vehicles currently represent only 20% of the total passenger fleet (compared to one third in NWE for instance). However, the share of diesel in new registrations has recently reached close to 50% and is projected to remain at around this level to 2015, before falling back slightly to 2030 as sales of electric vehicles start to impact and as consumers, in favouring purchase of smaller engine vehicles, make a marginal switch back to gasoline. Gasoline sales remain at just over 50% of total registrations right through the forecast period, despite the growing sales of electric vehicles. In overall terms the role of electric vehicles is likely to be minor, remaining at less than 5% of new car sales in 2030.

Gasoline demand is projected to fall through 2015 as consumers increasingly adopt diesel cars and as fuel efficiency standards improve. However with the gradual shift back to gasoline in new registrations, the fall in gasoline demand arrests and even rebounds slightly to 2030.

Jet/Kerosene

Jet/other kerosene demand growth has been strong across C&EE over the last five years, reflecting the growth in air travel helped by the growing success of budget airlines in Europe and growing consumer spending power. Growth will resume once the regional and wider EU economy recovers although it is unlikely that growth will return to previous levels since air traffic volumes have already grown strongly in the last five years or so. By the end of the forecast period growth it is possible that demand may start to decline as fuel efficiency gains start to outstrip traffic growth.

Diesel/ Gas Oil

Total diesel/gasoil demand in 2009 was a little over 28 Mt (580 kb/d), down about 2.5% on 2008. In the years leading up to 2008 demand growth had been very strong, mainly due to growth in road diesel demand. In other sectors demand has been shrinking since 2000.

By 2030 diesel cars will represent about 35% of the total car fleet, up from 20% currently. As a result and despite improving fuel efficiency, diesel demand for passenger vehicles is projected to double between 2009 and 2030. However diesel demand for commercial vehicles will still represent the bulk of diesel sales with demand in 2030 estimated to have increased by almost two thirds on the 2009 level.

Demand in non-road uses is expected to recover slightly as the economies recover. Small increases are expected in the commercial and residential sectors, while in industry demand is likely to remain relatively unchanged since uses here tend to be in stand alone applications and in mechanical or driving applications for which there are no real alternatives. However demand in agriculture, although there are no real alternatives to diesel and gasoil in most uses, will fall steadily as fuel efficiency improves.

With all the countries in C&EE being members of the EU, proposals to reduce the sulphur content of off road diesel will also have a significant impact in the region. EU Directive 2009/30/EC stipulates that from January 2011 all gas oil for use in non-road mobile machinery (currently 1000ppm sulphur) must contain no more than 10ppm sulphur - the same as current road diesel. Use by railways must switch to the lower specification no later than January 2012. Currently around 40% of deliveries to non-road sectors are of diesel quality. The majority, about 80%, represents agricultural diesel. However with the change in specifications in 2011 and 2012, non-road diesel demand is set to jump sharply, but then remain at around the 2015 level through the remainder of the forecast period.

The new IMO rules that limit sulphur content of marine fuels consumed in SECAs to 1% from 2010 and 0.1% from 2015 will also have an impact on gasoil demand. Current fuel oil bunker demand in the Baltic countries will need to change over from LSFO to distillate, implying an increase in gasoil demand.

Fuel Oil

Demand for fuel oil in the region has fallen consistently over the last twenty years, falling as energy demand has declined due to economic downturn and restructuring and as demand has been displaced by the growing availability of natural gas. By 2009 around one third of fuel oil was used in industry, a similar amount in power generation and 20% representing demand for marine bunkers.

In the future demand is expected to decline further. Inland demand has been falling as a result of substitution by gas in many markets. Much of the decline in inland fuel oil has been in the power generation sector where demand fell by over 50% between 1995 and 2000 - the result of increased gas and nuclear power generation. The decline rate has now levelled off across the region and although fuel oil will account for a declining proportion of inputs to power generation going forwards, the overall pace of growth in electricity demand is expected to keep volumes broadly flat. Industrial demand has also declined in the face of gas substitution, although less dramatically than power generation. Further gas substitution is expected to continue to reduce fuel oil demand, although this will be moderated by economic growth once the recession is over.

Although the bunker market is growing in size, the impact of new IMO regulations from 2015 means that there is a sharp drop in fuel oil bunker demand.

Historically all bunker demand in C&EE has been high sulphur (>1% sulphur). However, in the Baltic Sea, a market in low sulphur bunker fuel has developed to meet the requirements of environmentally sensitive Scandinavian ferry companies. In addition, IMO (International Maritime Organisation) and EU measures introduced a 1.5% sulphur limit on bunker fuel oil used in the Baltic Sea (designated as a SOx Emission Control Area or SECA) and in ferries on regular services between EU ports from May 2006. Subsequently, the creation of a second SECA made up of the North Sea and English Channel in November 2007 extended the use of 1.5% sulphur bunker fuel oil. In April 2008, the IMO published a number of proposals regarding the future sulphur content of bunker fuel oil. Based on these proposals, we have assumed that the sulphur content of fuel oil used in the European SECAs is reduced to 1% in 2010 before switching to distillates after 2015. IMO's proposal to move to a global specification of 0.5% sulphur content by 2020 is not assumed to be implemented. As a result of these changes, what C&EE bunker fuel demand that remains in the longer term is likely to be high sulphur material.

The current proportion of LSFO used inland in C&EE has grown to around 60% even though Romania and Bulgaria, both of which only recently joined the EU, mainly continue to use HSFO. In general, tightening EU regulations for inland fuel oil quality have increased the percentage of low sulphur fuel oil in inland demand. While EU legislation has required a limit of 1% sulphur in heavy fuel oil burnt inland since 2003, it is still possible to burn fuel oil with sulphur content in excess of 1% in existing plants provided emissions do not exceed certain limits. In practice, this limits use to power stations fitted with flue gas desulphurisation or the few industries where the sulphur is absorbed in the final product - notably cement manufacture. In addition, EU countries that do not contribute to acidification can apply for a derogation to continue to use 3% sulphur fuel oil until 2013. By 2015, the whole region is assumed to comply with EU regulations and we estimate that LSFO will account for over 70% of inland demand.

4.2.2 Supply

Refinery Supply

There are 14 main fuels refineries in C&EE, with a total refining capacity of 1.6 Mbcd (approx. 81 Mt). Four specialist refineries account for an additional 30 kbcd (approx. 1.5 Mt). The average refinery size of the main fuels refineries is 116 kbcd. There is a reasonably high level of future refinery investments in C&EE including three firm refinery expansion plans adding a total 130 kb/d of crude capacity.

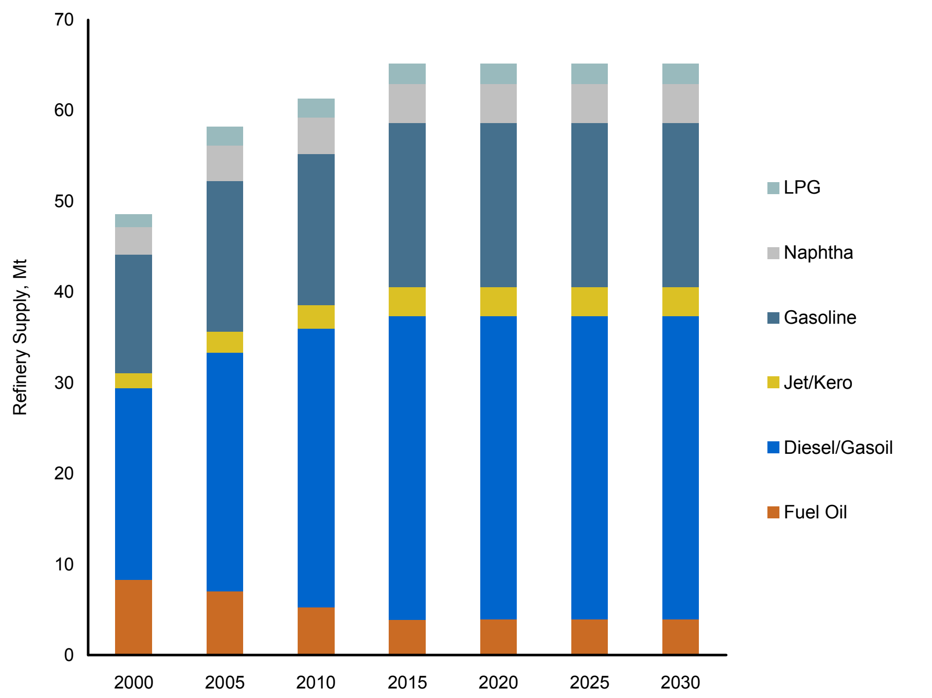
We expect upgrading capacity in the territory to also increase by 2015.

There is also a modest level of desulphurisation capacity investment, mainly taking the form of revamps of existing units. This investment is generally aimed at meeting tighter EU diesel quality specifications – there was a change to a 10ppm limit for road diesel on 1 January 2009 and most non-road diesel will change on 1 January 2011.

We estimate that in 2009, C&EE processed around 73 Mt of crude and feedstocks, achieving a utilisation rate of 80%. Our forecast is that throughputs will increase somewhat in 2010, due to additional refining capacity in Poland and Romania in 2010. However, utilisation is forecast to be lower as the new refining capacity is only partially utilised during the year. Utilisation and throughputs are forecast to increase by 2015 as the economy recovers. The increase in utilisation is limited, as the products surplus in the region remains and competition in the export markets increases.

Refinery production grows from 68 Mt (1.4 Mb/d) in 2009 (excluding refinery fuel and loss) to 75 Mt (1.6 Mb/d) in 2025 due mainly to the effect of increased refining capacity. Figure 33 shows our forecast of production of principle oil products out to 2030.

Figure 33: CEE Forecast Refinery Supply, 2000-2030

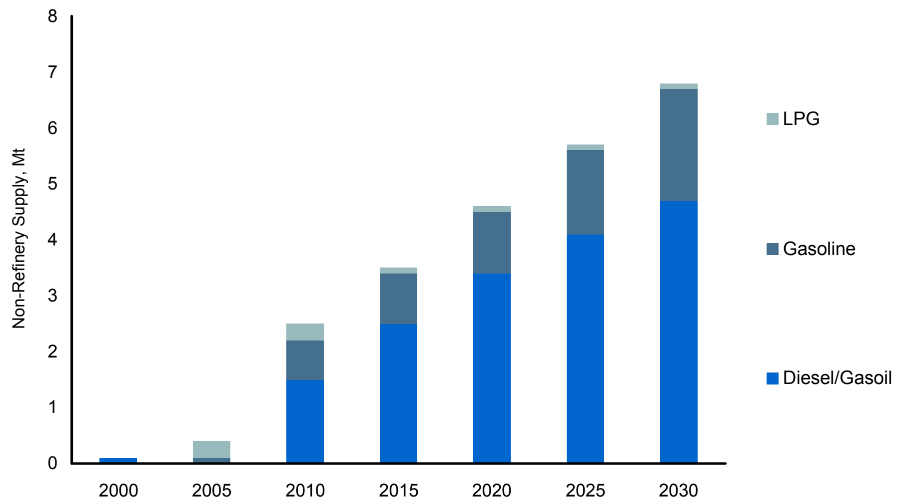


Source: Wood Mackenzie

Non-Refinery Supply

Total non-refinery supply in Central and Eastern Europe was 1.9 Mt (40 kb/d) in 2009, split between biofuels and NGLs. There is a very small amount (303 kt) of non-refinery supply of LPG from NGL production in Hungary. We expect this to decline in the future. We expect use of biofuels to grow in the future, and as a result total non-refinery supply increases to over 6.8 Mt (140kb/d) by 2030.

Figure 34: CEE Forecast Non-Refinery Supply, 2000-2030



Source: Wood Mackenzie

4.2.3 Balance

Refinery Supply Balance

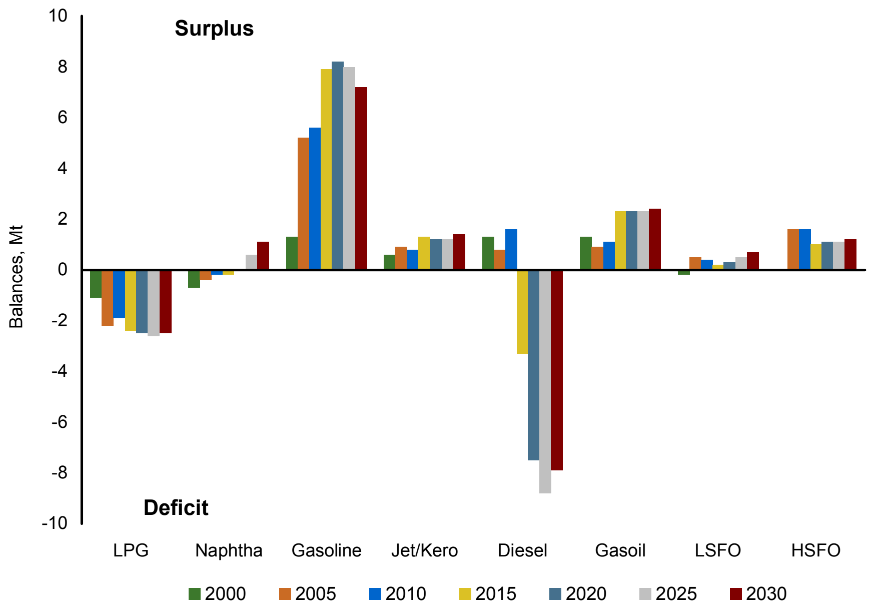
In 2009, Central & Eastern Europe (C&EE) was surplus refinery supply of total products versus domestic demand. LPG is currently the only main product with a significant deficit. We anticipate the total products surplus will decline post 2010 as demand growth returns. We forecast that a surplus in 2010 will turn into a slight deficit by 2030.

- The refinery supply deficit of LPG remains broadly constant
- Naphtha remains broadly balanced as demand grows at approximately the same rate as supply
- The gasoline surplus is forecast to increase strongly. Demand falls over this period and refinery supply decreases due to lower refinery yields of gasoline
- The small jet/kerosene surplus rises slightly through to 2015, as new supply outpaces demand growth, but then remains little changed for the remainder of the period
- Diesel is forecast to move from a balanced position in 2009 and 2010 to a large and growing deficit. This is due to strong demand growth after 2010 which outpaces increased refinery production despite new hydrocracking and hydrotreating capacity coming on stream
- The gasoil surplus,is expected to increase by 2015 and then remain flat for the rest of the forecast. We forecast a fall in demand as non-road diesel switches to ULSD quality from the start of 2011. Refinery supply is expected to remain little changed.
- The fuel oil surplus is forecast to decrease. LSFO remains broadly balanced, but the HSFO surplus falls due to refinery upgrading projects.

All Supply Balance

The addition of non-refinery supply to refinery output impacts upon the oil product balances by slightly increasing the overall surplus position. Figure 35 below shows the all supply oil product balance forecast. This includes NGLs production and biofuels.

Figure 35: CEE All Supply Product Balances, 2000-2030



Source: Wood Mackenzie

Central and Eastern Europe is currently slightly surplus all supply versus demand. This surplus is forecast decline as strong demand growth for diesel exceeds increased crude throughput and additional non-refinery supply.

- The impact of non-refinery supply (from NGLs) slightly reduces the LPG deficit in the territory
- The addition of ethanol use to gasoline supply adds to the surplus of gasoline
- The impact of growing biodiesel supply is to reduce the diesel deficit

4.3 Mediterranean Europe

In this section we will review Mediterranean Europe regional market which is comprised of the European Mediterranean countries of Albania, Bosnia, Croatia, Cyprus, Southern France, Gibraltar, Greece, Italy, FYR Macedonia, Malta, Montenegro, Portugal, Serbia, Slovenia, Spain and Turkey and also the non-European countries of Algeria, Egypt, Israel, Lebanon, Libya, Morocco, Syria and Tunisia (see Figure 36) since these countries markets are more associated to Mediterranean Europe than other regions.

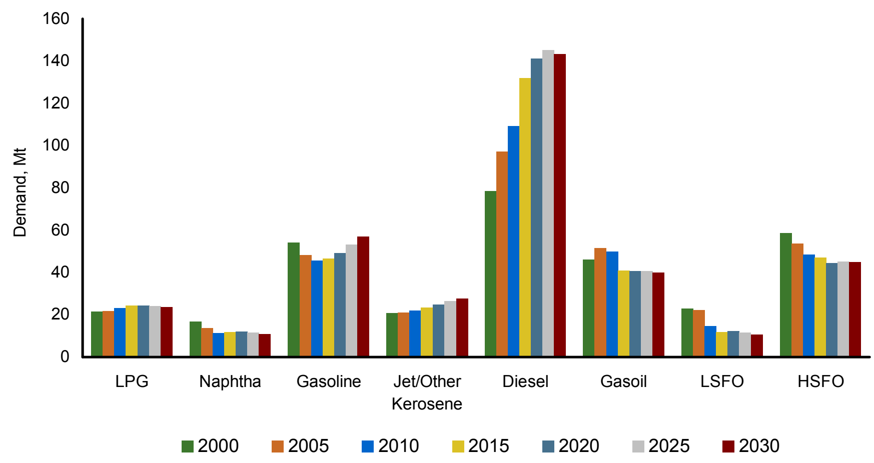
Figure 36: Mediterranean Europe Region

4.3.1 Demand

Total oil demand in the Mediterranean (Med) region in 2009 is estimated to have fallen by 2.5% on a year earlier to stand at 375 Mt (7.8 Mb/d) - 10 Mt lower than the year before. The decline in 2009 broke a run of ten years in which regional demand had shown a year-on-year increase, with growth over the period averaging almost 1% per annum. Almost all of this growth has taken place in the non-Euro Med countries, growth here averaging 2.5% per annum. In contrast demand in the Euro Med area has remained almost flat since 2000. In the last two years the contrast between the two sets of countries has become even more marked - demand falling in the Euro Med area by a combined 7% but growing in the non-Euro Med countries by 8.5%.

In the forecast total demand is set to rise by 11% by 2030, adding around 40 Mt to regional demand, which by the end of the period is expected to reach 416 Mt (8.7 Mb/d). We expect a similar pattern in the future with demand in the Euro Med area broadly flat over the period so that all the growth in regional demand takes place in the remainder of the region. Part of the reason for this is the stronger rate of GDP growth projected for the non-Euro Med area, with growth here averaging 4% per annum compared to the Euro Med 3% per annum. However the real difference comes in the more dynamic socio/demographic nature of the North African and East Mediterranean countries, where rising living standards coupled with a young and growing population is set to boost per/capita oil consumption, particularly in transportation. Furthermore, there is a clear differentiation even within the Euro Med bloc with demand prospects much more buoyant in Turkey and the Balkans than, for instance, in Italy.

Figure 37: Mediterranean Demand by Product, 2000-2030



Source: Wood Mackenzie

Egypt, Italy, Spain and Turkey dominate demand for oil products in the Mediterranean, accounting for nearly 60% of total demand in 2009. This share is expected to fall slightly over the forecast period as declining demand in Italy off-sets growth in Egypt and Turkey. The two large EU consumers, Italy and Spain, currently account for 40% of total demand, but by 2025 this will have fallen to 33%, illustrating the poor growth prospects in these more mature economies relative to the rest of the region.

Demand Trends By Product

LPG

Two thirds of regional LPG demand is in the residential sector and because of this, demand has been relatively unaffected by recession. The other main use for LPG is as an automotive fuel, although this is heavily concentrated in Turkey where high retail prices for gasoline and diesel have encouraged high levels of conversion to LPG. In the forecast demand for LPG will continue to grow from current levels with growth averaging 1-1.5% per annum to 2015 before weakening in the long term. LPG demand grows relatively strongly in the non-Euro Med countries due to the increasing availability of domestic supplies associated with oil and gas production and its attractiveness as a new fuel in developing energy markets. In Euro Med, residential demand falls slightly as electricity and gas demand increases, but in Turkey further increases in automotive LPG demand are expected.

Naphtha

Demand for naphtha fell sharply in the second half of 2008, slumping 13% as petrochemical production in Europe fell in the face of the sharp economic downturn across Europe. Demand fell by a further 10% in 2009. European countries account for almost 90% of total regional demand and 75% of total petrochemical feedstock demand. Demand recovers in line with the pick up in GDP growth, but competition from low-cost Middle East producers will mean that petrochemical production in Europe, and therefore feedstock demand, will remain constrained in the future.

Gasoline

Between 2005 and 2008, just under 60% of new car sales were diesel, but this was heavily skewed towards the Euro Med countries, which account for 90% of total diesel sales. Overwhelmingly, in North Africa and Eastern Mediterranean the vehicle of preference is gasoline and diesel has yet to gain widespread favour with consumers. Diesel is used in these countries by commercial vehicles, but not to any great extent by passenger vehicles. We assume here that this largely remains the case and that the proportion of diesel in new car registrations rises only marginally in non-Euro Med to 30%. In the Euro Med countries it is assumed that the proportion of diesel cars in new registrations falls gradually from the current level of close to 75% to around 60% in 2025, this reflecting:

- A shift in consumer preference towards vehicles with smaller capacities, likely driven by government taxation policies, should favour gasoline over diesel

- The fact that although the fuel efficiency of both diesel and gasoline engines will improve steadily, the absolute reduction in the case of gasoline is likely to be greater even though diesel will always remain more fuel efficient – but a narrowing of the gap in absolute efficiency may bring drivers back to gasoline

- Stronger diesel prices in the future, which are expected to rise more quickly than gasoline although not enough to eliminate the price differential

In the longer term electric vehicles start to gain market share, but in overall terms remain marginal. In 2030 electric vehicles (of all types) account for just over 3% of the total car fleet.

At the regional level, gasoline demand has been steadily falling. However while demand has declined more rapidly in the Euro Med countries, in the other countries it has been rising steadily. Today non-Euro Med countries represent 25% of the regional gasoline market compared to 18% ten years ago. By 2030 the non-Euro Med countries will account for 50% of the total regional gasoline market. Currently car ownership amongst these countries is a mere 60 cars per 1000 people and this is forecast to rise to over 110 per 1000 by 2030.

In the Euro Med countries the structural decline in gasoline demand that set in with the onset of dieselisation some years ago is projected to slow and then halt in line with trends in new registrations outlined above. Indeed post-2015 demand may actually recover very slightly. This coupled with the strong trend forecast in the other countries of the region leads to a significant rebound in regional gasoline demand.

Jet/Kerosene

Growth in jet kerosene demand has been relatively strong across the Mediterranean region as a whole, averaging around 2% per annum since 2000, although growth has been much stronger in the Euro Med countries compared with non-Euro Med. Air travel has been growing rapidly, helped by the growing success of budget airlines and the popularity of the Mediterranean as a holiday destination for those living in the colder climate of North West Europe. However the longer term trend was affected by traffic disruptions between 2000-2003, and demand growth since then has been much stronger, averaging close to 4% per annum between 2003 and 2008. Demand has dropped by 4% with the onset of recession, but with global and regional economic recovery, jet fuel demand is set to grow strongly again in the future. The forecast is for growth of 1.2% per annum across the region in the period to 2030, with growth weakening in the long-term.

Other uses of kerosene are very small in the Euro Med region, amounting to less than 2% of total kerosene, and little change in demand is forecast. In the non-Euro Med bloc, there is a reasonably high level of demand in the residential sector. This volume is forecast to remain flat over the forecast period as rising energy demand is offset by greater use of electricity.

Diesel/ Gas Oil

The bulk of diesel/gasoil demand, around two thirds, represents road diesel demand and so the trend in total diesel/gasoil demand largely follows that for road diesel demand. Demand for gasoil and non-road diesel has remained broadly unchanged since 2000 - in the period since 2000, demand generally has increased in agriculture and power generation, but has fallen in industry and the residential sector.

Almost 70% of road transport fuel demand in 2009 was diesel. Road diesel demand is projected to increase by over 20% through to 2030. Two-thirds of this increase is in the non-Euro Med area. Furthermore, within the Euro Med growth is strongest in Turkey and the Balkans while in Italy and other more mature economies demand peaks and then declines. About 70% of the growth in non Euro Med demand is for commercial vehicles, while in Euro Med the opposite is the case where passenger vehicles account for the bulk of the growth.

Non-road demand is forecast to grow by an average 1.3% per annum to 2015 and by just less than 0.5% per annum after that, with all sectors showing some growth although residential use remains largely unchanged.

The European Commission has proposed aligning diesel fuel quality requirements for non-road applications with the on-road sector by 2011 or 2012 in the case of railways. The Mediterranean region is a mix of current EU members, applicants to join the EU and countries that will not be joining the EU during the forecast period. We have assessed the potential future demand for non-road diesel on a sector-by-sector basis assuming that for EU Member States, the regulation requires an alignment of non-road and road by the end of 2011 and 2012. It is assumed that those countries currently seeking accession to the EU will also move into line with these new sulphur specifications in the period to 2020. No switch is expected to take place in the non-Euro Med countries.

Currently only around 12% of non-road diesel/gasoil in the Mediterranean region is of diesel quality. We estimate that this will increase to around one third after the specification change comes into force in 2011 and 2012. Off road diesel demand more than doubles during this change over period, mostly due to the change in agriculture although there are also large increases in industry and inland waterway uses.

Unlike in NWE there is no change in bunker specification since there is no SECA in the Mediterranean region. Therefore there is no switch in bunker demand out of fuel oil.

Fuel Oil

Almost 50% of fuel oil demand in the region was used in power generation in 2009. About 20% is industrial use and 30% represents marine bunkers. In overall terms demand has been declining steadily since 2000, due to falling consumption in power generation and industry. All of this fall has been due to developments in the Euro Med area, where in Italy and Spain in particular fuel oil has been displaced by natural gas in both sectors. In contrast demand in the rest of the region has risen by almost 20%, with consumption rising in all sectors. The only sector where demand has risen consistently and in all regions of the Mediterranean is marine bunkers.

Demand for fuel oil is forecast to fall further in the period to 2012, by around 10-15% in all. Although demand for bunkers will increase as trade picks up again, further steep falls in demand are expected in the power sector. This fall is due to further declines in the Euro Med countries, whereas in the rest of the region power sector demand is flat through the period. In industry, demand rises in the non-Euro Med countries, but continues to decline in Europe, the net result being a flat trend at the regional level. As inland demand declines, while bunker demand rises, the proportion of total demand accounted for by bunkers rises from 28% to 38% over the period.

Historically the bulk of bunker demand in the Med has been high sulphur (defined as >1 wt% sulphur, the bulk of which is closer to 2.5 wt%). However, in some countries e.g. Algeria, Libya and Tunisia, the bunker fuel is low sulphur as a result of the low sulphur domestic crude oil processed within the refineries. As a result, around 7% of bunker demand is estimated to be low sulphur in 2009 and that share is forecast to remain unchanged through 2025. Our forecast assumes that the Med does not become a SOx Emission Control Area (SECA) in this time period and that a recent IMO proposal for a global cap of 0.5%wt sulphur in bunker fuel is not applied by 2025.

As regulations for inland fuel oil quality tighten, the percentage of low sulphur fuel oil in inland demand will increase. While EU legislation has required a limit of 1% sulphur in heavy fuel oil burnt inland since the beginning of 2003, it is still possible to burn fuel oil with sulphur content in excess of 1% in existing plants provided emissions do not exceed certain limits. In addition, countries within the EU that do not contribute to acidification can apply for a derogation and may continue to use fuel oil with a sulphur content up to but not exceeding 3% until 2013.

The assumptions regarding the progress of EU membership shown for diesel/gasoil quality also drive the forecast of the demand for LSFO. The non-Euro Med countries do not have to meet EU specifications and have been assumed therefore to continue to burn HSFO, except where refinery supply is based on low sulphur crude. We estimate that almost 30% of inland demand will be for LSFO by 2025.

4.3.2 Supply

Refinery Supply

There are 71 main fuels refineries in the Mediterranean, with a total refining capacity of 8.2 Mbcd (approx. 410 Mtpa). Three specialist refineries account for just 30 kbcd (approx. 1.5 Mt). The average refinery size of the main fuels refineries is 116 kbcd.

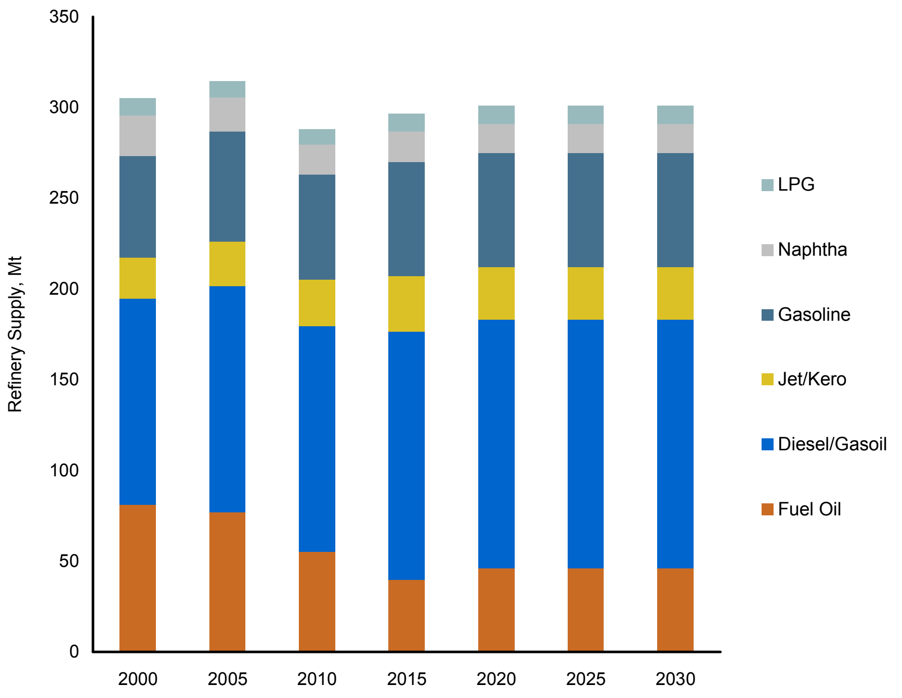
Within Euro Med, there are four firm refinery expansion plans, adding a total of around 280 kb/d of crude capacity between 2010 and 2015. In the non-Euro Med region, there are no projects to expand or build new CDU capacity that we believe will be completed by 2015.

In both Euro and non-Euro Med, there is a reasonably high level of investment in upgrading capacity. Around 220 kb/d of hydrocracking capacity and 130 kb/d of coking capacity is expected to come onstream in Euro Med between 2010 and 2013. In non-Euro Med, planned upgrading capacity additions total 40 kb/d of hydrocracking capacity and 17 kb/d of coking.

In 2009 around 305 Mt (6.2 Mb/d) of crude was processed in the Mediterranean, corresponding to a refinery utilisation rate of 74%. Our forecasts of refinery production out to 2030 project that utilisation will remain low over the forecast period due to the current economic climate restraining demand growth and impacting negatively on refining margins.

Refinery production (excluding refinery fuel and losses) is expected to remain low in 2010 at around 310 Mt (6.5 Mb/d) as refinery utilisation continues to be depressed by weak demand. In the Mediterranean as a whole, production is forecast to increase post-2010, but there are differences between the Euro Med region and non-Euro Med. Production in Euro Med is forecast to increase only slightly - due to increased capacity - remaining well below long-term average levels due to weak demand and overcapacity in other regions. In the non-Euro Med, demand growth is much stronger and we forecast that production will increase beyond historical levels due to increased capacity and higher utilisation. Figure 38 shows our forecast of production out to 2030.

Figure 38: Mediterranean Forecast Refinery Supply, 2000-2030

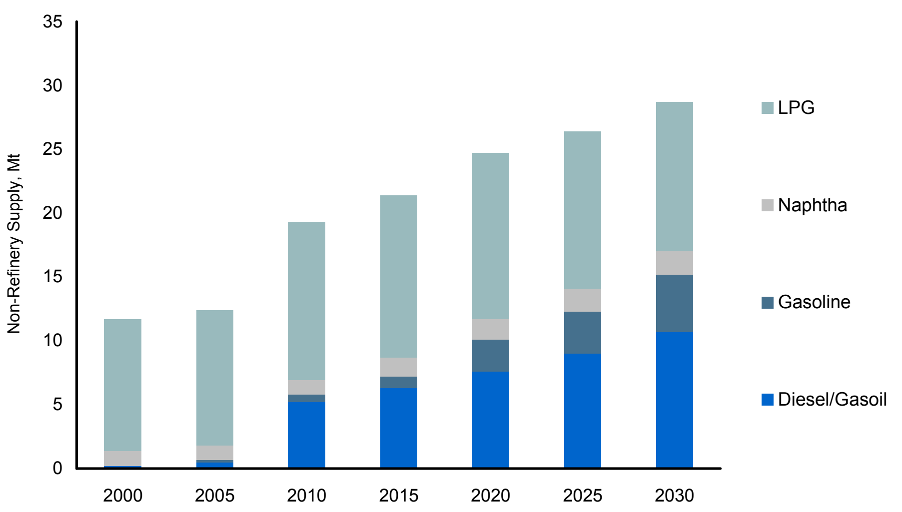


Source: Wood Mackenzie

Non-Refinery Supply

Non-refinery supply in the Med was estimated to be 18 Mt (480 kb/d) per annum in 2009, of which the majority (13.8 Mt) is NGLs - mainly from Algeria. However in the future biofuels are expected to play an increasingly important role. By 2030 we expect around 29 Mt per annum (680 kb/d) of non-refinery supply, of which biofuels could account for 15 Mt per annum (310 kb/d).

Figure 39: Mediterranean Forecast Non-Refinery Supply, 2000-2030



Source: Wood Mackenzie

4.3.3 Balance

Refinery Supply Balance

In 2009, the Mediterranean was 46 Mt per annum (1.0 Mb/d) deficit refinery supply versus total products demand. This deficit masks surpluses of naphtha and gasoline as well as slight surpluses of gasoil and LSFO. We anticipate that the total products deficit will stay at roughly the same level through 2010 as refinery utilisation remains low in response to weak demand and poor refining margins.

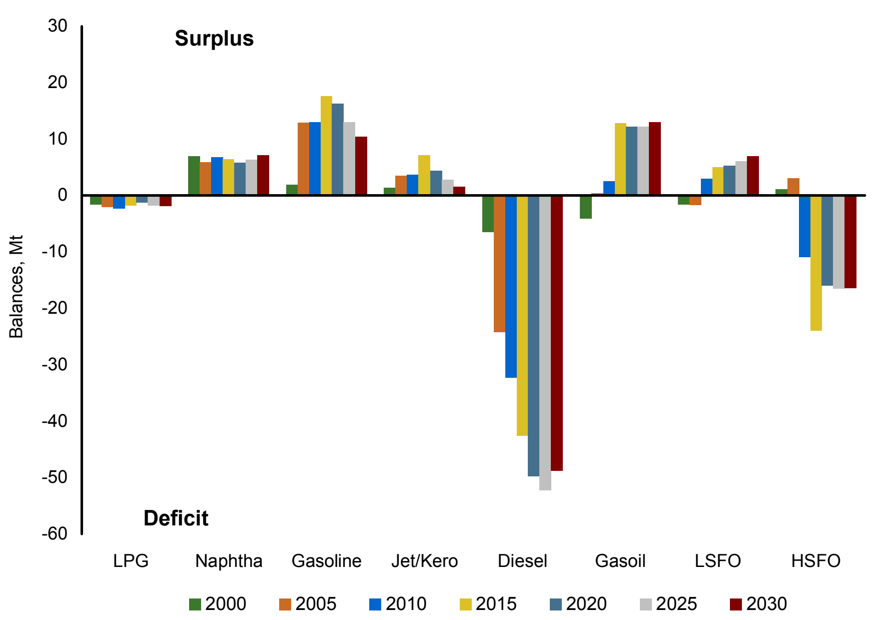
Post 2010 the total products deficit grows again, as demand growth outpaces growth in refinery supply from new capacity additions. .While at first glance this might appear to suggest that utilisation needs to increase, the deficit grows at a time when new export refining capacity comes on stream in the Middle East. These refineries will be pushing exports of diesel into the Med to satisfy this deficit.

- The naphtha surplus increases in the short-term as refinery supply increases due to higher naphtha yields, but then falls slightly as demand grows and refinery supply decreases, although both by only small amounts.
- We expect a large increase in the Mediterranean gasoline surplus until 2015, after which it is forecast to decline
- Jet/kerosene remains slightly surplus
- We expect the diesel deficit to increase through 2015. Demand increases) over this time period due to economic growth and the EU legislative change which requires non-road diesel to meet 10 ppm sulphur standards. This increase in demand outweighs growth in refinery supply. Post 2015 the deficit continues to grow as demand increases while our forecast for refinery supply remains broadly flat.
- Gasoil having been nearly balanced from 2005 is forecast to post a widening surplus after 2010, due to changing specifications requiring non-road diesel to meet diesel quality specifications from 2010.
- Even though demand is falling, the fuel oil deficit continues to widen due to significant investment in upgrading capacity. Most of the investment is aimed at upgrading HSFO, and this product moves significantly deficit.

All Supply Balance

The addition of non-refinery supply to refinery output impacts upon the oil product balances by reducing the overall deficit position. Figure 40 shows the all supply oil product balance forecast. This includes NGLs production and biofuels use.

Figure 40: Mediterranean All Supply Product Balances, 2000-2030



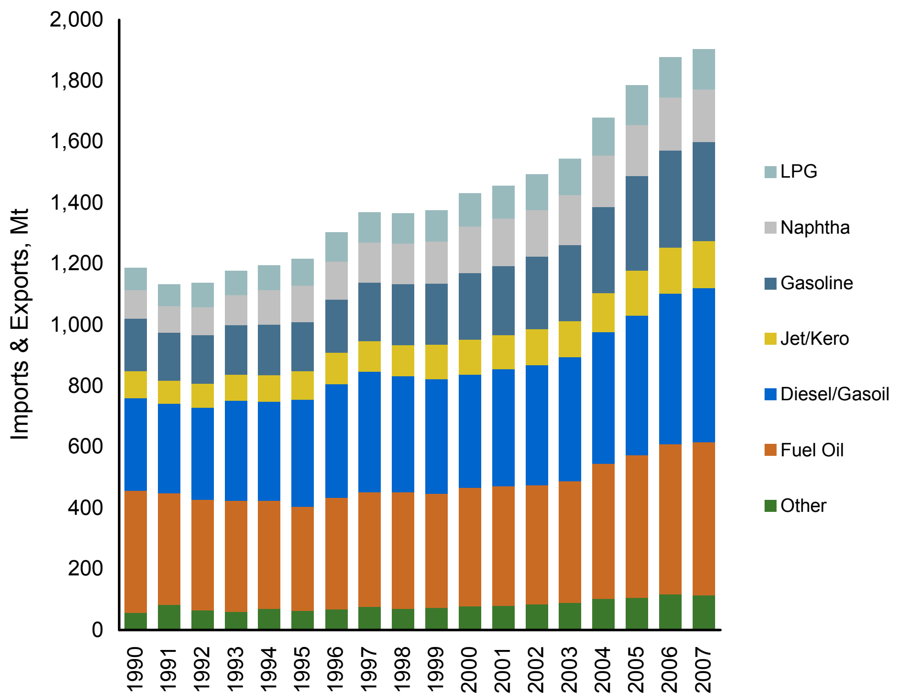
Source: Wood Mackenzie

5 Regional Trade Of Oil Products

The following section provides an initial view of oil product trade flows by main product category. These product trade flows are formed on the basis of the regional supply and demand balances examined in chapter 4 Regional Supply & Demand Of Oil Products and Regional Review Of Supply and Demand for Oil Products.

As regional oil product balances have become more imbalanced oil product trade has also increased to resolve these imbalances (see Figure 41). Oil product trade has been growing at an increasing rate. Between 1990 and 1995 growth averaged 0.5% per annum, between 1995 and 2002 it averaged 3% and between 2002 and 2007 growth averaged 5% per annum. Principle oil products traded are the transport fuels, gasoline, diesel and fuel oil. As discussed in chapter 4 regional oil product balances are expected to become increasingly imbalanced which is expected to require increased trade of oil products to resolve the imbalances.

Figure 41: Global Gross Trade by Product (Mt)



Source: IEA, Wood Mackenzie

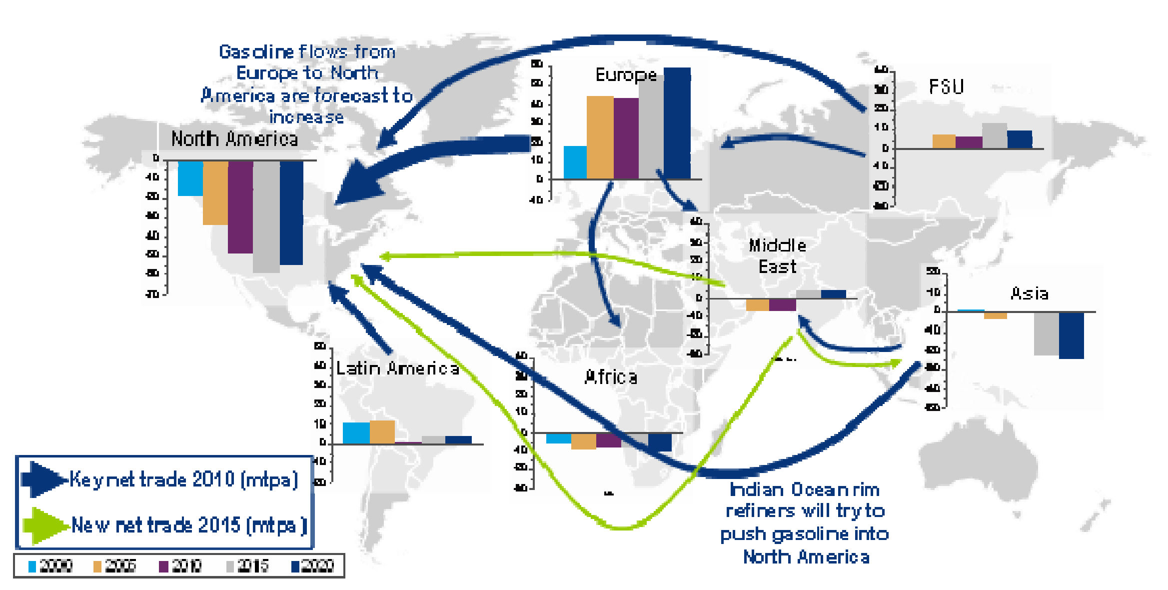
The supply modelling covered in the other sections of this report includes supply for future refineries whose development is planned and announced and for which we believe there is a good chance of the refinery being constructed. Investment projects announcements are typically within a five year horizon and the supply modelling covers investments which will come on stream by 2015. Refinery investments which are expected to come on stream post 2015 typically are not firm plans and are not included in our supply modelling.

In more distant future years this can lead to apparent deficits (especially in growth regions) which are highlighted rather than being adjusted for. Where a large regional oil product deficit develops post 2015 this in some cases would provide an incentive for new refinery investment projects in the future. Taking a view on unannounced future refinery investments would alter regional balances and result in speculative future trade patterns which we have not attempted to do in the following trade maps.

5.1 Gasoline

A forecast of falling demand in the Atlantic Basin will put more pressure on refiners in this region than that East of Suez where demand growth is forecast to be stronger. The greatest pressure on refineries will be on the regions where demand falls are largest, North America and Europe. The global gasoline surplus also puts most pressure on refiners with high gasoline yields. North American gasoline yields are the highest, approximately 40%, and we believe that refiners in this region will have to cut runs the most, as European refineries continue to push gasoline into North America.

Figure 42: Gasoline Trade Flows



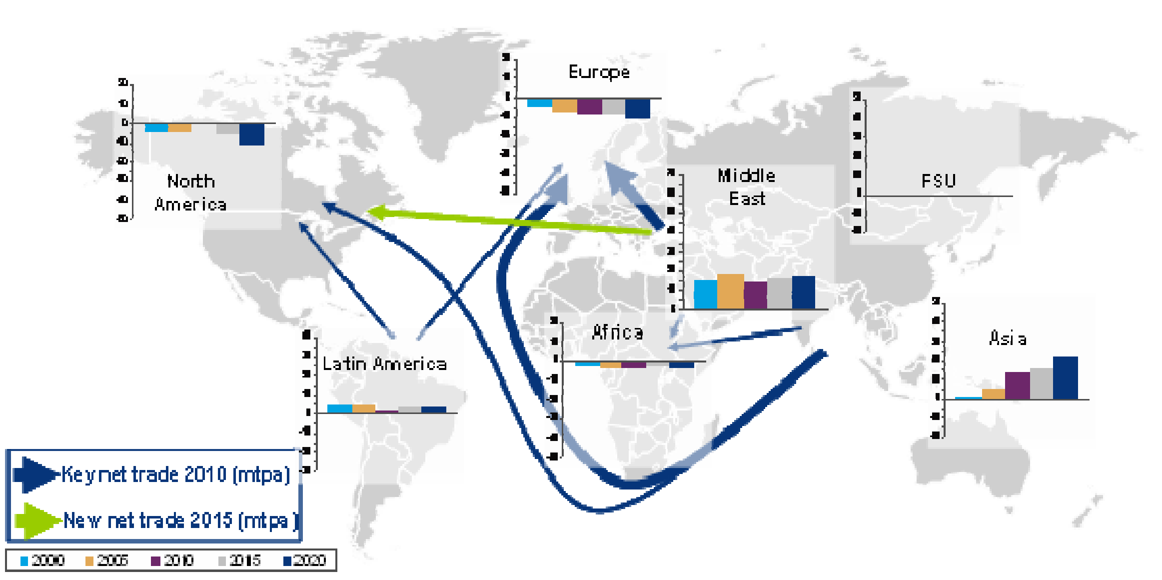
Source: Wood Mackenzie

Increasing competition to supply the North American gasoline is expected from major new export orientated refineries in the Middle East and India. This is expected to put further strain on North American refinery utilisations. As a result of US refiners cutting runs and switching yields away from gasoline to diesel/gasoil, the country's deficit of gasoline may start to grow again contrary to current expectations.

5.2 Kerosene/Jet fuel

The surpluses in the Middle East and Asia will compete for long haul jet/kero deficit markets. Continued demand growth in Greater Europe will increase Greater European kerosene deficits and draw in increased supply from other regions.

Figure 43: Jet/Kero Trade Flows

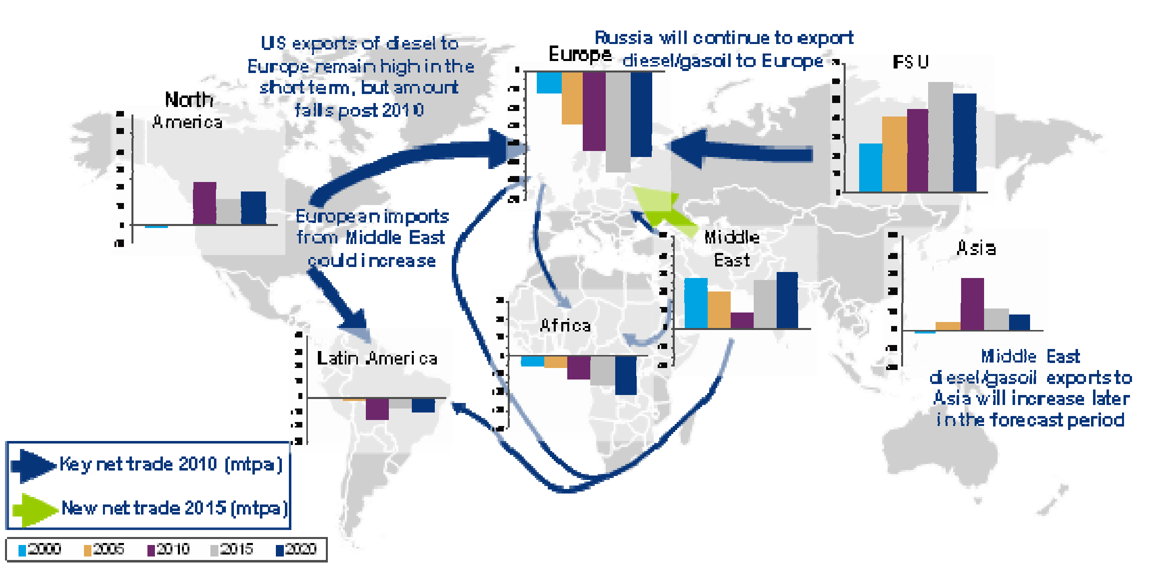


Source: Wood Mackenzie

5.3 Gasoil/Diesel

A forecast of increasing gasoil/diesel demand in Greater Europe is expected to help support Greater European refinery runs although they are still expected to be restrained due to falling demand for other products. Large deficits of gasoil/diesel are expected to grow which are expected to draw in large volumes of imports.

Figure 44: Gasoil/Diesel Trade Flows



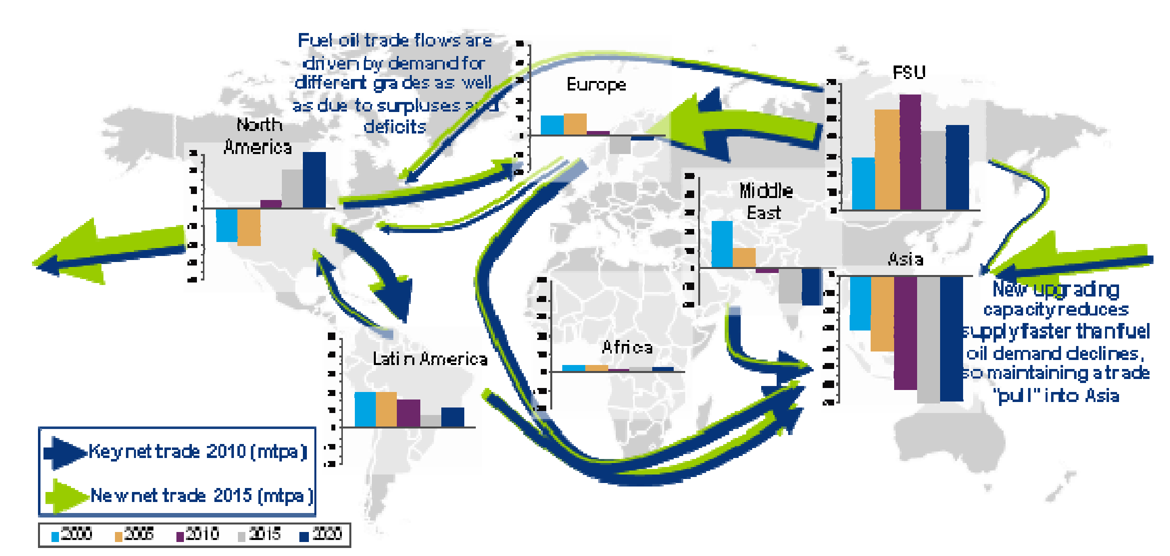
Source: Wood Mackenzie

The Former Soviet Union has a large surplus of gasoil/diesel and is expected to remain a principle supplier of gasoil/diesel to Greater Europe. New export orientated refineries in the Middle East are expected to target the large gasoil/diesel deficit in Greater Europe. Surplus production of gasoil/diesel in North America is expected to provide some limited support to some North American refineries with the surplus production expected to be sent to Greater Europe.

5.4 Heavy Fuel Oil

Demand for heavy fuel oil is expected to fall or stay flat in all regions with the exception of the Middle East and to a small extent Africa. As refineries seek to improve their margins many are upgrading their refineries to produce increased yields of lighter products at the expense of fuel oil yields. Fuel oil supply is expected to decline going forwards. As a result we expect changes to the present fuel oil trade (see Figure 45).

Figure 45: Fuel Oil Trade Flows



Source: Wood Mackenzie

Asian deficits of fuel oil are expected to remain the main driver behind global trade drawing in supply from almost all other regions. Refinery upgrade projects are expected to reduce the fuel oil surplus in the Former Soviet Union which is the worlds dominant fuel oil surplus region. Reduced fuel oil demand in North America is expected to create a growing surplus of fuel oil which is expected to result in increased exports to Asia.

6 Biofuels Experiences Around The World

In this chapter a review of the exiting biofuels mix in Europe is undertaken. This is then followed by experiences from past, current and predicted future biofuels implementation in other major global biofuels markets, such as the US, Brazil and Asian countries. The experiences of other countries is reviewed in the context of the following features of each of these markets:

- Availability of biofuel components.
- Legislative framework and fiscal incentives to promote biofuels.
- In-market experience including customer pull.
- Commercial business case for biofuels implementation.

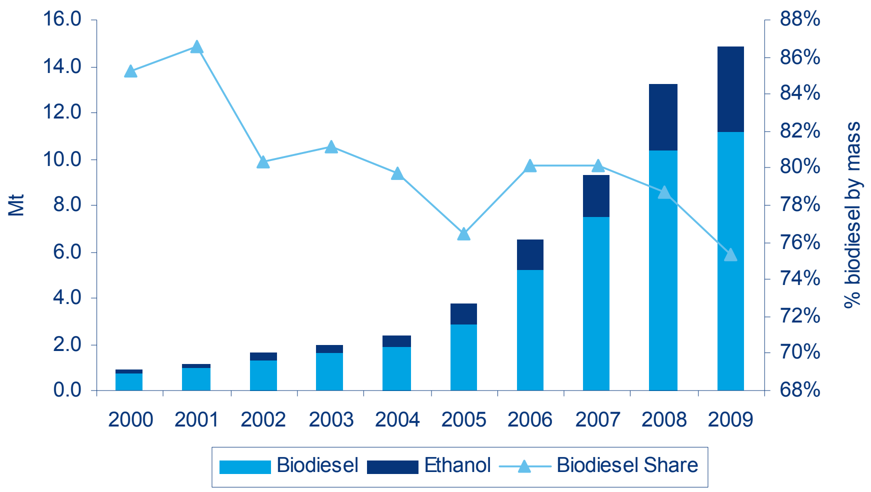
6.1 Review of the existing biofuels mix in the EU

6.1.1 EU Biofuel Consumption

Figure 46 shows how the consumption of biofuels developed in the EU between 2000 and 2009. In 2009 a total of just under 15 Mt of biofuels was placed on the European market, having grown from less than 1 Mt in 2000. Of the 2009 total, an estimated 11 Mt (75% by mass) was biodiesel and 3.5 Mt was ethanol.

Of the biodiesel, around 97% was fatty acid methyl esters (FAME), with around 2% hydrotreated vegetable oil (HVO) and 1% pure vegetable oil. Over 95% of the biodiesel was marketed in low-level blends (not exceeding 7% by volume) of biodiesel with conventional mineral diesel. There remain some niche markets for higher-level blends of biodiesel, or even pure biodiesel. In France, many city bus fleets run on a B30 blend. In Germany, the market for B100 fuel reached nearly 2 Mt in 2007, but has since collapsed to less than 0.3 Mt in 2009, as the excise duty subsidy on B100 fuel has gradually been reduced.

Figure 46: EU Biofuels Consumption, 2000 - 2009



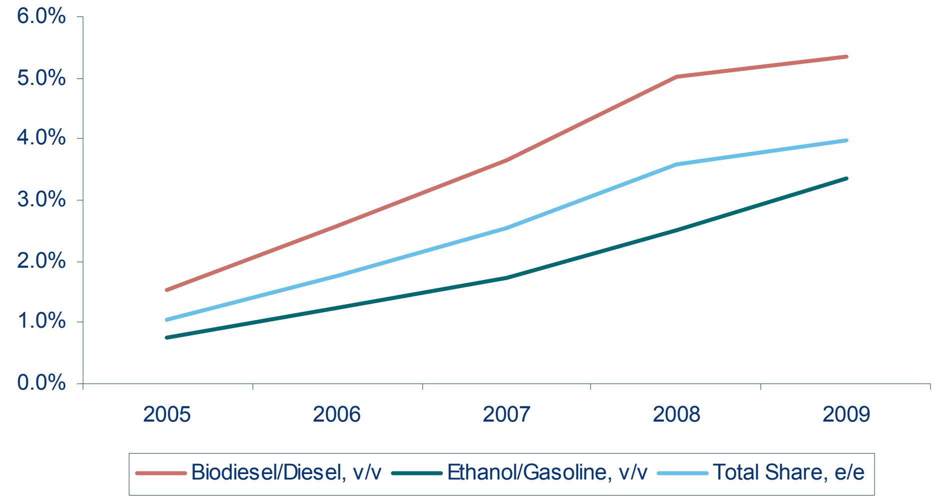
Source: IEA, EU Biofuels Barometer, Wood Mackenzie

Note – Biodiesl includes pure vegetable oil

Of the fuel ethanol consumed in the EU in 2009, over 95% was marketed as low-level blends in which the ethanol content did not exceed 5% by volume, or in which ethanol was included in the fuel in the form of ETBE. There are niche markets for E85 fuel in several EU countries, but Sweden accounts for the majority of the E85 market. Just over 40% of the fuel ethanol consumed in Sweden in 2009 was sold as E85, with the remainder sold in low-level blends.

Figure 47 puts these biofuel consumption figures into context with the overall road transport fuels market in the EU. Biodiesel accounted for an estimated 5.4% of the approximately 230 billion litre EU road diesel market on a volume basis in 2009. Ethanol accounted for an estimated 3.4% of the approximately 130 billion litre gasoline market, again on a volume basis. Overall, biofuels accounted for 4% of energy use in road transport; up from 1% in 2005. Directive 2003/30/EC – the Biofuels Directive – required biofuels to account for 2% of road transport energy demand by 2005, rising to 5.75% by 2010. The 2005 target was missed and it seems highly unlikely that the 2010 target will be hit, but nevertheless, much progress has been made towards the aims of that Directive and we estimate that biofuels could contribute just over 5% of road transport energy demand in 2010.

Figure 47: Biofuels Share of EU Road Transport Fuels Markets

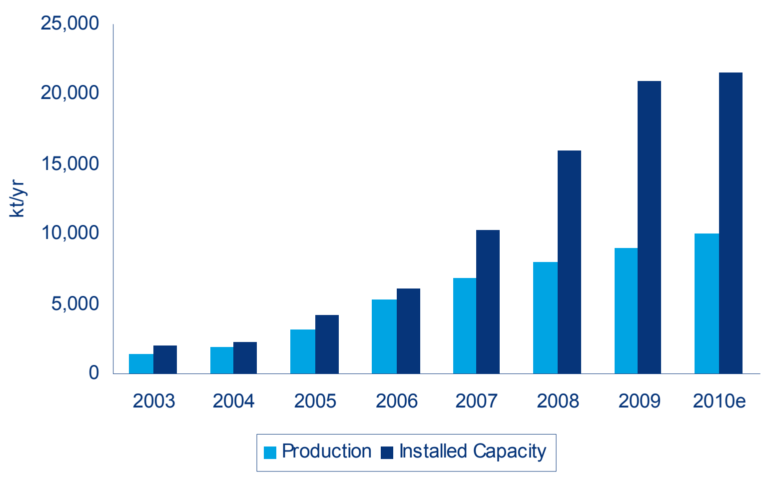


Source: Wood Mackenzie

6.1.2 EU Biofuel Production

Biodiesel production grew more than six-fold between 2003 and 2009 to reach 9 Mt (Figure 48). Biodiesel production capacity started to dramatically outpace actual production from around 2007 (Figure 48).

Figure 48: EU Biofuels Production and Installed Capacity, 2003 - 2009

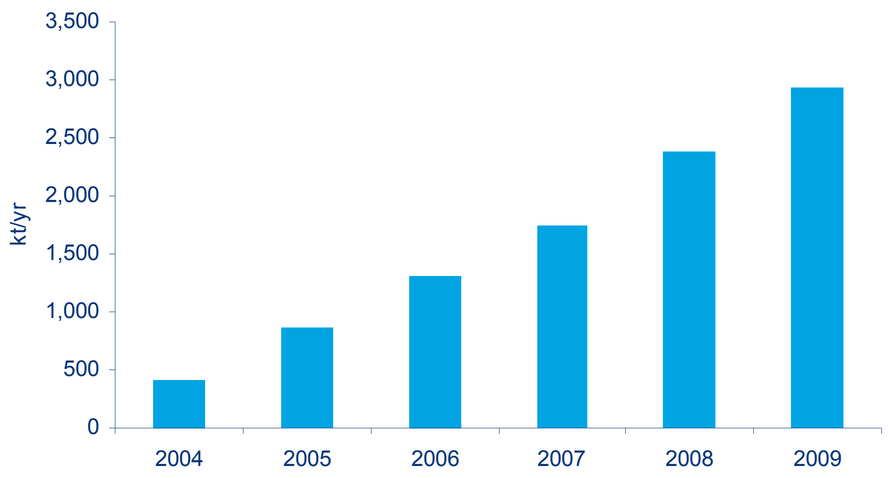


Source: Eurostat, EBB, Wood Mackenzie

The relatively low barriers to entry in terms of capital requirements and technology for esterification of vegetable oils, combined with a rising oil price and an apparently supportive regulatory environment led to a surge in investment in biodiesel production plants in the EU. As of July 2009, installed biodiesel production capacity is estimated to have totalled 22 million tonnes per year. With production of only just over 9 million tonnes in 2009, the average industry utilisation rate for the region was around 40%. A lot of biodiesel production capacity is currently lying idle and many European biodiesel producers are finding themselves in financial difficulties, which were exacerbated by the recent credit crunch. Rationalisation of existing capacity seems inevitable.

Of the 22 Mt per year of installed capacity, around 98% is FAME production capacity, with the remainder producing HVO. There are no commercial next-generation biodiesel production facilities currently in operation, or under construction.

Figure 49: EU Fuel Ethanol Production, 2004 - 2009



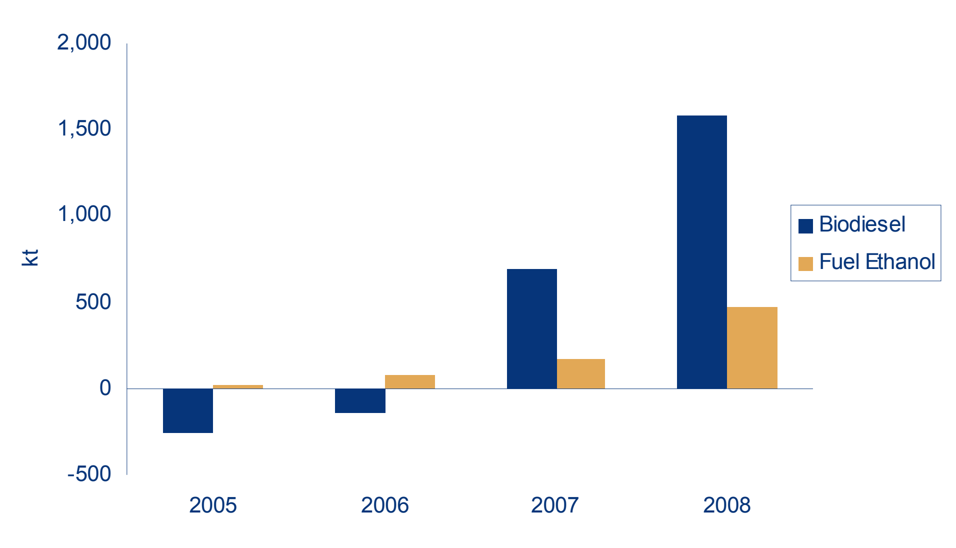
Source: Eurostat, EBIO, Wood Mackenzie

Figure 49 shows the development of fuel ethanol production in the EU between 2004 and 2009. Production grew more than seven-fold over this period to reach 2.9 Mt. Production is estimated to be growing rapidly in 2010 and could reach close to 4 Mt. Installed fuel ethanol production capacity in Greater Europe as of mid- 2010 is estimated at 5.7 Mt. A further 1.4 Mt of capacity is under construction, potentially raising total capacity to 7.1 Mt over the next couple of years.

6.1.3 EU Biofuel Trade

The EU was a net importer of biodiesel in 2008 (Figure 50). Most of those imports arrived from the US under what was termed the “splash and dash” trade loophole. Biodiesel is granted a US$1.00 per gallon tax credit when blended with at least 0.1% diesel in the US. Companies took advantage of this by creating “B99” blends to obtain the tax credit, then exporting the blend to Europe, where, thanks to the tax credit, they were able to substantially undercut domestic biodiesel producers. Most of the biodiesel exported to Europe in this way was produced in the US, but significant quantities were also produced in Argentina and South East Asia, blended with a splash of diesel in the US to obtain the credit and then re-exported to Europe. In March 2009 the EU imposed provisional anti-dumping duties on imports of biodiesel originating from the US and these were made permanent in June. The EU remains a net importer of biodiesel, but imports from the US have fallen away since the second half of 2009 and now Argentina and South East Asia are the major sources of EU biodiesel imports.

Figure 50: Biofuel Net Imports, 2004 - 2008



Source: Eurostat, Wood Mackenzie

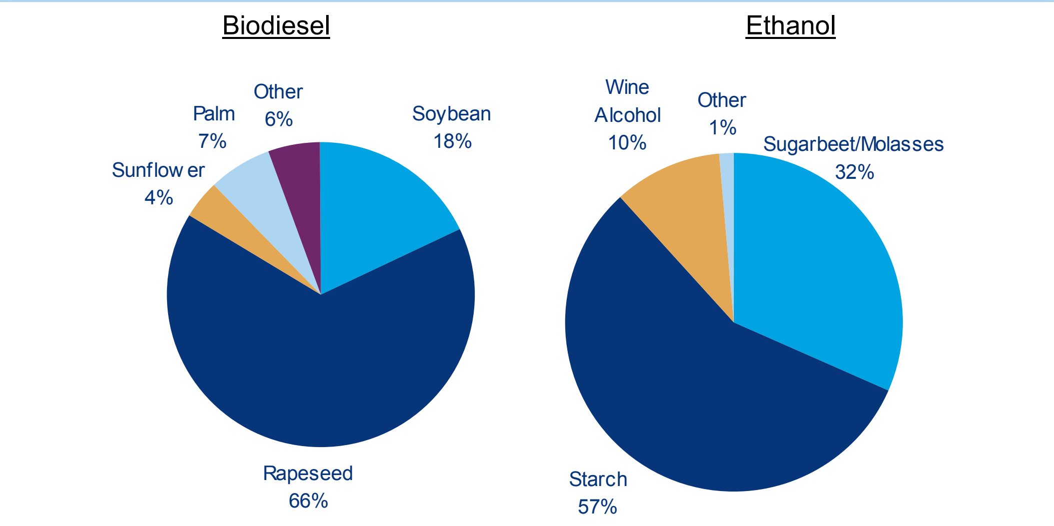
Greater Europe was a net importer of fuel ethanol in 2008. Brazil has been by far Europe's largest trade partner for ethanol in recent years. Brazilian ethanol has at times been very competitive in the European market depending upon the prevailing price in Brazil, the import tariff applied and the structure of tax incentives in the consuming country.

6.1.4 Biofuel Feedstocks

Figure 51 shows our estimate for the share of different feedstocks used to produce biofuels in the EU in 2008. The percentages shown represent the share of the total volume of each biofuel produced in the EU from those feedstock types.

Europe is a major producer of rapeseed, and consequently, biodiesel production in Greater Europe is currently dominated by rapeseed oil, which accounted for an estimated 66% of production in 2008. Soybean oil was estimated to be the second most important feedstock, responsible for 18% of biodiesel production. Palm oil, sunflower oil and other feedstocks (primarily waste oils and tallow) accounted for the remaining 17% of production combined.

Figure 51: EU Biofuel Production By Feedstock Type, 2008



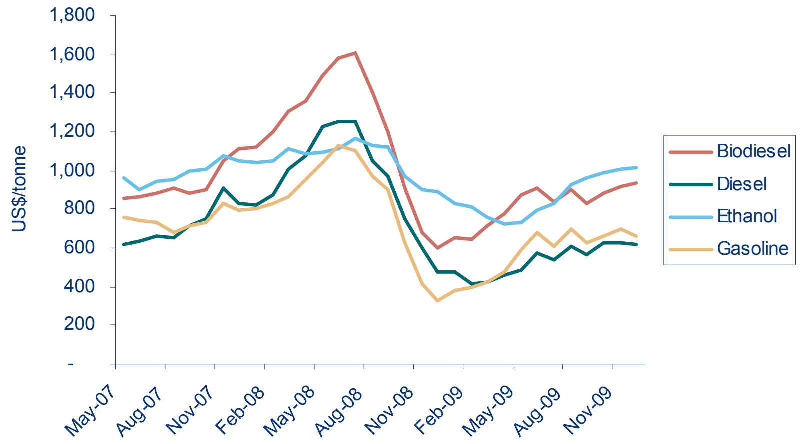
Source: Wood Mackenzie

In 2008 wheat starch was the most commonly used feedstock for ethanol production in the EU. Corn starch was only a minor source of ethanol in 2008. Other starch crops used included rye, triticale and potatoes. Sugar beet juice and molasses is estimated to have accounted for 32% of ethanol produced in the EU in 2008. Surplus wine sold under the EU's crisis distillation programme remained an important feedstock for ethanol production in 2008.

6.1.5 Biofuel Prices

Figure 52 compares biofuel wholesale market prices against those for conventional transport fuels. Biofuels have generally been priced at a premium to the competing conventional fuel, which has resulted in the need for subsidies, or mandates to ensure their entry to the market. Biodiesel has on average been priced at a slight premium to ethanol on a mass basis. Over the long term, the biodiesel price has correlated closely with the prevailing vegetable oil price and given the huge biodiesel capacity overhang we would expect that to continue to be the case in the future. It is less easy to find a simple correlation for the European ethanol price. The European price will be influenced by prices in exporting markets - mainly Brazil and the US - as well as by the prevailing gasoline and biodiesel prices.

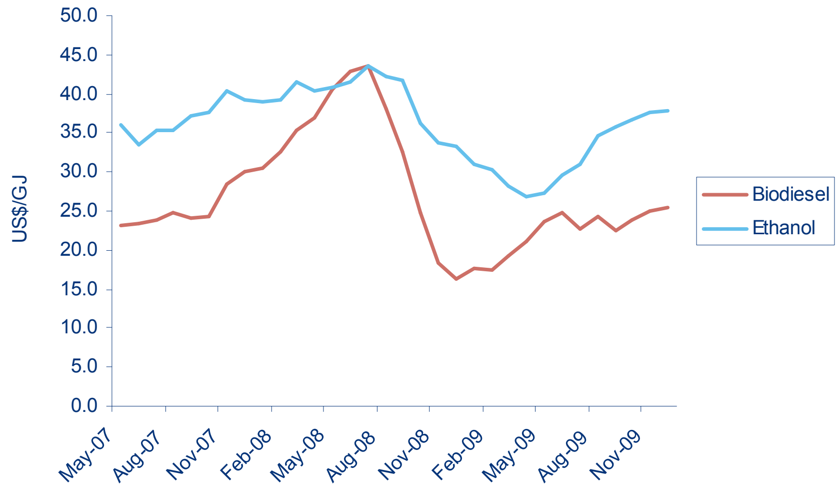
Figure 52: Biofuel Market Prices in NWE, 2007 - 2009



Source: Argus, FO Licht, Wood Mackenzie

It is interesting to compare the prices of the two types of biofuel on an energy basis (as shown in Figure 53) since the aims of the Biofuels Directive and the RED are stated in energy terms. On that basis, ethanol has been priced at a significant premium to biodiesel on average over the past two years.

Figure 53: Biofuel Price per Unit of Energy in NWE, 2007 - 2009



Source: Argus, FO Licht, Wood Mackenzie

6.1.6 The Future Biofuels Mix in the EU

The future mix of biofuels on the EU market will depend on the complex inter-relation between market forces and the regulatory framework put in place by Member States in order to fulfil their obligations under the Renewable Energy Directive and any other current, or subsequent, EC Directives affecting the transport fuels sector. In the following section we highlight some key questions which will shape the future mix of biofuels marketed in the EU.

What Policies Will EU Member States Employ to Ensure They Comply With Renewable Fuels Legislation?

Government policy has been a major factor in determining the mix of biofuels on the EU market in the past and it will continue to play a crucial role in the future. There is considerable uncertainty as to how each Member State will design its policies to ensure that it meets the requirements of the RED and any subsequent legislation on renewable transport fuels beyond 2020. Currently a very wide range of policy measures is enacted by EU countries in order to meet the requirements of the 2003 Biofuels Directive.

The main policy levers are the use of tax incentives to promote the use of different types of biofuels, or mandates to ensure either that specified volumes of biofuels are placed on the market, or that biofuels reach a specified share of the market. Often a combination of tax incentives and mandates has been used.

Probably the highest level of state control on the renewable transport fuels market in the EU has involved specific volumes of biofuels from specific plants being provided with excise duty exemptions, or reductions, which has at least partially controlled the volume of each type of biofuel placed on the market. Such policies have been seen in action as part of the biofuels policies in France, Portugal, Italy and Greece amongst others. Some countries have set mandates for each type of fuel – a certain share of the diesel market and a certain share of the gasoline market (e.g. Czech Republic, Belgium, Lithuania). Other countries have set non-fuel specific mandates on the total road transport fuels market, but have then specified that minimum levels of biofuel use must be met within the diesel and gasoline markets respectively (e.g. Germany and Netherlands). Other countries have not specified minimum levels in either fuel type, but have set an overall target level. Yet, even with these seemingly unbiased policies, there is often an accompanying excise duty incentive, which normally involves duty exemption for the biofuels. This tends to favour one type of biofuel over others, since the excise duties applied on diesel and gasoline are not often equal. Some policy targets have been set on an energy-basis (e.g. Germany, France, Spain, Poland), while others have been set on a volume basis (e.g. UK, Czech Republic, Ireland) - each type of policy has different implications for the biofuels mix given the differing volumetric energy content of different biofuels.

It is anticipated that a future emerging trend in renewable fuels policy will be to set targets based on an overall reduction in the life-cycle carbon emissions of the transport fuels pool. This would have different implications again on the biofuels mix, which it will not be possible to quantify until full details of the legislation emerge.

No country has yet set its renewable transport fuel policies all the way through to 2020, and even if they had, changes in policy are almost inevitable as regulators react to the prevailing market conditions, changing public opinion and changing governments. What is certain is that the EU renewable transport fuels legislation will continue to be implemented in a diverse number of ways, and this will have unknown consequences for the mix of biofuels on the market.

What is the Timeframe for the Commercialisation of Next-Generation Biofuels?

There is considerable uncertainty as to the time-scale for the commercialisation of the next-generation of biofuels production technologies, by which we mean technologies which would produce biofuels from non-food feedstocks. Within this category we would also include the development of novel feedstocks, such as algae, which may provide feedstocks which can be converted to liquid fuels in conventional biofuels production plants. Most of the envisaged production routes are described in Figure 68.

As yet, next-generation biofuels technologies are all unproven on a commercial scale and there are currently only a handful of pilot and demonstration facilities in Europe. 29 next generation biofuels projects, at various stages of development, were identified in a recent report for IEA Bioenergy Task 39 and are listed in Figure 54. This highlights the very early stage of industrial development of most of these technologies. The volumes of next-generation biofuels available within the next five years will likely be very small.

There are certainly a large incentive within the RED to market such advanced biofuels, whereby they count double towards the 10% energy target in 2020. This should ensure a market price well in excess of first-generation biofuels. However, to realise those prices, project developers first need to secure the capital required to build a commercial scale plant, which is no easy task when the technology is unproven at that scale and the sums being sought run into the many hundreds of millions of euros. Only time will tell if these technologies can be applied successfully at a large scale and at a cost which enables them to compete, albeit initially with the help of legislation, with first generation biofuels and other renewable energy sources.

Figure 54: Next Generation Biofuel Projects

Company	Country	Input Material	Product	Output, t/a	Type	Status	Start-up
Abengoa Bioenergy, Biocarburantes Castilla y Leon, Ebro Puleva	Spain	Wheat/wheat straw, corn stover	Ethanol	4000	Demo	Under construction	2010
BioGasol	Denmark	Grasses, garden waste, straw	Ethanol	4000	Demo	Planned	2016
BioGasol/AAU	Denmark	Flexible	Ethanol	10	Pilot	Planned	2010
Boorgaard Industries Ltd	Norway	Sulfite spent liquor	Ethanol	15800	Commercial	Operational	1930
Chemrec AB	Sweden	Sulfite spent liquor	DME	1800	Pilot	Under construction	2010
Chemrec AB	Sweden	Sulfite spent liquor	Methanol, DME	95000	Pilot	Planned	2013
Choren Fuel Freiberg GmbH & Co. KG	Germany	Dry wood chips	Biodiesel	14000	Commercial	Under construction	2010
Choren Industries GmbH	Germany	Dry wood chips	Biodiesel	200000	Commercial	Planned	2016
CTU - Conzepte Technik Umwelt AG	Austria	Lignocellulosics	Substitute Natural gas	576	Demo	Operational	2008
Cutec	Germany	Straw, wood, dried silage, organic residues	Biodiesel	N/A	Pilot	Operational	1990
ECN	Netherlands	Lignocellulosics	Substitute Natural gas	28800	Demo	Planned	2016
ECN	Netherlands	Lignocellulosics	Substitute Natural gas	346	Pilot	Under construction	2011
EtanolPiloten I Sverige AB	Sweden	Primary wood chips and sugarcane bagasse	Ethanol	80	Pilot	Operational	2004
Forschungszentrum Karlsruhe GmbH	Germany	Lignocellulosics	Biodiesel, biogasoline	608	Pilot	Under construction	2016
Inbicon (DONG Energy)	Denmark	Wheat Straw	Ethanol	4300	Demo	Operational	2009
Inbicon (DONG Energy)	Denmark	Wheat Straw	Ethanol	N/A	Pilot	Operational	2005
Inbicon (DONG Energy)	Denmark	Straw	Ethanol	N/A	Pilot	Operational	2003
Mossi & Ghisolfi - Chemtex Italia	Italy	Corn stover, straw, husk, woody biomass	Ethanol	50	Pilot	Operational	2009
Mossi & Ghisolfi - Chemtex Italia	Italy	Lignocellulosics	Ethanol	40000	Demo	Planned	2011
M-real Hallein AG	Austria	Sulfite spent liquor	Ethanol	12000	Demo	Planned	2016
NSE Biofuels Oy (Neste/Stora Enso JV)	Finland	Forest residues	Biodiesel	656	Demo	Operational	2009
NSE Biofuels Oy (Neste/Stora Enso JV)	Finland	Forest residues	Biodiesel	100000	Commercial	Planned	2016
PROCETHOL 2G	France	Lignocellulosics	Ethanol	2700	Demo	Under construction	2016
SEKAB	Sweden	Wood chips or sugarcane bagasse	Ethanol	50000	Demo	Planned	2014
SEKAB	Sweden	Lignocellulosics	Ethanol	120000	Commercial	Planned	2016
SEKAB Industrial Development AB	Sweden	Wood chips or sugarcane bagasse	Ethanol	4500	Demo	Planned	2011
Technical University of Denmark	Denmark	Wheat straw, corn fibre	Ethanol	10	Pilot	Operational	2006
Vienna University of Technology	Austria	Lignocellulosics	Biodiesel	N/A	Pilot	Operational	2005
Weyland AS	Norway	Wood sawdust	Ethanol	158	Pilot	Under construction	2010

Source: IEA Bioenergy Task 39

What Will be the Availability and Price of First-Generation Biofuel Feedstocks?

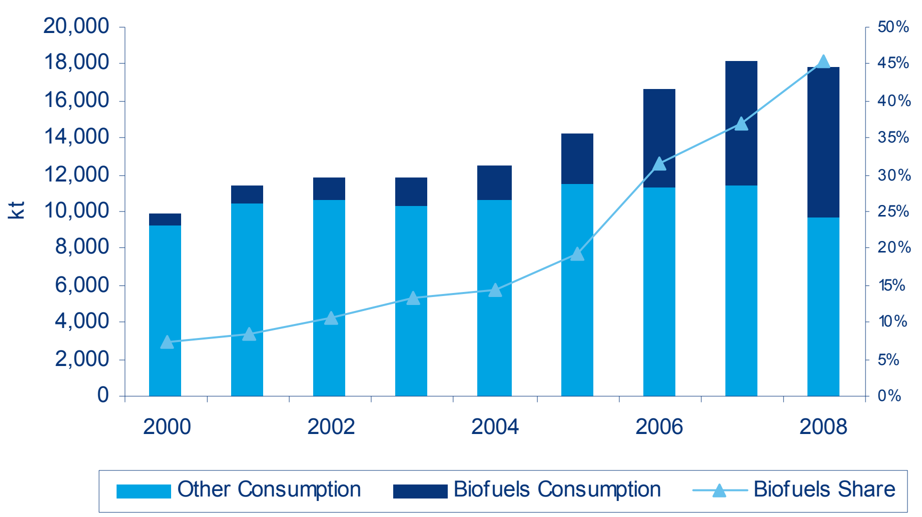
The current generation of biofuels are produced from food crops, most of which are internationally traded commodities. These raw materials account for a large proportion of the production costs for biofuels - well over 90% in the case of biodiesel and between 60 and 75% for ethanol production from grains. Changes in the relative prices of the different commodities will change the relative prices of biodiesel and ethanol and therefore the likely mix of biofuels which transport fuel suppliers use to comply with the renewable fuel mandates which they are subject to.

There are competing demands for these crops from the food and feed sectors, as well as from growing biofuels production and use in other parts of the world. Growing demand for biofuel production will require continuing growth in the production of these crops, over and above the growth already needed for food and feed use, which expands as the global population grows and as incomes increase. A combination of planting more land with the crops and improving the yields obtained will be required to continue to provide the world with both food and fuel.

Biodiesel is produced from vegetable oils and fats. Three vegetable oils - rapeseed oil, palm oil and soybean oil - account for approximately 75% of global vegetable oil production of just under 140 Mt. If biodiesel targets around the world are to be met, including those in the EU, then these three feedstocks are expected to supply the vast majority of that demand for at least the next decade.

As shown in Figure 55, biodiesel demand has taken an increasing share of the EU vegetable oils market in recent years. That share is projected to rise, as demand for biodiesel continues to grow rapidly. The EU produced around 13 Mt of crude vegetable oils in 2008. In that year, biodiesel demand was around 10 Mt. In the near future, biodiesel demand will exceed the total production of vegetable oils in the EU and imports of feedstocks and finished biodiesel will inevitably need to continue to rise to meet the demand.

Figure 55: Biofuels Share of the EU Consumption of Major* Vegetable Oils



Source: USDA, Celeres, Wood Mackenzie

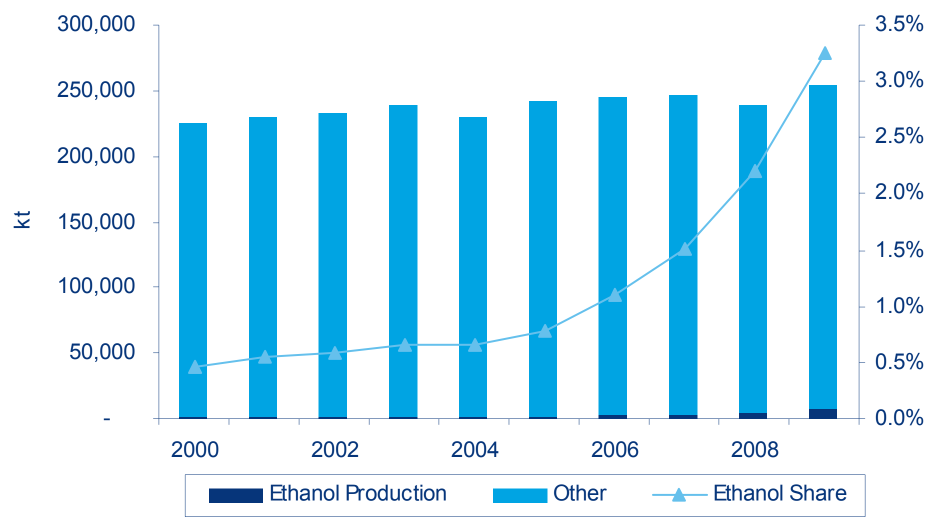
*Soybean Oil, Sunflower Oil, Rapeseed Oil and Palm Oil

Around 90% of the planted area for rapeseed is in Canada, China, the EU and India. China and India likely to consume all that they produce to feed their large, growing populations. The EU will therefore need to grow its own production to meet increasing demand from the biodiesel industry, with some help from imports from Canada. Over 80% of global palm oil production is from Indonesia and Malaysia. There is acknowledged to be limited additional scope for increasing palm oil area in Malaysia. While planted area in Indonesia will expand, it too is ultimately limited, especially for biodiesel production, given the sustainability rules concerning land-use which are contained within the EU RED.

Soybean production is less limited by land area constraints, as significant expansion could occur in Argentina and particularly in Brazil. However, soybeans have a low oil content – typically less than 20% by mass – making it a less than ideal crop to meet the expanding demand for vegetable oils from the food and fuels sectors. The supply/demand balance in the global vegetable oil market has tightened over the past decade, partly as a result of increasing biodiesel production, but also due to increasing consumption for food purposes. Our detailed country-by-country analysis of the oilseeds market suggests that the market will remain tight in the future. This will keep upward pressure on vegetable oil prices, with the potential for substantial price volatility.

There is considered to be less constraint on ethanol feedstocks in the EU. Figure 56 shows the share of ethanol production in total EU consumption of wheat, corn and barley, which was only around 3% in 2009.

Figure 56: Ethanol Share of the EU Consumption of Major* Grains



Source: Wood Mackenzie

* Wheat, Corn, Barley

On balance, due to the additional pressure which biodiesel might exert on the vegetable oils market we would expect the biodiesel price to rise relative to the ethanol price between 2010 and 2030.

How Will the Interaction of Biofuels With the Road Vehicles and the Fuel Distribution Infrastructure Impact the Biofuels Mix?

The future biofuels mix in the EU will be influenced by the types of vehicles on the road and their ability to use different types and proportions of biofuels and other renewable fuels. This issue is discussed in detail in Chapters 7 and 8. The nature of the fuel distribution infrastructure and its compatibility with different levels of biofuels could also impact the biofuels mix and this is discussed in Chapter 10.

6.2 Brazil

Brazil is probably the archetypal success story for the development of a large, sustainable biofuels market and is the only market in the world where biofuels are now the dominant transport fuels. This situation has been several decades in the making and is the result of sustained, supportive government policy, its unique sugarcane sector and more recently, developments in vehicle technology.

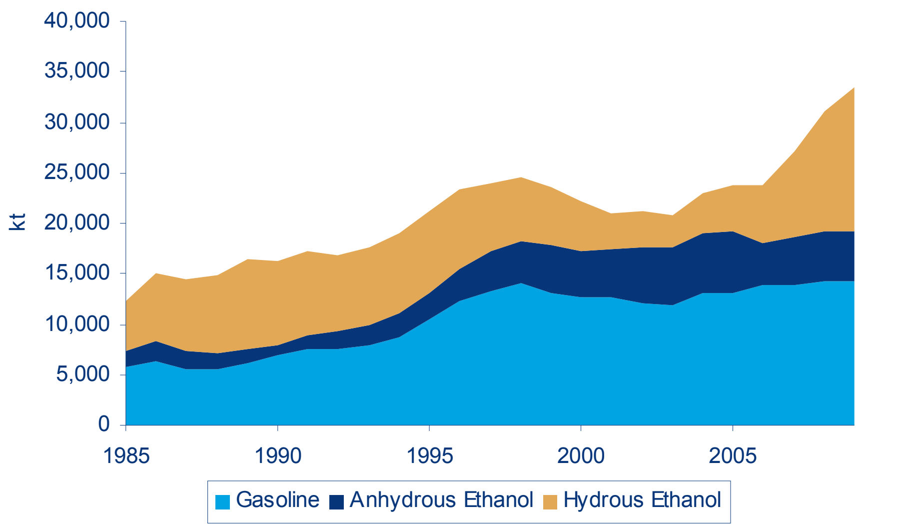
The inclusion of ethanol in gasoline was first mandated by the Brazilian government in the 1930s to support the sugar cane sector in response to a large fall in international prices. Fuel ethanol use continued over the decades and consumption climbed in World War II when shortages of conventional fuel were commonplace.

The oil crisis of the 1970s saw the creation of Brazil’s National Alcohol Program (Proalcool), in order to reduce the country’s dependence on imported oil and improve its balance of payments situation. Incentives were provided to finance the building of distilleries, and the ethanol price was fixed so that it was cheaper than using gasoline, thereby encouraging consumers to purchase the recently developed cars which ran on 100% hydrated ethanol.

Ethanol production and consumption soared until the mid-1980s, when falling oil prices started to make ethanol uncompetitive with gasoline. The world sugar price also increased, so that producers focussed on sugar production, thereby creating a shortage of ethanol. This reduced consumer confidence in the product, and sales of ethanol-only powered cars started to fall. During this time, the government fixed the level of anhydrous ethanol to be mixed with gasoline at a mandatory 22% to help support the market.

In the late 1990s, the alcohol program was further reformed, with the ethanol price and its distribution being liberalised. The mandatory blending level for anhydrous ethanol in gasoline was now to be varied between 20% and 24%.

Figure 57: Gasoline and Fuel Ethanol Demand in Brazil, 1985 - 2009

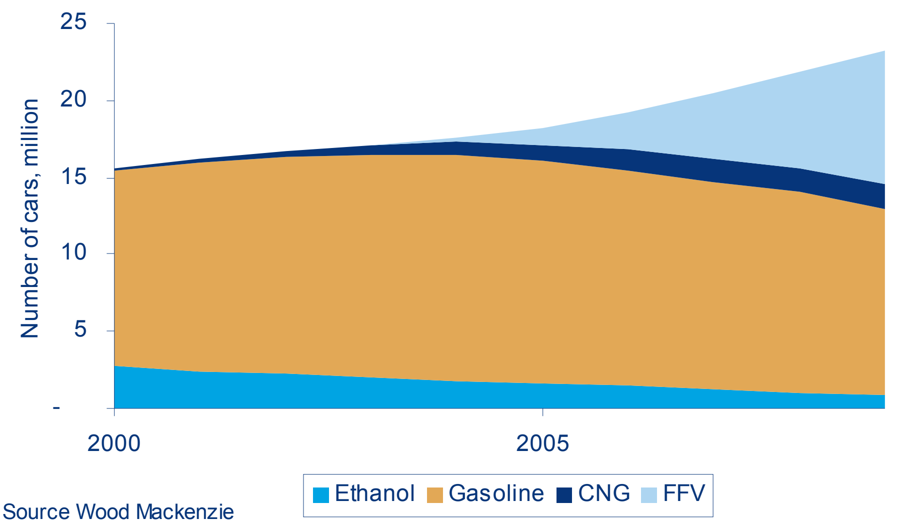


Source: IEA, Wood Mackenzie

The government currently sets a mandated level for the inclusion of ethanol in gasoline, which varies between 20-25% depending on the prevailing supply/demand balance in the ethanol market. Ethanol also benefits from tax incentives – an exemption from CIDES tax and a reduced level of PIS/CONFIS tax. Individual states also offer varying consumption tax incentives for ethanol. As a result of the long standing government support for the ethanol program, ethanol represented an estimated 56% of the overall gasoline pool in 2009, on a volume basis.

Having remained at around 10 Mt (0.2 Mb/d) throughout the 1990s and the first half of this century, 2007 saw the start of a strong upward trend in ethanol consumption in Brazil, as demand jumped by over 30% compared to the previous year and similar growth was recorded in 2008.

Figure 58: Brazil Light-Duty Vehicle Fleet



Source: Wood Mackenzie

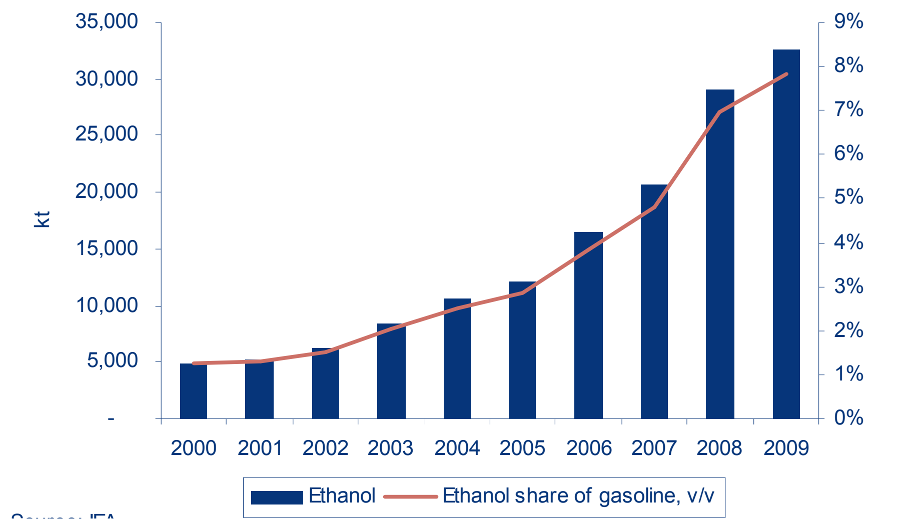
There are two major drivers to this explosion in demand. The first is the rise in the oil price in this period making ethanol a more economically attractive proposition for consumers. The second is the mass-market introduction of the flexible-fuel vehicle (FFV). These cars can run on either pure ethanol or gasoline, or any mixture of the two, and therefore expand considerably the number of vehicles which can use pure ethanol should the pump price relative to competing fuels, such as gasoline, incentive the consumer to choose ethanol. FFV sales started to take-off in 2005 and by 2007 accounted for around 90% of new car registrations in Brazil. The mixture of a competitive price for ethanol and a large and growing fleet of vehicles able to use it has resulted in very rapid growth in ethanol consumption and will continue to underpin its continued growth for the foreseeable future.

The development of the biodiesel market in Brazil is a much more recent phenomenon and has so far been dependent upon government mandates. From January 2008, a B2 mandate applied to all diesel fuel sold in Brazil. The mandate was raised to 3% from July 2008, then 4% in 2009 and 5% in 2010 – three years ahead of the original schedule of 2013. The mandate is administered by a state entity and compliance has been good.

6.3 USA

A combination of government mandates, tax incentives and fuel quality legislation has resulted in the US growing into the largest biofuel market in the world, with ethanol consumption totalling around 33 Mt in 2009.

Figure 59: US Fuel Ethanol Demand, 2000-2009



Source: IEA

Ethanol has been used as a fuel oxygenate in the US for several decades. The federal oxygenated gasoline and reformulated gasoline programs, aimed at improving air quality, were implemented in the 1990s, requiring gasoline to contain specific levels of oxygen. Although MTBE was the most widely used fuel oxygenate, ethanol was used in certain areas of the country. More recently, government mandates have been put in place, requiring increasing volumes of fuel ethanol to be placed on the market. In 2005 by the Energy Policy Act of 2005, which introduced a Renewable Fuels Standard (RFS) to ensure that increasing volumes of renewable fuels were placed on the market between 2006 and 2012. The target rose progressively to reach 7.5 billion gallons (22.5 Million tonnes of ethanol equivalent) by 2012. The requirement to blend renewable fuels falls on all refiners, blenders and importers that place fuel on the US market, except for small refineries, which are exempt for a period of five years and may apply for the exemption to be extended if economic hardship is envisioned. Ethanol demand was further boosted in this period by the effective banning of the use of MTBE as a fuel oxygenate due to problems with ground water contamination in many states.

In December 2007, the Energy Independence and Security Act (EISA) of 2007 was signed into law, containing amendments to the original RFS. These amendments significantly extend the renewable fuels volume target and assign certain proportions of the new target to specific types of biofuels as detailed in the table below.

- Advanced biofuels are defined as "renewable fuel, other than ethanol derived from corn starch, that has lifecycle greenhouse gas emissions … that are at least 50 percent less than baseline lifecycle greenhouse gas emissions".
- Biomass-based diesel is defined as "renewable fuel that is biodiesel … and that has lifecycle greenhouse gas emissions … that are at least 50 percent less than the baseline lifecycle greenhouse gas emissions". The biomass-based diesel requirement will not be lower than that set for 2012 in the following years.
- Cellulosic biofuel is defined as "renewable fuel derived from any cellulose, hemicellulose, or lignin that is derived from renewable biomass and that has lifecycle greenhouse gas emissions … that are at least 60 percent less than the baseline lifecycle greenhouse gas emissions".

Figure 60: US Renewable Fuels Standard

Year	Renewable Fuel (bn gal)	Of which - Advanced Biofuel (bn gal)	Of which - Cellulosic Biofuel (bn gal)	Of which - Biomass-Based Diesel (bn gal)
2006	4.00			
2007	4.70			
2008	9.00			
2009	11.10	0.60		0.50
2010	12.95	0.95	0.10	0.65
2011	13.95	1.35	0.25	0.80
2012	15.20	2.00	0.50	1.00
2013	16.55	2.75	1.00	At least 1 bn gal from 2012
2014	18.15	3.75	1.75	
2015	20.50	5.50	3.00	
2016	22.25	7.25	4.25	
2017	24.00	9.00	5.50	
2018	26.00	11.00	7.00	
2019	28.00	13.00	8.50	
2020	30.00	15.00	10.50	
2021	33.00	18.00	13.50	
2022	36.00	21.00	16.00	

Source: Wood Mackenzie

In addition to the mandates described above, fuel tax incentives have played an important role in encouraging the development of the ethanol market. Prior to 2005, E5.7, E7.7 and E10 blends of ethanol with gasoline were subject to reduced rates of federal motor fuels tax. The Volumetric Ethanol Excise Tax Credit (VEETC) was then introduced, giving blenders an excise tax credit of $0.51 per gallon of ethanol. This tax credit was reduced to $0.45 from January 2009 by the 2008 Farm Bill. The current credit expires at the end of 2010. Cellulosic biofuels are given a production tax credit of $1.01 per gallon, which expires at the end of 2012.

So far, ethanol use in the US has been confined almost exclusively to blends with gasoline. Fuel quality specifications allow a maximum level of 10% ethanol in reformulated and conventional gasoline. Compliance with the RFS would require ethanol to exceed this level unless a large market for E85, or some other high-percentage ethanol fuel, were to develop. The EPA is due to rule on raising the blend level in gasoline for certain segments of the vehicle market, according to age, during 2010.

Tax credits are also provided for biodiesel. A credit of $1.00 per gallon was available for biodiesel made from virgin oils and fats and $0.50 per gallon if it is made from recycled oils and fats. This was extended to the end of 2009 by the Emergency Economic Stabilisation Act of 2008, which also removed the distinction between biodiesel feedstocks, giving a $1.00 per gallon to all biodiesel.

Small biofuel producers (up to 60 million gallons per year capacity) are also eligible for a further tax credit of $0.10 per gallon for the first 15 million gallons of biofuel production. Individual states also provide tax incentives to boost biofuel consumption.

6.4 Asia

Asia has lagged behind the other major regions in implementing biofuels promotion policies and accounted for only 4% of the global biofuels market in 2008. Most Asian countries have investigated the promotion of biofuels use, but with widely varying outcomes. Some have decided against promoting biofuels, others have tried to implement promotion policies, which have failed for and a few have successfully promoted the growing consumption of biofuels in their transport fuel markets. We present here a small selection of some of the experiences of Asian countries with biofuels.

6.4.1 Indonesia

Biofuels were first marketed on a commercial scale by Pertamina, the state owned oil company, and Lemigas, the R&D centre for oil and gas technology, in the mid 1990s. A key driver was high oil price. The biodiesel blend of B30 (30% palm oil and 70% diesel) soon became uncompetitive, as oil prices declined in the late 1990s. Since then, biofuels have remained largely on a development scale in Indonesia. Because Indonesia had traditionally been an exporter of crude oil, there was not a strong incentive to build a biofuels industry as a means of reducing dependency on imported oil supplies.

However, Indonesia's oil and gas production has been on the decline in recent years. Coupled with a lack of investment in its domestic refining capacity, Indonesia now imports a significant amount of its oil products requirements from regional suppliers such as Singapore.

Indonesia's National Energy Policy has a framework for increasing renewable fuels in the national energy mix and targets biofuels use to increase from 2% by 2010 to 5% of the total energy mix by 2025. In a separate roadmap for ethanol and biodiesel, biofuels content in gasoline and diesel transport fuel is planned to increase progressively to 10% by 2010, 15% by 2015 and 20% by 2020.

However, there are significant challenges ahead before biofuels can become mainstream in Indonesia:

- **Dependency on Pertamina's Logistics Network.** Pertamina has a central role to play in distributing and marketing biofuels through its extensive retail outlets, and this includes making biofuels available into far flung areas of the Indonesian archipelago

- **Legacy of Oil Product Subsidies**. Indonesia currently subsidises transportation gasoline and diesel, which sells for below import parity prices and thus affects the economic competitiveness of biofuels against petroleum fuels

- **Economic Burden to Pertamina**. There are also unresolved issues around how Pertamina is compensated for purchasing and blending biofuels components into its gasoline and diesel. The state oil giant currently has no biofuels production capacity of its own and has to procure them from third party manufacturers. In the event that these components are procured at prices higher than the benchmark import parity prices, there are no legal mechanisms for Pertamina to claim these additional expenses from the government. Indeed, the effects of this have been seen in action over the past year; Pertamina has been marketing biodiesel blended with diesel in the metropolitan Jakarta area through part of their retail network. The blend level rose to 5% in 2008, as the relative movements of the oil and palm oil market prices made biodiesel more competitive. However, commodity price movements have again made biodiesel significantly more expensive than diesel in 2009 and the blend level was reduced back to 1%.

Figure 61: Indonesia Biofuels Mandate - Biodiesel

Sector	Minimum biofuels content					
	2008	**2009**	**2010**	**2015**	**2020**	**2025**
Transport (Public Service Obligation)	1%	1%	2.5%	5%	10%	20%
Transport (non- Public Service Obligation)		1%	3%	7%	10%	20%
Commercial and industrial	2.5%	2.5%	5%	10%	15%	20%
Power generation	0.1%	0.25%	1%	10%	15%	20%

Source: Wood Mackenzie

In October 2008 Regulation No. 32/2008 was passed mandating minimum biofuels content in fuels sold in Jakarta and Surabaya. Different blend levels are supposed to apply to fuel sold in different sectors of the economy. The blend levels gradually increase over time as shown in the tables below. Whether these hugely ambitious targets will be adhered to, given the unfavourable economics of biofuels blending remains to be seen.

Figure 62: Indonesia Biofuels Mandate - Ethanol

	Minimum biofuels content					
Sector	**2008**	**2009**	**2010**	**2015**	**2020**	**2025**
Transport (Public Service Obligation)	3%	1%	3%	5%	10%	15%
Transport (non- Public Service Obligation)	5%	5%	7%	10%	12%	15%
Commercial and industrial		5%	7%	10%	12%	15%

Source: Wood Mackenzie

6.4.2 Malaysia

Interest in promoting biodiesel must be seen through the context of the country's position as a leading palm oil producer. A large part of Malaysia's palm oil is still produced through the federal government's smallholders scheme (FELDA). As such, there is a strong driver to stabilise and raise the incomes of these smallholders through expanding the markets available for their palm oil production.

Malaysia implemented its first policy on biofuels development in 2005. The National Biofuels Policy has the stated aims of reducing the country's dependence on petroleum fuels and promoting growth for the agricultural economy. There are five strategic thrusts outlined in the biofuels plan:

- Promote the use of biofuels in the transport sector via the B5 biodiesel blend
- Supply B5 biodiesel for use in the industrial sector
- Promote the research, development and commercialisation of biofuels technologies
- Encourage initiatives to build manufacturing capacity for biodiesel export into major consuming countries/regions
- Reduce the use of fossil fuels and minimise the effect of greenhouse gases and other toxic emissions via the use of biofuels.

The targets are divided into short, medium and long term goals, and they cover development of specifications for biodiesel blends, steps to create a domestic market for biodiesel, and measures to establish the necessary technological expertise and capacity to produce biodiesel for domestic and export demand.

Apart from the National Biofuel Policy, the Malaysian government also supports the construction of biodiesel manufacturing facilities via the Promotion of Investments Act 1986, which grants various incentives to eligible projects.

Malaysia has been poised for several years to introduce B5 biodiesel into the transport fuels market, but this move is still on hold, pending agreements with industry players. One key issue to be discussed with the oil companies and automakers was the type of biodiesel blend to be marketed. The MPOB was promoting the ENVO biodiesel blend which is a mixture of 5% palm oil and 95% diesel, while most current standards are based on FAME biodiesel. Plans to promote ENVO diesel were recently dropped due to opposition from automotive manufacturers based on the quality of the fuel. Another minor factor restraining the introduction of the mandate is logistical considerations, including availability of the required fuel blending infrastructure.

It is likely that economic considerations are the main barrier to the mandate being implemented. Malaysia currently provides subsidies to fuel suppliers to enable consumer prices to remain below the international market price. Biodiesel will almost inevitably be higher cost than conventional diesel, so would either raise fuel prices slightly, or require an even greater subsidy to be borne by the government. In the meantime, Malaysia will continue to develop as an export-only biodiesel producer.

6.4.3 China

The main driver behind China's biofuels program is the desire to diversify away from imported oil supplies. Its biofuels program was initiated in 2002 with the introduction of ethanol gasoline blending mandates. The principal feedstock for ethanol in China has been corn. One of the key reasons behind China's decision to use corn as a feedstock was the existence of a large stockpile of stale corn owned by the state. Using this surplus corn for fuel ethanol production was considered to be an “economic” way to dispose of the excess.

In 2004, the National Development and Reform Commission (NDRC) introduced a compulsory use of a 10 percent blend of ethanol in the gasoline pool (E10) in five provinces: Heilongjiang, Jilin, Liaoning, Henan and Anhui. Later, the program was extended to a further 27 cities across the Hubei, Hebei, Shandong and Jiangsu provinces. The main reason that these provinces and cities were selected for the E10 program was their proximity to corn producing areas in China.

To support the E10 initiative, the NDRC directive also called for the establishment of a fuel ethanol industry. To date, there are five major fuel ethanol producers in China, with total production capacity of about 1.7 million tonnes of ethanol production per year.

The 2004 NDRC directive on biofuels contains the following policy measures for the implementation of the fuel ethanol program in China:

- Established an administration structure led by NDRC and comprised of the two major state oil companies CNPC (through its subsidiary PetroChina) and Sinopec, various government agencies, and local provincial governments
- Compulsory E10 program in five provinces and a partial program in 27 cities across four other provinces
- Setting up of a local fuel ethanol production industry
- Placed responsibility on PetroChina and Sinopec for the distribution of ethanol blended gasoline into the provinces and cities under the E10 program
- Established an incentive system which includes refunds from value added taxes and exemption from the 5% consumption tax for ethanol producers
- Established a pricing system for the ethanol, paid to producers by PetroChina and Sinopec – the formula is fixed at 91.11% of refinery gate price of the number 90 gasoline (90% gasoline and 10% ethanol) blend marketed by PetroChina and Sinopec.

In addition to the above policy measures, domestic fuel ethanol producers are provided with a direct fiscal subsidy (amount determined by the Ministry of Finance) to further compensate them for costs arising from the manufacturing of the fuel ethanol. Domestic producers are also given a measure of tariff protection from foreign competitors. A 45% import duty is levied on fuel ethanol.

Since the policy was published, ethanol blended gasoline has been made available in the identified provinces and marketed at the same price as normal gasoline fuel.

In 2006, a review was undertaken by a study group commissioned by NDRC, and it recommended an expansion of China’s ethanol program to target 5.2 million tonnes of ethanol consumption by 2010. However, the rapid run up of commodity prices since 2007, coupled with recent instances of grain supply shortages to the animal feed industry, has led the NDRC to reconsider the ambitious plans to increase biofuels production and usage. Its Renewable Energy Plan envisages non-grain fuel ethanol consumption reaching 2 Million tonnes by 2010 and total fuel ethanol use growing to 10 Million tonnes by 2020. For biodiesel, it expects consumption to reach 200,000 tonnes by 2010 and rise to 2 Million tonnes by 2020.

With priority given to security of food supply, China has taken steps to steer the development of the biofuels industry away from using grain crops as a feedstock. In September 2007, the NDRC issued a directive prohibiting the development of new fuel ethanol plants using corn or other grain crops as feedstock. New investments in the fuel ethanol sector are limited to a number of non-grain crops (i.e., cassava, sweet sorghum and sweet potato) or cellulosic technology.

Despite the change in policy direction on feedstocks, the Chinese government still sees biofuels as an important tool in reducing dependency on imported oil and reducing pollution. The future focus is likely to be on successfully producing the biofuels from non-food crops or from future production technologies.

6.4.4 India

India has seen some limited development in its biofuels policy over the past five years. The reasons behind its biofuels policies include: reducing dependence on crude oil imports, developing an alternative source of environmentally friendly fuel, and supporting the agriculture industry by developing another market for agricultural products.

India’s biofuels efforts revolve mostly around ethanol, due to its status as one of the world’s largest sugar cane growers and sugar exporters. The volatility of the sugar market has led to the industry lobbying for an alternative market which can absorb surplus production and provide increased pricing stability. Fuel ethanol production in India is limited to using molasses as a feedstock. The transport fuel market competes for this molasses-based ethanol with the liqueur and chemical industries, which use it in their manufacturing processes.

Beginning in 2003 a compulsory E5 mandate was introduced in nine states and four Union Territories. However, rapidly increasing ethanol prices and a serious shortage of supply quickly led to the mandate being revised to a voluntary one, which applied only when the “economics”, as well as stability in ethanol supply, were deemed to be feasible.

Following record sugar production on the back of a bumper sugar cane crop in 2006/07, there was a revival of interest in using ethanol for gasoline blending. As a result, the Indian government announced an E5 mandate across 20 states. A fixed price for ethanol was negotiated between the oil industry and the ethanol producers to Rs 21.50 per litre. But taxes and excise duties in some states made this an unattractive price for ethanol producers and the mandate was only partially fulfilled. Lower sugar production in 2007/2008 limited ethanol supply and made it even more unattractive for producers to supply, so the mandate has again been unfulfilled.

Seemingly undaunted by these previous failures, the government announced a nationwide E5 mandate from October 2008, which was to rise quickly to 10%. However, supply limitations will again mean that this target is not met.

The biodiesel industry in India is nascent, and jatropha, a non-food crop, has gained prominence as the “crop of choice” for producing biodiesel. Because India is a significant importer of edible oil, biodiesel from edible oil sources does not make economic sense. Jatropha is favoured because of its ability to grow on marginal land (and thus not compete for scarce agricultural land) and because of its non-food crop status. The government set a target of planting between 11 and 13 million hectares of “waste” land with jatropha by 2012 to support a nationwide B20 blending mandate. It is highly doubtful that even a small percentage of this target will be achieved.

In 2005, the government also announced a “Biodiesel Purchase Policy”, under which the oil companies can procure biodiesel at a pre-determined price for blending into diesel to produce B5 blends. The price was fixed at Rs 26.5 per litre of biodiesel to be sold into 20 collection centres nationwide. However, this price is far below biodiesel production costs and so the programme has not resulted in any significant biodiesel consumption.

6.4.5 Thailand

Biofuels initiatives in Thailand gained momentum in 1985, when HM King Bumiphol of Thailand launched the Royal Chitralada Project to study ethanol production from sugar cane molasses. The pilot plant project was also supported by Thailand’s national oil company, PTT, which subsequently launched an ethanol-blended gasoline on a trial basis. However, low oil prices rendered the project unviable on a wider commercial scale, and the fuel ethanol efforts remained on a research scale for many years.

In 2000, biofuels, or more specifically, fuel ethanol, regained momentum on the national agenda as an alternative fuel to reduce Thailand’s dependence on imported oil. The Thai government then set up the National Ethanol Committee, the predecessor of several similar committees established later, to coordinate the development of the fuel ethanol/biofuels sector in Thailand.

In 2003, Thailand set ambitious targets for adopting biofuels into the transport fuels market. The plan called for Thailand to achieve an annual 1,600 million tonnes of liquid biofuels consumption by 2012. The implementation included plans to mandate ethanol use to replace MTBE by 2006, followed by conversion of part of the gasoline pool to gasohol by 2011. For biodiesel, a nationwide mandate for B2 was planned by 2008, followed by a B10 mandate by 2012.

Since 2004, biofuels uptake has grown rapidly in Thailand, mainly in the metropolitan area of Bangkok. State companies PTT and Bangchak Petroleum have been at the forefront of promoting biofuels usage and the sale of ethanol-blended gasoline (10% ethanol by volume) in the form of 91 RON and 95 RON gasohol has increased rapidly.

Thailand has adopted a policy of encouraging users to switch to biofuels blends through competitive pricing for biofuels blends at the pump. Ethanol blended gasoline and biodiesel are priced lower than petroleum fuels. E10 gasohol is marketed at a level of 4 baht/litre lower than 95 RON gasoline. In 2008 E20 fuel was introduced to the market. It is marketed at a further 2 baht/litre discount to E10. Later in 2008, E85 fuel was introduced to the market; again at a lower price than E20. The price discounts are encouraged by biofuels blends being subjected to lower fuel tax rates, as well as a much lower level of oil fund contribution. The oil fund component, in effect, acts as a subsidy to producers and marketers. The oil fund component is adjusted periodically to ensure that gasohol and biodiesel retain a price advantage over normal fuels.

As a further incentive for the higher gasohol blends, a lower vehicle excise duty is payable on cars which are capable of running on E20 and additional vehicle excise duty reductions are available for cars capable of running on E85.

As of February 2008, biodiesel blending at a level of B2 was mandated in Thailand. There are plans to increase this to B5 from 2011 and B10 from 2012, but this will be subject to review on the success of the B2 mandate.

The policy framework has also attempted to provide some measure of stability to biofuels producers and oil companies, by introducing a pricing mechanism for both ethanol and biodiesel produced domestically. The ethanol pricing formula is based on the delivered cost of imported ethanol from Brazil (with additional components such as freight, producer's margin etc) and the biodiesel formula is based on the crude palm oil price (with processing cost and producer's margin).

7 Automotive & Specification Issues

This chapter discusses the key issues:

- Mix of biofuels that
  - A) cannot be used in conventional vehicles (e.g. biogas)
  - B) can be used in conventional vehicles but are quite different from petroleum fuels (FAME and ethanol)
  - C) can be used in conventional vehicles and resemble petroleum fuels more closely (e.g. hydrotreated vegetable oils (HVO), biomass to liquid (BTL))
- Current and proposed fuel specifications for automotive vehicles
- Technical constraints to usage of biofuels (adaptation of the vehicles and engines)

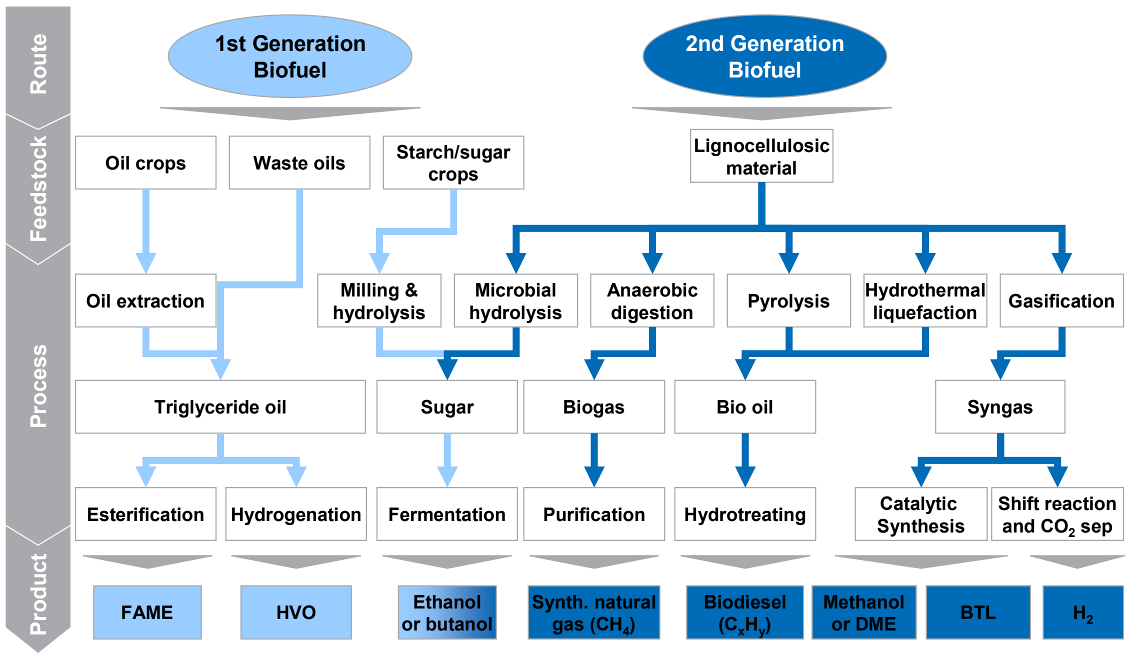
The chapter also outlines the current development trends in engine technology and what design considerations are required to ensure future vehicles will tolerate higher biofuel blends. . The references referred to in this chapter are listed in Appendix E.

The discussions on the technical constraints associated with using biofuels form the boundary conditions for determining the likely biofuel blend options in 2020 and 2030 for each scenario, as presented in Chapter 12 In turn, these blend options then provide the input into understanding the expectations about changes in fuel specification in relation to the share of fuels in group (b) and the impact on specifications for final oil products (octane, cetane, etc.), see Chapter 12.6.

7.1 Biofuels for Automotive Applications

There are numerous biofuel options which could be used to fuel automotive vehicles, either as blending substitutes for diesel and gasoline petroleum products, or as alternative fuel types. These fuels can be manufactured from a variety of feedstocks. Some of the biofuel options are already available within the market place, such as FAME and ethanol, while others are under development, such as fuels derived from algae.

Figure 63: Example biofuel production pathways



Source: Ricardo

Group A) Biofuels that cannot be used in conventional vehicles

Biofuels that cannot be used in conventional vehicles include biogas (also known as biomethane) and hydrogen.

Biogas is produced by breaking down organic matter by means of anaerobic digestion (decomposition without oxygen). The raw material is usual a waste product, from sources such as sewage treatment plants, landfill waste sites, agricultural waste, or organic industrial waste streams. Biogas is typically made up of 50-80% methane, 20-50% carbon dioxide, and traces of gases such as hydrogen, carbon monoxide, and nitrogen. In contrast, natural gas is typically made up of more than 70% methane, with most of the rest being other hydrocarbons (such as propane and butane) and only small amounts of carbon dioxide and other contaminants. Therefore, for use in road transport, biogas is upgraded to a higher standard of purity (95% biomethane). This is normally performed in a two step process that involves removing other substances from the gas, including carbon dioxide.

Hydrogen is considered to be a potential future alternative to fossil fuels since vehicles operating on hydrogen produce zero or near zero carbon emissions at the point of use. However for hydrogen to be considered as renewable energy, it must be generated from renewable and sustainable feedstocks. There are many options for producing hydrogen from CO_2-neutral sources, as discussed in depth by Steinberger-Wilckens et al. (2008). However most of these methods are currently at the laboratory stage of development, without a clear route to commercialisation.

Both biogas and hydrogen can be used in internal combustion engines, but require the engine to be adapted for the fuel. These adaptations include changing the fuel injection system, fuel lines and pumps, seals, and adjusting the engine calibration strategy for the fuel. The vehicle is required to have a separate tank for on-board storage of the fuel, usually in the form of compressed gas. Biogas can be used in vehicles designed for CNG. Hydrogen is the main energy vector for fuel cell vehicles.

The main issues with increasing the use of biogas or hydrogen as an automotive fuel at the European level are the provision of vehicles that use the fuel and the development of an international refuelling infrastructure for these gaseous fuels.

Biogas is currently being investigated as a potential fuel for bus and truck applications. It has been trialled in several European countries (e.g. UK) and is commercially in Sweden, Switzerland, Germany and Austria. However, at the time of this study, it was difficult to predict the growth rate of biogas for road transport, since it can be used as renewable energy source for many other applications, such as generating electricity or for heat. Therefore biogas was not considered in the study scenarios.

Similarly, since the role of bio-hydrogen within the European automotive sector is likely to remain within small-volume or niche applications until at least 2030, bio-hydrogen has not been included in the scenarios developed in this study.

Group B) Biofuels that can be used in conventional vehicles but are quite different from petroleum fuels

Biofuels that can be used in conventional vehicles, but are quite different from petroleum fuels include fatty acid methyl esters (FAME) and ethanol.

FAME is a first generation biodiesel replacement for fossil diesel. The physical and chemical properties of FAME ultimately depend on the type of feedstock used, production process, and quality control. FAME can be produced from a range of feedstocks, including oil seed crops such as rapeseed, soybean and palm oil, or animal based fats, such as tallow or fish oil. The production process involves a transesterification reaction of the parent fat or oil triglyceride with methanol in the presence of a suitable catalyst such as potassium hydroxide (KOH). Depending on the raw material, FAME can have a different range of side chain lengths and degrees of unsaturation. These fundamentally impact the cold flow, volatility and cetane number of the product, in addition to impacting the basic resistance to oxidation. A comparison of the properties for rapeseed methyl ester (RME), soybean methyl ester (SME) and coconut methyl ester (CME) is provided in Figure 64. It should be noted that even with a single oil source, there can be differences in the triglyceride make up, and hence fuel properties, due to regional differences, climatic conditions and genetic variability.

FAME which is to be blended into conventional diesel base-stock has to meet EN14214 specification in Europe and ASTM D6751 in the US. Further information on EN14214 is provided in Section 7.2.

Generally the advantages of FAME biodiesel are good Cetane Number (CN), high natural lubricity, no aromatics and low sulphur. However, the main compromises are low heating value, low and narrow volatility range and poor cold flow properties. The high density of FAME components helps to partially offset the low heating value.

Figure 64: Chemical properties of biofuel replacers for diesel

	FAME			HVO*	BTL	Diesel
	RME	SME	CME			
Density, 20°C [kg/m³]	~0.885	0.884	0.8762	0.775-0.785	0.770-0.785	~0.835
CN	~53	52	70	84-99**	>75	~53
Heating Value [MJ/l]	33.2	33	31.1	34.4	34	35.0-35.8
Heating Value [MJ/kg]	38	38	35.5	44	43.6	43
Viscosity @ 40°C [mm²/s]	~4.5	4.2	2.65	2.9-3.5	2.9-3.5	~3.5
Aromatics Content [%wt]	0	0	0	0	<0.3	15-25
Polyaromatics Cont. [%wt]	0	0	0	0	<0.01	4
Oxygen [%wt]	11	11	14	0	0	0
IBP [°C]	330	131	~160	180	207	180
T10 [°C]	~340	~328	~200	260-270	~260	~200
T90 [°C]	~355	352	327	295-300	325-330	~350
FBP [°C]	380	346	~325	320	313-340	360
Cloud Point [°C]	~-5	-4 - +2	-5	-5 - -30	0 - -25	~-5

*NExBTL **Blending CN ***Feedstock Dependant

Source: Ricardo

Ethanol can be used to replace gasoline. Like other biofuels, ethanol can be produced from a range of feedstocks. First generation ethanol has largely been produced by fermentation of corn, wheat, sugar beet or sugar cane. The dominant producers are the U.S. where ethanol production is mostly from corn grown in the mid-west, and Brazil which produces ethanol from sugar cane fermentation. Second generation ethanol will be produced from lignocellulosic material, which are hydrolysed to obtain sugars for fermentation.

Key strengths for ethanol are its high latent heat and octane quality. However its low heating value and high volatility lead to increased fuel consumption and compromised performance.

Group C) Biofuels that can be used in conventional vehicles and resemble petroleum fuels more closely

Biofuels that can be used in conventional vehicles and that resemble petroleum fuels more closely include, Hydrogenated Vegetable Oil (HVO), next generation biodiesel such as Biomass to Liquid (BTL), and butanol.

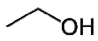
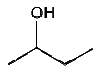
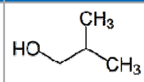
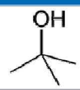
HVO and BTL are potential diesel replacers. They contain middle distillate molecules which are substantially more diesel-like in character than FAME. They are characterised by very high cetane numbers (CN), no aromatics or sulphur and high heating values (see Figure 64). Their low density however, compromises the volumetric heating value.

HVO can be produced from the same raw materials as FAME. The production process involves direct hydrogenation of the parent triglyceride. Since the hydrogenation of the parent oils and fats produces linear chain hydrocarbons, it is usual for a degree of isomerisation of the product to be carried out to improve the cold flow properties of the molecules.

There are several difference pathways for producing next generation biodiesels. BTL is an example of one such product. It can be made from a range of raw materials containing lignocellulosic matter, such as, agricultural waste, forestry waste or used paper. The production process relies on high temperature gasification of biomass to syngas (hydrogen and CO mixtures), which is then converted through the Fischer-Tropsch process to longer chain hydrocarbons. This conversion process is akin to the GTL production process and, therefore, produces molecules with very similar characteristics. The BTL product is isomerised to produce molecules with better cold flow properties which can then be blended directly into diesel.

Butanol is a potential replacer for gasoline, with properties that are part way between ethanol and gasoline. Butanol is available in four isomers (1-butanol, 2-butanol, 2-methyl-1-propanol (i-butanol) and 1,1-dimethylethanol (t-butanol)), each with different fuel characteristics (see Figure 65).

Figure 65: Chemical properties of biofuel replacers for gasoline

	EtOH	1-BuOH	2-BuOH	i-BuOH	t-BuOH	Gasoline
						-
Density, 20°C [kg/m³]	790	810	808	802	781	720-775
Latent Heat [kJ/kg]	904	595	565	578	544	~272
Heating Value [MJ/l]	21.3	27.0	29.1	26.4	25.4	32.2-32.9
RON	130	94	101	110	109	95
MON	96	80	82	89	94	85
DVPE@ 5% /10% [kPa]	213/ 138[1]	44/ 44[1]	-	-	-	< 60/90[2]
Oxygen [%m/m]	34.7	21.6	21.6	21.6	21.6	< 2.7
BP [°C]	78.3	117.7	99.5	107.9	82.4	< 210

[1] Blend values of vapour pressure
[2] Summer/Winter specifications

Source: Ricardo

1-Butanol is produced from the Acetone-Butanol-Ethanol process (ABE), a relatively mature fermentation process using clostridium microbes. It has a number of advantages as a biogasoline component compared to ethanol. At fixed fuel oxygen content, 1-butanol can add relatively more bio-derived carbon into the fuel. Vapour pressure, water solubility, elastomer compatibility and corrosion are also more advantageous for 1-butanol compared to ethanol. However, ethanol has a significantly higher octane number (130RON, 96MON).

The use of 2-butanol or i-butanol confers all the advantages of 1-butanol but at improved octane levels. Currently, there are no commercially viable fermentation routes for producing t-butanol, but due to its high octane value, this would likely be the favoured butanol for production.

Other bio-replacers for gasoline include ethyl tert-butyl ether (ETBE), which is made from etherification of isobutylene (53% v/v) with bio-derived ethanol (47% v/v). Since isobutylene tends to be derived from fossil sources, ETBE is not a pure biofuel. ETBE is used as an oxygenate additive to improve the combustion and gasoline and, therefore, reduce emissions. Current European fuel specification (EN 228:2008) allows ethers (with five or more carbon atoms) to be blended into gasoline in any proportion up to 15%vol. Following the introduction of Directive 2009/30/EC (FQD), this limit will be increased to 22%vol.

Alternative Options

In addition to the biofuels described above, there are numerous other bio-derived fuels which have the potential to replace conventional gasoline and diesel in the future. These include biofuels derived from algae. However the development of these biofuels is currently at the laboratory research stage. Since a clear pathway to commercialisation does not yet exist for these fuels, they have not been considered in this study.

7.2 Current and Proposed Fuel Specifications

Diesel

Within the European Union, there are two sets of standards which define the specifications of biodiesel fuels:

- EN 590 – European Diesel Fuel Specification
- EN 14214 – Fatty Acid Methyl Ester (FAME) Fuel Specification

These specifications define a range of properties of the fuel, some of which are related to the intrinsic chemistry of the molecules, e.g. cetane number (CN), viscosity and iodine number, and some of which are more related to the processing method, e.g. residual glycerides, water content, sterol glucosides, alkali metals and free acids.

With the exception of the reduction in sulphur limits and increase in allowable FAME content, the EN 590 specifications have remained unchanged in recent years. Pre EN 590:2004 FAME was not permitted in the diesel fuel blend. EN 590:2004 first allowed FAME content at a maximum level of 5%vol. This was increased to 7%vol with EN 590:2009.

EN 590:2000	0%vol FAME
EN 590:2004	5%vol FAME
EN 590:2009	7%vol FAME

In all cases the B100 used as a blend stock for conventional diesel fuels must meet the EN 14214 specification. Unlike the U.S. fuel standard ASTM D 6751, which only allows neat biodiesel to be used as a blending component and not as a final fuel, EN 14214 specifies that B100 can be used as a final fuel in engines designed or adapted for biofuel use.

With regard to higher biodiesel blends, several Member States have developed national specifications. In February 2009, legislation enabling the marketing of B7 took effect in Austria and Germany. Poland markets a B20 diesel (20%vol FAME), while France markets B30 (30%vol FAME) for captive fleets. Several Member States (e.g. Germany, Poland, Spain) sell pure biodiesel (B100) to dedicated fleets.

Currently, the maximum content of non-FAME biofuel components, such as diesel-like hydrocarbons made from biomass using the Fischer-Tropsch process or from co-processed or hydrotreated vegetable oil (HVO), is not specified in EN 590. In 2008, as part of their Roadmap for Biofuels, Germany proposed allowing a 10%vol biodiesel blend consisting of 7%vol FAME (as described by EN 590:2009) and 3%vol of HVO (BMU, 2008).

Future revisions of EN 590 are expected to allow FAME content up to 10%.

Further information on these diesel and biodiesel fuel specifications is provided in Appendix D.

Gasoline

Within the European Union, the standards that define the specifications for gasoline and biogasoline are:

- EN 228 – European Gasoline Fuel Specification
- EN 15376 – Neat Ethanol Specification
- CWA 15293 – E85 Fuel Specification

Limits for ethanol and other oxygenates in gasoline have been changed through the updated Fuel Quality Directive (Directive 2009/30/EC amending Directive 98/70/EC). The FQD is increasing the ethanol limit from 5%vol to 10%vol (increased oxygen content from 2.7 %wt. to 3.7 %wt.). An overview of the changes to oxygen and oxygenates in gasoline, as proposed in the FQD, is provided in Figure 66. EU Member States must ensure that gasoline placed in their markets meets the quality specifications listed in this Directive (E10). However, since E10 is not suitable for some older vehicles, it is necessary that Member States ensure the appropriate coverage of gasoline with a maximum ethanol content of 5 %vol, until at least 2013 or longer if Member States deem it necessary.

Figure 66: Comparison in changes to specified oxygen and oxygenates contend in Gasoline in Europe

	Directive 2003 / 17 / EC	Directive 2009 / 30 / EC
Oxygen	2.7 %wt	3.7 %wt
Methanol	3 %vol	3 %vol
Ethanol	5 %vol	10 %vol
Iso-propyl alcohol	10 %vol	12 %vol
Tert-butyl alcohol	7 %vol	15 %vol
Iso-butyl alcohol	10 %vol	15 %vol
Ethers containing five or more carbon atoms per molecule	15 %vol	22 %vol
Other oxygenates	10 %vol	15 %vol

Source: IFQC

Ethanol used in automotive fuels must meet the specifications stipulated in the CEN standard EN 15376:2007.

With regard to the use of E85 fuel (up to 85 %vol ethanol and 15 %vol gasoline) in flex-fuel vehicles (FFVs), CEN is currently working in developing a technical standard. Some Member States such as France, Austria, Sweden, Hungary, Poland and the Czech Republic have adopted national standards.

It should be noted that while Europe has only recently included the ethanol blend limit to 10%vol, E10 has been widely available within the U.S. market for the past decade.

Further information on these gasoline and biogasoline fuel specifications is provided in Appendix D.

7.3 Engine Technology

Internal combustion engines for automotive applications can be classed by fuel-type and size. This study has considered the impact of the use of biofuels on light duty diesel engines, heavy duty diesel engines and light duty gasoline engines. The purpose of this section is to present a high level overview of the engine technology development in recent years, and expected evolution towards 2020 and 2030. The impact of the use of biofuels in these engine technologies is discussed in Section 7.4.

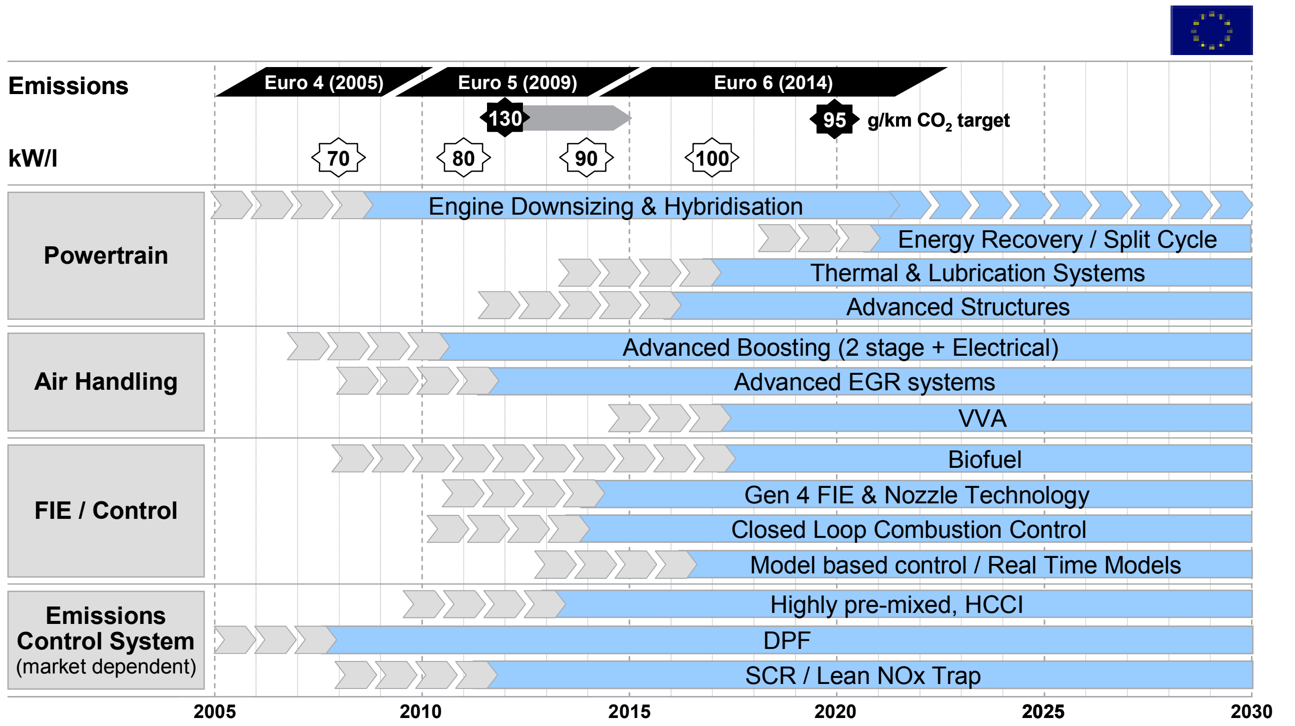
Over the past 30 years, the development and evolution of automotive engines in Europe has primarily been driven by emissions legislation. Therefore to aid the discussions, the engines have been categorised by the relevant emission limits – Euro 4 (2005-2009), Euro 5 (2009-2014) and Euro 6 (2014 and beyond) for light duty vehicles, and Euro IV (2006-2008), Euro V (2008-2014) and Euro VI (2014 and beyond) for heavy duty vehicles. For each engine type, a Technology Roadmap and comparison table have been provided to illustrate the main technology trends. An explanation of the arrows and colours used in the Technology Roadmaps is provided in Appendix C.

A brief explanation of the acronyms used is provided below:

CAI	Controlled Auto Ignition	HCCI	Homogeneous Charge Compression Ignition
CO	Carbon Monoxide	HP	High Pressure
CO_2	Carbon Dioxide	LNT	Lean NOx Trap
CPS	Cam Profile Switching	NOx	Nitrogen Oxides emissions
DOC	Diesel Oxidation Catalyst	PM	Particulate emissions
DPF	Diesel Particulate Filter	Pmax	Maximum cylinder pressure
EGR	Exhaust Gas Recirculation	PMC	Particulate Matter Catalyst
FIE	Fuel Injection Equipment	SCR	Selective Catalytic Reduction
FWC	Four Way Catalyst	T/C	Turbocharger
GPF	Gasoline Particulate Filter	TWC	Three Way Catalyst
GDI	Gasoline Direct Injection	VGT	Variable Geometry Turbocharger
Gen 4	Fourth generation	VVA	Variable Valve Actuation
HC	Hydrocarbon emissions	WOT	Wide Open Throttle

7.3.1 Light Duty Diesel

Figure 67: Technology Roadmap for Light Duty Diesel engine development in Europe



Source: Ricardo

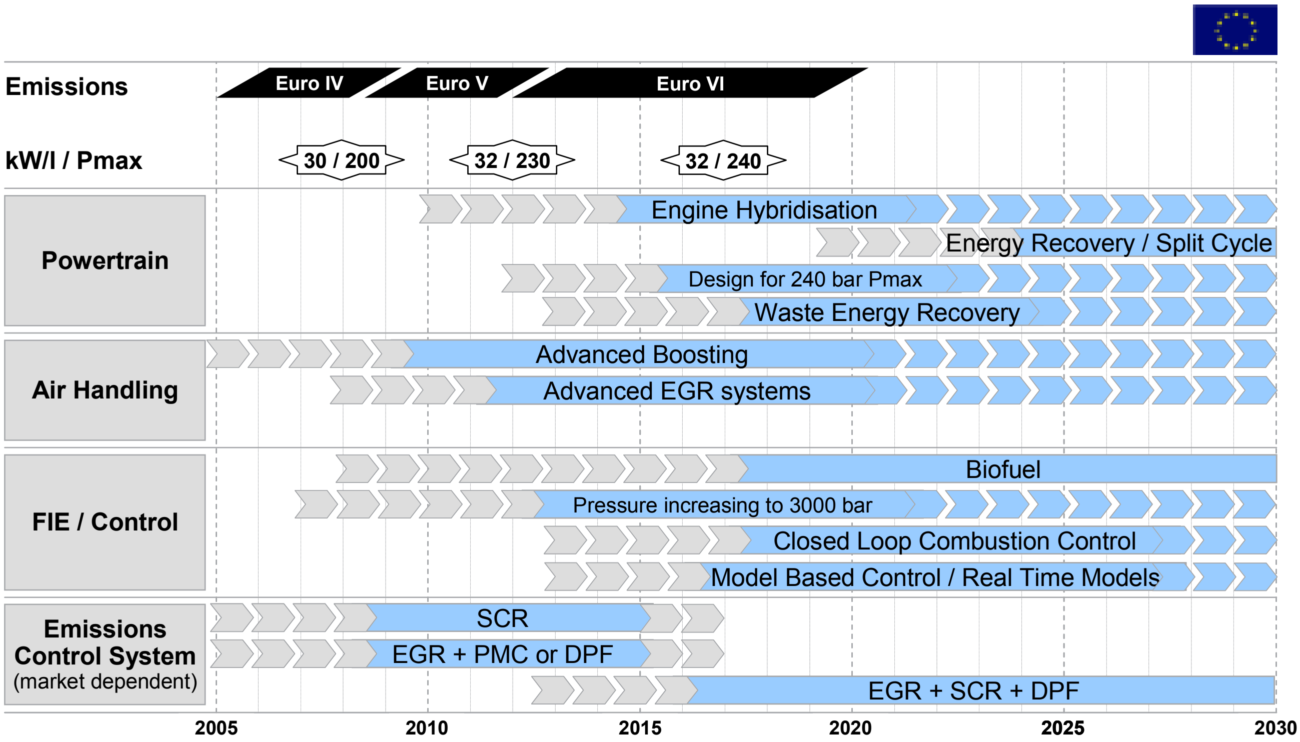
Figure 68: Comparison of Light Duty Diesel engine technologies for Euro 4, Euro 5 and Euro 6

	Euro 4	Euro 5	Euro 6
Powertrain / Engine	• Base Engine	• Downsizing (↓CO_2) • Increased peak cylinder pressures • VGT (↓CO_2) • Thermal Management (↓CO_2) • Friction reduction • Hybridisation (↓CO_2)	• More Downsizing (↓CO_2) • Increased peak cylinder pressures • More VGT + Two Stage Turbocharger (↓CO_2) • Advanced Thermal Management (↓CO_2) • Friction Reduction • Lightweight design (↓CO_2) • More Hybridisation (↓CO_2)
Combustion Process	• High Pressure EGR (HP) • Common Rail Injection (1600-1800 bars)	• HP Cooled EGR (↓NOx) • Increased EGR-rates (↓NOx) • Increased injection pressure (↓PM) • Increased rail pressure (↓PM) • Closed loop combustion control (↓CO_2, PM & NOx) • Lower Compression Ratio	• HP and Low Pressure EGR (↓NOx) • Increased EGR-rates (↓NOx) • Increased injection pressure • Increased rail pressure (↓PM) • Closed loop combustion control (↓CO_2, PM & NOx) • Lower Compression Ratio
Aftertreatment System	• Diesel Oxidation Catalyst (DOC) • Limited (Diesel Particulate Filter (DPF) cases	• DOC • DPF (↓PM) • (limited LNT, SCR or FWC) (↓NOx)	• DOC • DPF (↓PM) • LNT or SCR (↓NOx) • (limited FWC) (↓PM & NOx)

Source: Ricardo

7.3.2 Heavy Duty Diesel

Figure 69: Technology Roadmap for Heavy Duty Diesel engine development in Europe



Source: Ricardo

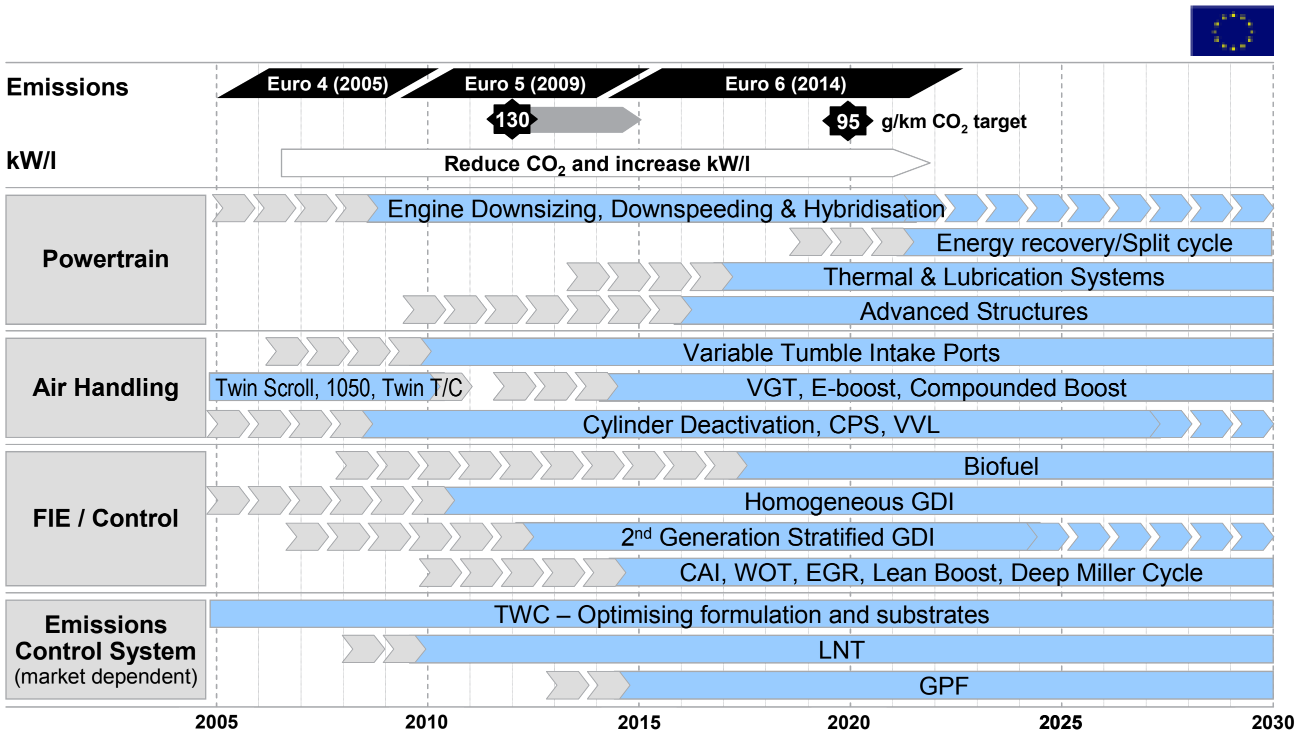
Figure 70: Comparison of Heavy Duty Diesel engine technologies for Euro 4, Euro 5 and Euro 6

	Euro IV	Euro V	Euro VI
Powertrain / Engine	• Base Engine	• Base Engine	• Potential Hybridisation (↓CO_2) • Advanced Thermal Management with potential Waste Heat Recovery (↓CO_2) • Friction Reduction (↓CO_2) • Advanced Auxiliary Technologies (↓CO_2) • VGT and Two Stage Turbocharger (↓CO_2) • Lightweight design (↓CO_2)
Combustion Process			• HP and potentially Low Pressure EGR (↓NOx) • Increased injection pressure (↓PM) • Increased rail pressure (↓PM) • Multiple injection (↓NOx)
Aftertreatment System	• SCR • (limited number with EGR + PM control)	• SCR • (limited number with EGR + PM control)	• DOC (↓PM) • DPF (↓PM) • SCR / LNT (↓NOx)

Source: Ricardo

7.3.3 Gasoline

Figure 71: Technology Roadmap for Light Duty Gasoline engine development in Europe



Source: Ricardo

Figure 72: Comparison of Light Duty Gasoline engine technologies for Euro 4, Euro 5 and Euro 6

	Euro 4	Euro 5	Euro 6
Powertrain / Engine	• Base Engine	• Reduced size and speed (↓CO_2) • Increased peak cylinder pressures • Addition of twin scroll turbocharging (a few VGT) • Reduced friction (↓CO_2) • Variable valve-control (↓CO_2) • Hybridisation (↓CO_2)	• Further reductions in size and speed (↓CO_2) • Further increases in peak cylinder pressures • More Twin Scroll T/C and VGT • Lightweight design Turbines • Further friction reduction (↓CO_2) • Variable valve-control (↓CO_2) • Cylinder de-activation • More Hybridisation (↓CO_2)
Combustion Process	• Port Fuel Injection	• More Direct Injection • Some Stratified/Lean Combustion • Cooled EGR / increased EGR-rates / Low Pressure EGR (↓NOx) • Higher Compression Ratio	• Mainly Direct Injection • More Stratified/Lean Combustion • Cooled EGR / increased rates / Low Pressure EGR (↓NOx) • Higher Compression Ratio • WOT EGR (↓CO_2) • Cylinder Deactivation (↓CO_2) • Self Ignition (CAI, HCCI) (↓CO_2, PM & NOx)
Aftertreatment System	• Three-Way Catalyst	• Advanced TWC (↓NOx) • or TWC + LNT (↓NOx)	• Advanced TWC (↓NOx) • or TWC +LNT (↓NOx) • GPF (↓PM NOx)

Source: Ricardo

7.4 Technical Constraints to usage of Biofuels

There are a number of well documented technical constraints associated with the use of biofuels that limit the acceptable biofuel content for current vehicles. These constraints need to be addressed if biofuel blend volumes are to be increased. The purpose of this section is to discuss these technical constraints, with particular regard to the effect of biofuels on the combustion system, lubrication, exhaust gas recirculation (EGR), engine-out emissions, aftertreatment systems and material compatibility. The issues are discussed first with relation to biodiesel products, especially FAME, then with regard to effect of ethanol in gasoline engines.

7.4.1 Technical Constraints associated with the use of Biodiesel products

This section focuses on the technical constraints associated with operating a diesel engine on a diesel blend containing FAME.

Since HVO and next generation biofuels are chemically closer to conventional fossil diesel, it is generally considered that these types of biofuels will not have a serious impact or constrain the diesel engine operation.

Effect of FAME on the combustion system

FAME contains a relatively high amount of oxygen, compared to conventional diesel. For products such as RME and SME which are predominantly comprised of fatty acids of 18 carbon chain lengths (C18), the oxygen content of the neat biofuels is ~11% m/m. For light products such as Coconut Methyl Ester (CME), which has fatty acid chains predominantly in the C12-C14 range, the oxygen content is greater at ~14% m/m. Current technology for control of diesel combustion systems is open loop. The increase in oxygen content of the fuel with such control systems will give rise to reduced peak power and torque, and increased volumetric fuel consumption, in line with the quantity of FAME blended into the diesel. The use of closed-loop control systems can help to mitigate this (Fussey et al., 2009).

The use of FAME-type biofuels in diesel engines can also affect the combustion system through the increase in deposits that foul the injectors, plug the filters and accumulate within the combustion chamber. The deposits are caused by the reduced overall back-end volatility of the fuel and the tendency of the heavier fuel components to survive combustion. The FAME components that survive combustion condense more readily than petroleum diesel in lower temperature regions, and associate with existent carbon deposits on the combustion chamber walls. FAME may also polymerise to form large, stable complexes.

Modern light duty diesel engines have common rail systems with multi-hole fuel injectors. The trend is towards increasing the number of nozzle spray holes and reducing the hole size in order to improve the fuel spray for better combustion. This makes the fuel injectors more sensitive to the deposits from FAME biodiesels, leading to injector fouling. Two types of injector fouling can occur, on the outside of the nozzle or inside the nozzle spray hole.

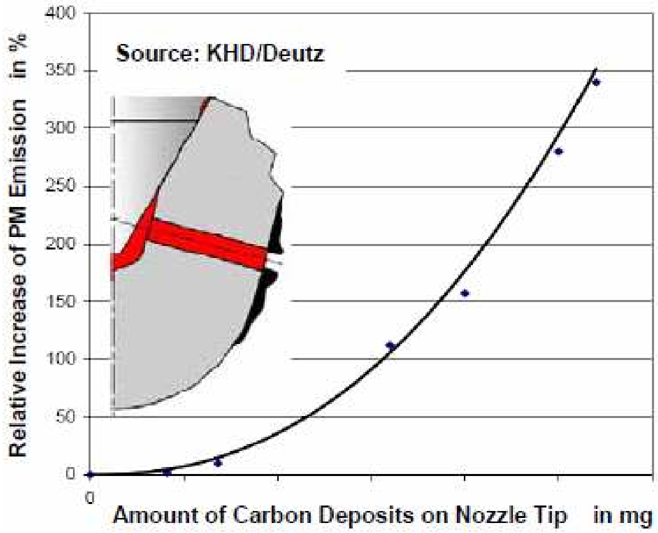
Caprotti et al. (2007) measured the airflow loss response of fuel injectors following the use of different B10 FAME blends. Their results showed that the RME and SME had a negative impact, increasing injector coking, compared to the fossil diesel reference fuel. Hyundai (2007) have shown that even moderate FAME biodiesel blends can cause significant power loss from deposits inside the injector nozzle. This effect can be mitigated through the use of an appropriate fuel additive.

Figure 73: Fuel injector nozzle showing 17 mg of deposits following 300 hours of operation in a commercial vehicle using B100 FAME

Source: Hyundai (2007)

Hyundai (2007) also showed that deposits on the external nozzle surface lead to an increase in particulate emissions. Figure 73 shows the deposit formation on a diesel injector following 300 hours of operation in a commercial vehicle using B100 FAME. As the quantity of deposits increased, higher particulate emissions were observed (see Figure 74). The potential root cause of this build up of deposits was a combination of the oxidation stability and high iodine number of the fuel, and the resultant cool operating temperatures. The report suggested that the addition of fuel additives is very important for high FAME biodiesel blends, along with the hardware adaptation, for improved self cleaning. This implies that the issues surrounding injector nozzle fouling could be rectified through the use of appropriate fuel additives and nozzle design.

Figure 74: Effect on particulate emissions of carbon deposits on injector nozzle tip



Source: Hyundai (2007)

FAME type biofuels also have the potential to corrode or oxidise the metal components within the fuel system, as discussed further in the Material Compatibility paragraph below.

Effect of FAME on EGR

EGR systems involve routing part of the exhaust gases back into the engine intake system. These systems are widely used in light duty diesel engines in order to reduce the production of NOx during the combustion process. For Euro 5 and Euro 6 LDD engines, the re-circulated exhaust gases are passed through an intercooler to reduce the temperature of the exhaust gas. This helps to increase the required EGR rate and to reduce the combustion temperature, which helps to restrict the formation of NOx emissions during combustion. EGR technology is also employed in some Euro V heavy duty diesel engines, and is likely to become part of the standard Euro VI HDD engine package.

When Sluder and Storey (2008) and Sluder et al. (2009) studied the effect of Soy Biodiesel blends (B0 – B20) on EGR cooler performance and degradation, their studies concluded that there was a noticeable effectiveness degradation which occurred within only a few hours. However the rate and extent of the degradation is comparable for all blends tested suggesting biodiesel has no effect EGR cooler deposit formation. A 1000-hour durability evaluation conducted by Bartoili et al. (2009), which used B20 SME, also found normal levels of soot accumulation on the EGR cooler and valve.

Effect of FAME on lubrication

The negative impact on lubrication from the use of FAME type biodiesels is a consequence of increased fuel in oil dilution. This increase is due to the properties of the biodiesel. Depending on the source, FAME usually has a higher molecular weight and lower volatility than conventional fossil diesel (C18 methyl esters boiling point ~345-360ºC). A small amount of fuel in oil dilution occurs during normal engine running. Raising the biodiesel content increases the amount of oil dilution as the heavier hydrocarbons remain in the lubricant resulting in slower recovery. Jones and Adamczewska (2009) suggested that a 5% FAME biodiesel concentration in the fuel will result in a significantly higher concentration of fuel in the sump oil compared to operation with FAME-free diesel.

DPF aftertreatment systems can increase the rate of fuel in oil dilution if the regeneration strategy involves late injection of fuel into the cylinder. Post injection is used periodically to assist the combustion of soot as the fuel continues to combust in the exhaust line, consuming the carbon stored in the DPF. These post-injection strategies used to regenerate DPFs can result in fuel impinging on the oil layer on the cylinder wall. The fuel oil layer passes the piston rings returning to the sump, increasing the rate of fuel in oil dilution.

Biodiesel in oil dilution can cause problems with viscosity control. Excessive fuel in oil dilution over a typical oil drain interval can compromise the lubricant viscometrics and disturb oil film thickness, potentially opening up the possibility of increased wear. The increased content of FAME biodiesel in the sump can reduce the viscosity of the fuel. However, the situation is not clear as some reports suggest no significant differences are observed with B20, while other studies observed that wear reduces (Sinha et al. 2007 and Dinh et al. 2005.)

FAME in oil contamination might affect acidity control due to the introduction of more acids or substances that can oxidise more easily to form acidic components. This could contribute to increased corrosion of soft metals such as copper, lead, bronze and brass. The increase in the oxidation tendency of the lubricant could react to form polymers leading to deposits, gums and sediments.

The current trend is towards increased the oil drain interval, which will contribute to higher cumulative levels of biofuel, peroxides, polymers and acids in the oil before draining. If the current in-cylinder DPF regeneration strategies continue, the development of lubricant additive technology will need to focus on maintaining the integrity of the lubricant under high dilution conditions. However alternative technologies do exist.

One such technology is the introduction of in-exhaust injectors which inject fuel directly into the exhaust stream during DPF regeneration. In addition to reducing oil dilution, this solution also improves fuel consumption as the fuel is not lost to the sump or to in-cylinder combustion. However, the inclusion of an additional injector does add complexity and cost to the control and injection systems.

Another alternative strategy is split far post injection, where the late injection is split into two events. The reduced injection quantities result in shorter injection times. In combination with the seat throttling effects during opening and closing of the injector nozzle, the overall result is a lower mean injection pressure. This reducing the spray momentum and penetration to the cylinder wall (Fadolo et al. 2009). This approach would be expected to have a limited positive effect on fuel dilution.

The extent of the impact from biodiesel varies by lubricant formulation with higher quality oils minimising the risk of biodiesel induced deposits. Advanced first generation products, such as HVO, and second generation options, such as BTL, offer respite from these problems.

Effect of FAME on engine-out emissions

Most studies show that using FAME contributes to reducing engine out particulates (PM), hydrocarbons (HC) and carbon monoxide (CO), but increases engine out nitrogen oxides (NOx), when compared to conventional fossil diesel. Some studies suggest the magnitude of these effects continue to increase with increased biodiesel content. However others show different trends. For example one study concluded that the emissions reduction attributed to the use of FAME reached a maximum limit for a blend of 60% by volume.

There are many potential explanations for the mechanism which causes NOx emissions to increase with the use of FAME, such as those proposed by Bannister et al. (2010) and Mueller et al. (2009):

- The higher oxygen content of the fuel promotes a higher adiabatic flame temperature which reduces in-cylinder soot but lowers radiative heat loss resulting in higher flame temperatures and, therefore, more NOx production
- Fuel borne oxygen results in a pre-mix stage which is closer to stoichiometry, leading to higher local temperatures and increased NOx
- An increased pedal position is required to overcome the lower calorific value of the fuel. This changes the point of operation on the calibration map effecting EGR rates and injection timing, which ultimately effects emissions concentrations and fuel consumption

A report by the Environmental Protection Agency (EPA, 2002) reported a 15% increase in NOx emissions with soybean-oil derived biodiesel (SME), a 12% increase with rapeseed-oil biodiesel (RME) and 3% increase for biodiesel derived from animal fats. Hyundai (2007) argued that the NOx generating characteristics of the different feedstocks was due to the Iodine Number. The Iodine Number describes the chemical reactivity (degree of unsaturation) of the fuel – with a higher Iodine Number resulting in a higher combustion velocity.

Studies differ concerning the impact of FAME type biodiesel on PM emissions. Some reported an increase with FAME, whereas most observe a decrease (CRC, 2009). It is apparent that the magnitude the effect is dependant on the feedstock used to make the biofuel and, also, on the drive cycle selected for the study (EPA, 2002).

Whether any given blend of FAME will result in reductions in PM emissions depends on the FAME type, combustion mode and presence of emissions control devices. Although the elemental carbon fraction of PM appears consistently reduced with FAME, incomplete combustion of heavy hydrocarbons could prove problematic for some types of bio-content, especially in high level blends containing the longest chain fatty acid methyl esters. The total PM measured comprises the elemental carbon fraction, the organic carbon fraction and other inorganic materials. For engine-out PM, the additional heavy HCs seen with high FAME blends, relative to diesel, may exceed the mass of carbon eliminated by the increased oxygen provided the FAME. The presence of a DOC, and high exhaust temperatures, may eliminate some of these HCs resulting in a mean PM reduction.

It has been shown that FAME combustion also leads to an increase in some non-regulated emissions such as acetaldehyde and formaldehyde.

FAME type biofuels have a lower calorific value than conventional fossil diesel. Therefore more fuel is required to provide the same energy. This increases the tank-to -wheel CO_2 emissions of the vehicle (Knothe et al., 2005).

Effect of FAME on aftertreatment systems

Modern diesel engines use a combination of aftertreatment technologies to ensure the tailpipe emissions are within the legislative limits. These technologies include diesel oxidation catalysts (DOC), diesel particulate filters (DPF), lean NOx traps (LNT) and selective catalytic reduction (SCR). The use of FAME type biodiesels has the potential to reduce the efficiency of these systems.

The use of FAME instead of fossil diesel can lead to a reduction in the exhaust gas temperature, making the DOC less effective and increasing tailpipe emissions of CO and HC. Bannister et al. (2010) showed CO and HC conversion efficiencies dropped by 14% and 10% respectively at 25°C ambient temperature when B50 was compared to B0. At 5°C ambient temperature this reduction increased to 18% for CO and HC. The drop in efficiency was attributed to an average 2.3% reduction in exhaust gas temperature between the fuel blends.

Increasing the biodiesel blend content can result in more rapid loading of the DPF. With high level blends of FAME under low exhaust gas temperatures, the rate of mass of PM added to the DPF can increase. This is not caused by an increase in carbon emissions (as discussed above, PM can reduce with biodiesel content), but rather by the unburned HC adsorbing to the soot as the in-cylinder temperature decreases during the expansion stroke and cooling occurs in the exhaust line. To prevent overloading of the DPF, regeneration intervals may need to be reduced which will further agitate the fuel in oil dilution issue associated with FAME type biodiesel (Hyundai, 2007). However, there are some indications that increased levels of oxygen rich HCs on the DPF may lower activation energy for light-off and lower the balance point temperature during regeneration. Future calibration efforts may be able to exploit these effects.

Effect of FAME on material compatibility

The development of engine systems for biodiesel use must consider the long term chemical robustness of the component materials against the solvent character of the esters and the increased water content of the fuel, since FAME type biodiesel contains up to 2.5 times more water than EN590 Diesel. A summary of materials that are compatible, that may be compatible and which are not compatible with FAME type biodiesel is provided in Figure 75.

Gaskets and seals are available that are suitable for use with FAME type biodiesel. Hyundai (2007) identified that the four main vehicle fuel system modifications required for B10 to B100 compatibility were:

1) Fuel tank – focus on tank material

2) Feed pump – focus on pump design

3) Fuel lines – focus on material selection

4) Fuel filter – focus on filter sealing and water separation

Consideration of engine seal materials outside of the fuel circuit is also important due to the potential for exposure to the biofuel through fuel in oil dilution effects. In some cases material coatings can be used for passivation protection, e.g. oxide coatings on diesel fuel pump casings. New materials and new applications of existing materials to fuel and lubricant require consideration of compatibility e.g. timing belt in oil.

Figure 75: Summary of material suitability for FAME

	Materials that are compatible	Materials that may be compatible	Materials that are not compatible
Metals	Steel Aluminium	Bronze Brass Copper Lead Tin Zinc	
Elastomers	Fluoroelastomer (FKM) [Viton®]	Ethylene propylene diene monomer rubber (EPDM)	Polychloroprene (CR) [Neoprene®] Natural Rubber Nitrile rubber (NBR)
Polymers	Polyamide 6 (PA 6) [Nylon 6] Polyamide 66 (PA 66) [Nylon 66] Teflon		Polypropylene Polyvinyl Chloride (PVC) Tygon

Source: Ricardo

It is possible to design a diesel engine for higher FAME biofuel contents, but an area of key concern is the backward compatibility of the existing fleet to increases in biofuel concentrations. Vehicle parc turnover will eventually reduce this problem.

7.4.2 Technical Constraints associated with the use of Ethanol

Effect of ethanol on the combustion system

The addition of ethanol into gasoline increases the available oxygen for combustion. Therefore more fuel is required to operate at stoichiometry, since the stoichiometric AFR for ethanol is 9:1, compared to 14.7:1 for gasoline. This leads to the risk of enleanment if the fuel injectors are too small or if fuel system is open loop. For ethanol blends, the fuel injectors need to operate over a wider flow range and with reduced fuel viscosity. The injector dynamic range needs to increase to cover light load / idle operation on gasoline to high load operation on ethanol. This may result in poor fuel control in the low flow region due to injector linearity.

The fuel pump and injector components may experience higher long term wear when running on ethanol blends because of the reduced viscosity of the fuel. The removal of the passive / stabilised deposits formed during the use of gasoline may lead to fuel filter blockages and the plugging of fuel metering components. There is the potential of corrosion of the metal components of the fuel system as the hydroxyl group in ethanol has acidity functionality.

Effect of ethanol on lubrication

A problem which may result in any alcohol-fuelled engine is dilution of the lubricating oil with alcohol caused by condensation from blow-by gases or fuel which finds its way past the piston rings. Due to the hydrophilic property of ethanol, the water content of the lubricant can increase and lead to the formation of an emulsion. This increases the oil viscosity, and can lead to the premature corrosion of some engine components.

Boons et al. (2008) found that the use of E85 coupled with short journey driving and low-temperature engine operation could significantly increase the levels of water in engine oil by up to 16%, compared to the use of E10. This high water content did not appear to have an influence on the rust formation on some engine parts. Nevertheless, they concluded that increased levels of corrosion inhibitors and metal deactivators should be considered in these cases.

Effect of ethanol on engine-out emissions

The use of ethanol blends can reduce the engine-out CO, HC and NOx emissions of gasoline engines. Since these emissions are well controlled by the aftertreatment catalysts, there is almost no change in tailpipe emissions.

Particle number emissions from SI engines are generally low and generated under enrichments or cold start. The presence of oxygen may limit the formation of these particulates. When operating rich, oxygenated blends reduce both the number concentration and the mean diameter. When operating at homogeneous lean AFRs both the particle diameter and the number concentration are lower than under rich conditions. The effects however will be minimal since emissions are initially low.

Like FAME, ethanol has a lower calorific value than the conventional fossil fuel is it replacing (the calorific value of ethanol is around two thirds of that of gasoline). Therefore more fuel is required to provide the same energy, which increases the tank-to -wheel CO_2 emissions of the vehicle.

Effect of ethanol on evaporative emissions

Evaporative emissions include hydrocarbon emissions from the vehicle fuel system, and static permeation, running loss, hot soak, and diurnal emissions from a vehicle's materials. One of the key contributing factors to evaporative emissions is the fuel vapour pressure. This varies by fuel composition and ambient temperature. As the ethanol content increases to 10%vol the fuel vapour pressure increases. However between 10-20%vol ethanol, this trend reverses and the vapour pressure reduces as ethanol is increased further. Therefore, for ethanol blends between 5-20%vol, evaporative emissions increase. However for blends of more than 50%vol ethanol, evaporate emissions may decrease.

Effect of ethanol on material compatibility

As for all biofuels, when designing an engine to operate with biofuel content, it is important to select materials that are compatible with the biofuel. A list of materials that are compatible, that may be compatible and that are not compatible with ethanol is provided in Figure 76.

Figure 76: Summary of material suitability for ethanol

	Materials that are compatible	Materials that may be compatible	Materials that are not compatible
Metals	Steel Bronze	Aluminium Tin	Zinc Brass Copper Lead
Elastomers	Fluoroelastomer (FKM) [Viton®] Ethylene propylene diene monomer rubber (EPDM) Hydrogenated nitrile rubber (HNBR) Nitrile rubber (NBR)	Polychloroprene (CR) [Neoprene®] Natural Rubber	Urethane rubber
Polymers	Polyamide 6 (PA 6) [Nylon 6] Polyamide 66 (PA 66) [Nylon 66] Polypropylene Teflon		Polyurethane (PUR) Polyvinyl Chloride (PVC) Tygon

Source: Ricardo, U.S. Renewable Fuels Agency, Jones et al. (2008a, 2008b, 2008c)

7.5 Technologies to improve biofuel compatibility of future vehicles

Co-engineering powertrain systems with new biofuels is the key to maximising efficiency and improving customer acceptance. Conventional gasoline and diesel products have developed in tandem with the storage, distribution and retailing infrastructure, and the engine and vehicle technologies. This has created a system which, to a large extent, is already optimised from an operational perspective. Inevitably, introduction of biofuel components with different chemical and physical properties generates new requirements that can initially result in a number of disadvantages compared to the traditional fossil products.

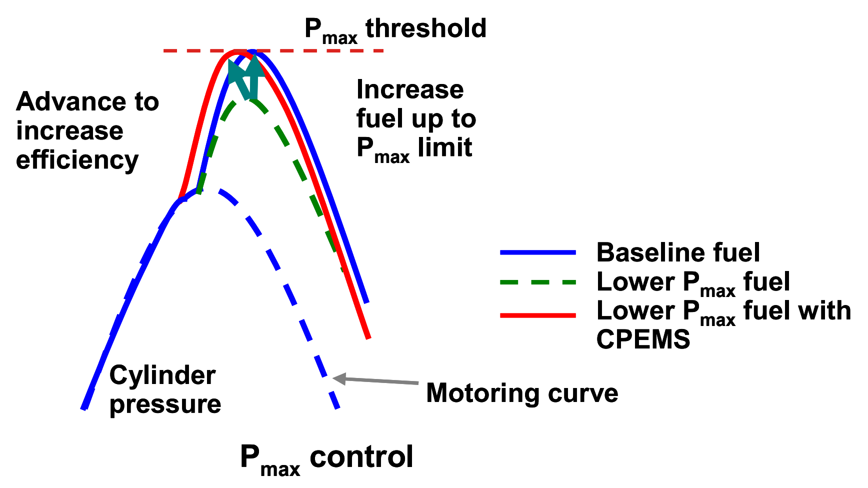
For vehicle technology, the challenge for industry is to ensure the co-development of future engine systems to utilise biofuels in an efficient and uncompromising manner. This will mean minimising the impact of negative features, such as reduced heating value, active chemistry and reduced operability, whilst seeking to benefit from the characteristic advantages, such as high octane or cetane number. This sub-chapter contains examples where optimising engine combustion and control systems for use on biofuels can help to achieve of this objective.

7.5.1 Biodiesel

Combustion control for diesel engines requires closed loop adaptation to allow continual optimisation for different fuels. Different fuel types influence the combustion within diesel engines through a combination of chemical and physical parameters. Traditional diesel combustion control is open loop and therefore only optimised for the fuel on which it is originally calibrated. Continual recalibration of a control for different in-field fuels can be achieved through an adaptive control strategy. The controller requires information on combustion response to a particular formation in order to calculate the optimum combustion parameters. This information is mostly embedded in the cylinder pressure trace, which can be analysed by a Cylinder Pressure based Engine Management System (CPEMS) to calculate the heat release rate, ignition delay, peak cylinder pressure (Pmax) and brake Mean Effective Pressure (BMEP)

Figure 77 contains a diagram to illustrate how Closed Loop Combustion Control can be used to adapt the engine calibration strategy to achieve the optimisation criteria. In this example the optimisation target is to utilise the maximum cylinder pressure controller to restore peak torque.

Figure 77: Diagram to illustrate how closed loop combustion control can be used



Source: Ricardo

A number of different strategies for closed loop adaptation are possible. A typical strategy could utilize CPEMS to adapt the injection timing, injection quantity, air handling and other parameters which impact combustion, for changes in fuel composition. A typical optimisation target could be to utilise the maximum cylinder pressure controller to restore peak torque. In practice, the impact of these changes on other combustion parameters, including emissions and exhaust temperature should also be considered, and might provide some constraints on the ability to meet the targets of the strategy fully. As more advanced sensors come to market the complexity of closed loop combustion system could increase

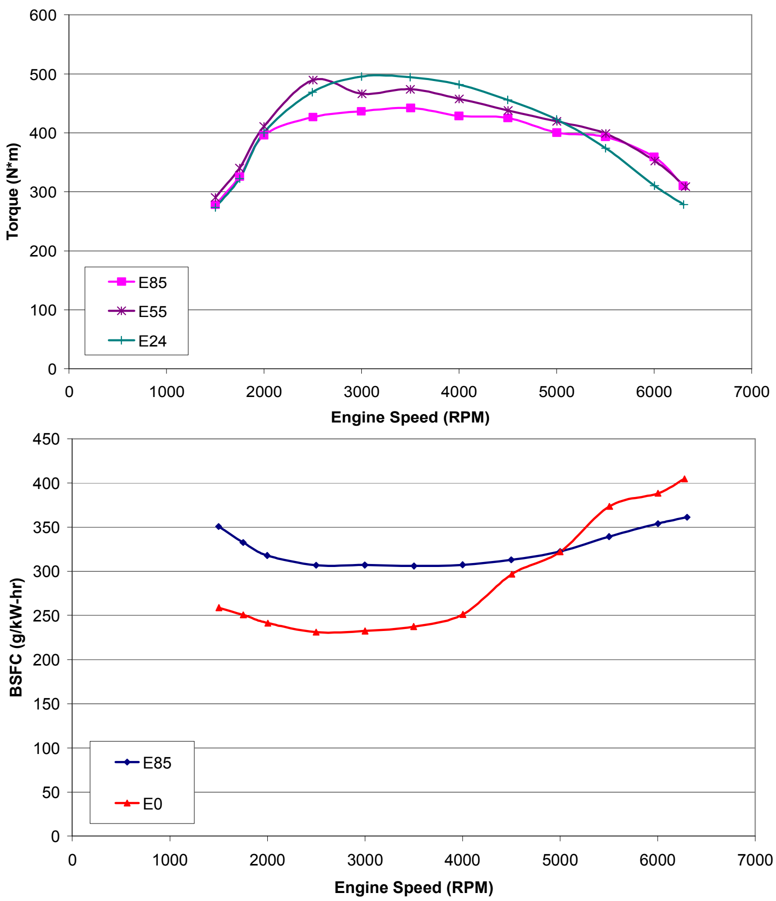
7.5.2 Ethanol

The benefits of ethanol charge cooling are particularly synergistic with downsized gasoline direct injection engines. The high latent heat of ethanol results in significant charge cooling, which in downsized DI engines leads to increased volumetric efficiency and reduced risk of detonation. This is due to lower end-of-compression temperatures, particularly with late injection strategies. At fixed spark timing this carries through to similar reductions in exhaust temperature. In gasoline DI engines, over fuelling strategies are used at high load conditions to control maximum exhaust temperature. Therefore at fixed timing high ethanol blends offer the possibility of a relative improvement in fuel consumption through reduced over fuelling requirement.

Another benefit of ethanol blends is the octane uplift which can allow more advanced timing and ultimately knock-free full load stoichiometric operation. Downsized engines often require quite retarded full load combustion to prevent knock due to high in-cylinder pressures. The octane and charge cooling advantage of E85 allows operation at or close to MBT, even under conditions where gasoline operation would be retarded to prevent knock. In practice, this allows the 50% MFB angle to be held at the thermodynamic optimum of 8ºATDC. Under similar conditions, the retarded operation with gasoline further increases the exhaust temperature and therefore the overfuelling requirement.

Optimised combustion for E85 at full load may challenge engine Pmax limits, but significant fuel consumption benefits are available. Due to the superior charge cooling and octane number, on E85 it can be possible to run the engine at stoichiometric AFR and MBT at full load. However, this can lead to high rates of cylinder pressure rise. In some cases the maximum cylinder pressure criterion, Pmax, may be reached which limits the torque output. In these cases, re-engineering for higher Pmax levels, e.g. 150 bar+, is required to exploit the full capability of E85. With the combustion system optimised for E85, thus allowing stoichiometric, advanced combustion, the thermal efficiency can reach ~40%. At high speed, full load BSFC can actually be lower than gasoline despite the significantly reduced heating value (see Figure 78).

Figure 78: Torque and BSFC Penalty from Ethanol Blends



Source: Ricardo

7.6 Overview of the Technical Impacts of different Biofuel Blends

This chapter concludes with a series of tables designed to illustrate the relative impacts of different biofuel blends on the engine technologies considered. The purpose of these tables is to help define the acceptable limits of biofuel content for Euro 4, Euro 5 and Euro 6 engines.

For diesel engines, the following biodiesel blends were considered:

- B5 with 5%vol FAME
- B7 with 7%vol FAME
- B10 with 10%vol FAME
- B20 with 20%vol FAME
- B30 with 30%vol FAME
- B100 with 100%vol FAME

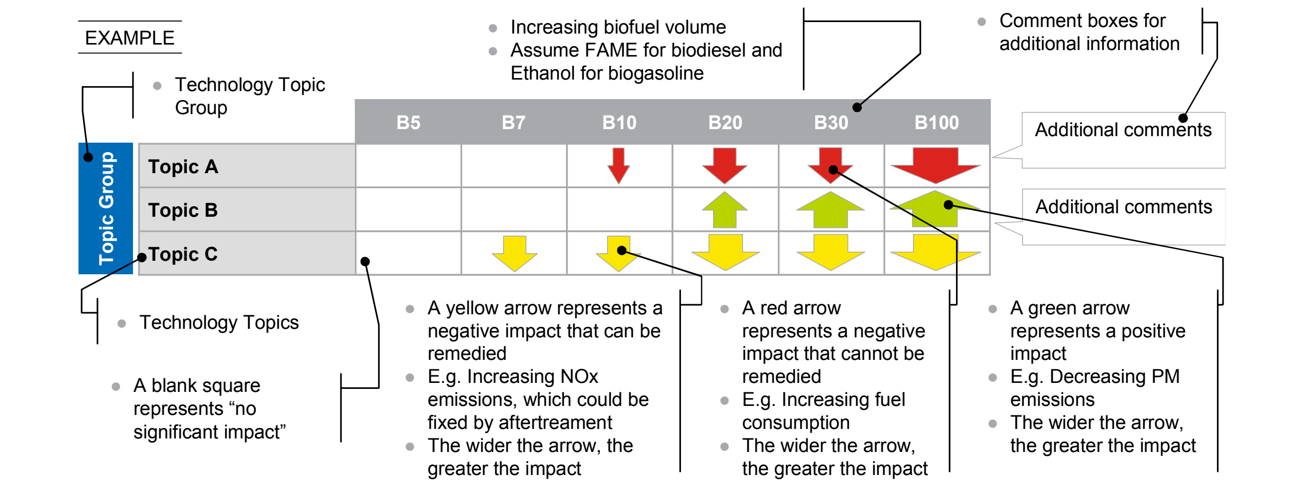
For gasoline engines, the following ethanol blends were considered:

- E5 with 5%vol ethanol
- E10 with 10%vol ethanol
- E20 with 20%vol ethanol
- E85 with 70-85%vol ethanol

It was assumed that E85 would only be run in a flex-fuel vehicle (FFV) designed to operation on E85, therefore negating many of the impacts associated with running gasoline engines on higher ethanol blends.

The tables contain arrows to indicate the relative impact. Down arrows represent negative impacts, such as increases in fuel consumption. Up arrows represent positive impacts, such as a decrease in engine-out emissions. The width of the arrow indicates the relative size of the impact. Arrows of larger width have a bigger impact. Following the stakeholder consultation, it was decided to split the negative impacts into two categories - those impacts which could be fixed and those which could not. Figure 79 contains a diagram to help explain how to interpret the impact tables presented in this sub-chapter.

Figure 79: Diagram to explain how to interpret the biofuel blend impact tables Torque



Source: Ricardo

The tables consider the impact of different biofuel blends on the engine combustion system, engine-out emissions, lubricants and seals. It should be noted that all road vehicles are fitted with suitable aftertreatment systems to ensure that the tailpipe emissions are within the legislative limits. Therefore any decrease (positive impact) or increase (negative impact) of biofuels on engine-out emissions may not been observed in the tailpipe emissions. Therefore, following the stakeholder consultation, it was decided to present the impact of biofuels on engine-out emissions in the tables, rather than tailpipe emissions.

7.6.1 Light Duty Diesel Engines

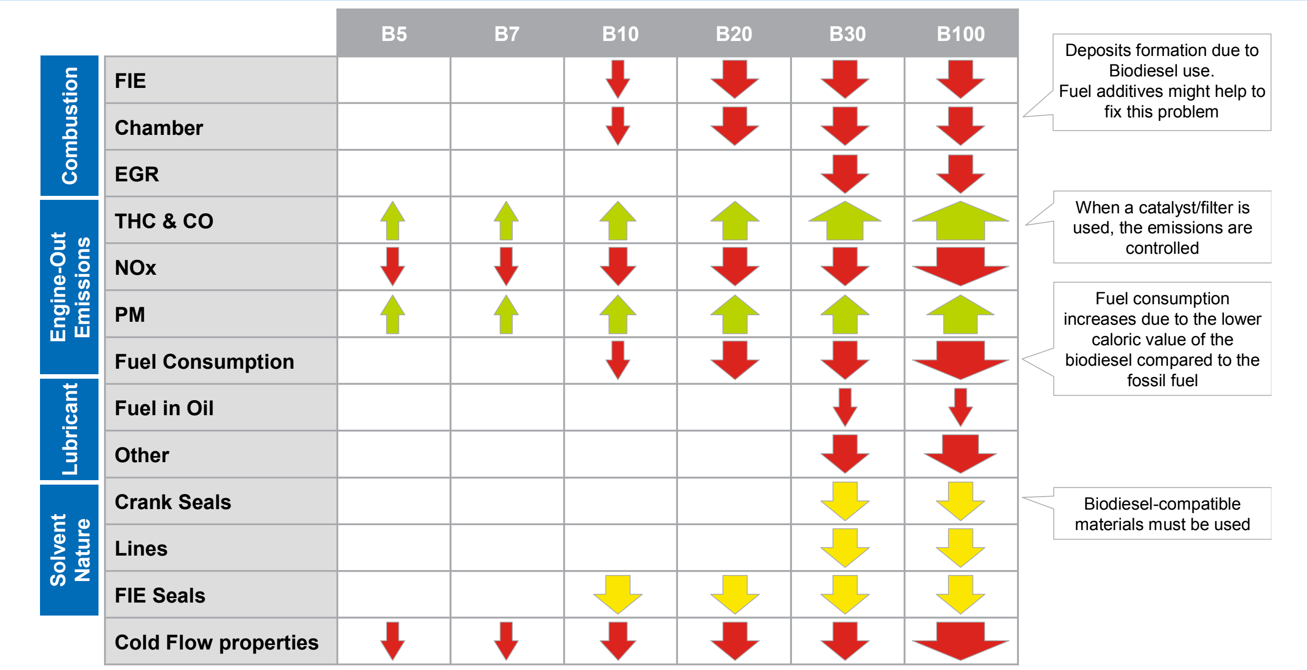
The biofuel blend impact tables for light duty diesel vehicles are presented below. The following engines have been considered:

- Light Duty Diesel Euro 4 (without DPF aftertreatment) (Figure 80)
- Light Duty Diesel Euro 5 (with DPF aftertreatment) (Figure 81)
- Light Duty Diesel Euro 6 (with DPF and NOx control aftertreatment) (Figure 82)

For all three engines the level of relative impact increases at the FAME content increases. For blends up to 7%vol FAME, the impacts are relatively minor. As the blend ratio increases to 10%vol and above, the impacts appear to become more significant. This implies that biodiesel blends with 7%vol FAME (or less) will be suitable for Euro 4, Euro 5 and Euro 6 LDD engines. This view was confirmed by the stakeholders during the stakeholder consultation.

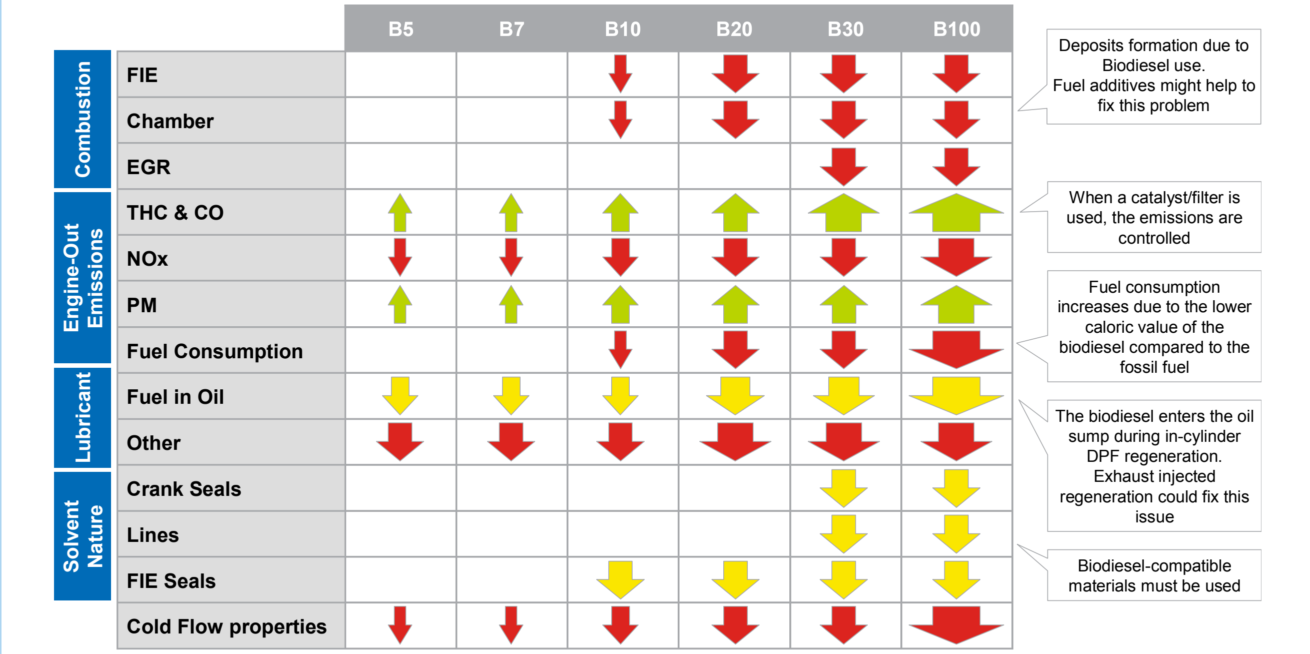
Euro 5 and Euro 6 LDD engines appear to be effected more by the biofuel content than for Euro 4. This is because Euro 5 and Euro 6 LDD engines will be fitted with DPF aftertreatment. As discussed in Section 7.4.1, if the strategy for regenerating the DPF involves post injection of fuel into the cylinder, this can increase the rate of fuel in oil dilution.

Figure 80: Biofuel blend impact table – Light Duty Diesel Euro 4 (no DPF)



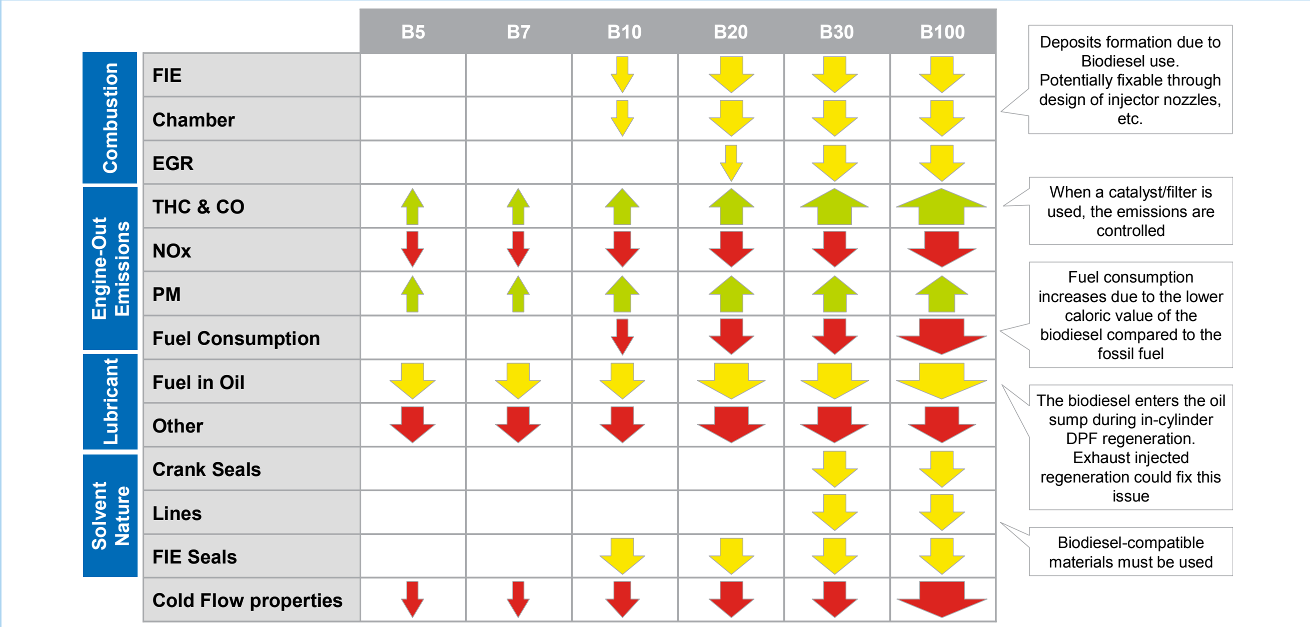
Source: Ricardo

Figure 81: Biofuel blend impact table – Light Duty Diesel Euro 5 (no DPF)



Source: Ricardo

Figure 82: Biofuel blend impact table – Light Duty Diesel Euro 6 (DPF + NOx Control)



Source: Ricardo

7.6.2 Heavy Duty Diesel Engines

The biofuel blend impact tables for heavy duty diesel vehicles are presented below. The following engines have been considered:

- Heavy Duty Diesel Euro IV (without DPF aftertreatment) and Euro V (without DPF, but with SCR aftertreatment) (Figure 83)

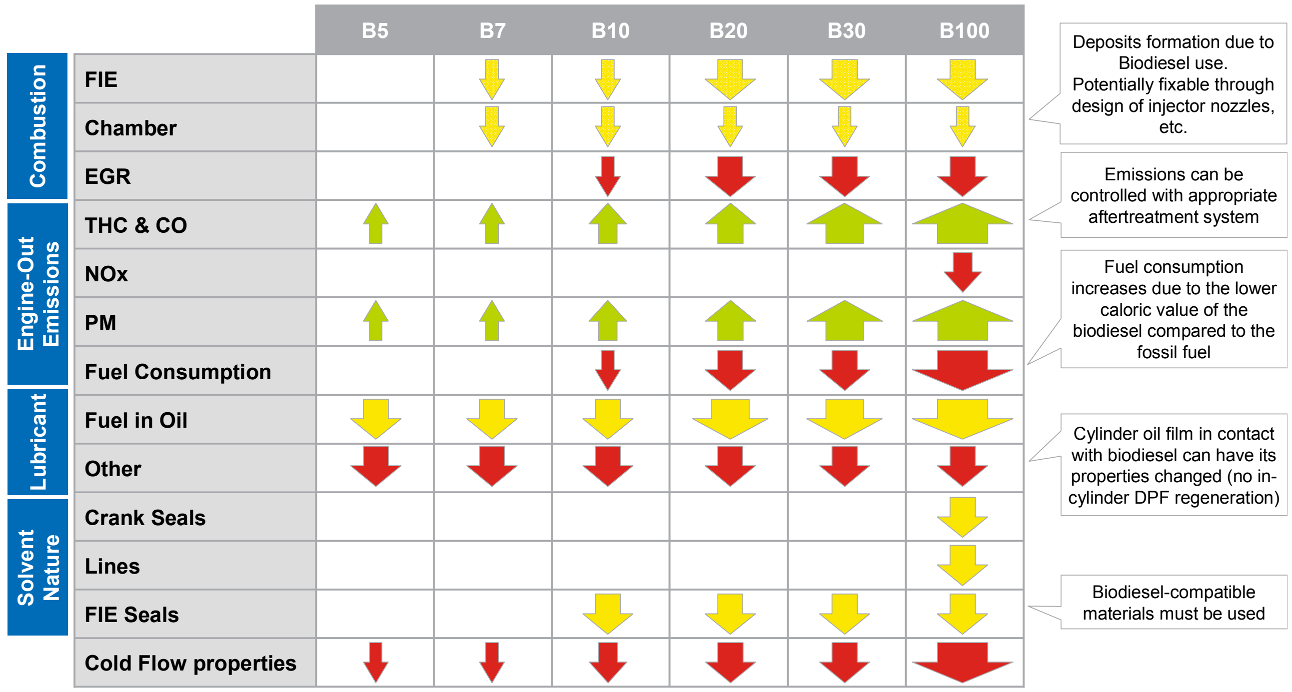
- Heavy Duty Diesel Euro VI (with DPF and SCR aftertreatment) (Figure 84)

As for LDD, for HDD applications the level of relative impact increases at the FAME content increases. The impact is relatively minor for blends up to 7%vol FAME, but become more significant as the blend ratio increases to 10%vol and above.

Figure 83: Biofuel blend impact table – Heavy Duty Diesel Euro IV (no DPF) and Euro V (no DPF, with SCR)

Source: Ricardo

Figure 84: Biofuel blend impact table – Heavy Duty Diesel Euro VI (DPF + SCR)



Source: Ricardo

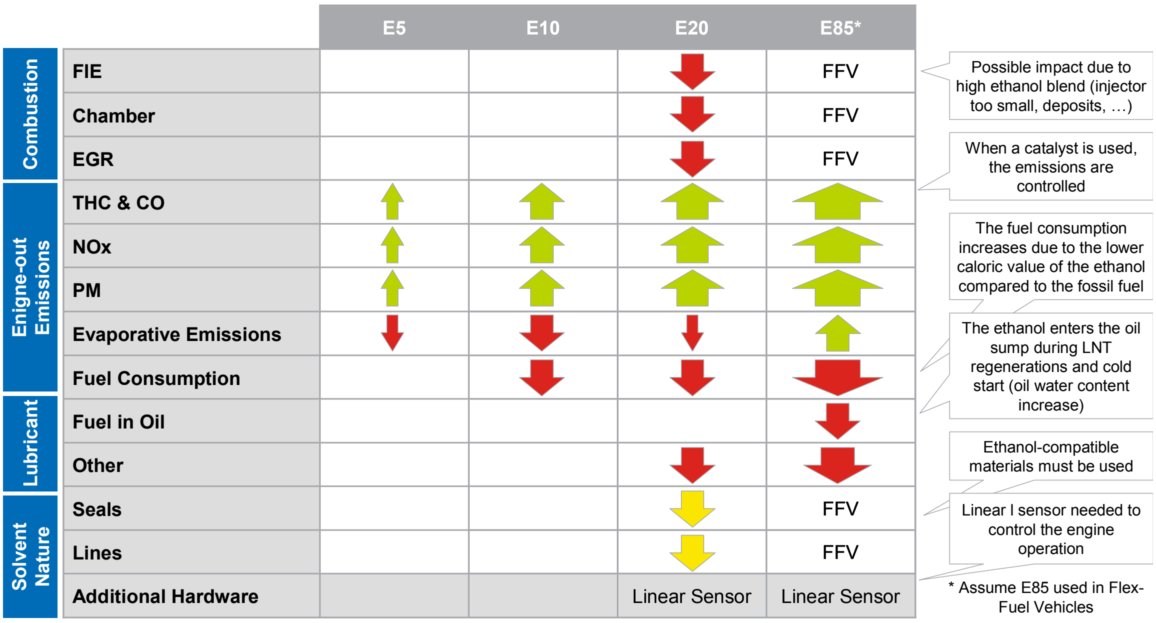
7.6.3 Light Duty Gasoline Engines

The biofuel blend impact tables for light duty gasoline vehicles are presented below. The following engines have been considered:

- Light Duty Gasoline Euro 4 (with stoichiometric operation strategy) (Figure 85)
- Light Duty Gasoline Euro 5 and Euro 6 (with stoichiometric operation strategy) (Figure 86)
- Light Duty Gasoline Euro 5 and Euro 6 (with lean operation strategy) (Figure 87)

For all three engines the level of relative impact increases at the ethanol content increases. The impacts are relatively minor for E5, but become more significant for E20. Many of the impacts of E85 are mitigated through designing and developing the engine for the fuel.

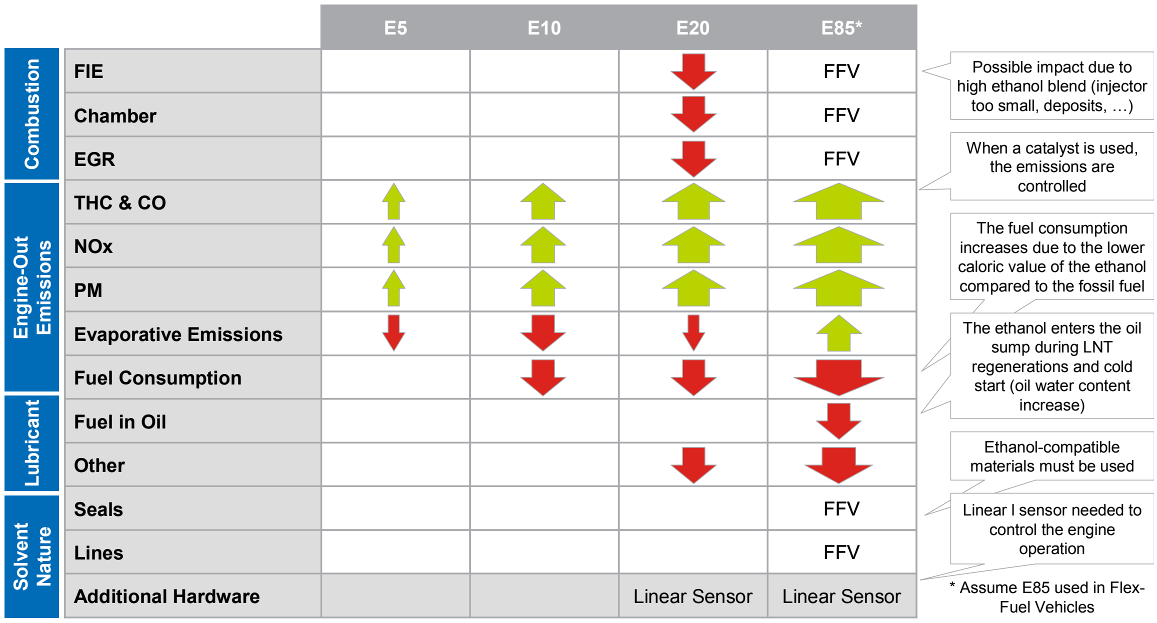
Figure 85: Biofuel blend impact table – Light Duty Gasoline Euro 4 (Stoichiometric)



Source: Ricardo

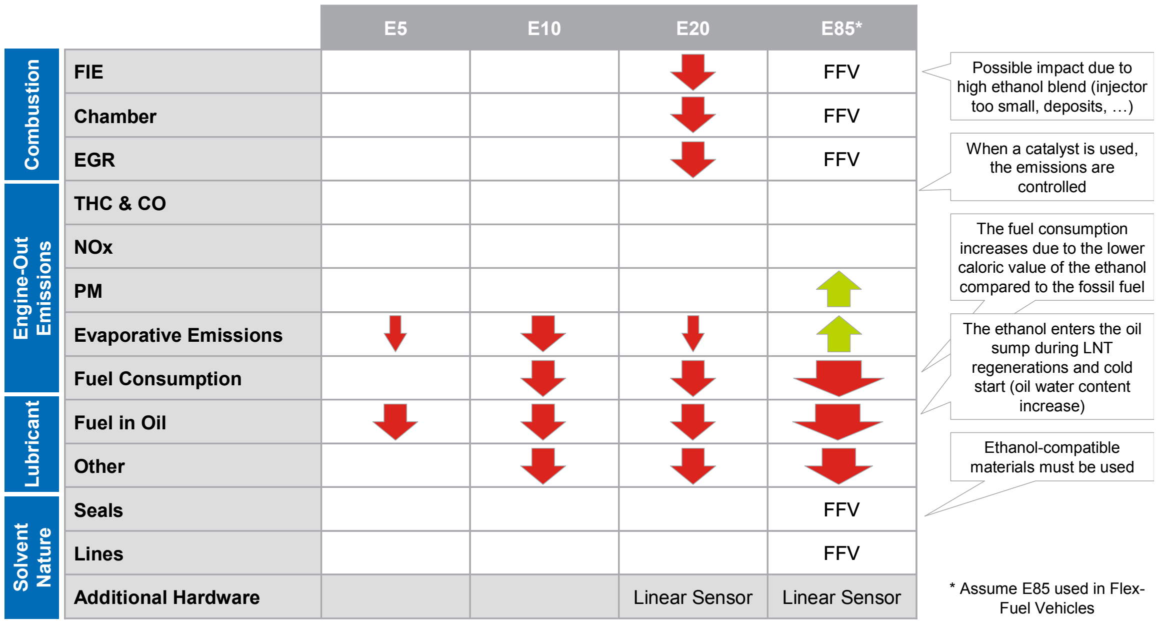
Since the Fuel Quality Directive has specified that the ethanol limit for gasoline is to be 10%vol, this study has assumed that E10 will be suitable for Euro 4, Euro 5 and Euro 6 gasoline engines. This assumption was confirmed during the stakeholder consultation.

Figure 86: Biofuel blend impact table – Light Duty Gasoline Euro 5 and Euro 6 (Stoichiometric)



Source: Ricardo

Figure 87: Biofuel blend impact table – Light Duty Gasoline Euro 5 and Euro 6 (Lean)



Source: Ricardo

8 Future Passenger Vehicle Technologies

The purpose of this chapter is to provide information on the relative penetration of the car of the future (hybrids, electric and fuel cells). The focus is on Europe. The different vehicle technology options are discussed and a technology roadmap presented to indicate when these technologies are likely to enter the European market.

In addition to the European passenger car market, commentary is provided on the differences and similarities in technology trends in USA, Japan and China.

8.1 Europe

Over the next decade and towards 2030 the range of technology options within the European passenger car parc is expected to diversify. The objective of this diversification will be to improve the powertrain efficiency and to reduce the vehicle tailpipe CO_2 emissions. Available technologies will include:

Conventional internal combustion engine (ICE) vehicles

These vehicles will continue to run on a liquid or gaseous fuel, such as gasoline, diesel or CNG. Engine design will continue to evolve to improve efficiency and reduce fuel consumption while meeting the increasingly stringent tailpipe emissions legislation. Further information on current and future engine technology is provided in chapter 7.3.

Mild and full hybrid vehicles (HEV)

A hybrid vehicle uses an electric motor as well as a conventional engine to move the vehicle. The vehicle is charge sustaining, with all energy originating from one source – the liquid or gaseous fuel used to power the engine. If the hybrid can operate in “EV mode”, then it is classed as full hybrid. Examples of hybrid vehicles include the Toyota Prius and Lexus RX400h.

Plug-in hybrid vehicles (PHEV) and range extended electric vehicles (RE-EV)

Plug-in vehicles have the same functionality as full hybrid vehicles, but with a larger EV range. They are classed as charge depleting because they can be plugged into the mains electricity to recharge, i.e. energy originates from more than one source. These vehicles may be either versions of hybrid vehicles that can be connected to the grid, or electric vehicles with range-extender engines. Examples of proposed plug-in vehicles include the Opel Ampera.

Electric vehicles (EV)

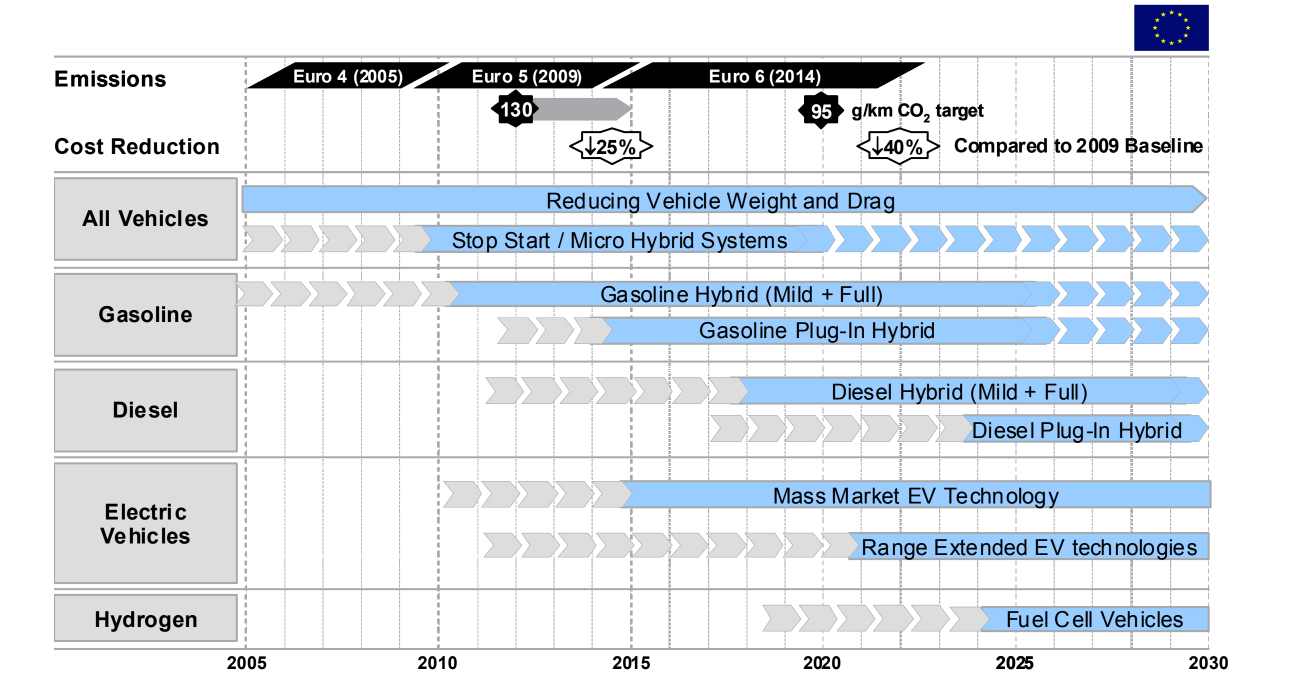
For these vehicles, the sole energy vector is electricity. The vehicle has on-board devices for storing the electrical energy, such as batteries or capacitors. Electric motors convert the electrical energy into kinetic energy to drive the wheels. There are currently several large-scale demonstration trials of EVs on-going throughout Europe. Examples of EVs include the Nissan Leaf and Mitsubishi i-MiEV.

Fuel Cell Vehicles (FCV)

In this case, the vehicle’s prime mover is a fuel cell system, probably requiring hydrogen as the energy vector. The main challenges for the introduction of this technology are the cost of the hydrogen on-board storage tank and the development of an international hydrogen refuelling infrastructure. Several OEMs have stated their intention to launch fuel cell products into the automotive market place in 2015. It is expected that these vehicles will initially only be available in Japan and parts of the USA such as California. However fuel cell vehicles could be available in Europe by the end of the next decade. The current state-of-the-art fuel cell prototype vehicles include the Daimler B-Class F-Cell and the Honda FCX Clarity.

Ricardo’s Technology Roadmap for the introduction of these future technologies in Europe is shown in Figure 88. This technology roadmap builds on the consensus OEM product roadmap developed by the UK New Automotive Innovation and Growth Team (NAIGT, 2010). An explanation of the arrows and colours used in the Technology Roadmap is provided in appendix Appendix C.

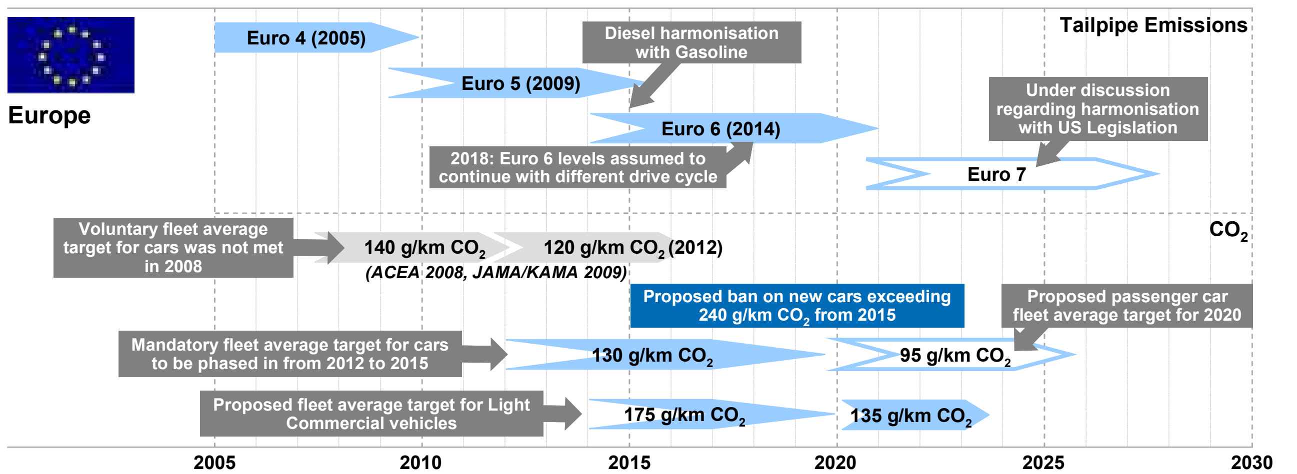
Figure 88: Technology Roadmap for future passenger vehicle technologies in Europe



Source: Ricardo

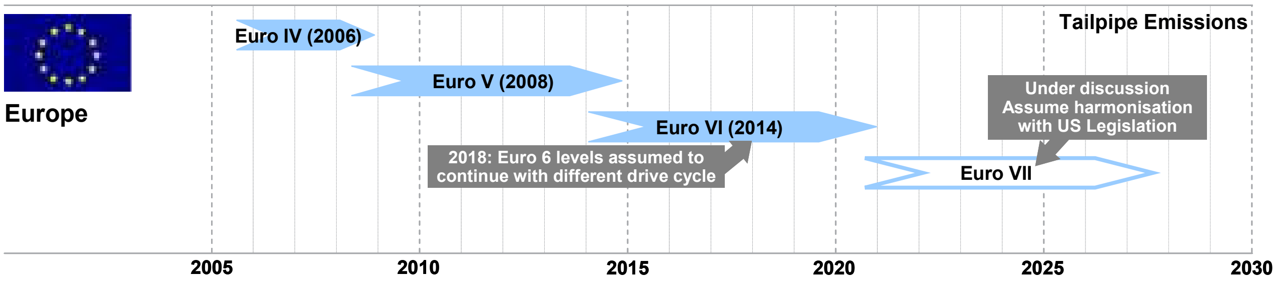
There are many factors driving the diversification in vehicle powertrain technologies, but the most significant is government legislation. Over the past 30 years, European tailpipe emissions legislation limiting the vehicle emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulates (PM) has shaped the development of the internal combustion engine. Each phase of emissions legislation has tightened the limits, leading to the introduction of technologies designed to improve combustion, such as exhaust gas recirculation (EGR), and to the clean the exhaust gases, such as the three-way catalyst (TWC) and diesel particulate filter (DPF). The current limits for light-duty and heavy-duty vehicles are defined in Euro 5, with Euro 6 limits becoming mandatory in 2014 (see Figure 89 and Figure 90). It is expected that tailpipe emissions legislation will tighten again between 2020 to 2030 with the introduction of Euro 7. However proposals for these limits have not yet been published. Further information on the technologies used in Euro 4, Euro 5 and Euro 6 vehicles to help meeting the emissions legislation is provided in chapter 7.3

Figure 89: Overview of European emissions legislation for light duty vehicles



Source: Ricardo EMLEG

Figure 90: Overview of European emissions legislation for heavy duty vehicles



Source: Ricardo EMLEG

Along side the tailpipe emissions legislation, the European Union is adopting a fleet average CO_2 target for new passenger cars (M1 vehicles), with super-credits for low emission vehicles, and non-compliance penalties for OEMs that do not meet the targets. The fleet target of 130 gCO_2/km will phase in between 2012 to 2015, with an additional 10 g/km reduction expected to come from the adoption of complementary measures such as gear shift indicators, more efficient air conditioning, low rolling resistance tyres, aerodynamics and biofuels.

The specific CO_2 targets are defined by vehicle mass. The targets apply to the manufacturer's fleet average, with no requirements for each individual vehicle to meet its target. Between 2012 to 2016, super-credits will be available for new passenger cars with specific CO_2 emissions of less than 50 g/km. However the penalty scale for non-compliance increases with excessive emissions.

The proposed long-term target for fleet average CO_2 is 95 g/km by 2020.

The European Commission have proposed introducing similar CO_2 legislation for light-duty commercial vehicles (LCVs) (class N1 and N2). The current proposed target is 175 gCO_2/km phased-in from 2014 to 2016, with the long-term target of 135 g/km fleet average CO_2 by 2020. As for passenger cars, there will be a penalty system for non-compliance.

Over the past 10-15 years, CO_2 and fuel consumption related taxation and incentives, along side the introduction of technologies such as common rail injection, have driven the uptake of diesel passenger car vehicles to the extent that in some European countries diesel passenger cars represent over 50% of new car sales (e.g. France, Spain). Over the next decade, it is expected that sales of diesel passenger cars will continue to increase until diesel represents approximately 50-55% of new car sales across Europe.

However it has been acknowledged that the 2020 target of 95 gCO_2/km cannot be met by diesel technology alone. This is driving a revival in gasoline vehicle development, with an emphasis on smaller cars, and the introduction of alternative powertrains, such has plug-in hybrids and electric vehicles. The sale of hybrid vehicles is expected to increase as more manufacturers introduce more models into the European market.

Across Europe there is currently strong political support for low carbon vehicles, especially EVs, with several Member States setting targets and introducing incentives to encourage production and sales of low carbon vehicles in Europe. (see Figure 91).

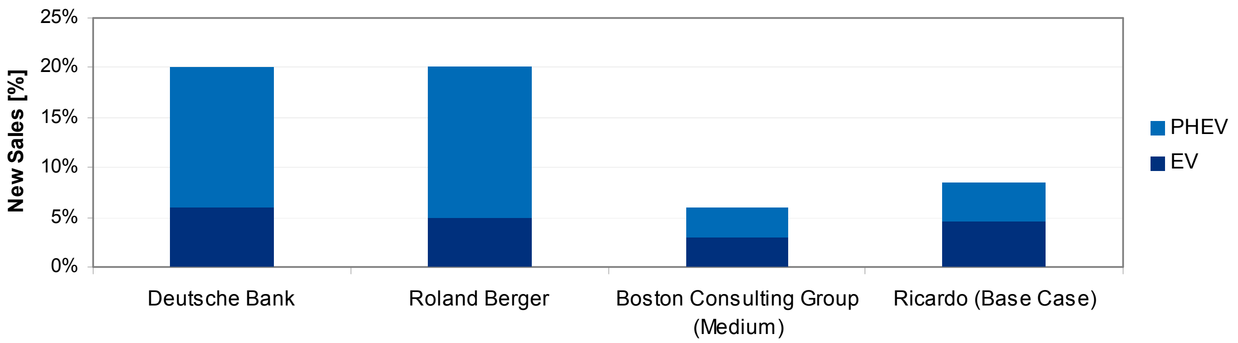
Figure 91: Examples of grants and incentives for low CO2 vehicles

Country	Incentives for low CO_2 vehicles
Austria	**Bonus-Malus:** Starting on 1 July 2008, cars emitting less than 120g/km receive a maximum bonus of €300. Cars emitting more than 180g/km pay a penalty of €25 for each gram emitted in excess of 180g/km. (160 g/km as from 1 January 2010). Alternative fuel vehicles attract a bonus of maximum €500.
Belgium	**Tax incentives:** Granted to private persons purchasing a car that emits less than 115g CO_2 /km. The incentives consist of a reduction of the invoice price with the following amount: ▪ Cars emitting less than 105g/km: 15% of the purchase price, with a maximum of €4,540 ▪ Cars emitting between 105 – 115g/km: 3% of the purchase price, with a maximum of €850
France	**Bonus-Malus:** Bonus, decrease in purchase price of a new car when its CO_2 emissions are below 130g/km is given and a Malus, increase in purchase price implemented, when it's CO_2 emissions exceed 160g/km ▪ The maximum "Bonus" is €5,000 (below 60g/km). A "super-bonus" of €1,000 is granted when a car of at least 10 years old is scrapped simultaneously ▪ The maximum "Malus" is €2,600 (above 250g/km). The different thresholds are strengthened by 5g/km every two years. In addition there is a yearly tax of €160 for vehicles emitting >250g/km CO_2
Italy	**Scrappage:** For the purchase of new vehicles emitting a maximum of 130g/km (diesel) and 140g/km (other fuels) an incentive of €1,500 is available if a vehicle that is 9 or more years old is scrapped simultaneously. Higher incentives apply for alternative fuel vehicles (CNG, LPG, electricity and hydrogen)
Sweden	**Purchase grant:** SEK 10,000 is granted for the purchase of "environmentally-friendly cars": ▪ Petrol/diesel/hybrid cars with CO_2 emissions up to 120g/km ▪ Alternative fuel/flexible fuel cars with a maximum consumption of 9.2 l (petrol) / 8.4 l (diesel) / 9.7cm^3/100 km (CNG, biogas) ▪ Electric cars with a maximum consumption of 37 kWh/100 km

Source: ACEA Tax Guide 2009

In spite of the strong drivers of political will and legislation, since electric and plug-in vehicles are new to the consumer, it is difficult to predict the early market growth. Estimations and scenarios vary widely. An overview of recently published market share projections for PHEVs and EVs is provided in Figure 92.

Figure 92: Market Share projections for plug-in vehicles in Europe in 2020



Source: Deutsche Bank (2009), Roland Berger (2010), Boston Consulting Group (2009), Ricardo

For the purpose of this study into the impact of biofuels on fuel specification, the base case has assumed a low level of electricification, with EVs and PHEVs representing less than 1% of new passenger car sales in 2020. For the third scenario, a higher level of electrification has been assumed, with EVs and PHEVs gaining market share of 5% by 2020 and 17% by 2030. Further information on the development of the study scenarios is provided in chapter 12.

8.2 USA

There are a number of key differences between the U.S. and European passenger car markets. The majority of the vehicles sold in USA are light trucks followed by passenger cars. These vehicles are larger than their European equivalents, usually with bigger engines, more cylinders and greater engine displacements. The majority of light duty vehicles are fuelled with gasoline. Light duty diesel vehicles accounted for only 5.3% of market share in 2006 (Ward's AutoInfoBank). The majority of these diesel vehicles were light trucks. The market share for gasoline hybrid vehicles is also low (1% in 2010 (Ward's AutoInfoBank)), but growing rapidly.

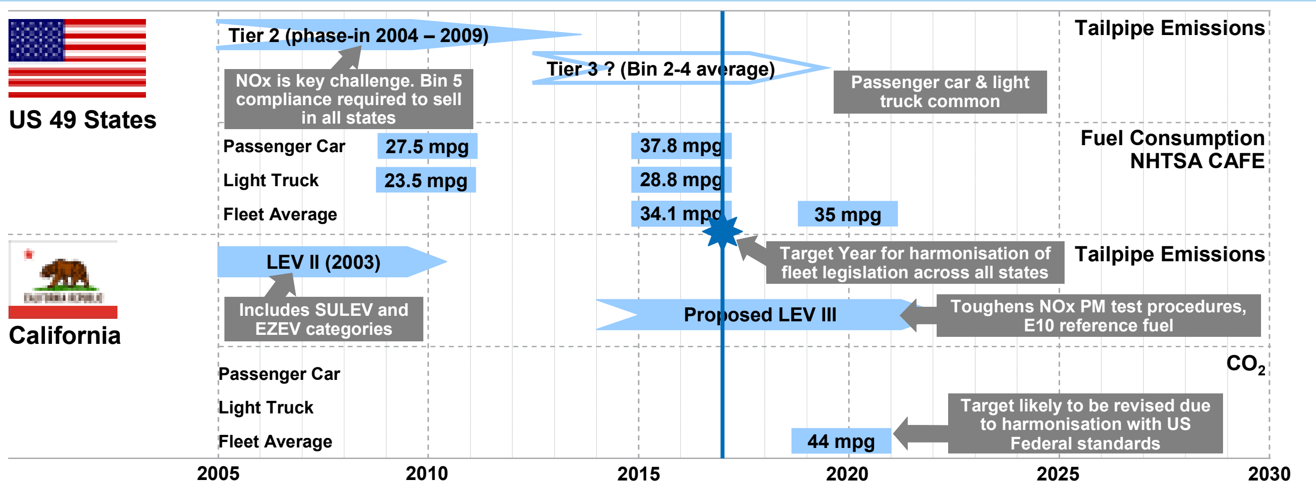
As for Europe, emissions legislation has been a key driver in the development of light duty vehicles in USA. U.S. Federal emission standards are fuel independent and are measured over the US FTP 75 drive cycle. All passenger vehicles and light duty trucks (LDTs) built and registered since 2004 have had to conform to Tier 2 standards. The same emission limits are applicable for cars, minivans, sports utility vehicles (SUVs) and light duty trucks (LDTs). Since the emission standards are fuel independent, gasoline, diesel, and alternative fuelled vehicles must meet the same emission levels.

NOx is the key challenge of U.S. Tier 2 emissions legislation, with even Euro 5 compliant EU diesels requiring significant NOx reduction to be compliant.

In addition to the U.S. Federal emission standards, several states have set their own limits for vehicle tailpipe emissions and fuel economy. Historically, California has the toughest emissions legislation within USA. However, in May 2009, the White House unveiled proposals to harmonise fuel economy and emission standards between U.S Federal and California by 2017.

An overview of U.S. emissions legislation for passenger cars is provided in Figure 93.

Figure 93: Overview of U.S. emissions legislation for passenger cars and light duty trucks



Source: Ricardo EMLEG, Stakeholder Consultation

Historically, fuel prices in USA have been significantly lower than in Europe. As a consequence, fuel economy has not been a key driver in the development of light duty vehicles in North America. However concern regarding energy security has lead to the National Highway Traffic Safety Administration (NHTSA) increasing the targets for Corporate Average Fuel Economy (CAFE) to 35 mpg by 2020.

The drive towards improving fuel economy will encourage the introduction of new products within the U.S. light duty market over the next decade. Expectations for the development of the U.S. light duty market include:

- Gasoline engines will continue to dominate the market.
- Trends in engine technology will include downsizing (e.g. V8 to V6), increasing power density, and employing cylinder deactivation in larger engines
- USA hybrid technology will continue to gain market share as more OEMs introduce new models into the market
- The majority of the HEV market will continue to be gasoline full hybrid (e.g. Toyota Prius) configurations

- Plug in hybrid vehicles will enter the market around 2011 (e.g. GM Volt, Toyota Prius plug-in)
- Market entry for electric vehicles will be in 2011 (Nissan Leaf)

8.3 Japan

In Japan, the passenger car market is dominated by small vehicles with the Mini and Subcompact segments accounting for approximately 50% of annual sales. Passenger cars are predominantly gasoline with a low penetration of hybrid vehicles and negligible diesel vehicles. Diesel passenger cars are not liked in Japan. Diesel penetration has continued to fall since 2000 and now accounts for less than 0.1% of new sales. The reasons for the Japanese dislike of diesels include the "dirty" image, noise and smell. The majority of Japanese live in city environments and their annual mileage is low. Therefore they do not benefit from the better fuel economy of a diesel passenger car. The Japanese driving environment is more suited to hybrid technology. This, along with the Japanese love of technology, is contributing to the increasing sale of hybrid vehicles, with the new Toyota Prius outselling supply.

Passenger cars in Japan tend to have small engines with capacities under 1.5L. For example, the “Kei” cars (mini segment) tend to have 660 cc engines and represent 30% of the market. The majority of Japanese passenger cars use automatic transmissions.

Japan‘s emissions legislation is amongst the most stringent in the world, including limits for particulates from lean burn gasoline DI engines. The Japanese drive-cycle for emissions legislation (JC08) is very similar to the European drive-cycle.

Fuel economy targets for passenger cars for 2015 are driving the development of technologies that improve fuel consumption. The Japanese like engine technology. The range of hybrid options is expected to diversify, with more choice available to the consumer. Stop-start technology suits the Japanese driving style (city congestion), but must be perfect in terms of performance. Gasoline full hybrid is also an attractive low fuel consumption option. Next generation CVT transmissions are growing in popularity in Small and Medium cars.

Fuel economy certification is available for all vehicles performing above set fuel economy targets, which can lead to tax reductions. If vehicles are classified as Low-Emission Vehicles further tax reductions can be available

In addition to encouraging the uptake of low carbon technologies, Japan has also encouraged uptake of alternative fuels. The vast majority of taxis in Japan are LPG.

Fuel prices in Japan, like Europe are higher than USA, with gasoline more expensive than diesel and subject to higher taxation.

8.4 China

In China, passenger cars are similar in size to their European equivalents. The Compact and smaller segments dominate the market, accounting for over 60%. Passenger cars in China predominantly have engines with capacities between 1.5 and 2L and use manual transmissions.

China is following the European emission standards, with emissions regulations based on EURO-norms with an implementation time lag of around 5 years. Large cities, such as Shanghai and Beijing, have pulled ahead their implementation timing, with requirements for new vehicles to comply with Euro 4 emission limits in 2008. Euro 4 will apply to the rest of the country in 2011.

Fuel consumption standards were introduced in 2005 and required 32 different car and truck weight-based classes to achieve between 21 and 43 mpg by 2008. This was not a fleet average, but required each vehicle within a weight class to meet the fuel consumption standards over the NEDC.

China is following the same technology model as Europe to meet the emissions and fuel economy regulations. Chinese OEMs are developing the latest European technology for home and export markets. Diesel is not currently popular in China and fuel quality is likely to stem growth until sulphur levels are reduced (sulphur can impact the fuel injection equipment and aftertreatment systems).

Micro-hybrid technology is appropriate for the Chinese market, given fuel consumption regulations and high levels of traffic congestion in cities. China is actively pursuing EV technology and was the first country to launch PHEV technology into the market with the commercially available BYD Auto F6DM PHEV.

9 Potential for Biofuels In Other Sectors

The following section examines the potential for biofuels introduction into other transport sectors in the European market in order to form a view on the extent of contribution to the overall renewable energy use targets in road transport that might be made from such sources. The section first examines the aviation market before moving on to take a look at the marine market.

9.1 Aviation

The study examined the potential for biofuels introduction into other transport sectors in the European market in order to form a view on the extent of contribution to the overall renewable energy use targets in road transport that might be made from such sources.

In considering the potential for biofuels use in aviation to contribute to the RED and TFQD, the study looked at current activities associated with testing and introduction of renewable and synthetic aviation fuels. There are many initiatives ongoing in different parts of the world, with participation from airlines, standards and regulatory authorities, feedstock growers, refiners, aviation marketing and supply companies, engine and airframe manufacturers and industry associations.

As part of its objective supporting reduction of airline CO2 emissions, the International Airline Transport Association (IATA) has increased its previous target for 6% of aviation fuel to come from renewable sources by 2020. The current IATA target is for 10% of aviation fuel demand to be satisfied through renewable sources by 2017. This accelerated target reflects the importance placed by the industry on the ongoing management of emissions and the potential economic implications to airlines flying in European airspace as a result of extension of the EU Emissions Trading Scheme (ETS) from 2012.

For aviation, from 2010 the EU ETS requires that overall CO2 emissions of the aviation industry are capped: initially at 97% of 2005 emissions levels, and from 2013 onwards at 95% (i.e. a 3% reduction in 2012 and a 5% reduction on 2005 levels from 2013 onwards). All operators flying to and from the EU will have to surrender one allowance for every tonne of CO2 emitted on a flight to, from, and within, Europe. The process for allocation of allowances is ongoing during 2010, when benchmarks relating to transported passengers and cargo will be established. A further 15% of available allowances may be auctioned. It is anticipated that the proposed allocations may fall short of requirements and operators emitting more than their allocated amount of CO2 will need to reduce emissions or - more likely - procure extra allowances. The impact for individual operators (or types of operator) is anticipated to vary significantly, driven by aspects such as route profile (short-haul / long-haul split) and age / ownership of aircraft fleet.

Aviation has experienced significant growth since 2005, but also volatility as the impact of global economic recession has structurally changed travel demand patterns for many operators. This makes forecasting 2012 emissions levels relative to 2005 challenging, however achieved passenger and freight growth to date means emissions levels for the industry are already estimated to be more than 20% higher than in 2005. The required reductions in 2012 and beyond are therefore very challenging and at an assumed carbon cost of 25-30 euro per tonne CO2 the economic incentives on aviation operators to reduce emissions are significant.

Longer term, emissions reduction targets under the EU ETS are estimated to be 10% by 2020, and potentially by as much as 30% by 2030 (relative to 2005 levels). Our discussions with stakeholders during the course of this project suggest a consensus that emissions reduction targets of this order cannot be met through engine technology or operational factors. Given this regulatory environment, the attractiveness of renewable or synthetic aviation fuel for jet use appears high.

The case for renewable jet fuel is therefore based on 3 premises:

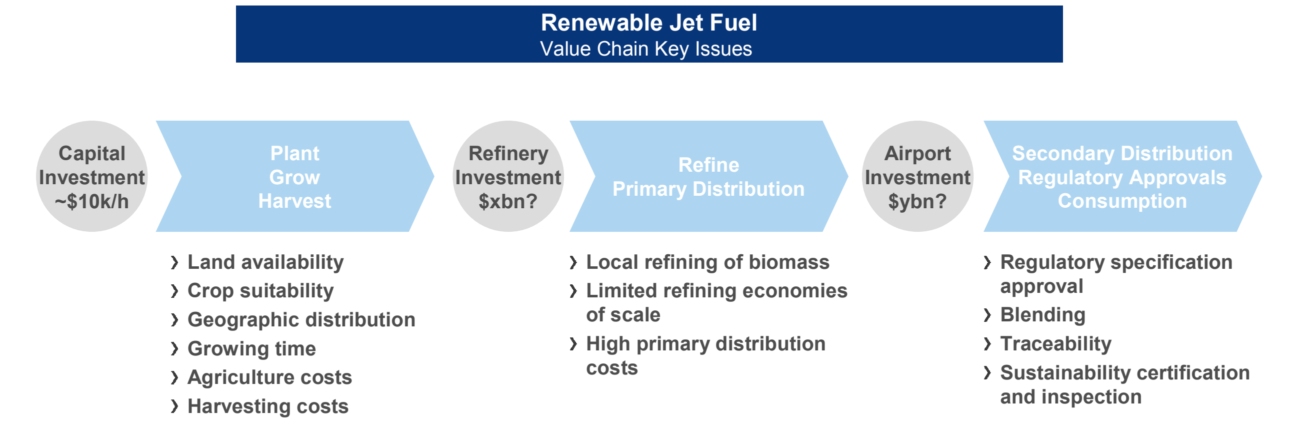
- Facilitate CO2 emissions reduction, enabling users to meet stringent EU emissions targets and minimize ETS costs;
- Increase energy source security;
- Reduce dependency on fossil fuels for transport.

However, while there is significant effort and investment being made by aviation industry stakeholders, incorporation of renewables into jet fuel presents a broad range of significant and potentially economically insurmountable challenges, summarized in the Figure 94.

Meeting IATA's stated target of 10% of biofuels in commercial aviation by 2017 would imply biofuel production for renewable jet fuel of the order of 20 – 25 million tones per annum. The challenges in achieving sustainable supplies of biofuel for commercial aviation consumption can be summarized as being:

- Capital
- Time to Production at Scale
- Refining
- Infrastructure
- Regulation.

Figure 94: Renewable Jet Fuel Challenges



Source: Wood Mackenzie

Planting, cultivation and harvesting costs and biofuel crop yields vary significantly by plant type. However, at an assumed $10k / hectare investment cost it is estimated that capital of the order of $20bn would be required to establish sufficient crop sources to meet production requirements at the levels being indicated by IATA. There is wide-ranging debate about the availability and cost of capital required to meet such investment levels, given the current economic environment. Airlines are highlighting their low returns on capital and weak profitability levels, and the levels of tax contribution already made via Air Passenger Duty, likely ETS auctions for CO2 credits and other taxes, to lobby for government support to biofuel crop investments.

The long time frame between investment and the resulting cashflow from production at scale 5 – 6 years later makes the likelihood of sustainable returns on investment low without some form of subsidy or regulatory economic support.

Beyond the challenges of securing appropriate investment in the necessary agriculture base, the land and water use of crops such as jatropha and camelina introduce questions about sustainability and alternative crop use. Essentially these challenges boil down to the trade off implications of growing these crops for fuel manufacture versus growth in crop production for food use. Even when land used for growth is judged not to be suitable for food crop production, the higher water consumption requirements versus food crops, and deforestation of alternative land for food production, raise questions about the full-lifecycle environmental cost and benefits of such biofuels. Synthesis of a renewable jet fuel from secondary or waste biomass remains unproven at commercial scale, although an alternative synthetic jet fuel using a proprietary coal-to-liquids technology has been developed by Sasol in South Africa in association with UOP. This product is not however derived from a biofuel source and for the purposes of this study the assumption is made that its introduction would simply reduce the total demand for renewable jet fuel, thereby displacing biofuel (and hence reducing the potential contribution to RED and TFQD that could be made by biofuels in aviation).

However, if it is assumed that the necessary capital investment is made in the agriculture to achieve production at scale, the next challenges relate to the high water content of the biomass as a refinery feedstock and the consequent need to refine close to source. This is necessary to minimize primary transport costs associated with non-value adding product between field and refinery, and raises the challenge of limited economies of refining scale leading to high biomass refinery capital investment costs per unit of production. If sufficient capital investment is secured to develop the necessary agriculture base, a concomitant investment in local refining capacity to process the biomass is required. This implies a multitude of small scale processing plants, and subsequent aggregation of refined product for distribution to consuming sites. The geographical challenges associated with biofuel production remote to principal consumption locations and the associated logistical constraints are considered a further barrier to economic production of renewable jet fuel. These challenges also introduce significant questions about the security of supply, and implications for the industry in the event of feedstock or refinery interruption.

Further challenges beyond capital investment for agriculture, refining and primary distribution reflect the need to ensure compliance with regulatory authorities and the necessary infrastructure for delivery to airline consumers at major aviation hubs. Current strategy is for regulatory approval for “drop-in” standards for renewable jet fuel containing a blend of Jet-A1 and biofuel. A wide range of testing by airlines, commercial and military aviation engine manufacturers has accompanied development of proposed renewable jet fuel standards under approval by ASTM , military organizations and various international standards organizations. Proving flights for a variety of different blends of biofuel and Jet A1 have been carried out successfully by a range of different airlines and military airforces around the world. This work has established wide acceptance of the suitability of a “drop-in” blended biofuel / Jet A1 mix that could feasibly be supplied at major consumption points globally. Remaining actions to enable implementation are associated with the logistical and administrative factors, involving signoff by individual suppliers, infrastructure owners, airports and military and engine / airframe operators on a case by case basis. In terms of the challenges along the whole value chain the regulatory approvals and administrative issues are viewed as being in hand and largely surmountable with appropriate planning and involvement by relevant parties.

Of greater concern however are the logistical challenges associated with supply infrastructure of renewable jet fuel, either as a “drop-in” substitute or in parallel with “normal” Jet A1. There are challenges in 2 key areas. Firstly it is estimated that the top 50 major airport hubs supply approximately 60% of world commercial jet fuel demand. For these airports, typical fueling systems use networks of underground fuel distribution pipes to aircraft stands, making it impractical to run parallel fuelling systems for renewable and non-renewable Jet fuels. In addition, stakeholders from major airport hubs highlighted the limitations of existing on-airfield storage infrastructure, and the supply infrastructure to airfield-based terminals, that would prevent operation of parallel systems for renewable Jet A1 blend and pure Jet A1. It is therefore assumed that the only feasible method of supply through major airports would require a drop-in biofuel / Jet A1 blend. This in turn could limit the ability of commercial users who did not wish to operate aircraft on renewable jet fuel to fly from major transport hubs. To mitigate this risk, it is judged likely that airports would need to continue to offer some facilities (perhaps tanker based) for fuelling of Jet A1 segregated from the renewable jet fuel blend, and this would therefore be likely to increase operating costs for fuel. It is also worth noting that a move to a renewable jet fuel delivered through a common airport infrastructure would place consumers in the position of needing to pay the price of the “drop-in” fuel cost – almost certainly a more expensive operating cost than current Jet A1 which is already estimated to account for almost 25% of an airlines typical opex.

The second difficulty if a drop-in renewable jet fuel became the “normal” fuel supplied to aircraft at major transport hubs is the issue of traceability. Current plans to credit airlines with emissions reduction through use of renewable jet fuel require traceability of purchased biofuels into the user’s aircraft. This is not achievable through the typical fueling networks of a large airport, and it is anticipated that some changes to these regulations will be required as a result. A final issue related to traceability is the need for renewable jet fuels to meet defined sustainability criteria, and to have appropriate certification and inspection to validate. This places a challenge on stakeholders across the value chain and requires significant integration of activities by regulators, growers, refiners, distributors, airport operators, airlines and military organizations. While traceability and sustainability certification challenges are not insurmountable, the represent a significant administrative burden, potential additional cost.

All these challenges may also be viewed as an additional risk factor for investors, as without resolution it is possible that consumption of renewable jet fuel could not gain widespread traction (or ultimately offer the solution to emissions costs that consumers hope it represents). If this is the view formed by potential investors then achieving production at anything approaching a commercially viable scale for the airline industry appears highly unlikely.

As a result of analysis of the challenges described above, this study has concluded that it is not appropriate to assume any contribution of renewable jet fuels towards meeting RED or TFQD requirements. In reaching this conclusion careful consideration has been given to the likelihood of renewable jet fuel being introduced at sufficient scale in sufficient locations in a timeframe that is consistent with the aims of the RED and TFQD.

9.2 Marine

Bunker Fuel Demand

Marine vessels are almost all oil fuelled. Heavy fuel oil currently constitutes the main bunker fuel, comprising over 80% of bunker fuel demand globally, with marine gasoil/diesel used by smaller vessels and since 2010 by EU regulation, by all vessels when in port in EU waters.

As described in Section 3.4, there are further regulations to be implemented by 2015 that will require the consumption of bunker fuels with a maximum of 0.1 % sulphur in North West European waters. A similar regulation is expected to be implemented around the same time within North American waters. Few heavy fuel oils have sulphur contents this low, so in practice it will be necessary to burn gasoil in these areas. The alternative will be to install an approved exhaust scrubbing technology, which will allow vessels to burn higher sulphur fuel oil and achieve equivalent sulphur emissions to having burnt low sulphur fuel. This approach may be viable, especially once such technologies are more proven, for vessels operating a high proportion of time in a sulphur emission controlled area.

Figure 95: Proposed North American ECA

Source: US Environmental Protection Agency

MARPOL regulations also stipulate a move to a global bunker fuel specification limit of 0.5 wt% sulphur, effective 1st Jan 2020. Wood Mackenzie believes this is likely to be postponed to 2025 under a feasibility review scheduled to be completed no later than 2018. The lower sulphur content would imply a global swing to distillate (or at least a distillate/fuel oil mix) and the amounts of extra gasoil/diesel required would be well over 100 Mta, with a corresponding sudden decline in heavy fuel oil demand. We expect this will be delayed or will not happen at all as the 2018 review and potential for delay will become self-fulfilling.

Bunker Quality Issues

Marine engines are normally of slow speed diesel design and therefore not suitable for biogasolines. However a number of engine manufacturers have acknowledged that in principle they can be fuelled with biodiesel, as well as a wide range of other diesel compression combustion fuels.

In practice, use of biodiesel in marine contexts brings particular challenges of the types set out in Section 7. In particular, fuel delivery systems (pumps, lines etc) may need to be adapted to resist corrosive properties of biodiesel. To the extent that new engines may be required to tolerate biofuels, this will take longer to achieve in the marine industry than for ground motor vehicles as engine life is around twice as long for marine vessels.

Operators are becoming prepared for traces of biofuels appearing in bunker gasoil as multiproduct supply systems are more likely to bring carryover. Bunker specifications are likely to be adapted to accommodate such traces. Revision of the ISO 8217 marine fuel standard has awaited the availability of an adequate test method for traces of FAME.

It should be noted that the advantageous properties of FAME in diesel, notably its high cetane index, are not as valuable in the marine gasoil/diesel market as in the ground fuel market. Marine gasoil has a cetane index specification of no more than 45. Given also that there is a surplus of gasoil (not diesel) in many coastal areas of Europe, it is unlikely that biodiesel would be adopted as a fuel there purely on economic grounds.

Prospects for Demand for Biodiesel in Marine Markets

Studies by the Institut fuer Physik der Atmosphere (IPA) and the College of Marine and Earth Studies, University of Delaware, have indicated that carbon emissions from the shipping sector are of a similar order to those from the aviation sector globally (2.7% of all anthropogenic emissions from shipping, 2.2% from aviation compared with 14% from road transport).

Initiatives have been under discussion recently for reduction of carbon emissions from marine traffic. At the MEPC 60 (International Maritime Organisation Marine Environment Protection Committee), discussion centred on establishing an Energy Efficiency Design Index for new vessels. Mandatory carbon emissions reduction measures appeared a distant prospect.

Certain operators have, however, been performing extended tests on the suitability of biodiesel to power marine engines. AP Moller Maersk has been testing on a container ship 'Maersk Kalmar' as part of its efforts to meet its voluntary target to reduce carbon emissions from its container fleet, per unit moved, by 20% in the ten years from 2007 (slow steaming is one means to achieve such a target). NOx emissions (thought to be around 15% from shipping due to high engine operating temperatures) arising from biofuels are one issue under study. Earlier, Royal Caribbean bunkered their cruise ships out of Vancouver and Seattle with palm oil biofuel blends since 2005.

Given the global nature of the shipping industry and the current poor profitability of the sector, as well as its relatively low carbon emissions, we do not expect regulatory, still less practical implementation of any initiatives for the use of biofuels in the marine sector to be rapid or straightforward.

10 Distribution & Logistic Needs For Biofuels

In this section we will address the implications of the future increasing use of biofuels for oil products logistics, especially in the context of supply of EU requirements.

We first identify key challenges posed by biofuels in the oil product supply chain.

We then assess the current and future import requirements for biofuels to 2020, and in the longer term under the three scenarios we have developed for future biofuel use in the EU. We then consider the logistic solutions currently employed for the import and supply of biofuels in European countries.

We summarise feedback received from stakeholders in response to questions we have posed on the implications of biofuels in bulk oil logistics and reach conclusions on a number of implications of biofuels in the logistics sector, for refining companies and other industry participants.

10.1 Key Challenges Posed by Biofuels in the Oil Product Supply Chain

Ethanol and FAME have a number of quite different physical and chemical properties compared with fossil gasoline and diesel fuels. This has significant implications for the ways that these materials, either in pure form or in blend with fossil fuels, are stored, transported and dispensed.

Phase Separation:

Unlike conventional gasoline, ethanol is highly soluble in water (and vice-versa). During transportation and storage, water content in ethanol must be kept low. If, on blending with gasoline, water content in ethanol reaches a certain level, the ethanol/water phase will separate from the gasoline and accumulate at the bottom of a storage vessel.

Microbial growth:

This tends to occur in water phase in diesel storage in any case, but addition of FAME increases the availability of nutrients for microbes, making this more of an issue. This can increase corrosion and may result in blockages in fuel dispenser filters and lines, especially at retail level. Biodiesel tends to oxidise more quickly than conventional diesel: the US Biodiesel Board recommends a maximum storage duration of six months.

Solvent Properties:

Biofuel blends such as E5 and especially B5 are solvents for a wider range of substances than conventional gasolines and diesel. They thus have a cleaning effect on systems being switched to biofuel use, releasing organic residues, but these may then again cause blockage of filters. In general, procedures for the handling of biofuel blends dictate higher standards of cleanliness of systems than was the case for conventional fuels.

Especially in the case of FAME, the solvent property is likely to lead to swelling of seals made from eg natural and nitrile rubbers.

B100 permeates certain plastics such as polyethylene and polypropylene: fluorinated plastics and nylon are more compatible.

Electrical Conductivity and Corrosion:

Ethanol has been found to cause stress corrosion cracking, especially in pipeline applications over prolonged periods. Biofuel blends, especially those including ethanol, have a greater electrical conductivity than conventional fuels. This increases the tendency for galvanic and electrolytic corrosion especially at the interface between certain materials. B100 is not compatible with copper and copper alloys or galvanised surfaces over long periods for this reason.

Cold properties:

Many biodiesels and their precursors have higher cloud points than conventional diesel. In most cases, storage at a minimum of around +5 deg C is advisable and this may entail heating in certain climates.

The above properties generally imply a requirement for checks on the compatibility of existing systems in respect of materials of construction, their interfaces (for corrosion), and glands seals and valves, before introducing biofuels.

Mild and stainless steel, aluminium, Teflon and fibreglass are all considered acceptable materials of construction for handling biofuels but copper, bronze, tin and zinc may lead to corrosion and sedimentation.

To minimise water pickup in transit, ethanol is normally transported and stored separately from conventional gasoline or multi-product systems, up to the final distribution depot. This clearly creates a requirement for a completely discrete supply chain vs conventional gasoline, adding to overall supply costs. The higher vapour pressure of ethanol vs conventional gasoline gives rise to a need for higher safety standards in transportation.

Figure 96: Biofuel Logistics Challenges Overview

Biofuels and their precursors pose distinct logistics challenges in the downstream oil supply chain

Biodiesel/Vegoil Precursors

- **High pour point (certain vegoils) that may necessitate heating in storage**
- **Sludge from (bio)degradation of unstable fatty acids**
- **Sludge from solvency problems of FAME in diesel**
- **Limited shelf life (biodiesel 4-6 months, vegoils 9-12 months with additives)**
- **Maximum 5 ppm FAME permitted in jet fuel (DEF STAN 91-91)**

Bioethanol

- **Miscibility with, and absorption of water**
  - Unlike crude oil sourced gasolines and other non-oxygenate hydrocarbons
  - Implies need for separation from crude oil sourced gasoline as far as possible along the supply chain
- **Corrosiveness**
  - Attacks certain rubbers used in seals
  - Glass fibre double walled tanks at retail sites
- **Electrical conductivity**
  - Thorough earthing of tanks etc
  - Implies use of polymer pipes
- **Particular fire-fighting foams required**
- **Limited shelf life (ca 90 days with additives, warm climate)**

Biofuels are included in the EU REACH (Registration, Evaluation, Authorisation and restriction of Chemicals) regulations adding to administrative burden for handlers of such products

Source: Wood Mackenzie

10.2 EU Biofuel Import Outlook

We first consider the ***recent and current balances for biofuels in the EU27***, firstly bioethanol:

Figure 97: EU 27 Recent and Near Term Bioethanol Balance

Bioethanol (kt)	2006	2007	2008	2009	2010	2011
Production	1,284	1,450	2,096	2,742	3,491	4,239
Imports	181	788	867	709	599	654
Exports	39	47	55	75	102	102
Consumption	1,371	2,143	2,797	3,444	3,987	4,791
Closing Stock	55	102	213	150	150	150
No. Biorefineries	41	54	61	67	74	76
Annual Capacity	1,923	3,144	4,314	5,252	5,674	6,312

r= revised, e = estimated, f = forecast

Source: USDA EU Annual Biofuels Report June 2010/Wood Mackenzie

After increasing sharply from 2006-2008, bioethanol imports have declined since then, on increasing local production. EU production plant capacity has been well in excess of production in recent years, but in 2009 wheat feedstock prices were lower while grain co-product (animal feed) and ethanol prices were relatively high so bioethanol refiners saw relatively good margins.

The only countries importing over 100kta of bioethanol up to now have been Netherlands, Germany and Sweden, though the UK's imports are expected to increase sharply in future.

It is noteworthy that the number of ethanol refineries in the EU is quite similar to the number of oil refineries, but the average capacity is only around 80kt. The sources of EU ethanol supply are therefore quite widely distributed. The distribution of production by member state is shown below:

Figure 98: EU 27 Recent and Near Term Bioethanol Production by Country

Bioethanol kta	2006	2007	2008	2009e	2010f	2011f
France	236	418	583	701	749	749
Germany	339	315	457	591	646	678
Benelux	16	32	63	213	402	646
United Kingdom	0	0	39	55	221	552
Spain	315	284	276	457	457	457
Poland	126	158	189	347	402	402
Other	252	244	489	378	615	756
Total	1,284	1,450	2,096	2,742	3,491	4,239

r= revised, e = estimated, f = forecast

Source: USDA EU Annual Biofuels Report June 2010/Wood Mackenzie

France is currently the largest producer of bioethanol, though output is increasing in several other states. Sugar beet is the feedstock for around half of EU indigenous production, with wheat, corn, rye and barley in declining order also used.

Figure 99: EU 27 Recent and Current Biodiesel Balance

Biodiesel (kt)	2006r	2007r	2008r	2009e	2010f	2011f
Production	4,720	6,000	7,755	8,400	10,300	10,200
Imports	60	1,000	1,780	1,711	1,950	2,040
Exports	0	70	60	66	90	90
Consumption	4,780	6,930	8,710	10,260	12,360	12,160
Closing Stock	0	0	865	710	510	500
No.Biorefineries	119	185	241	257	265	263
Annual Capacity	5,760	11,370	16,470	20,346	22,616	22,996

r= revised, e = estimated, f = forecast

Source: USDA EU Annual Biofuels Report June 2010/Wood Mackenzie

EU imports of biodiesel have recently been running around three times higher than imports of bioethanol. While falling a little on general demand declines in 2009, they are on an increasing trend.

EU biodiesel capacity is almost twice current demand. There have been rumours of likely financial insolvencies in the industry, especially after high vegoil and low oil product prices from 2009 squeezed production margins.

Once again the average unit production capacity is only around 80-90kta and for biodiesel there are over 250 production units spread across the EU, so the supply is very widely distributed.

Figure 100: EU 27 Recent and Current Biodiesel Balance

kta	2006	2007	2008	2009	2010	2011
France	572	1,152	2,086	2,281	2,298	2,297
Germany	2,404	2,886	2,861	2,509	3,002	2,200
Benelux	44	255	379	699	1,100	1,452
Spain	123	150	194	516	863	950
Poland	88	53	167	376	599	748
Italy	599	466	669	594	599	598
Others	889	1,038	1,400	1,425	1,840	1,954
Total	4,720	6,000	7,755	8,400	10,300	10,200

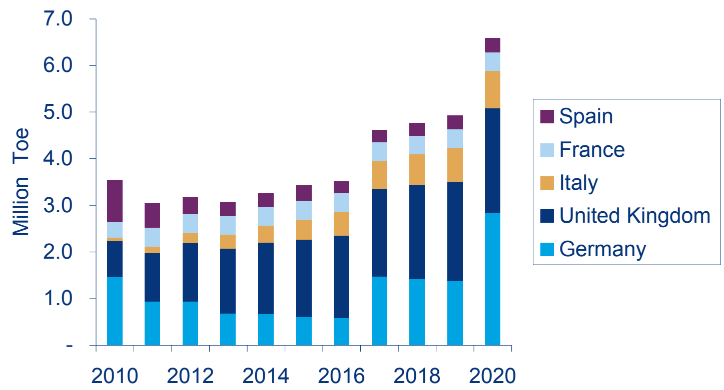
r= revised, e = estimated, f = forecast

Source: USDA EU Annual Biofuels Report June 2010/Wood Mackenzie

EU biodiesel production is currently over 70% based on rapeseed oil feedstock, with the remainder spread evenly across soy, sunflower, palm, recycled vegoils and animal fats.

We have considered the ***ten year forward outlook for future imports of biofuels to the EU***, through consideration of Member States' National Renewable Energy Action Plans, 2010. Certain Member States (eg Poland, Belgium) had not, by end August 2010, submitted their national plans, so we have considered those of the largest five countries available, for France, Germany Italy, Spain and the UK (the 'Big Five'). Based on our Scenarios for biofuel consumption over the decade to 2020, these five countries' total demand are expected to constitute over 50 per cent of EU27 biofuel demand over the period.

Figure 101: Planned Biodiesel Imports by Member State, Mtoe

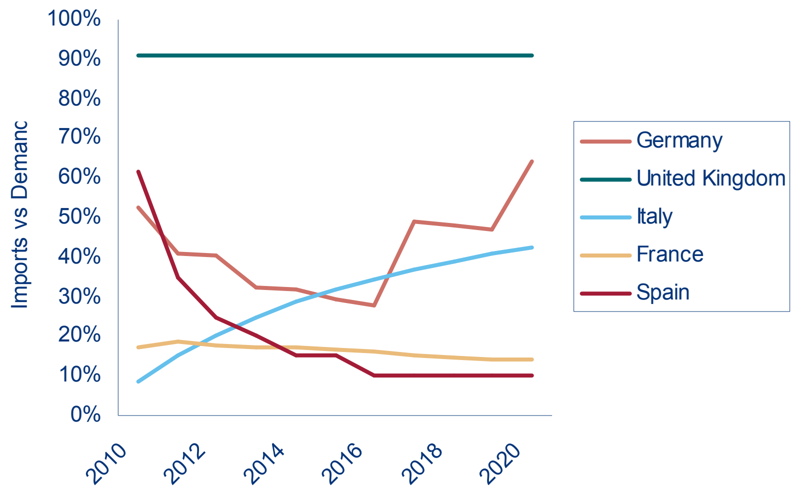


Source: Wood Mackenzie

By 2020, biodiesel imports by the Big Five are planned to total 6.6Mtoe, Germany (2.8mtoe) and the UK (2.2 Mtoe) being the largest importers. Germany expects its imports to increase from current levels only suddenly in 2020, while the UK expects steadily increasing import volumes.

These imports are shown as a fraction of each Member State's national demand in the following chart:

Figure 102: Planned Biodiesel Imports by Member State as % of Demand

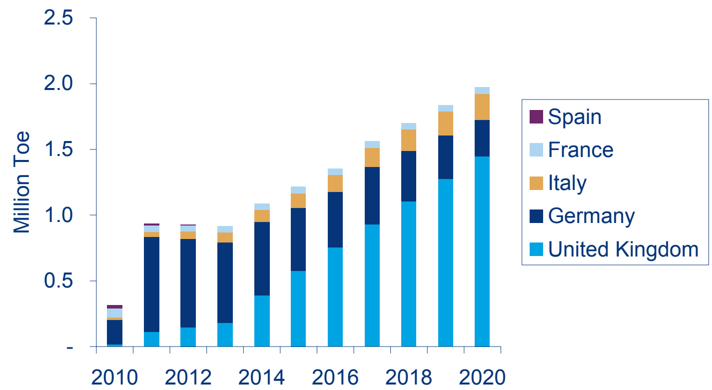


Source: Wood Mackenzie

The UK expects an ongoing high import dependence of over 90% while Germany foresees increased domestic supply in the near term with greater dependence only as 2020 approaches. Italy sees increasing import dependence while France and Spain foresee the reverse trend with their own production growing. Average import dependence across the Five reaches 45% by 2020, asit is in 2010, though it falls to 33% in the middle of the decade.

In respect of biogasoline imports a more distinct picture is apparent.

Figure 103: Planned Biogasoline Imports by Member State



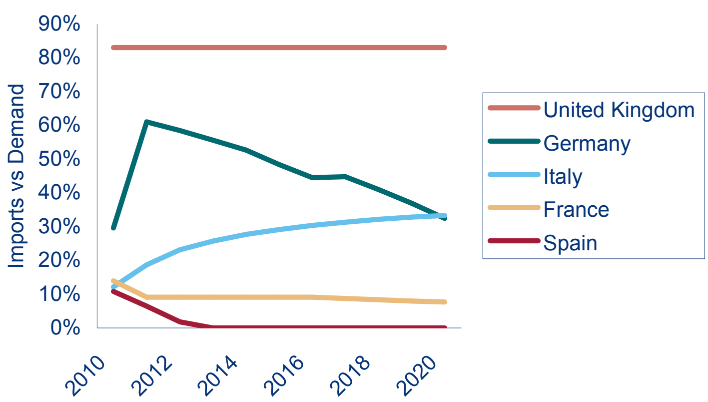
Source: Wood Mackenzie

The UK plans clearly the largest imports of bioethanol with a steady increase to over 1.5 Mtoe by 2020. After a sharp increase in imports planned for 2011, Germany's imports are planned to decline gradually, along with declining consumption. The other Big Five countries' imports remain at relatively minor levels (and indeed other countries such as Netherlands and Sweden plan larger imports than Italy, at 240 and 290 kToe in 2020 respectively.)

Once again the Uk's high planned import dependence (83%) is shown for bioethanol. As an island with a large number of independent import terminals as well as coastal refineries, it may be more economic to import bioethanol to this member state than to countries with deeper hinterlands.

Across the Five, the average import dependence rises quickly from 20% in 2010 to reach 46% by 2020.

Figure 104: Planned Biogasoline Imports by Member State as % of Demand



Source: Wood Mackenzie

For the other Big Five states, bioethanol import dependence generally falls below 50%.

On the basis of the above, with the Big Five representing around 2/3 of European biofuel demand, and in the absence of plan data for all Member States, we may tentatively estimate that EU biodiesel imports can be expected to increase from 5 to 10 Mtoe per annum from 2010 to 2020, while bioethanol imports may increase from around 0.5 to 3 Mtoe over the same period.

10.3 Import Gateways for Biofuels into the EU

We consider firstly the current and future marine “gateways” to the EU through oil terminal facilities.

(The non-marine gateways to the EU are largely at borders with FSU countries. These are not expected to be large suppliers of finished biofuesl and, except in the case of Baltic States, the rail gauge is different from one side of the border to the other).

In many cases, biofuel feedstocks are imported to bio-processing plant at marine locations. For ethanol production the imported feedstocks would generally be grains, while for biodiesel production the feedstocks are a variety of vegetable oils. For bioethanol the yield of co-products is similar to that of the bioethanol so it is more likely that finished bioethanol would be exported than the feedstock. Biodiesel production occurs with a much higher yield of the main product.

Biofuels themselves may be imported either through coastal refineries, and delivered on a blended/integrated basis with conventional fuels into inland markets, or they may enter via bulk liquid terminals. The latter are of principal interest here, in that these facilities are likely to be most open to access from marginal suppliers and independent buyers of ground fuels. Such sites are also likely to be open in principle to incremental investment, though this is often based on future demand underwritten by a client.

The independent bulk liquids industry in Europe is well developed but also relatively fragmented. Information available to us includes a total of over 70 million cum of gross storage capacity at coastal terminals in the EU , excluding the islands of Malta and Cyprus. This total also excludes most storage capacity owned by major oil companies and at refineries, for which in both cases data are not normally publicly available.

The largest independent international bulk liquids terminal operators and their storage capacities in Europe are shown below:

Company	Capacity, Million cum
Vopak	12.1
Oiltanking	9.4
Nordic Storage	2.5

Other international operators including InterPipeline/Simon Storage, NuStar, Rubis and Odfjell all have 1-2 million cum of bulk liquid storage capacity in Europe.

A number of other operators that provide services to third parties operate in single countries, such as CLH (Spain) which operates 2.5 Million cum, Pern (Poland) and Mero (Czech Republic).

Categorisation of this capacity by its potential range of uses is difficult as, to some extent, terminals have flexibility to handle bulk oil products, vegoils and chemicals on the same site and sometimes tanks may be used to handle a range of such products over time. Data available to us indicates whether each terminal handles oil products, vegoils and chemicals but the data do not specify the extent of each type of business.

We show below summaries of the data, itemised by country. (We have excluded Malta and Cyprus as sites in those islands may handle disproportionate amounts of transit business). Sites categorised as able to handle oil products are not also separately listed as vegoil terminals, even if they are able to handle both. The same principle has been applied for chemicals terminals (though some terminals may be included both as chemicals and vegoil facilities).

Figure 105: EU Independent Bulk (mineral) Oil Products Terminals

Country	No. Terminals	Total Capacity kcum	Average Capacity kcum
Belgium	16	5,332	333
Bulgaria	3	315	105
Denmark	22	3,117	142
Estonia	14	2,356	168
Finland	12	662	55
France	24	11,711	488
Germany	18	3,042	169
Greece	4	269	67
Ireland	7	173	25
Italy	36	4,836	134
Latvia	12	2,129	177
Lithuania	2	587	293
Netherlands	28	15,740	562
Poland	6	321	54
Portugal	10	1,079	108
Romania	4	2,380	595
Slovenia	2	513	257
Spain	43	7,567	176
Sweden	44	6,002	136
United Kingdom	39	5,826	149
Total	346	71,728	207

Source: Port Storage Group/Wood Mackenzie

It should be noted that the vast majority of capacity in the Baltic States is normally used for the export of oil products, many of which emanate from non- EU sources, principally Russia Belarus and Kazakhstan.

Clearly the Netherlands and Belgium, containing the key Amsterdam-Rotterdam-Antwerp ('ARA') port region, is exceptionally well equipped with bulk liquids capacity, which in practice serves the hinterland not only of those countries but also Western Germany, Luxembourg, Northern France and Switzerland. These areas, as well as ports in France (and Romania) contain on average larger oil products facilities than other States.

Figure 106: EU Independent Bulk Chemicals Terminals

Country	No. Sites	Total Capacity kcum	Average Capacity kcum
Belgium	7	599	86
Bulgaria	1	19	19
Denmark	1	18	18
Estonia	2	176	88
Finland	5	226	45
France	2	186	93
Greece	2	29	15
Ireland	4	51	13
Italy	11	459	42
Latvia	1	60	60
Netherlands	22	2,158	98
Poland	3	42	14
Portugal	3	85	28
Romania	2	48	24
Spain	5	162	32
Sweden	4	172	43
United Kingdom	7	135	19
Total	82	4,325	53

Source: : Port Storage Group/ Wood Mackenzie

Only 4 million cum of capacity handles chemicals but not oil products.

It is apparent that chemicals terminals tend to be of smaller average size than oil products facilities, though once again the average size is larger in ARA and France than most other locations.

Figure 107: EU Independent Bulk Vegetable Oil Terminals

Country	No. Sites	Total Capacity kcum	Average Capacity kcum
Belgium	3	65	22
Denmark	1	18	18
France	2	186	93
Ireland	2	24	12
Italy	5	283	57
Netherlands	12	1,601	133
Poland	1	6	6
Portugal	1	10	10
Spain	3	145	48
United Kingdom	4	53	13
Total	34	2,358	69

Source: Port Storage Group/ Wood Mackenzie

Vegetable oil terminals are also of small typical size, averaging less than 70 kcum on this data set, with ARA and France once again showing higher average size range. This category includes only 2 million cum.

10.4 Logistic Solutions for Biofuels in Europe

Biofuel logistics are in several respects more complex than for conventional fossil fuels:

- The biofuel supply chain entails an integration across the agricultural, biofuel and conventional oil supply chains
- Biofuel manufacturing plants are on a smaller scale, on average less than 100 kta, more than an order of magnitude smaller than oil refineries and are widely dispersed, often nearer sources of agricultural supply than centres of population and demand.
- Inclusion of biofuels therefore entails decisions over the points at which the oil and biofuel supply chains join (at a refinery, a marine terminal, an inland depot or even at the point of final retail or commercial supply). These decisions are driven both by technical and commercial parameters.

Figure 108: Biofuel Logistics Challenges- Implications

The distinct requirements for biofuels handling has several potential logistics implications as biofuel content in motor fuels increases

- Further new tankage required at terminals and depots to handle biofuels and their feedstocks
- In many cases, planning process for developing such new infrastructure is difficult, increasing NIMBY challenge
- With no specific volume targets by biofuel type (eg with 2nd generation counting double) financial underpinning of infrastructure developments will be challenging
- Potential need for parallel streams, to retail pump level, of E5 and E10 until all motor engines can accept the higher levels.
- All imply higher cost base

Biodiesel

- Distributed production within EU helps to ease logistic challenge
- New infrastructure required at refineries and import terminals, not at distribution depots
- Sequencing of multi-product pipelines, use of additives and flushing critical in diesel/jet pipelines

Bioethanol

- Tank capacity needs can be up to 3 times that for fossil gasoline due to drying of imports
- Especially to the extent imported, greater market penetration is likely to imply more need to move ethanol into hinterland rather than focussing sales near coastal ports
- Road and rail distribution to point of final depot adds to cost vs existing pipelines and barges for gasolines

Source: Wood Mackenzie

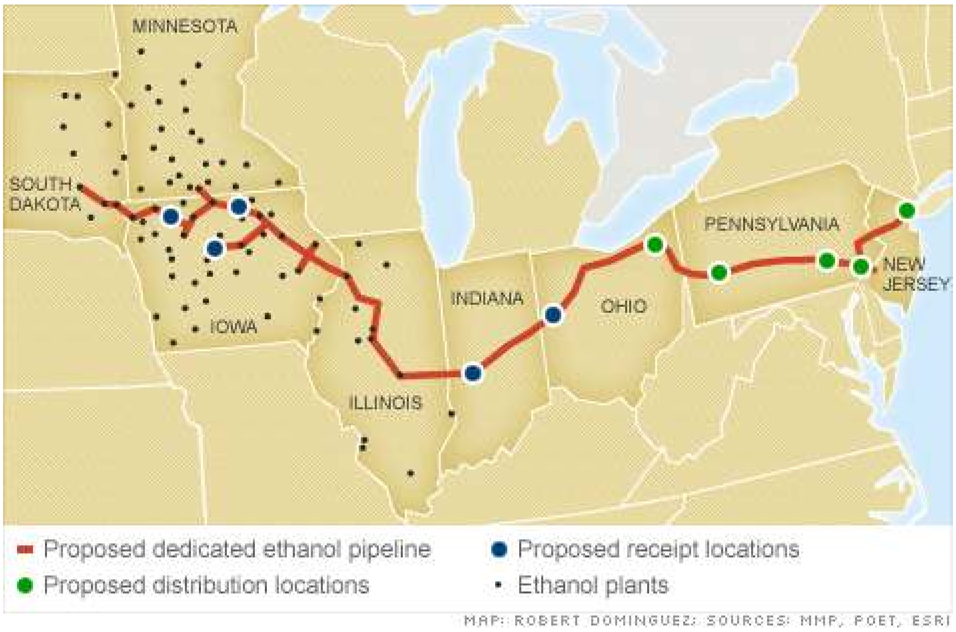
Currently, pure biofuels are most commonly transported in the EU by rail, barge and road trucks. This allows appropriately small scale and flexibility of delivery which are not provided by pipeline solutions. However, barge transportation depends on the availability of inland waterways, and rail and especially road delivery are normally significantly more expensive, at least in respect of operating costs and higher energy consumption, than waterway or pipeline solutions.

Biodiesel inclusion in diesel transported in multi-product pipelines, such as exist in several EU member states, create a risk of FAME contamination of jet fuel. FAME's freeze point is well above that allowed for jet fuel and FAME could cause other problems in jet engines. Based on engine manufacturer agreement a limit of 5 ppm of biocontent in jet fuel was included in the European jet fuel specifications DEFSTAN 91-91 in August 2008. The oil industry Joint Inspection Group (JIG) has been attempting to deal with this issue. Extensive trials on the French Trapil pipeline led to implementation of multi-product oil product pipeline transportation including FAME in diesel fuel. But discovery that a batch of jet fuel supplied at Birmingham airport (from pipeline-supplied Kingsbury depot) contained around 20 ppm FAME led to renewed focus on the issue. In 2009 JIG (Bulletin 26, Jun 2009) recommended emergency acceptance procedures where jet fuel is supplied with up to 30 ppm FAME, put a request to aero engine manufacturers to accept up to 100 ppm FAME and set out recommendations for multi-product pipeline operation with intermediate batches of eg gasoline between diesel and jet fuel.

In the USA, the USDA (Ethanol Transportation Backgrounder Sep 2007) reports that in 2005, 60% of ethanol transportation was by rail, 30% by truck and 10% by barge.

Pipelines are commonly used for transporting ethanol short distances inside production plant, but long distance transportation by this means has been rare until recently. Experience of stress corrosion cracking of steel pipelines and seal and valve wear have led to caution in undertaking such operations. However, in the USA, Kinder Morgan has been running ethanol through its Central Florida pipeline since late 2008. Magellan/Poet are considering an 1800 km 40 kcum per day (15 million cum pa) pipeline from S Dakota to the New York area that could be in operation by 2015. Its estimated capital cost is $3.5 Bn and a feasibility study published in July 2010 indicated the project could be feasible as higher blends of ethanol (E10+) are widely established, provided federal loan guarantees are made available. It has been quoted as likely to reduce carbon emissions/transportation energy costs by 30% vs rail and 90% vs truck transport. The proposed route is shown below:

Figure 109: Proposed First USA Purpose Built Long Distance Ethanol Pipeline



Source: Fortune, Mar 2010

10.5 Estimating the Magnitude of the Challenge

10.5.1 Potential Quantities

At present, biofuels can be accommodated relatively easily within oil import infrastructure. As stated in section 11.1, EU imports of biofuels are expected to total less than 2 million tonnes of biodiesel and 0.6 million tonnes of bioethanol in 2010. Liquid bulk import terminals can typically turn over their capacity at least once per month, and thus in principle import of all this biofuel should require capacity of only approximately 0.3 million cum of oil terminal capacity, whereas we have identified around 80 million cum of storage above and are aware that further coastal storage is held by integrated oil companies, at refineries and elsewhere.

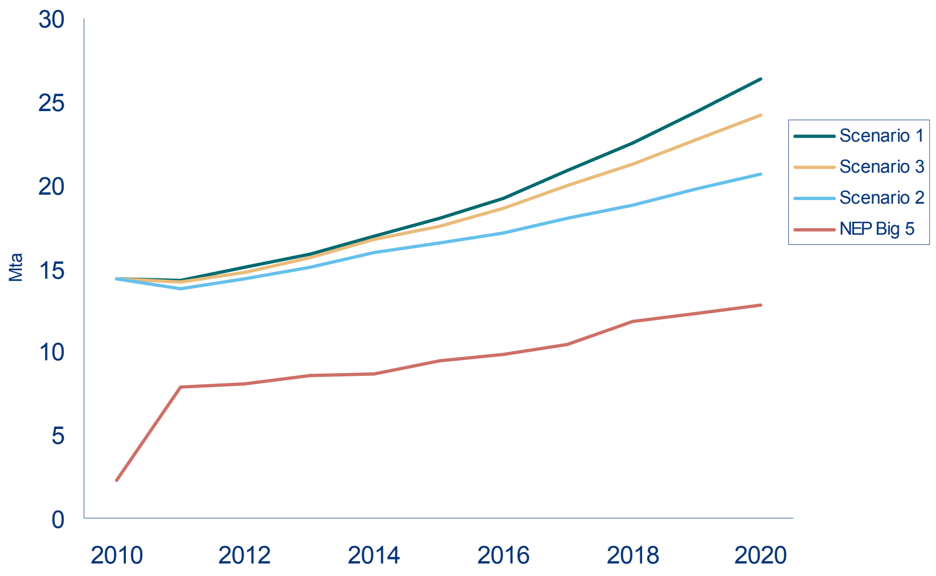
Based on our industry contacts we believe that, to a significant extent, increasing biofuels imports have been accommodated in recent years at EU terminals where turnover of liquid chemicals has declined, especially with the financial downturn since 2008.

The data set out in section 11.2 for the 'Big Five' member states suggests that, by 2020, their import dependency will be approximately 45%.

In the Figures below we compare the forecasts for biofuel demand for the entire EU 27 in our scenarios with the total demand forecast in the 'Big Five' member states' energy plans.

For biodiesel, demand growth for the EU27 appears likely to be at similar rates or lower rates than for the Big Five. Therefore the import % for the Big Five in 2020 of 45% may be a little higher than for the EU27 overall. ***If we assume, for illustrative purposes, an import dependence of 40% in 2020 this implies import requirements of 10.5, 8.2 or 9.7Mt of biodiesel in 2020 under our Scenarios 1,2 and 3 respectively. Extending the illustration with 40% import dependence in 2030 the biodiesel imports would be respectively 16.6, 12.6 or 13.7 Mta under the three Scenarios.***

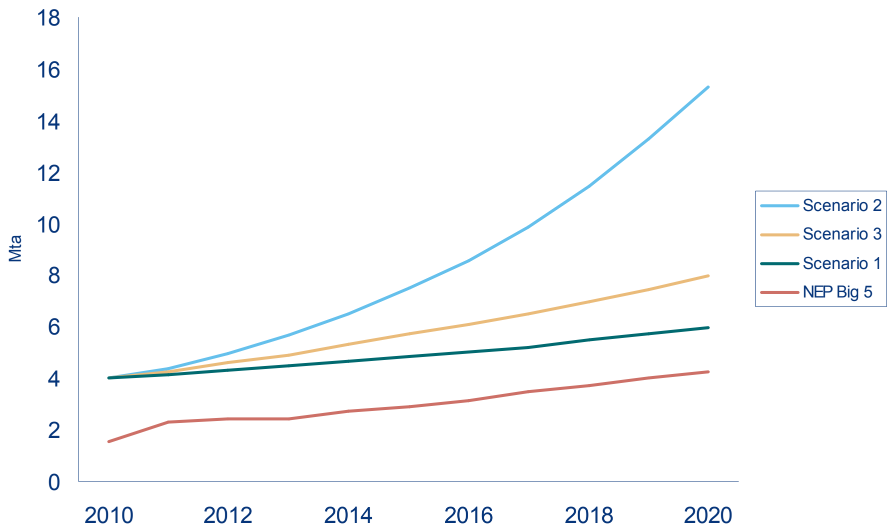
Figure 110: EU Biodiesel Demand Scenarios Comparison with NEP



Sources: Wood Mackenzie, National Renewable Energy Plans

For bioethanol, demand growth for the Big Five appears proportionately higher than for the EU27 under scenarios 1 and 3 but much lower than in Scenario 2.

Figure 111: EU Bioethanol Demand Scenarios Comparison with NEP's



Source: Wood Mackenzie, National Renewable Energy Plans

With an import % of 46% planned for the Big Five for 2020, we will assume, as an illustration, import %'s of 30%, 80% and 40% in Scenarios 1,2 and 3 respectively in 2020 and (we assume) continuing to 2030. ***This would lead to***

bioethanol imports of 1.8, 12.2 or 3.2 Mta respectively in 2020 and 5, 27 or 6 Mta in 2030. Clearly Scenario 2 is a quite distinct outcome.

10.5.2 Implications for Coastal import Facilities

Imports of bioethanol require a discrete supply chain from mineral gasoline, at the coast and onwards inland. This is therefore incremental capacity relative to gasoline storage. If we assume a typical terminal import tariff equivalent to approximately €10 per tonne, this gives rise to an incremental annual throughput charges of €270 million pa in Scenario 2 by 2030. Assuming one tank turn per month once large scale operations are achieved, this implies a requirement for approximately 3 million cum of coastal storage capacity to accommodate ethanol imports.

Imports of bioethanol may lead to incremental exports of gasoline from the EU. To a large extent this will take place from coastal refineries but there is likely also to be a requirement for further hub facilities for gathering gasoline components and blending to export market specifications. We note that incremental capacity targeting such business is currently under development in the ARA region, for example Vopak's new Amsterdam Westpoort terminal.

Imports of biodiesel are likely to require separate reception tanks at coastal terminals, which in some cases may need to be heated unlike those for mineral diesel and gasoil. The costs for storage and throughput for these tanks is likely to be higher than for conventional diesel, especially taking into account heating costs. However, in all our scenarios the import of biodiesel only contributes to the overall import requirement for diesel and thus is not incremental to the import demand that would otherwise anyway exist.

Overall, biofuels imports are just one element of what we expect to be a substantial increase in overall EU oil products imports and exports over the next decade, with increases in exports of (fossil) gasoline and increases in imports of diesel and jet fuel.

10.5.3 Implications for Inland Logistics

It can be anticipated that solutions will eventually be found to the current difficulties with transportation of biodiesel blends in multi-product pipelines.

For bioethanol, carriage in fossil oil product pipelines is not expected to develop generally. Over the next few years the volumes of ethanol being introduced to the market in EU countries are not expected to justify developments of dedicated ethanol pipelines. The largest imports are planned into the UK but even these will be less than 2 Mta and the demand will distributed around the country.

In the longer term, whilst in Scenarios 1 and 3 we would expect EU inland bioethanol logistics to continue to be by rail, road and inland waterway, the quantities indicated in Scenario 2 suggest that one or more ethanol pipeline solutions may eventually be feasible, for example into Central European countries. Such a solution might be considered late in this decade if Scenario 2 is emerging, with low imported ethanol prices, and especially if an ethanol pipeline is operating elsewhere, for example in the USA. At the same time in such a scenario, pipeline facilities for exports of mineral-sourced gasoljne from inland refineries, displaced by ethanol imports, may be viable.

10.6 EU Government Strategic Oil Storage Issues

At present EU Council Directive 2006/67/EC is the active legislation imposing an obligation on Member States to maintain minimum stocks of oil for the purpose of security of oil supply, at a level equivalent to 90 days' internal consumption, with a deduction of up to 25% for States with their own production. Stocks are categorised generally in three classes: light oil such as gasoline, other distillates such as jet fuel gasoil and diesel, and heavy fuel oil.

Stocks are eligible for inclusion, inter-alia, if they are located in ports of discharge, on board oil tankers in port for the purpose of discharging, once the port formalities have been completed, or as supplies held in tanks at the entry to oil pipelines and also if held in refinery tanks.

The above Directive will be repealed from 2012 by Council Directive 2009/119/EC. This will modify the overall stockholding obligation to the greater of 90 days' imports or 61 days' consumption. This brings greater alignment with IEA obligations. Member States are being encouraged to establish their own central stockholding entity as a means to enhance control and monitoring of stocks.

A further aspect of the new Directive is an ‘invitation’ to commit to maintaining specific stocks of products which are to a significant extent not interchangeable with oil products of other types. The list of specific stocks includes ethane; LPG; motor gasoline; aviation gasoline; gasoline-type jet fuel (naphtha-type jet fuel or JP4); kerosene-type jet fuel; other kerosene; gas/diesel oil (distillate fuel oil); fuel oil (high sulphur content and low sulphur content); white spirit; lubricants; bitumen; paraffin waxes; petroleum coke. If there is no commitment to maintain 30 days of specific stocks, Member States must ensure they hold at least one third of stocks as oil products (rather than crude oil equivalent).

The Directive’s position on biofuels (and additives) is significant in the context of the subject matter of this section. It states that:

‘When calculating stockholding obligations and stock levels actually maintained, biofuels and additives shall be taken into account ***only where they have been blended with the petroleum products concerned***. Furthermore, under certain conditions, part of the biofuels and additives stored on the territory of the Member State in question may be taken into account when calculating stock levels actually maintained’.

Obviously, further regulatory detail will be required to clarify and interpret this clause. If it is the case that only biofuels stored in blend with mineral oils will count towards strategic oil stock levels the implications will be increasingly marked as biofuel consumption grows:

Pure biodiesel held in refinery and other (coastal) storage tanks, at biodiesel production sites and in vessels in port, and not yet blended with mineral oil, may not qualify;

For ethanol the same applies but given that the bioethanol supply chain is likely to be generally discrete and separate from mineral oil further downstream, to the final distribution point, the degree of ineligibility is likely to be even higher, although the material is likely to have been denatured further upstream.

To the extent that the regulations under this Directive will apply different treatment to stocks of biofuels and mineral oils within a Member State (or held on its behalf elsewhere) they are likely to result in a need for higher overall stockholdings. The cost of holding stocks of biofuels will normally be higher than the cost of holding stocks of crude oll which is used to a significant extent to contribute to overall stock levels, not only because biofuels have higher values and thus tie up more working capital as stock, but because crude oil can be stored more cheaply as strategic stock, eg in caverns, and rarely needs to be turned over as oil products do.

Whilst the cost of holding stocks that are eligible as strategic stocks can in most cases be passed on to the final customer through established mechanisms, there is not such mechanism to pass on the cost of holding incremental stocks. The result of this will be a penalty on those participants owning and storing biofuels from the beach to the point of blending, relative to any that are focussed on mineral oils.

One can imagine potential means of ‘qualifying’ biofuels through splash addition of small amounts of mineral oil at the first available point.

10.7 Stakeholder Feedback on Implications of Biofuels for Oil Logistics

We have solicited stakeholder views on impact of biofuels from a range of oil logistics operators present in the EU; both independent operators that offer oil storage for lease to third parties and international oil trading companies that hold oil storage capacity primarily to facilitate their own proprietary physical oil trading activities. Responses were received from stakeholders in both these classes.

We received attributable input from FETSA, the Federation of European Tank Storage Associations, who commented on the sector profile, consequences of the chosen scenarios, biofuels in general and logistical considerations.

Profile of Sector: FETSA represents the larger part of tank storage companies in Europe. Tank storage provides indispensable links for all surface transport in, for instance, the world energy supply chain. Many can be found in maritime or riverside ports. Our members are independent which means that they do not own or trade the products they store, independent tank storage companies are logistics service providers to producers, traders and distributors. Typically, a major part of the energy supplies to automotive, maritime, freshwater and air transport flow through the installations of our members. At request of our customers products may be blended on site to arrive at the required market specifications. Our businesses have a global orientation through the maritime connections, but may be indispensable for the distribution functions to the hinterland, not specifically limited to one nation state. For the storage of compulsory stocks, a National obligation under IEA and EU rules, independent tank storage companies often are indispensable.

Scenario's and consequences: We assume that the 3 scenario's presented are equally likeable developments with an equal starting point in the present. Tank storage will be affected by a growing portion of BF's in the energy mix. It may require the adaptation of existing storage capacity and the normally connected equipment needed for blending, loading and off-loading, heating. Depending developments expansions adding new capacity may be needed.

We would remark, that since companies in our sector are providers of logistic services, these companies cannot be leading in the advancement of BF's.

Secondly, companies in our sector are capital intensive enterprises with a long term outlook. The capital lay-out of a single installation of say several 100 000's of cubic meters is high.

Lastly, we should realise that the future does not contain facts. History does or should at least, showing forecasts in the past that for some unforeseen reason did not materialize leaving too early investments unrewarding. Therefore it seems reasonable to expect that individual tank storage companies will weigh for themselves case by case the opportunities and risks related to the advancement of the demand of storing, blending transhipping etcetera, of BF's.

Bio Fuels: Generally speaking, the storage of BF's may be more demanding than is the case for many other products. This also holds for the marketed products in which these BF's are blended. This particularly may be true for longer term storage [for instance compulsory stocks]. The required quality [one should think about energy content per unit of volume, viscosity, ignition temperature, solidification temperature, vapour pressure, density, etcetera] of these products may be influenced by slow oxidation, hydrophilic properties and more. Independent tank storage companies will be able to handle these aspects but not without an effort. Governments should be prepared to facilitate these developments at the required speed.

Logistics: The true (military) meaning of logistics is the science of forecasting requirements and satisfying these by provisions at the right time and the right place. No system capable of doing this can work without some degree of storage capacity for longer or shorter periods of time, compare for instance a PC. Since the study relates to transport the whole logistic network should be seen against the background of existing (and planned) roads, airport and ports, import / export and production facilities and population data. This requires a tailor-made approach in which independent tank storage companies and the various National tank storage associations, members of FETSA, can be helpful.

In addition the following specific points, made on a non-attributable basis, are highlighted:

Question	Company A	Company B	Company C
How would you describe your organisation's overall view of these directives?		Clear mandatory directives (e.g on sustainability and 'allowed' biofuels) with a fixed timeline are required for market participants to be able to prepare and invest for these developments. Uniform processes and standardisation across the EU are required to create an open marketplace and avoid inefficiency.	Positive
Do you anticipate requirements for additional storage, blending, distribution and marketing infrastructure for bio-components in the period to 2020/2030?	Yes	Yes	Yes
What level of new capacity growth do you forecast?	2-5% pa	2-5% pa	0-2% pa
What level of capacity substitution do you forecast (from 2010 base)? - 0-2%	0-2%	No specific level	2-5%
What issues do you see with respect to investments in infrastructure to handle biofuels?		The unclear route to reaching the 10% mandate in 2020 makes it difficult to invest. Uncertainty in policy is the biggest issue.	Lack of robust contract backing from biofuels manufactureres / traders with an uncertain credit rating. also lack of certainty that fiscal / government incentives will reamin through the contract duration required in order to justify the investment.
What risks / implications arise from transfer of bio-components through multi-product storage and pipeline systems?		Dedicated systems are required for the biocomponents, which requires additional investments.	None if managed properly. otherwise possible cross contamination issues.
What specific commercial considerations arise to accommodate bio-components into Road Transport fuel pools?		-	The need for additional storage and blending facilities requires capex investment and a suitable contract to support this
What specific infrastructure considerations arise to accommodate bio-components into Road Transport fuel pools?		Additional tank capacity, dedicated systems, blending capabilities, requirement for gasoline/diesel and biofuels stored on one terminal.	Additional storage facilities and bulk / batch / online blending facilities
What geographic considerations are there with respect to required infrastructure for Road Transport fuel pools?		Decide on the best place to make and distribute the blend. Having infrastructure available to transport biofuels by rail. Having an easy accessible trading hub available to trade imports flows / EU produced product	Coastal import terminals are likely to be favoured as many components are / will be imported

10.8 Conclusions

- Biofuels have a number of quite distinct physical and chemical properties relative to mineral-derived fuels. As such there are particular handling requirements that pose challenges for existing oil products logistics systems.
- Import dependence for biofuels among the five largest Member States is planned to reach 45-50% by 2020, with the UK exceptionally high at around 90%.
- In addition to refinery import facilities there are currently close to 80 million cum of coastal independent bulk liquids terminal capacity, over 70 million of which is designated for oil products, the balance dedicated for chemicals and vegoils.

- Inland, pure biofuels are normally transported by rail, barge and road trucks. Pipeline transport of biodiesel blends is complicated in multi-product pipelines by low tolerance for FAME in jet fuel. These issues are likely to be resolved in time. Mineral oil pipelines are not used for ethanol or blends thereof due to its hygroscopic nature.

- Our three scenarios produce very different demands for incremental infrastructure. Scenario 2 assumes high ethanol uptake based on low import prices; our illustration foresees an import demand of around 27 Mta by 2030 which could require around 3 Million cum of dedicated coastal storage capacity and may bring consideration of one or more dedicated ethanol pipeline into deeper inland regions. The other scenarios imply lower incremental infrastructure requirements.

- The new Directive governing EU strategic oil stocks from 2012 allows for biofuel stocks to count towards strategic stock requirements only once blended with mineral oil. Unless mitigated this is likely to lead to a significantly higher stock holding costs for the companies that they will be unable to pass on through the stockholding mechanisms.

- Stakeholders have highlighted a number of challenges in adapting oil logistic systems to future biofuel demands, which we see as including

    - The distinct technical requirements for handling biofuels vs mineral oils

    - The uncertainty for future demand in respect of the relative growth of biodiesel and biogasoline uptake and the proportions of second generation fuels which, counting double towards targets, result in lower total demand for logistics than would be the case with first generation supplies

    - The relatively weak financial standing of a number of actors in the biofuel market, due to the smaller size of operations vs oil refining and due to the financial impact of agricultural and oil price volatility on such operators

    - The increasing use of mandates rather than duty incentives to drive the industry towards targets

    - The potential for politically set targets to change (as has occurred for example in the UK following the Gallagher Review).

11 European Refining Greenhouse Gas Emissions Review

In this section we will set out the proposed future measures to apply a cost of carbon more significantly to the EU refining industry and illustrate the impact such measures could have against the overall industry business environment. We do not give consideration to measures relating to emissions of other substances such as NOx or SOx.

11.1 Proposed Future Measures for Carbon Emissions Costs on the EU Refining Industry

The cost impact to the EU refinery industry of carbon emissions has historically been limited as relatively small as allocation of CO2 allowances simply reflected historical emissions levels through phases I and II of the Emissions Trading Scheme (ETS).

ETS phase III comes into effect in 2013 and will bring a drop in free allocations arising from the refining process for the industry. However, refining has been deemed to be at significant risk of carbon leakage based on an assessment of the cost to refining as a percentage of its gross value added and of the industry's "trade intensity". As such some free allowances will still be allocated to the industry, with the distribution being set by a 'benchmarking' methodology.

The allocation of free allowances in phase III should be made to each installation through a ranking versus its peers. Our interpretation is that this approach is intended to achieve:

- Minimisation of carbon leakage by avoiding an excessive reduction in competitiveness of the EU industry vs. imported refined products from other regions

- A framework to encourage investments to reduce future carbon emissions towards a recognised 'best practice' level which depends on the specific characteristics of each individual site

The legislation suggests a CO2 per unit product approach be used where possible. The refinery sector is likely to use a "specific emissions" methodology. Central to this will be an assessment of each site's 'Carbon (CO2) Weighted Tonnes', a function of refinery configuration and throughput.

This is the theoretical 'product' for each refinery, calculated using indices developed by Solomon.

Each site's specific emissions (ie, Carbon Intensity) is calculated as = tCO2/CWT

i.e. the normalised CO2 emissions for benchmark period divided by the site's CWT in the benchmark period

Carbon Intensity will then be used to benchmark EU refiners. The allocation mechanism will benchmark sites against the average Carbon Intensity of the top 10% performing sites (in terms of CO2/CWT). 2007/2008 are expected to be the reference years.

There remains uncertainty over the exact method, but allocations are to be finalised towards end 2010.

Advice regarding the benchmarking methodology has been provided to Wood Mackenzie by Europia and Concawe, however, no refinery-specific data provided by them is made available here, for reasons of confidentiality.

It is expected that a notable proportion of CO2 emissions, arising from refining, from the majority of sites will incur a cost under ETS III.

It should be noted that refineries will typically also pay a cost of carbon emissions associated with electricity generation, whether they generate their own power or they import it from other generators, except possibly in areas where nuclear power generation is a price setter.

11.2 Estimation of Order of Cost of Carbon Emissions

Given that carbon intensity is being benchmarked against the top 10% best performing refinery sites in the EU, it can be expected that only a very few sites may have 100% or more of their emissions covered by allowances. At the other extreme, several refineries may have less than 50% of their emissions costs based on 2007-8 utilization rates available as allowances.

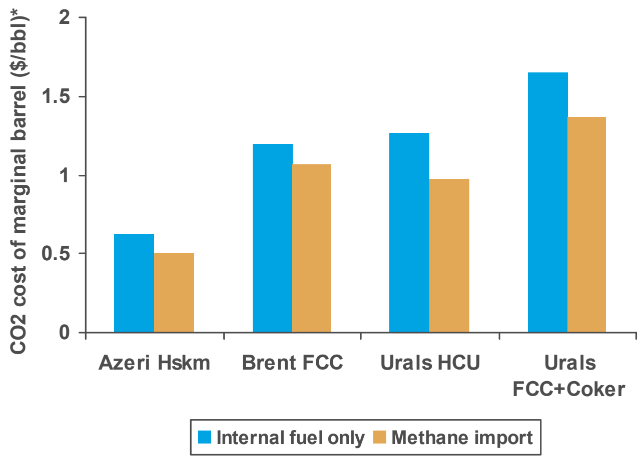
The impact will be relieved to the extent that refinery utilization rates are below those of 2007-8 which is likely, at least in the initial years of the ETSIII scheme.

However at this time it is not clear as to how processing at lower utilization rates (or indeed mothballing capacity for a period) will affect allocation of emissions allowances in future years, if at all.

It may be, therefore, that refiners will largely apply a marginal approach to the economics of this issue, making decisions as to whether to process a marginal barrel of crude oil and use an emissions allowance, or alternatively not to process and avoid buying (or monetize their own) incremental allowance.

Wood Mackenzie has estimated the marginal cost of carbon emissions for a variety of benchmark refinery configurations and crude diets using a carbon cost of $50/tonne (see Figure 112).

Figure 112: Estimated Refineries' Marginal Cost of Carbon Emissions, ETSIII



Source: Wood Mackenzie (WM indicator refinery configurations,

CO2 cost = $50/t, CO2 emissions linearly proportional to crude throughput)

As would be expected, simple refineries processing lower sulphur crude oils have lower emissions at the margin than more upgraded refineries running higher sulphur crude oils. The marginal cost of carbon may be of the order $1.5/bbl processed for the latter case. This is a significant proportion of a refinery's net cash margin, especially in the current low margin business environment.

11.3 Implications

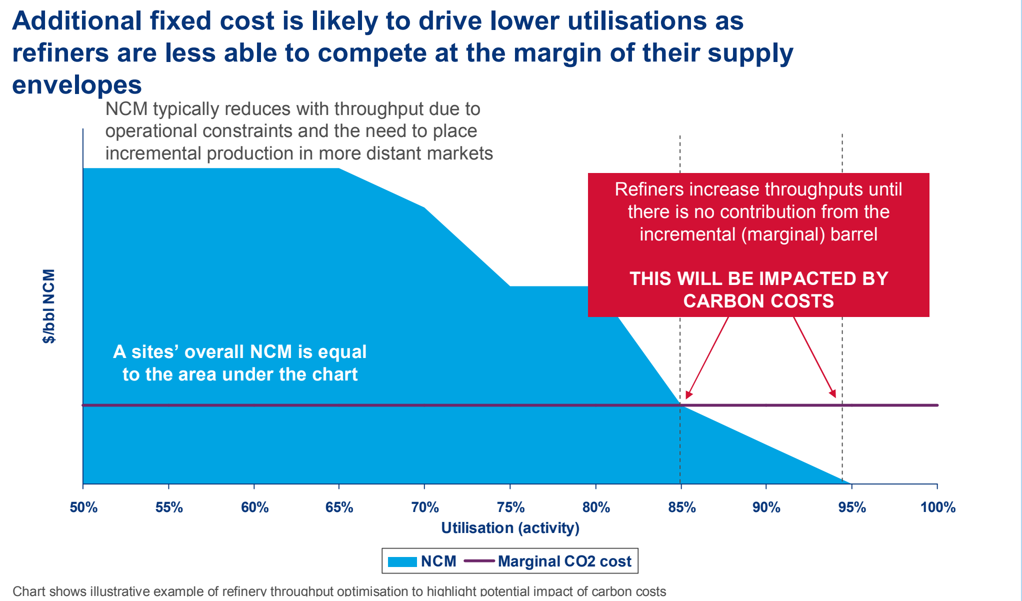
We would expect the marginal cost of carbon emissions to result in generally lower throughputs as the point of zero incremental margin is reached at a lower utilization rate:

Refiners will be less able to compete at the edges of their product supply envelopes. They will be particularly vulnerable to competition from products imported from non-EU sources where refiners are not subject to a cost of carbon emissions.

In principle, the marginal cost of carbon will be greatest for refineries whose net cash margins are lower (less sophisticated refineries processing lower sulphur crude oils). This would therefore conceptually flatten out the competitive environment for refiners. However in practice we would expect the impact of cost of carbon to still be more significant for less competitive (ie usually less sophisticated) refiners.

EU refiners less subject to competition from non-EU refiners (for example inland refineries in Central Europe) can be expected to have greater potential to pass on the costs of carbon emissions in higher product prices in consumer markets.

Figure 113: Conceptual Impact of Marginal Cost of Carbon Emissions on Refining



Source: Wood Mackenzie

One uncertainty around the implementation of ETSIII for refiners is in respect of recognition of changes in refinery configuration. One would expect changes in configuration to result in an update of the benchmarking for a refinery and thus a rebasing of its carbon intensity. To the extent that new plant are installed in refineries to hydrofine vegetable oils, these are likely to result in incremental carbon emissions. It remains to be seen whether production of such second generation biofuels in refineries will be assessed for carbon emissions differently from any such production outside refineries.

12 Scenarios

The aim of this study is to investigate the potential impact of biofuels on the refining industry and fuel specifications. That impact will be different depending on the following:

- The overall volume of biofuels incorporated into the EU transport fuels market
- The mix of each type of biofuel within that overall volume
- The properties of those biofuels

As described in Chapter 6.1, there is considerable uncertainty surrounding each of these factors. We have therefore developed three potential scenarios for the level of future biofuels consumption and the mix of biofuels, with the aim of exploring a wide range of possible impacts on the refining sector and on fuel specifications.

12.1 Scenario development

12.1.1 Assumptions Applicable Across All Scenarios

Renewable Energy Targets

This study assumed that the targets set out in the Renewable Energy Directive (RED) and Fuel Quality Directive (FQD) for 2020 will be met:

- RED requires Member States to 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 road transport in that Member State
- FQD requires suppliers of road transport fuels to reduce the life-cycle greenhouse gas emissions per unit of energy from fuel and energy supplied by up to 10% by the 31st December 2020

It should be noted that the objectives of this study do not include analysis regarding the real-world feasibility of achieving the RED and FQD targets.

An interesting aspect of the RED legislation is that the contribution to the 10% target 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, for the calculation of the electricity from renewable energy sources consumed by electric road vehicles, that consumption shall be considered to be 2.5 times the energy content of the input of electricity from renewable energy sources. Both of these aspects of the RED are modelled in the Scenarios.

As yet, no firm targets have been set for the share of renewable energy in the EU transport sector beyond 2020. A number of communications published by the European Commission in recent years have indicated that lower greenhouse gas emissions and increasing use of renewable energy in the transport sector will continue to be a policy goal for decades to come. These include:

- In its 2009 communication on “A sustainable future for transport: Towards an integrated, technology-led and user friendly system” the Commission stated that: “To respond to the goals of the EU SDS and reduce transport’s environmental impacts involves progress towards a number of environmental policy objectives. Lowering consumption of non-renewable resources is essential for all aspects of transport systems and their use”
- In its 2007 Communication on “Limiting Global Climate Change to 2 degrees Celsius - The way ahead for 2020 and beyond” the Commission stated: “The Council has agreed that developed countries will have to continue to take the lead to reduce their emissions between 15 to 30 % by 2020. The European Parliament has proposed an EU CO2 reduction target of 30 % for 2020 and 60 to 80 % for 2050

Given that growth in the share of renewable fuels in the transport sector will continue to be a policy goal in the EU after 2020, we have assumed for this study that renewable energy will be required to account for 20% of EU transport energy demand by 2030.

Economic and Population Growth

The forecasts for economic and population growth are assumed to be the same across the scenarios. These are the same as described in Chapters 2 and 4.

Size of Vehicle Fleet and Distance Travelled

The overall number of vehicles on the road and the distances travelled by those vehicles are assumed to be the same in each scenario. The EU car parc was assumed to grow from around 245 million cars in 2010 to over 300 million cars by 2030.

Biofuels Meet Minimum Sustainability Standards

For each scenario there was assumed to be sufficient supply of biofuels meeting the minimum sustainability standards laid out in the RED, FQD and any subsequent renewable fuels legislation.

12.1.2 Scenario 1

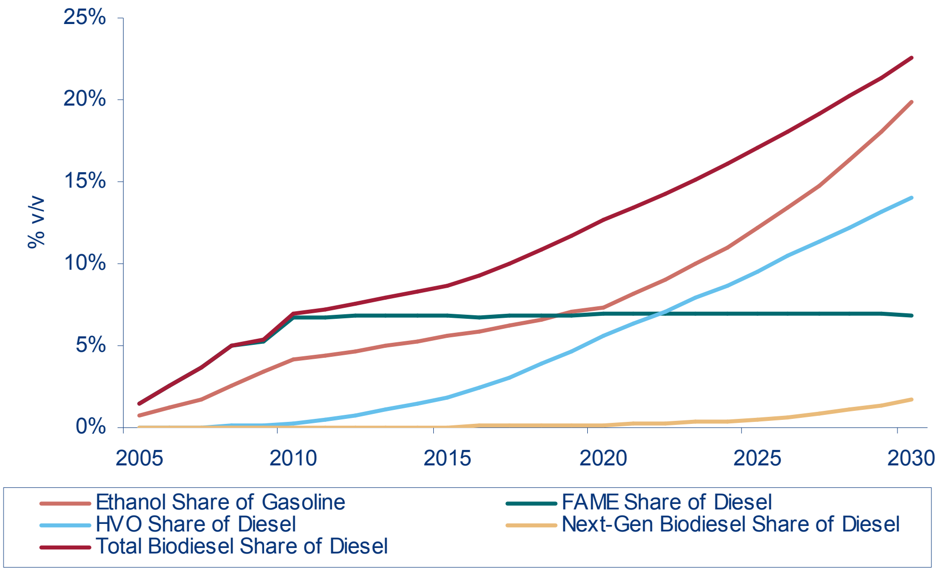
Scenario 1 assumes that the Renewable Energy and Fuel Quality Directives are met with a relatively high share of biodiesels and a relatively low ethanol share. This pattern then extends through to 2030. This scenario extends the historical pattern in the EU biofuels mix, with biodiesel finding much greater acceptance in the market. It assumes that biodiesel continues to be the favoured way of meeting renewable energy targets by fuel suppliers due to factors including; its greater ease of integration into the fuel supply infrastructure than ethanol and lower pricing than ethanol on an energy equivalent basis.

In this scenario, the majority of the biofuels are from first-generation sources, even in 2030. There is limited contribution from next-generation biofuels, as their commercialisation continues to be delayed for economic and technological reasons. Their share does grow slowly over time, as some production plants are built, but these mainly rely on substantial government support.

The uptake of plug-in electric vehicles is low, with EVs representing less than 1% of market share in 2020 and less than 6% in 2030. Therefore the contribution from renewable electricity towards the RED target is low.

Figure 114 illustrates how the volume share of biofuels in the total EU road fuel market changes over time. Under this scenario, biodiesel accounts for just under 13% of the road diesel pool by 2020 and 23% by 2030. Keeping the FAME volume share just below the 7% limit in the FQD, results in the HVO volume needing to rise substantially over time. The ethanol share of the gasoline market reaches just under 7.5% in 2020. The ethanol share rises rapidly after 2020, reaching just under 20% by 2030, as the growth in biodiesel slows somewhat due to restraints in the availability of feedstocks.

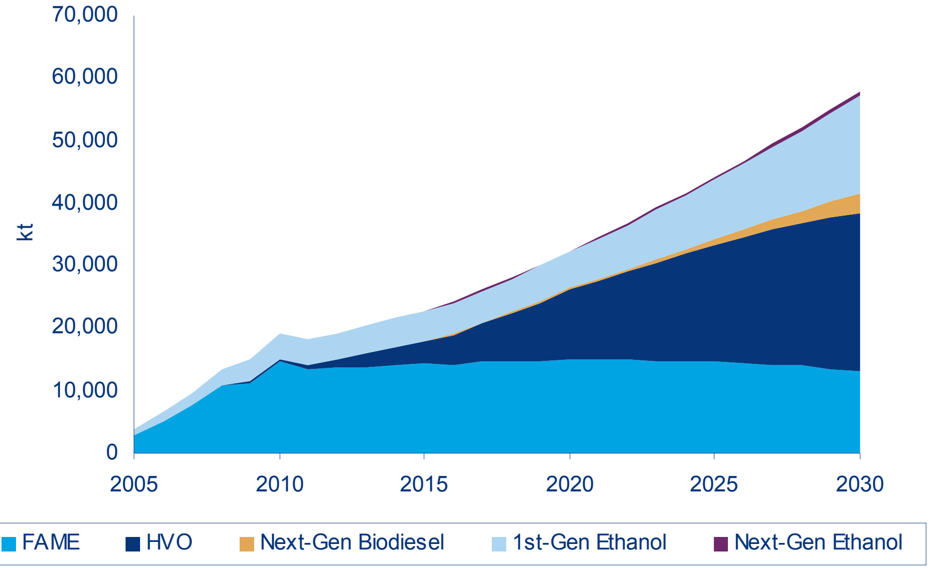
Figure 114: Scenario 1 – Biofuel volume share, 2005 – 2030



Source: Wood Mackenzie

Figure 115 shows how the consumption of biofuels grows over time in Scenario 1. Total biodiesel demand grows from around 3 Mt in 2005 to 26 Mt by 2020 and 41 Mt by 2030. Of this total the majority is produced using currently commercial technologies, with next-generation biodiesel consumption being less than 0.5 Mt in 2020 and 3 Mt in 2030. Fuel ethanol consumption rises from 0.8 Mt in 2005 to 6 Mt in 2020 and 17 Mt in 2030. Of this total, next-generation ethanol accounts for less than 1 Mt by 2030.

Figure 115: Scenario 1 – Biofuel consumption, 2005 – 2030

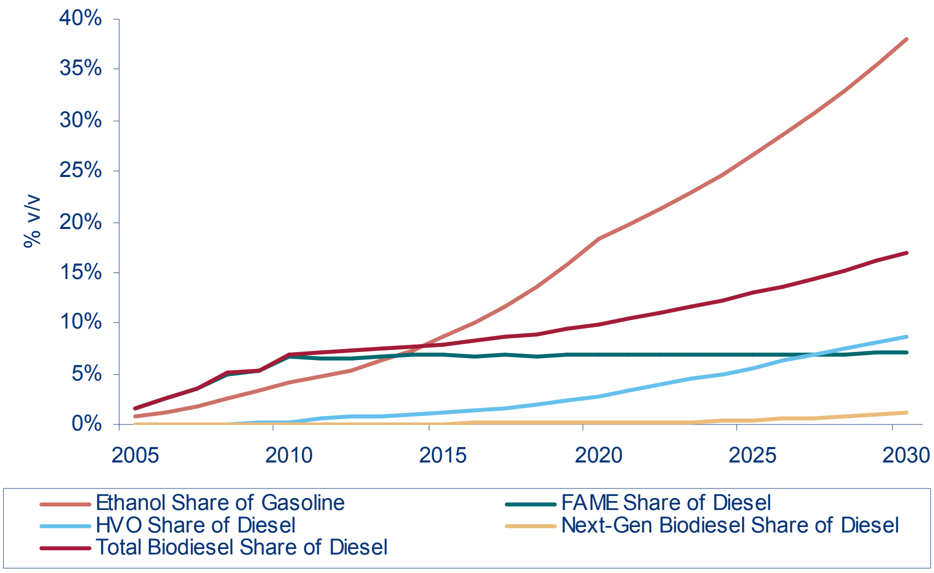


Source: Wood Mackenzie

12.1.3 Scenario 2

Scenario 2 assumes that the Renewable Energy and Fuel Quality Directives are met with a relatively high share of ethanol and a relatively low biodiesel share. This pattern then extends through to 2030. This scenario assumes that the price of biodiesel rises considerably compared to ethanol, which could be envisaged given some restraint in the feedstock markets in particular. As a result, more ethanol is pushed onto the market to meet the renewable fuels legislation than in Scenario 1.

Figure 116: Scenario 2 – Biofuel volume share, 2005 – 2030



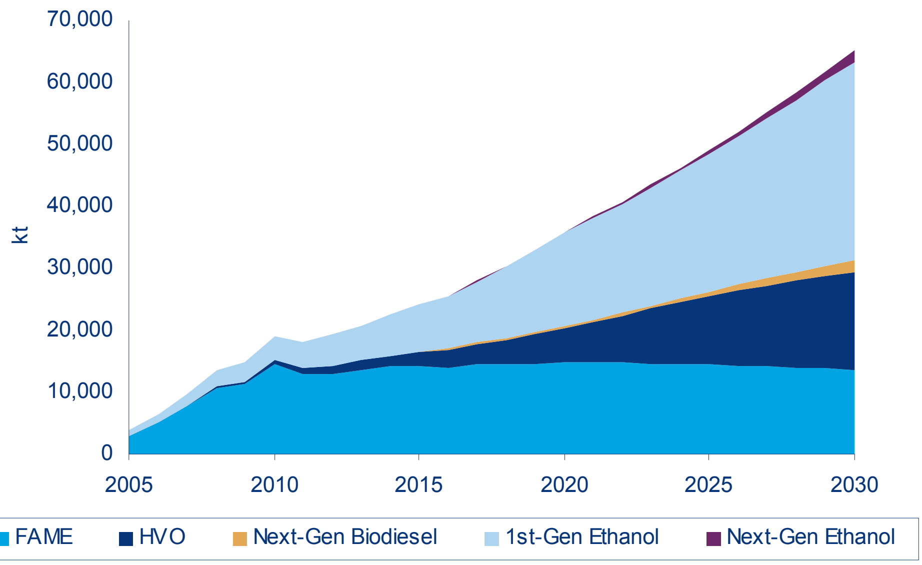
Source: Wood Mackenzie

As for Scenario 1, the majority of the biofuels are from first-generation sources, even in 2030. Similarly, the uptake of plug-in electric vehicles is low, with EVs representing less than 1% of market share in 2020 and less than 6% in 2030. Therefore the contribution from renewable electricity is low.

Figure 116 illustrates how the volume share of biofuels in the total EU road fuel market changes over time. Under this scenario, biodiesel accounts for just under 10% of the road diesel pool by 2020 and 17% by 2030. The ethanol share of the gasoline market reaches just over 18% in 2020 and 38% in 2030.

Figure 117 shows how the consumption of biofuels grows over time in Scenario 2. Total biodiesel demand grows from around 3 Mt in 2005 to 21 Mt by 2020 and 31 Mt by 2030. Of this total the majority is produced using currently commercial technologies, with next-generation biodiesel consumption being less than 0.5 Mt in 2020 and 2 Mt in 2030. Fuel ethanol consumption rises from 0.8 Mt in 2005 to 15 Mt in 2020 and 34 Mt in 2030. Of this total, next-generation ethanol accounts for less than 2 Mt by 2030.

Figure 117: Scenario 2 – Biofuel consumption, 2005 – 2030



Source: Wood Mackenzie

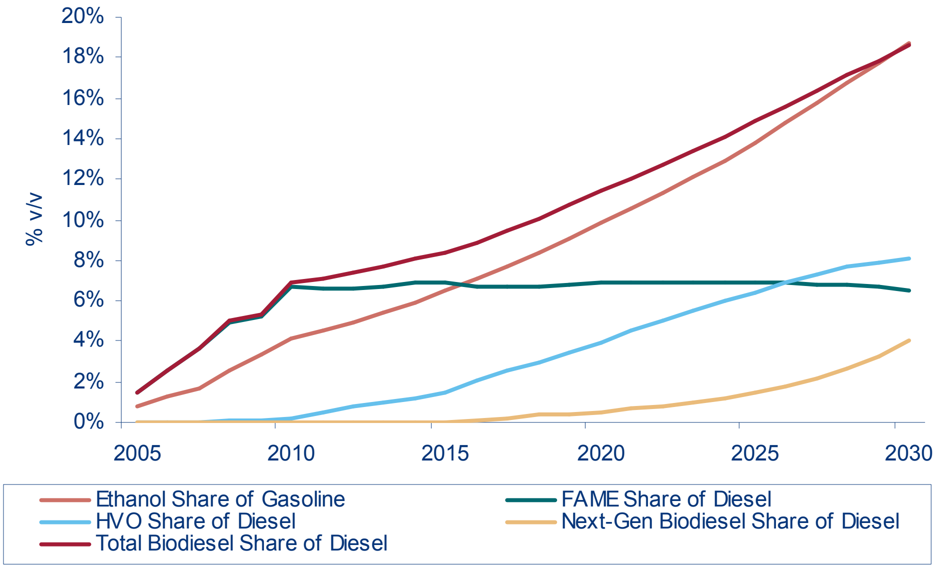
12.1.4 Scenario 3

Scenario 3 assumes that the Renewable Energy and Fuel Quality Directives are met with a high share of next generation biofuels and renewable electricity. This pattern extends through to 2030. Next generation biofuel production technologies reach commercialisation and make a significant contribution towards the EU's renewable transport fuels targets, especially by 2030.

The uptake of plug-in electric vehicles is higher in this scenario, with EVs representing 10% of market share in 2020 and 22% in 2030. The contribution from renewable electricity towards renewable energy targets starts to become significant by 2030.

Figure 118 illustrates how the volume share of biofuels in the total EU road fuel market changes over time. Under this scenario, biodiesel accounts for just under 12% of the road diesel pool by 2020 and 20% by 2030. The ethanol share of the gasoline market reaches just under 10% in 2020 and grows to just under 20% by 2030.

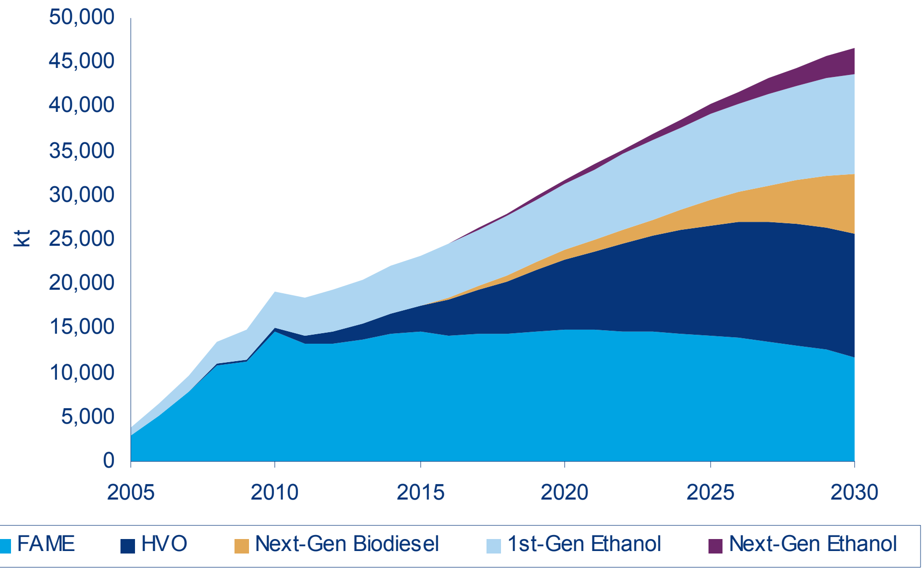
Figure 118: Scenario 3 – Biofuel volume share, 2005 – 2030



Source: Wood Mackenzie

Figure 119 shows how the consumption of biofuels grows over time in Scenario 3. Total biodiesel demand grows from around 3 Mt in 2005 to 24 Mt by 2020 and 34 Mt by 2030. Of this total the majority is still produced using currently commercial technologies, but next-generation biodiesel consumption grows rapidly after 2020 to reach over 7 Mt by 2030. Fuel ethanol consumption rises from 0.8 Mt in 2005 to 8 Mt in 2020 and 15 Mt in 2030. Of this total, next-generation ethanol accounts for over 3 Mt by 2030.

Figure 119: Scenario 3 – Biofuel consumption, 2005 – 2030



Source: Wood Mackenzie

12.2 Downstream Impact Methodologies

This section explain the methodology used to evaluate the three scenarios impact in terms of:

- Carbon emissions
- Refining economics
- Crude demand
- Biofuel blends options

12.2.1 Carbon Emissions

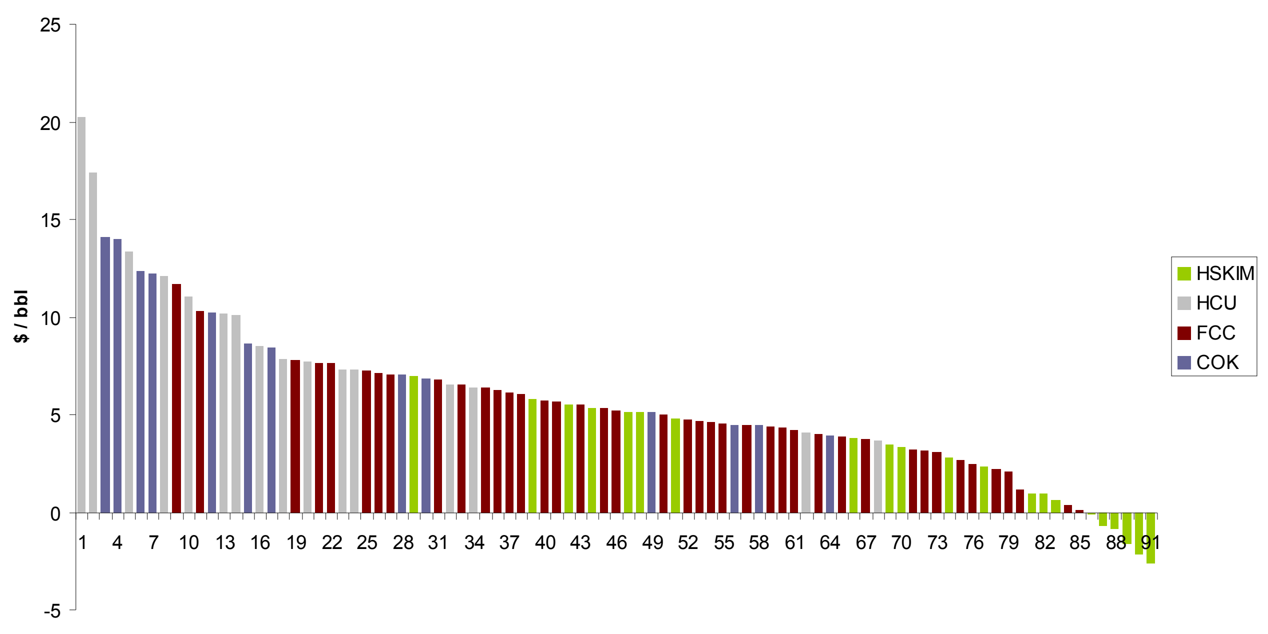
The increased role of biofuels is expected to play a role not only on refining economics but also upon the amount of carbon emitted by the refining sector. Carbon emissions are expected to fall as refineries reduce their runs in response to lower demand for refined products due to increasing biofuels volumes.

By mandating increased biofuel content demand for refinery produced oil products is expected to fall and refineries are expected to respond by reducing their production, thereby reducing their carbon emissions.

Chapter 3.3 discusses that economic performance is not the sole factor in deciding whether to close a refinery. However refining economic performance in terms of NCM is still the best method for assessing which refineries are likely to reduce their production, especially in environments like the EU where most refineries are run as businesses rather than purely for security of supply. Fourth quartile refineries on the Net Cash Margin chart are considered to be the most likely to be affected by the reduced demand for oil products.

In any one year refinery margins can be affected by non-typical events. For example, Hurricane Katrina in 2005 shut down many USGC refineries for an extended period and supported large European refinery exports and strong refinery margins. In what is considered a typical refining year, referred to as a mid-cycle position, such events are assumed not to occur and refining supply for oil products is considered to be in a sustainable position. In such a year our modelling suggests that hydroskimming refinery configurations would account for 45% of fourth quartile refining capacity, fluid catalytic cracking 35%, coking 14% and the remaining 6% would be hydrocracking configurations (see Figure 120).

Figure 120: Refinery NCM (Mid Cycle Year) by Configuration



Source: Wood Mackenzie

Chapter 11 explains that the European Union is expected to introduce Phase 3 of the EC's Emissions Trading Scheme. From 2013 this is expected to introduce a carbon cost on refining which will materially impact refining economics and alter refinery margins. Each refineries carbon emissions differ dependant on factors including the refinery size, crude type and energy use. More complex refineries typically have more refinery units, run heavier crude and have higher energy demands and therefore produce more carbon than simple refineries. Complex refineries are expected to face a higher carbon cost. The NCM and the relative positioning of refineries on the curve alters with the introduction of a carbon cost at the margin, though allowances will depend on a benchmark system. To evaluate which refineries are likely to be fourth quartile performers once carbon legislation is implemented the NCM curve has been adjusted to take into consideration marginal carbon cost.

Refining carbon costs have been calculated for four typical refinery configurations in Europe based on European refinery data for refinery fuel and loss and refinery capacity. The following describes the methodology for calculating carbon costs:

1. For each refinery type a crude was assumed based on the refinery configuration and typical crude runs of European refineries. The assumed crudes processed are Azeri Light for hydroskimmer refineries, Brent for FCC refineries and Urals for both hydrocracker and coking refineries.

2. The refinery fuel and losses were calculated for each refinery type and split by the source of the refinery fuel sources.

3. The assumed carbon emissions for each source of refinery fuel and loss were assigned on a tonnes basis; for example one tonne of fuel oil emits 3.216 tonnes of carbon[3], one tonne of refinery offgas is assumed to emit 2.5 tonnes of carbon.

4. A carbon cost of USD 50 per tonne of emissions is assumed.

5. The carbon cost per barrel processed was calculated assuming that carbon emissions are linearly related to the amount of barrels processed.

Figure 121: Average marginal carbon cost per refinery type

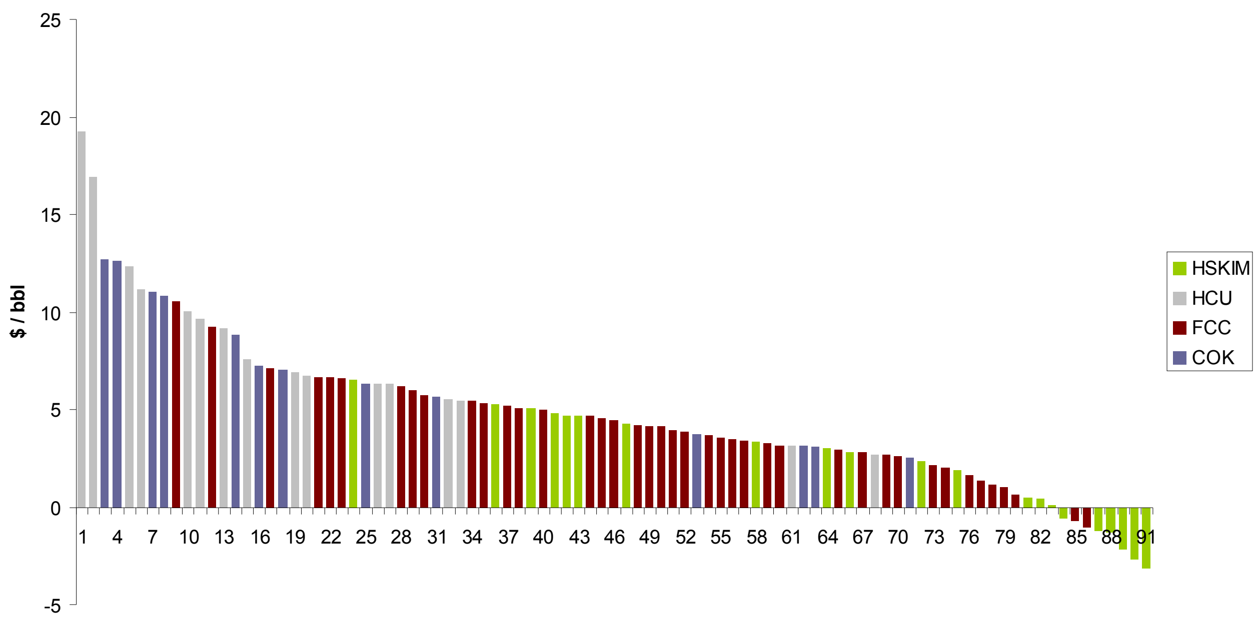
	Coking	Fluid catalytic cracking	Hydrocracking	Hydroskimming
Carbon cost prior to credit allocation ($/bbl)	1.37	1.07	0.97	0.50

Source: Wood Mackenzie

Under Phase 3 of the EC's Emissions Trading Scheme refineries are expected to be allocated some free emission allowances based on a mechanism benchmarking refineries against the most emissions efficient refineries. We have assumed no free carbon allocations at the margin due to the uncertainty regarding how these will be applied and which refineries will receive the allocations. The results of this analysis are shown in Figure 121 and highlight that the more complex refineries are expected to be most affected by a cost of carbon.

[3] http://www.nef.org.uk/greencompany/co2calculator.htm

Figure 122: Refinery NCM (Mid Cycle Year) by Configuration Accounting For Carbon Costs

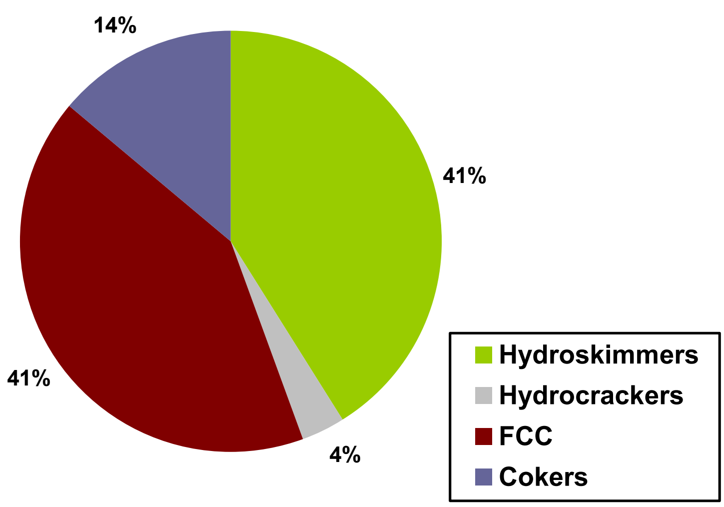


Source: Wood Mackenzie

The NCM curve for European refineries has been recast to show what it would look like if cost of carbon is included (Figure 122). The introduction of a carbon cost alters the composition of the fourth quartile. The split of fourth quartile refining capacity after the inclusion of a carbon cost is shown in Figure 123. Cat cracking refineries now constitute a larger share of the quartile, up from 35 to 41%, while hydroskimming takes a lower share, down from 45 to 41%.

Any reduction in refinery capacity as a result of increasing biofuels is expected to occur to fourth quartile refineries. Our methodology for calculating the reduced carbon emission has been to assume any reduced refinery production due to the greater use of biofuels is split between the different refinery types based upon how much of the fourth quartile refinery capacity they account for. The carbon emission reduction for each refinery configuration is then calculated based upon the inputs used for determining the average carbon cost per refinery type (see earlier in this section).

Figure 123: Fourth quartile mid cycle refining capacity by refinery configuration (after accounting for carbon cost)



Source: Wood Mackenzie

Whilst this report reviews the reduced carbon emissions from European refineries it does not attempt to review the net impact on carbon emissions beyond this. To do this would require an evaluation of upstream effects, of the emissions during the freight of both oil products and crude and also emissions from European refining trading partners.

12.2.2 Refining Economics

A methodology has been developed to isolate the impact the increased biofuels content will have on European refineries. The base assumption behind the methodology is that as biofuel demand increases there will be an equivalent fall in demand for refinery oil products within Europe.

Europe is short middle distillates but long gasoline. European refineries are assumed to already be maximising gasoline exports. If European demand for refinery gasoline falls due to rising ethanol content in the gasoline pool then the gasoline displaced by biofuels in Europe would need to look for more distant markets. The gasoline export parity pricing would therefore subsequently fall and some marginal refineries would reduce their production.

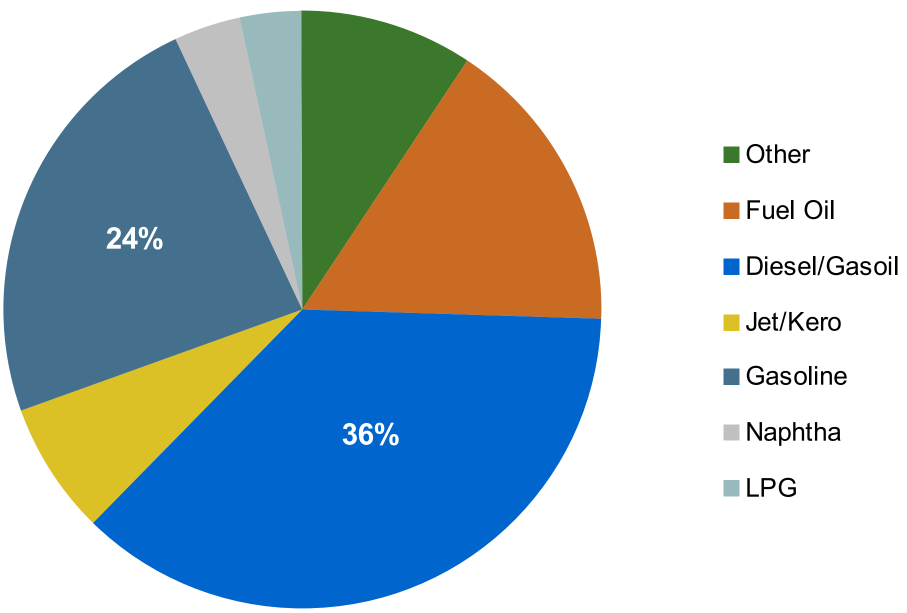
European refineries are expected to generally maximise their middle distillate yields due to Europe being long gasoline and short middle distillates. As marginal refineries reduce their gasoline production they also would reduce their supply of other oil products such as middle distillates. The pricing impact of this however is expected to be negligible due to the large amount of export orientated refineries in the Former Soviet Union, India and the Middle East.

European diesel deficits are currently around 16 mt and forecast to grow. If European demand for refinery diesel falls due to rising biodiesel content in the diesel pool then European imports of diesel would fall. Only once the inclusion of increased biodiesel volumes changes European diesel to a long position would European refineries be expected to reduce their production. The pricing impact of reduced imports due to biodiesel supply is expected to be negligible due to the large diesel deficit still being expected to require imports from the export orientated refineries in the Former Soviet Union, India and the Middle East and elsewhere.

The result of these pricing and refinery supply changes is expected to alter a refinery's NCM position. Fourth quartile European refineries on the NCM curve accounting for carbon costs can be considered to be Europe's marginal refining capacity and the downward pricing pressure is expected to worsen their margins. We have therefore assumed fourth quartile refineries on the NCM curve accounting for carbon costs are likely to reduce their production in response to this changed environment.

The total amount of refining capacity expected to be affected by biofuels use is equivalent to the change in supply of gasoline / diesel divided by the corresponding yield of the fourth quartile refineries (see Figure 123). For example, a reduced gasoline demand would reduce total European refinery supply of gasoline by the same amount but the total oil products would fall by the change in supply divided by the gasoline yield of fourth quartile refineries.

Figure 124: Fourth quartile NCM refining yields accounting for carbon cost – wt%

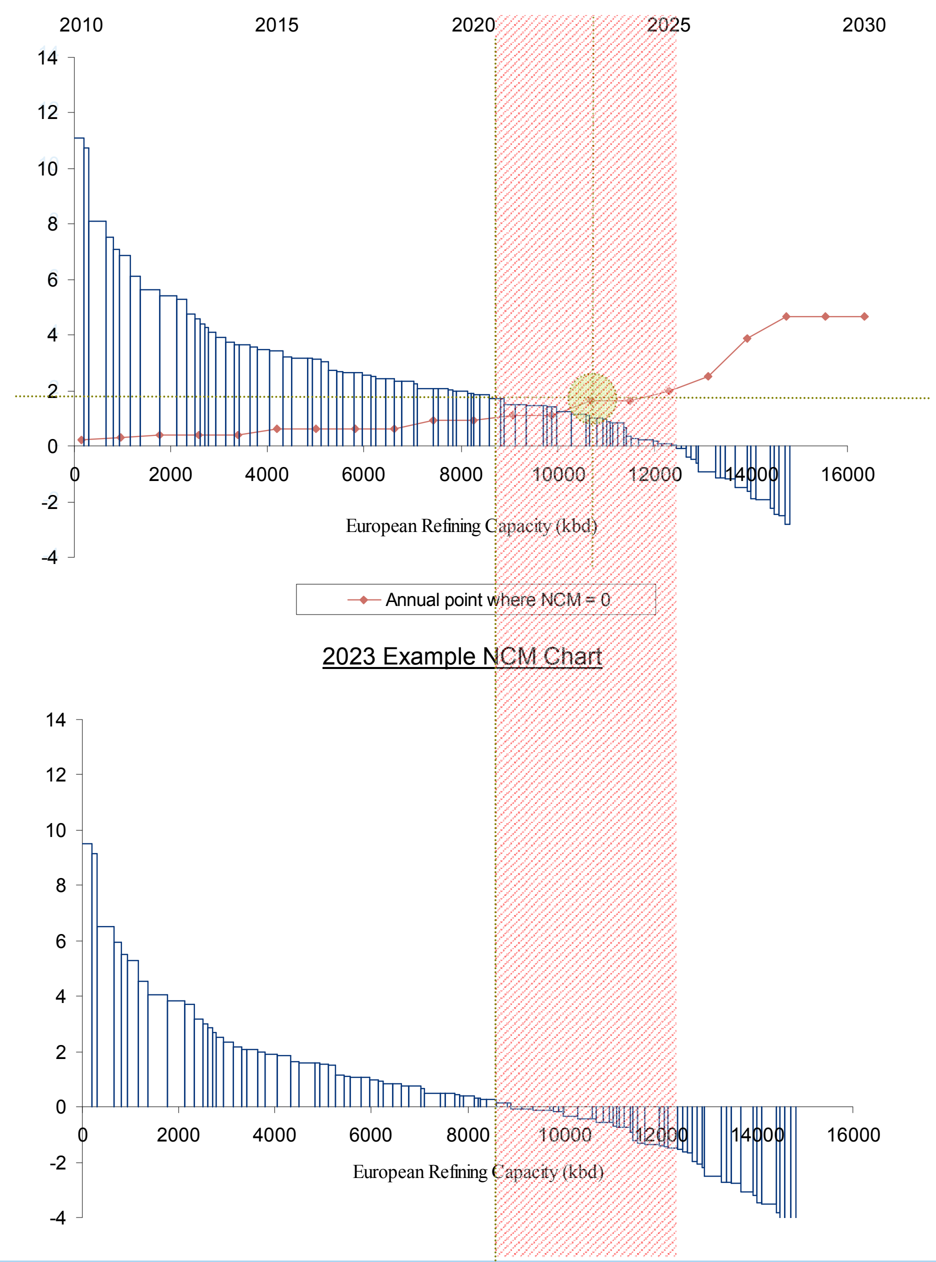


Source: Wood Mackenzie

To show the relative economic competiveness of refineries in Europe an approach based upon NCM has been taken. In each year the change on the European NCM curve has been modelled on the basis of the mid-cycle NCM curve accounting for carbon costs (see chapter 11). The change in European NCMs is equivalent to the total change in European refinery supply.

The results of this analysis are presented on the mid-cycle NCM curve. To explain the findings some example results are shown in Figure 125. The chart shows the NCM curve by refinery capacity which is plotted on the x axis. Overlaid onto this chart is a red line with points on it, with each point representing a year between 2010 and 2030 as indicated by the top x axis. Each point on this line represents the point at which the NCM (y axis) would equal 0 in any one year due to the biofuel assumptions made in each scenario. The example in Figure 125 shows that in 2023 the NCM of refineries would be almost 2 $/bbl less than under a mid cycle year and would result in approximately a further 3000 kb/d of refining capacity having a negative NCM (as shown in the red shaded area). Beneath the results chart is an example of what the NCM chart would look like in 2023 in this example.

Figure 125: Example change in the NCM curve due to the inclusion of biofuels



Source: Wood Mackenzie

12.2.3 Crude Demand

The increased role of biofuels is expected to reduce the amount of refinery supply from European refineries. Based upon the expected reduction in refinery supply of oil products the reduced demand for crude processing and hence crude is identified. Much of European crude demand is sourced from relatively nearby sources, such as the North Sea, and the Former Soviet Union. OPEC countries are largely a balancing supplier in the market. It can therefore be assessed that much of the reduction in European crude demand would reduce oil demand from OPEC member countries, excluding more nearby OPEC states such as Libya, Algeria and Iraq (supplies via Ceyhan).

12.2.4 Biofuel Blend Options

Understanding the impact of the use of biofuels on fuel specification is based on applying the scenarios to the future vehicle parc. The process involved determining the likely biofuel blend options for each scenario, and then assessing the consequences with regard to fuel specifications and the future vehicle. The methodology developed to ascertain the possible biofuel blend options used the following assumptions:

Refuelling Infrastructure

It is assumed that in 2020 and 2030 four fuel grades will be available in re-fuelling stations through-out Europe. It is assumed that two of these grades will be for diesel-type fuels, and that two grades will be for gasoline-type fuels. Some service stations situated on major truck routes may have more that four grades of fuel available, especially aimed at the heavy good vehicle market. This assumption was discussed during the Stakeholder Consultation undertaken by Ricardo in May-July 2010. The stakeholders interviewed agreed with this assumption.

Road Transport Vehicle Parc in Europe - Average Age of Vehicles

In 2020, the split by age of vehicles within the vehicle parc is assumed to be:

Vehicle Age (2020)	Passenger Cars	Commercial Vehicles	Comments
New	7%	7%	Euro 6 vehicles
1-5 years	27%	27%	Euro 6 vehicles
5-10 years	33%	33%	Euro 5 vehicles
>10 years	33%	33%	Euro 4 vehicles (or below)
TOTAL	**100%**	**100%**	

In 2030, the split by age of vehicles within the vehicle parc is assumed to be:

Vehicle Age (2030)	Passenger Cars	Commercial Vehicles	Comments
New	7%	7%	?
1-5 years	27%	27%	Euro 7 vehicles
5-10 years	33%	33%	Euro 7 vehicles
>10 years	33%	33%	Euro 6 vehicles (or below)
TOTAL	**100%**	**100%**	

Thresholds for the use of biofuels in European vehicles

For Light Duty Diesel vehicles, it is assumed that:

Euro 4 and Euro 5 engines will tolerate up to 7%vol FAME (inline with current proposals for fuel specification)

Euro 6 engines will tolerate up to 10%vol FAME

For Heavy Duty Diesel vehicles, it is assumed that:

Euro IV and Euro V engines will tolerate up to 7%vol FAME (inline with current proposals for fuel specification)

Euro VI engines will tolerate up to 10%vol FAME

For Light Duty Gasoline vehicles, it is assumed that:

Euro 4 and Euro 5 engines will tolerate up to 10%vol Ethanol (E10) (inline with current proposals for fuel specification)

Euro 6 engines will tolerate up to 10%vol Ethanol (E10)

It is assumed that future engines beyond Euro 6 will be designed to toleration higher biofuel blends.

Biofuel Blend Options

In order to compare the mix between the use of high blends (B100, E85) in specialised vehicles, and the use of lower blends in the ordinary vehicle fleet, the methodology proposed three biofuel blend options and two biogasoline blend options. The criteria for these options were as follows:

Biodiesel Option A: One commodity blend

In this option, only one biodiesel blend was created by mixing all the biodiesel products into the diesel

Biodiesel Option B: B100 (100%vol FAME)

In this option, two diesel grades were created. The first grade was B100, with 100%vol FAME. The second grade mixed the remaining biodiesel products into the diesel. The split between B100 grade and other biodiesel grade was determined based on ensuring the other biodiesel grade contained less than 7%vol FAME.

Biodiesel Option C: Protection biodiesel blend B10 (7%vol FAME, 3%vol HVO)

As for option 2, in this option two diesel grades were created. The first grade was the protection grade for the older vehicles in the vehicle parc. It consisted of 7%vol FAME (maximum) and 3%vol HVO. In 2020, this protection graded need to represent 60-70% of the total diesel stock. The second grade was a mix of the remaining biodiesel products and diesel.

Biogasoline Option A: One commodity blend

As for the Biodiesel Option 1, in this option, all the ethanol was mixed with the reference gasoline to obtain one biofuel blend.

Biogasoline Option B: E85

For this option, two blends were created. The first blend was E85, with assumed ethanol content of 75%vol. The second blend contained the remaining ethanol and reference gasoline. The split between the two blends was determined by ensuring the second blend had less than 10% ethanol in 2020 and less than 20% ethanol in 2030.

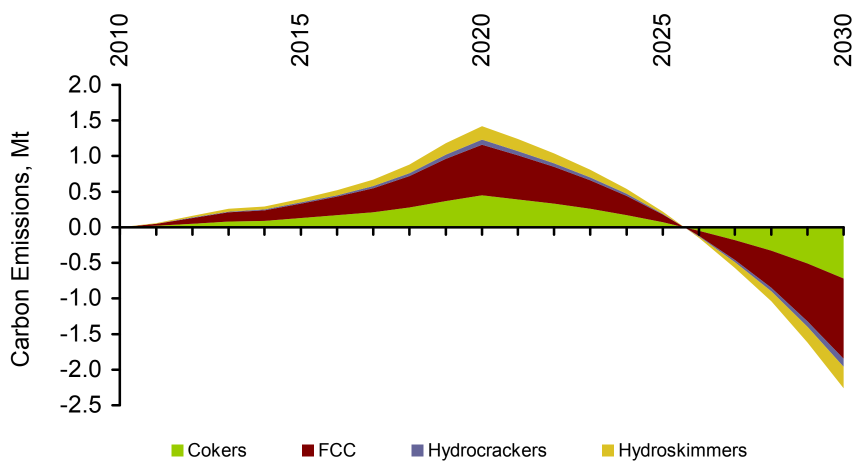
12.3 Scenario 1 Implications

Scenario 1 has an increasing role especially for biodiesel whilst the biogasoline content in the gasoline pool is low in initial years and grows post 2020. This increases European demand for refinery gasoline and results in a slight increase in gasoline prices. As a result European refineries are initially able to increase their production. Post 2020 demand for refinery gasoline starts to fall and the consequent falls in gasoline prices are expected to reduce European refinery production.

12.3.1 Scenario 1 Carbon Emission Implications

The lower biogasoline content in the gasoline pool encourages European refineries to increase their production to meet this opportunity to satisfy Atlantic Basin gasoline supply and also take advantage of satisfying Europe's middle distillate deficits. As a result the carbon emissions from European refineries are expected to increase under this scenario out to 2020 from today's levels.

Figure 126: Scenario 1 Carbon Emissions Change



Source: Wood Mackenzie

NB - These are nominal emissions based on our previously explained benchmark configuration emissions and do not take account of any potential changes in refinery emissions per barrel processed.

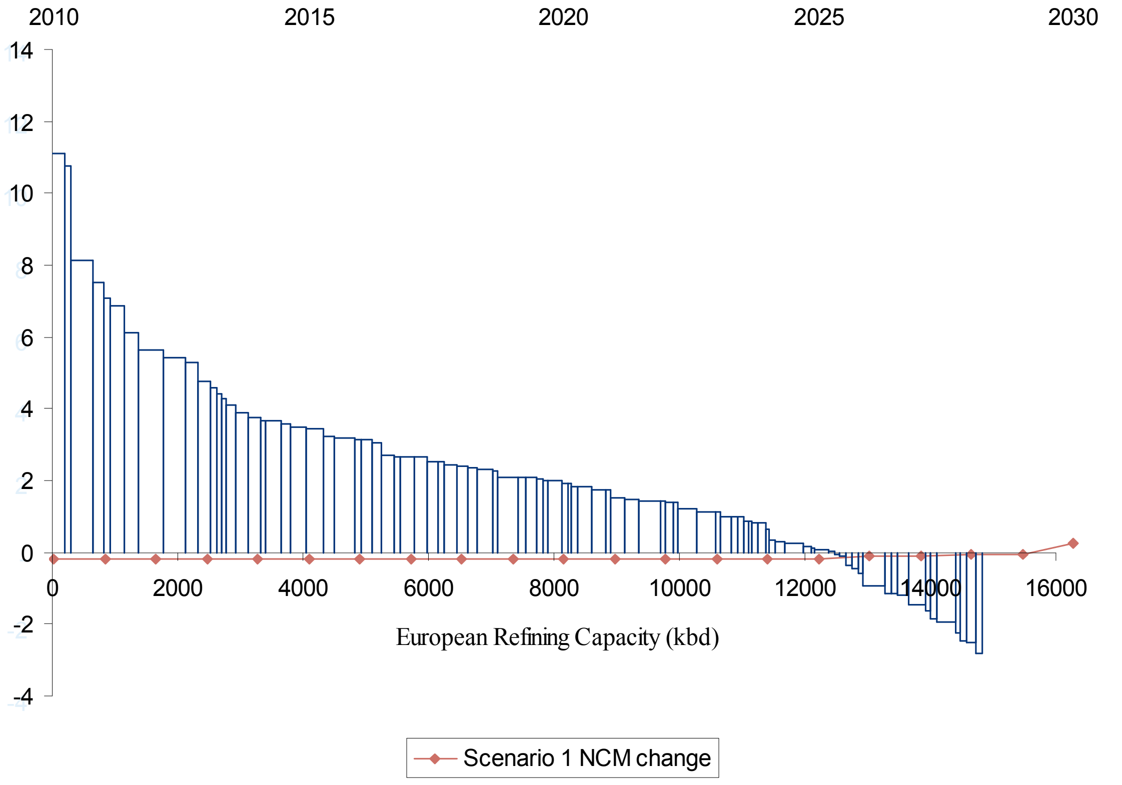
Post 2020 when increased biogasoline content starts to enter the gasoline pool European refineries respond by reducing gasoline supply which results in a decline in European refining carbon emissions. By 2030 carbon emissions under this scenario are 2.5 Mt less than under the mid cycle refining year. The FCC refinery type accounts for half of the changes in carbon emission whilst coking configurations account for approximately one third of the emission differences.

12.3.2 Scenario 1 Refinery Economics Implications

Scenario 1 has a low impact on refining economics until almost 2030 (see Figure 127). The small increase in demand for refinery gasoline supports a slight increase in European gasoline prices and a similarly slight improvement in European refining margins. The increased biodiesel content in the diesel pool is low relative to the European middle distillate deficits. Europe remains short middle distillates with middle distillate pricing movement expected to remain almost unchanged.

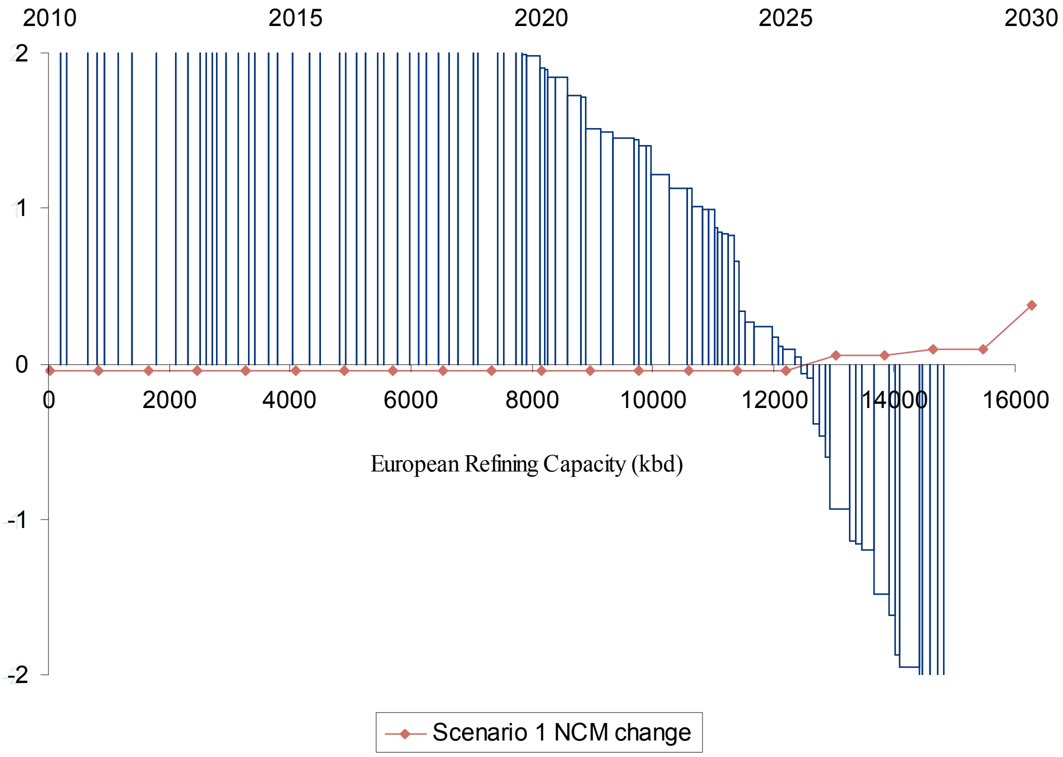
Post 2025 increasing biogasoline in the gasoline pool is expected to reduce the demand for refinery gasoline and European gasoline prices are expected to decline and start to reduce the margins for European refineries. The margin declines are small, under 0.10 $/bbl prior to 2030. A close up view of the NCM results is shown in Figure 128. By 2030 Scenario 1 European refining margins are 0.38 $/bbl worse compared to the mid cycle margins

Figure 127: Scenario 1 – Refinery NCM Changes vs Mid Cycle Position



Source: Wood Mackenzie

Figure 128: Scenario 1 – Refinery NCM Changes vs Mid Cycle Position (Close Up)



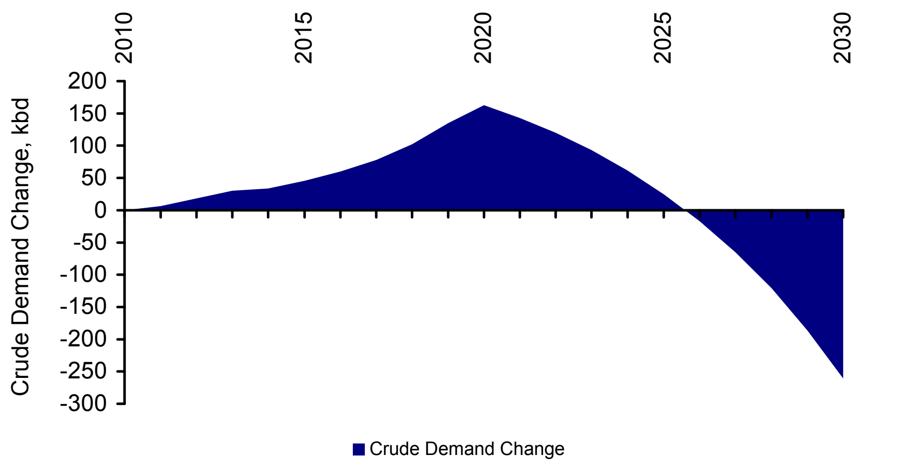
Source: Wood Mackenzie

The reduced refining margins results in a small threat of further refinery closure. As margins start to decline post 2025 two European refineries develop negative NCMs cash margins due to the increased content of biofuels in the gasoline and diesel pools. By 2030 this has risen to seven refineries.

12.3.3 Scenario 1 Crude Demand Implications

In this scenario the initial small increase in demand for refinery gasoline drives European refineries to increase their production. This initially results in their crude demand rising, peaking at an additional demand of approximately 160 kb/d in 2020. Falling demand for refinery gasoline reduces refinery runs post 2020 and crude demand drops. By 2030 crude demand is down 260 kb/d relative to our mid cycle datum (see Figure 129).

Figure 129: Scenario 1 – Reduced Crude Oil Demand

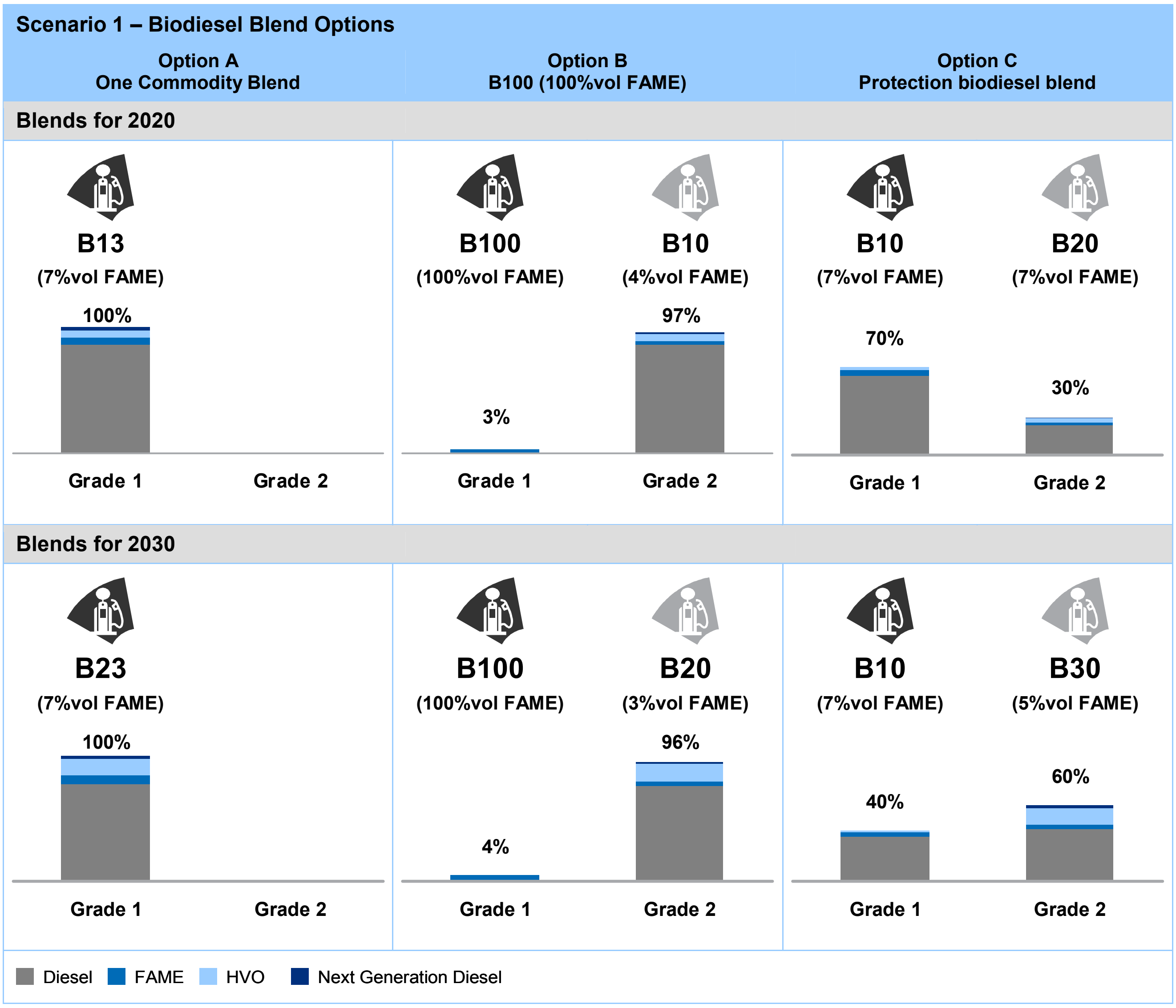


Source: Wood Mackenzie

12.3.4 Scenario 1 Biofuel Blend Implications

A summary of the different biofuel blend options for Scenario 1 is provided in Figure 130 and Figure 131. There are three options for biodiesel and two options for biogasoline. Each option comprises of one or two fuel grades which have been selected to achieved the biofuel mix set out in the scenario. The bar charts aim to illustrate the relative split between the fuel grades and their compositions. Further information on the grade combinations for each option is provided in the pages following the summary tables.

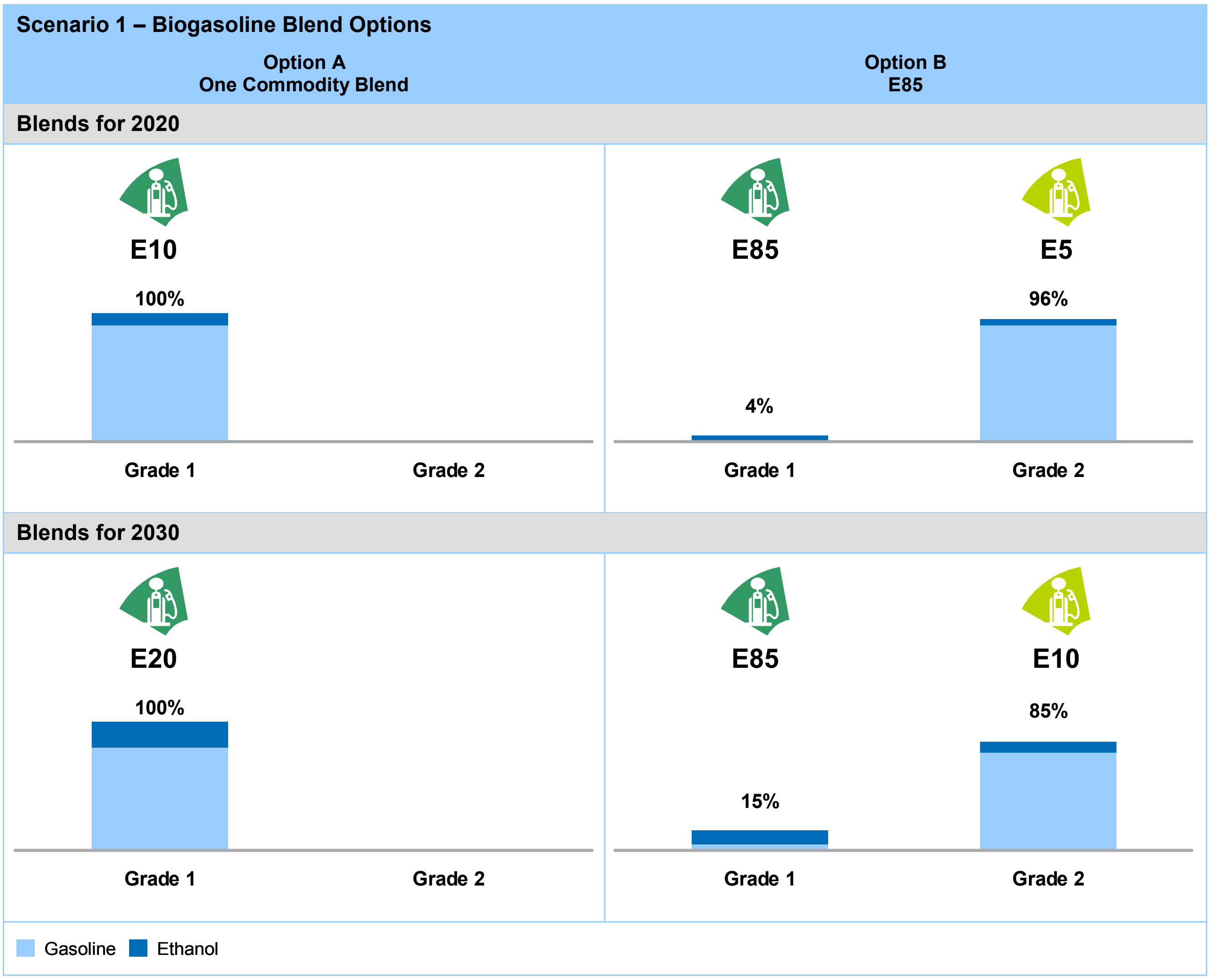
Figure 130: Scenario 1 – Overview of the Biodiesel Blend Options



Source: Ricardo

Any of the three biodiesel options presented would be suitable for Scenario 1. Option A would be preferred, since one commodity blend is the easiest to administer. However, for Scenario 1, in 2020 FAME represents 6.9%vol of the diesel stock. To ensure the annual average is 6.9%vol, the fuel specification for this fuel grade may need to allow for higher FAME contents, up to 8-10%vol. This is to provide a buffer for regional and seasonal variations in the fuel mix. However 10%vol FAME in 2020 may cause some issues for older vehicles. Research studies would be required to establish if 10%vol FAME would be suitable for older vehicles in the vehicle parc in 2020.

Figure 131: Scenario 1 – Overview of the Biogasoline Blend Options



Source: Ricardo

If it was decided that 10%vol FAME was not suitable for older vehicles in the vehicle parc in 2020, then either of the other two options could be implemented. Option C is likely to be easier to implement that Option B, since Option C does not require vehicles designed for B100, and because it is assumed the Euro 6 diesel vehicles would be designed for higher biofuel contents.

For Scenario 1, biogasoline blend option A is preferred, since with this option there is only one fuel grade and no flex fuel vehicles are required. Since in Scenario 1 ethanol represents 7.2%vol of the total gasoline stock in 2020, the E10 specification will be sufficient to allow for seasonal and regional variations in the ethanol content. With this option, it is assumed that the ethanol blend will increase to E20 by 2030, requiring a revised fuel specification allowing for higher ethanol content.

Scenario 1

Biodiesel Blend Option A

One Commodity Blend

Blends for 2020

Grade 1:

B13

Diesel	87.0	%vol
FAME	7.0	%vol
HVO	5.7	%vol
Next Generation Biodiesel	0.3	%vol

Split by grade:

Grade 1	**100**	**%vol**

Blends for 2030

Grade 1

B23

Diesel	77.0	%vol
FAME	7.0	%vol
HVO	14.2	%vol
Next Generation Biodiesel	1.8	%vol

Split by grade:

Grade 1	**100**	**%vol**

Consequences

Although the biodiesel increases from 13%vol in 2020 to 23%vol in 2030, the FAME content remains constant at 7%vol annual average. This is at the limit of the assumed tolerance to FAME of Euro 4 and Euro 5 diesel engines, which suggests that all diesel vehicles in 2020 and 2030 will be able to run on these two biodiesel blends.

However, to ensure that the annual average of 7%vol FAME is achieved, the fuel specifications may need to allow for higher FAME content, possibly up to 10%vol FAME. If this occurs, then there may be some issues with running older vehicles on this biofuel blend.

Since HVO and next generation biodiesel (e.g. BTL) have similar chemical and physical properties to conventional diesel, it is assumed that future vehicles will be able to tolerate 15-20%vol content of these biofuels.

Fuel specifications for 2020 and 2030 will need to allow for higher contents for HVO and next generation biodiesel (up to 15-20%vol).

Advantages	Disadvantages
⊕ Only one diesel grade required ⊕ FAME content remains constant between 2020 and 2030 ⊕ Higher biodiesel blends achieved through HVO and next generation biodiesel	⊖ The upper limit for FAME in EN 590 may need to be increased to 10% FAME, to allow for regional and seasonal variations

Source: Ricardo

Scenario 1	Biodiesel Blend Option B B100 (100%vol FAME)

Blends for 2020

Grade 1: B100			Grade 2: B10		
Diesel	0	%vol	Diesel	90.0	%vol
FAME	100	%vol	FAME	4.0	%vol
HVO	0	%vol	HVO	5.8	%vol
Next Generation Biodiesel	0	%vol	Next Generation Biodiesel	0.2	%vol

Split by grade:

Grade 1	**3**	**%vol**	**Grade 2**	**97**	**%vol**

Blends for 2030

Grade 1: B100			Grade 2: B20		
Diesel	0	%vol	Diesel	80.0	%vol
FAME	100	%vol	FAME	3.0	%vol
HVO	0	%vol	HVO	15.0	%vol
Next Generation Biodiesel	0	%vol	Next Generation Biodiesel	2.0	%vol

Split by grade:

Grade 1	**4**	**%vol**	**Grade 2**	**96**	**%vol**

Consequences

If approximately half of the available FAME stock is used to create a B100 blend, then the FAME content of the commodity blend is reduced to less than 5%vol (annual average). This is equivalent to the current fuel specification, which allows up to 5%vol FAME. Therefore, the commodity blend (Grade 2) would be suitable for older diesel vehicles in the vehicle parc.

A relatively small portion of the diesel stock would be required to be B100 FAME (3% in 2020 and 4% in 2030). However this would require 3-4% of the diesel vehicle parc to be B100 compatible by 2020. This would require OEMs to develop B100 vehicles, and for the market penetration of these vehicles to ramp up to 10-15% of new diesel vehicle sales by 2020.

This would also require Europe-wide development of a refuelling infrastructure for B100.

Heavy goods vehicles, buses or other fleet vehicles would be a good target sector for B100 vehicles. In this case, infrastructure development could be restricted to major trunk routes, or fleet depots. It would also limit the development effort required to ensure there are sufficient B100 vehicles. Since HGVs and buses consume significantly more fuel than passenger cars, a smaller number of B100 vehicles would be required to consume the B100 fuel.

It is likely that suitable government incentives would be required to ensure the development of the B100 infrastructure and the market uptake of B100 vehicles.

Changes to fuel specifications would be minor, focusing on the increased content of HVO and next generation biodiesels.

Advantages

- The commodity grade (B10 in 2020 and B20 in 2030) contains <5%vol FAME, which means there will be no compatibility issues for older vehicles in 2020 or 2030
- Fuel specification for B100 already exists
- The existing fuel specification allows for up to 7% FAME, suggesting no changes to FAME content in fuel specification required

Disadvantages

- Requires infrastructure development for B100
- Requires the portion of B100 compatible vehicles in the vehicle parc to increase rapidly up to 2020
- Requires OEMs to develop more B100 compatible vehicles (although this could be limited to heavy duty applications)
- Requires strong political will to ensure B100 infrastructure development and market uptake of B100 vehicles
- Modifications to fuel specifications required to allow for higher levels of HVO and next generation biodiesel

Source: Ricardo

Scenario 1

Biodiesel Blend Option C

Protection biodiesel blend

Blends for 2020

Grade 1: **B10**

Diesel	90.0	%vol
FAME	7.0	%vol
HVO	3.0	%vol
Next Generation Biodiesel	0.0	%vol

Grade 2 **B20**

Diesel	80.0	%vol
FAME	7.0	%vol
HVO	12.0	%vol
Next Generation Biodiesel	1.0	%vol

Split by grade:

Grade 1	**70**	**%vol**	**Grade 2**	**30**	**%vol**

Blends for 2030

Grade 1 **B10**

Diesel	90.0	%vol
FAME	7.0	%vol
HVO	3.0	%vol
Next Generation Biodiesel	0.0	%vol

Grade 2 **B30**

Diesel	70.0	%vol
FAME	5.0	%vol
HVO	22.0	%vol
Next Generation Biodiesel	3.0	%vol

Split by grade:

Grade 1	**40**	**%vol**	**Grade 2**	**60**	**%vol**

Consequences

In 2020, approximately two thirds of the vehicle parc will be Euro 4 and Euro 5 vehicles. The projection grade with ≤ 7%vol FAME ensures these vehicles will remain operational beyond 2020.

Although the second grade has higher biofuel content (20%vol in 2020 and 30%vol in 2030), FAME remains ≤ 7%vol, which implies the second grade would also be suitable for older vehicles. However the fuel specification for the second grade (B20 in 2020) may need to allow for FAME content up to 10%vol to act as a buffer for regional and seasonal changes.

Advantages

- Older vehicles are protected
- The existing fuel specification allows for up to 7% FAME, suggesting no changes to FAME content in fuel specification required for B10 grade

Disadvantages

- Two diesel grades with different biofuel contents, yet both are suitable for the diesel parc
- The fuel specification for B20 grade in 2020 may need to allow for up to 10%vol FAME to ensure the annual average is 7%vol

Source: Ricardo

Scenario 1

Biogasoline Blend Option A

One Commodity Blend

Blends for 2020

Grade 1:

E10

Gasoline	90	%vol
Ethanol	10	%vol

Split by grade:

Grade 1	**100**	**%vol**

Blends for 2030

Grade 1

E20

Gasoline	80	%vol
Ethanol	20	%vol

Split by grade:

Grade 1	**100**	**%vol**

Consequences

Up to 10%vol ethanol in 2020 is inline with the assumptions regarding ethanol tolerance for Euro 4, Euro 5 and Euro 6 gasoline vehicles.

However, if gasoline vehicles will be operating on E20 by 2030, then Euro 6 gasoline vehicles will need to be designed for 20%vol ethanol content.

Advantages	Disadvantages
⊕ Only one gasoline grade required ⊕ E10 in 2020 is inline with the current proposals for future fuel specification	⊖ Euro 6 gasoline vehicles will need to be E20 compatible ⊖ New European fuel specification for E20 required by 2030

Source: Ricardo

Scenario 1

Biogasoline Blend Option B

E85

Blends for 2020

Grade 1:			Grade 2		
Gasoline	25	%vol	Gasoline	95	%vol
Ethanol	75	%vol	Ethanol	5	%vol
E85			**E5**		

Split by grade:

Grade 1	**4**	**%vol**	**Grade 2**	**96**	**%vol**

Blends for 2030

Grade 1			Grade 2		
Gasoline	25	%vol	Gasoline	90	%vol
Ethanol	75	%vol	Ethanol	10	%vol
E85			**E10**		

Split by grade:

Grade 1	**15**	**%vol**	**Grade 2**	**85**	**%vol**

Consequences

By using approximately one third of the ethanol to produce E85 ensures that the remaining commodity grade is suitable for the rest of the gasoline vehicle parc in 2020 and 2030. (The current fuel specifications allow for 5%vol ethanol, suggesting no changes in fuel specification would be required for 2020. It is proposed to change the fuel specification to allow 10%vol ethanol, which would be suitable for the 2030 second grade fuel.)

In 2020, E85 would represent ~4% of the gasoline stock. However, this would require >4% of the gasoline vehicle parc to be E85 compatible by 2020. This implies OEMs will need to develop more E85 compatible flex-fuel vehicles. Market penetration of these FFVs will need to ramp up to 10-15% of new gasoline vehicle sales by 2020.

Market share for FFVs needs to continue to grow beyond 2020, to reach ~20% by 2030, to ensure >15% of the gasoline vehicle parc can operation on E85.

This option also requires the Europe-wide development of a refuelling infrastructure for E85.

Changes to fuel specification would not be required, beyond the proposed change to increase the ethanol content to 10%vol.

It should be noted that the 2020 split between E85 and Grade 2 was selected to allow Grade 2 to be E5, since E10 in 2020 was already considered in Option A.

Advantages

- A protection grade for older vehicles is available in 2020 and 2030
- No changes in current (and proposed) fuel specification required

Disadvantages

- Two gasoline grades required
- Requires development of E85 refuelling infrastructure throughout Europe
- Requires OEMs to development more E85 compatible flex-fuel vehicles
- Requires strong political will to ensure development of E85 refuelling infrastructure and suitable market uptake of E85 vehicles

Source: Ricardo

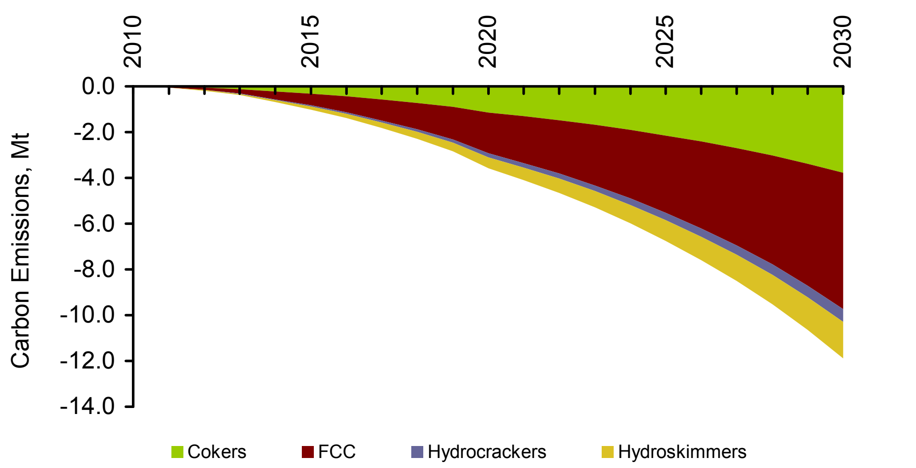
12.4 Scenario 2 Implications

Scenario 2 has an increasing role for biogasoline. As a result of the biogasoline content in the gasoline pool increasing European demand for refinery gasoline falls and European gasoline prices fall. European refineries margins decline and refineries respond by reducing production. As time develops the biogasoline content in the gasoline pool continues to increase further depressing margins and European refinery production.

12.4.1 Scenario 2 Carbon Emission Implications

As biogasoline content in the gasoline pool increases in this scenario, European refinery production falls. As a result carbon emissions from European refineries are expected to gradually fall throughout the period under review.

Figure 132: Scenario 2 Carbon Emissions Change



Source: Wood Mackenzie

NB - These are nominal emissions based on our previously explained benchmark configuration emissions and do not take account of any potential changes in refinery emissions per barrel processed.

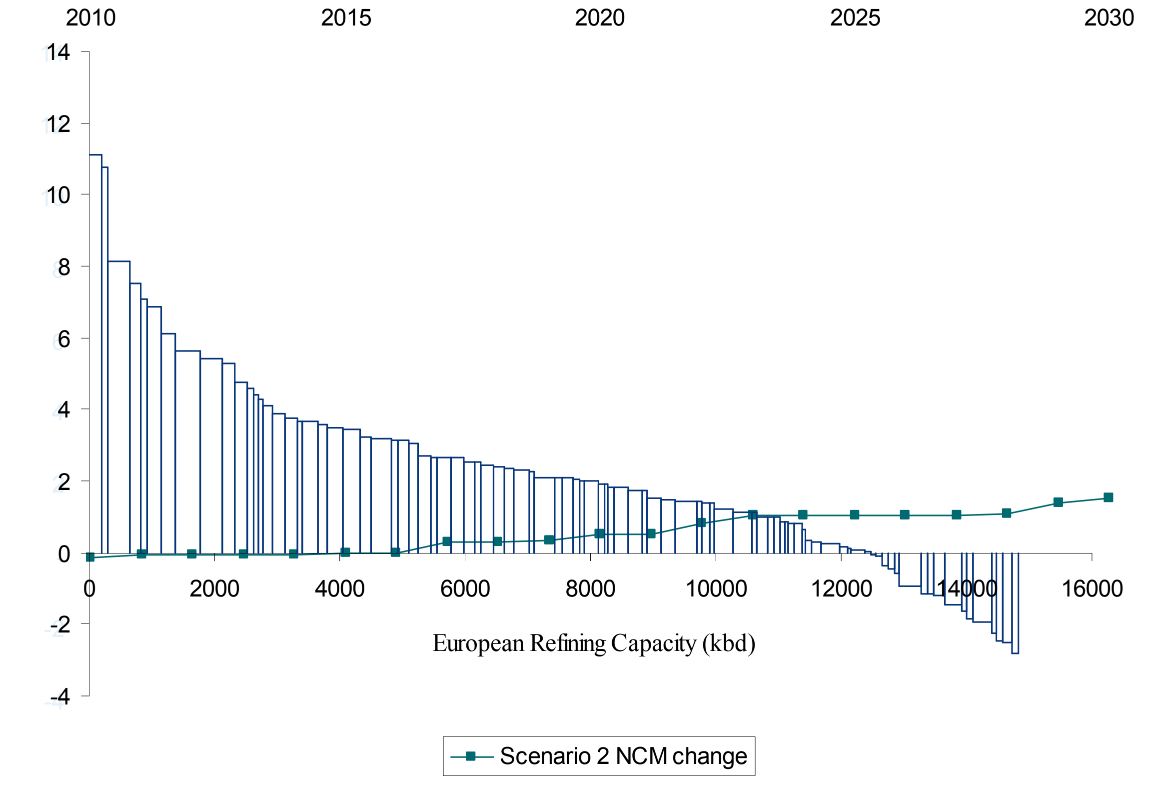
By 2030 carbon emissions under this scenario are almost 12 Mt less than under the mid cycle refining year. The FCC refinery type accounts for half of the changes in carbon emission whilst coking refineries account for approximately one third of the emission differences.

12.4.2 Scenario 2 Refinery Economics Implications

The reduced demand for refinery gasoline results in a gradual worsening of refinery economics (see Figure 133). The decrease in demand for refinery gasoline negatively impacts European gasoline prices and European refining margins decline as a result. Europe remains short middle distillates with middle distillate pricing movement expected to remain almost unchanged, though export refiners will be able to place more middle distillates in Europe.

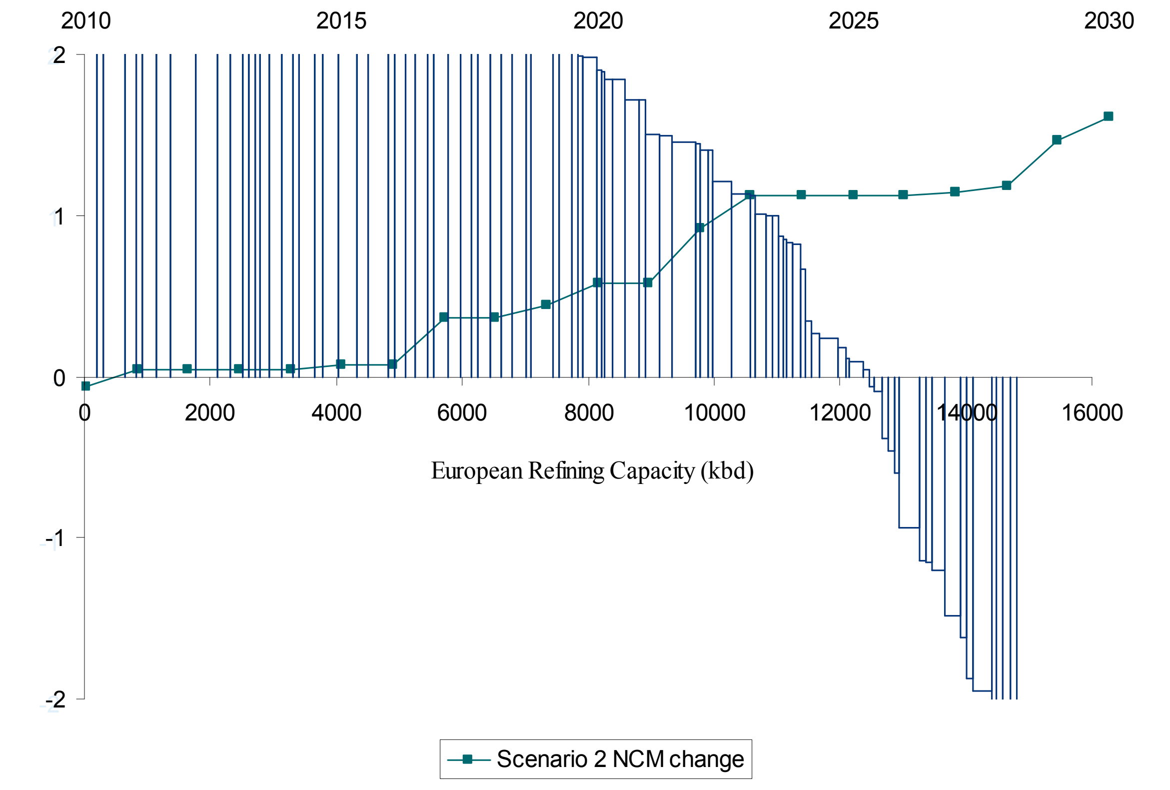
Margin declines for European refineries still remain small and a close up view of the NCM results is shown in Figure 134. In 2017 European refining margins are 0.38 $/bbl less than those under the mid cycle NCM. This rises to 0.60 $/bbl by 2020, 1.14 $/bbl by 2023 and over 1.6 $/bbl by 2030.

Figure 133: Scenario 2 – Refinery NCM Changes vs Mid Cycle Position



Source: Wood Mackenzie

Figure 134: Scenario 2 – Refinery NCM Changes vs Mid Cycle Position (Close Up)



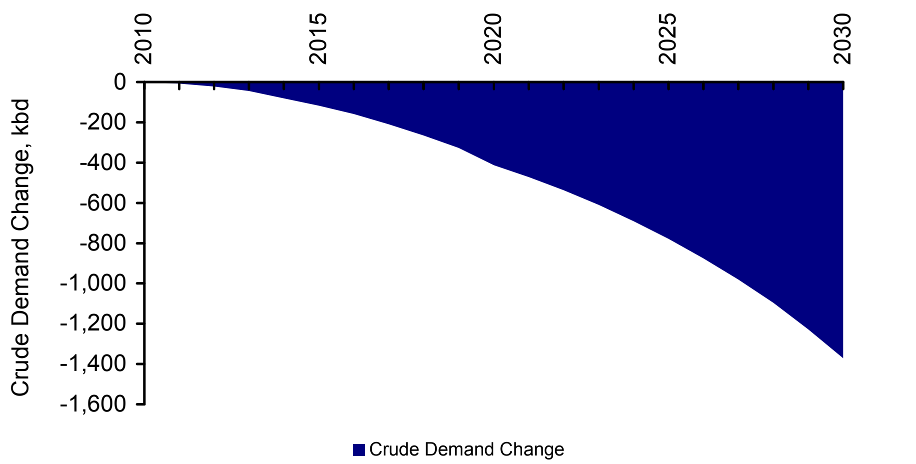
Source: Wood Mackenzie

The reduced refining margins results in a greater threat of further refinery closures than in Scenario 1. As margins start to decline by 2017 seven European refineries develop negative net cash margins due to the increased content of biofuels in the gasoline and diesel pools. This rises to sixteen refineries by 2023 and by 2030 24 European refineries have negative NCMs.

12.4.3 Scenario 2 Crude Demand Implications

In this scenario the decreasing demand for refinery gasoline results in European refineries gradually cutting their production runs and hence reducing their demand for crude. By 2020 the reduced crude demand is over 400 kb/d. By 2030 this has risen to almost 1400 kb/d (see Figure 135). However, increased European demand for middle distillates is likely to lead to higher refining runs outside Europe, including potentially in export refineries located in OPEC countries.

Figure 135: Scenario 2 – Reduced Crude Oil Demand



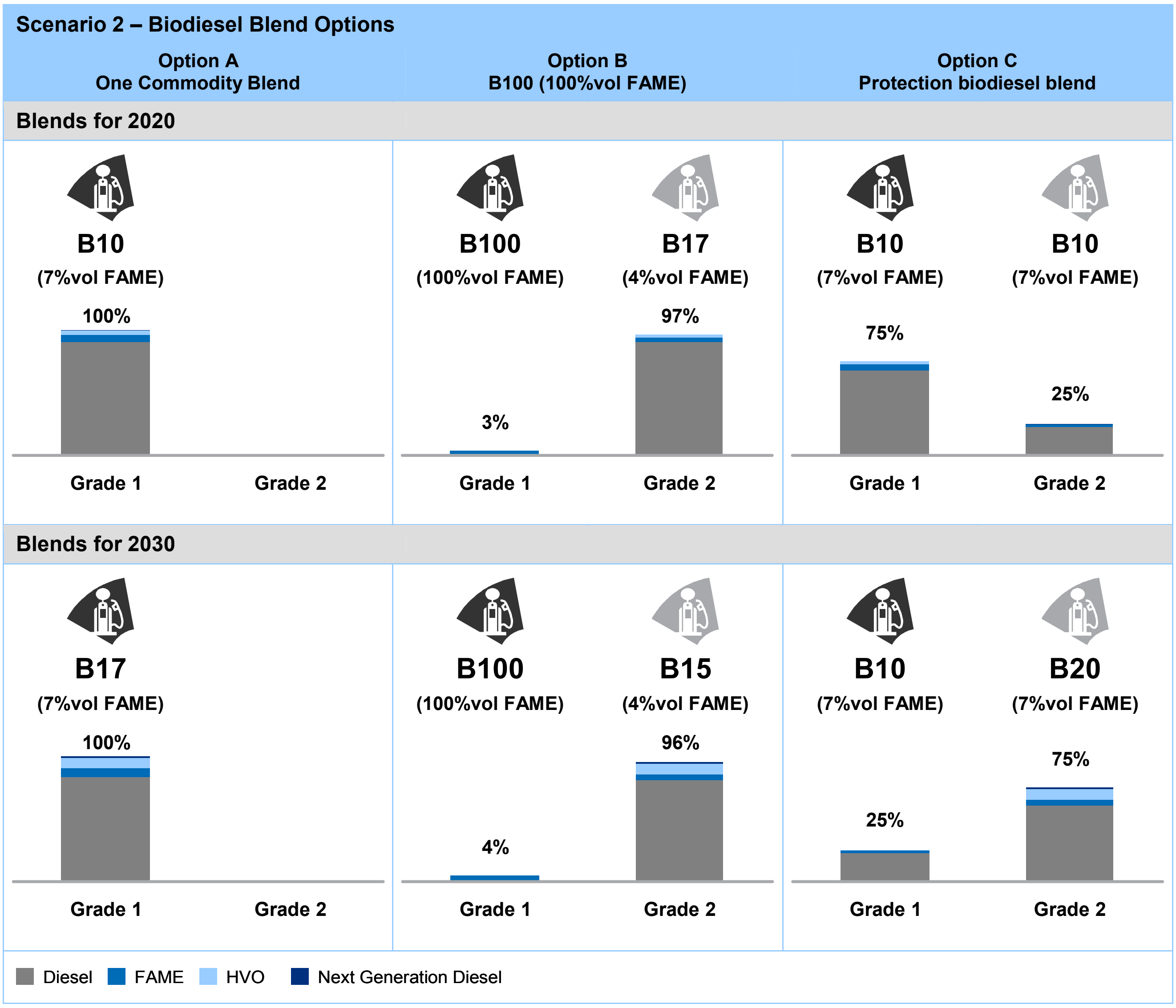
Source: Wood Mackenzie

12.4.4 Scenario 2 Biofuel Blend Implications

Figure 136 provides a summary of the three biodiesel blend options for Scenario 2. Three sets of blend options have been considered. Each option comprises of one or two fuel grades which have been selected to achieve the biofuel mix set out in the scenario. The bar charts aim to illustrate the relative split between the fuel grades and their compositions.

Any of the three options would be suitable for Scenario 2 since the FAME contents of all grades, except B100, is equal to or below the threshold of 7%vol. However, since the annual average for FAME is 6.9%vol in 2020 and 6.7%vol in 2030, it may be necessary to change the fuel specification to allow up to 10%vol FAME to account for regional and seasonal changes. This may cause some issues for older vehicles in 2020 which have not been designed to operate on 10%vol FAME blends. Further investigative work would be required to determine if 10%vol FAME would be acceptable for Euro 5 and older diesel vehicles.

Figure 136: Scenario 2 – Overview of the Biodiesel Blend Options

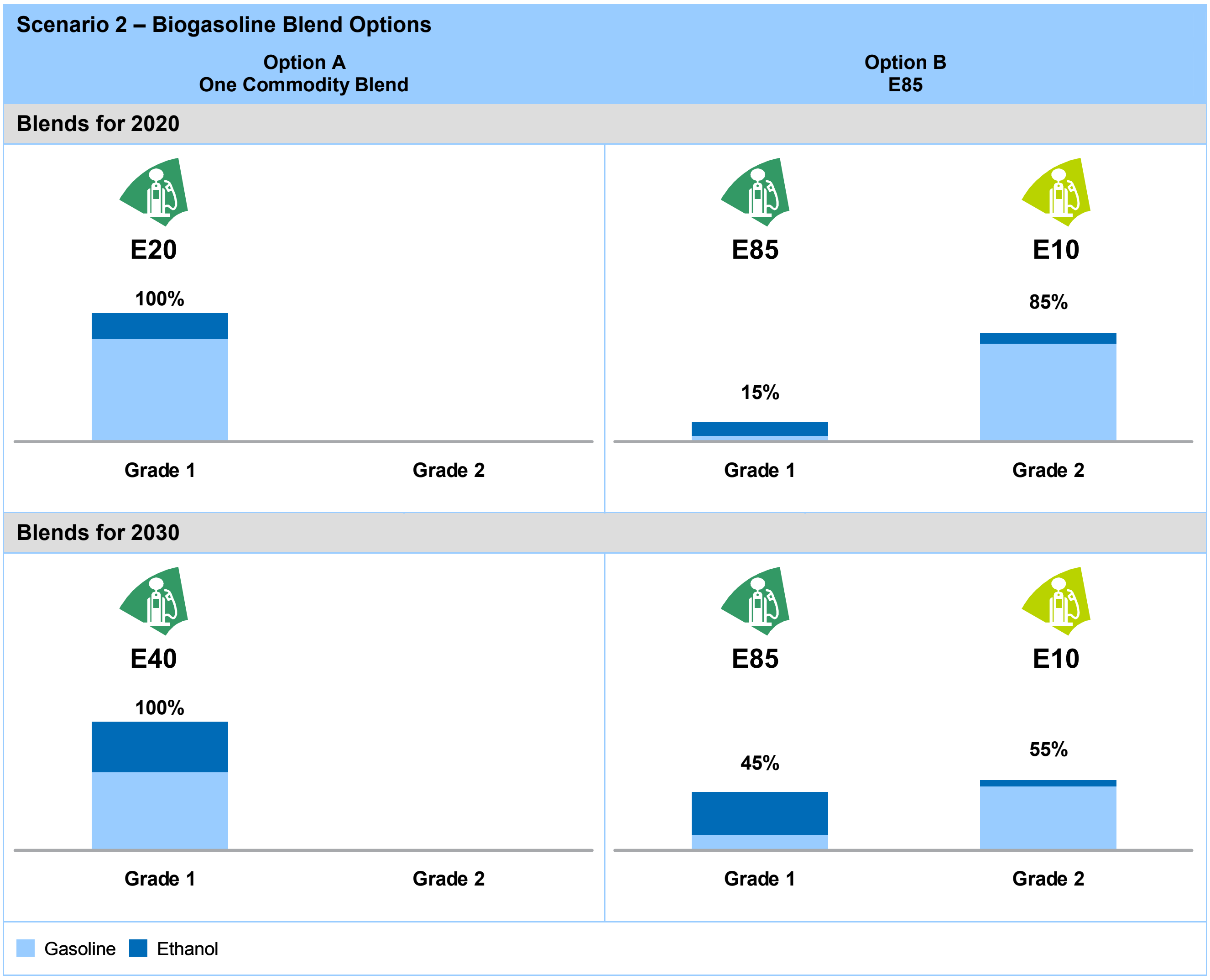


Source: Ricardo

Figure 137 provides a summary of the biogasoline blend options for Scenario 2. For this scenario, Option B is preferred, because E20 in 2020 will not be suitable for older vehicles in the vehicle parc, thus necessitating the move to E85 and flex fuel vehicles.

Further information on the grade combinations for each biodiesel and biogaosline option is provided in the pages following the summary tables.

Figure 137: Scenario 2 – Overview of the Biogasoline Blend Options



Source: Ricardo

Scenario 2

Biodiesel Blend Option A

One Commodity Blend

Blends for 2020

Grade 1:

B10

Diesel	90.0	%vol
FAME	7.0	%vol
HVO	2.8	%vol
Next Generation Biodiesel	0.2	%vol

Split by grade:

Grade 1	**100**	**%vol**

Blends for 2030

Grade 1

B17

Diesel	83.0	%vol
FAME	7.0	%vol
HVO	8.8	%vol
Next Generation Biodiesel	1.2	%vol

Split by grade:

Grade 1	**100**	**%vol**

Consequences

Although the biodiesel increases from 10%vol in 2020 to 17%vol in 2030, the FAME content remains constant at 7%vol annual average. This is at the limit of the assumed tolerance to FAME of Euro 4 and Euro 5 diesel engines, which suggests that all diesel vehicles in 2020 and 2030 will be able to run on these two biodiesel blends.

However, to ensure that the annual average of 7%vol FAME is achieved, the fuel specifications may need to allow for higher FAME content, possibly up to 10%vol FAME. If this occurs, then there may be some issues with running older vehicles on this biofuel blend.

Since HVO and next generation biodiesel (e.g. BTL) have similar chemical and physical properties to conventional diesel, it is assumed that future vehicles will be able to tolerate 5-15%vol content of these biofuels.

New fuel specifications will be required for 2020 and 2030 to allow for higher contents for HVO and next generation biodiesel.

Advantages	Disadvantages
Only one diesel grade required FAME content remains constant between 2020 and 2030 Higher biodiesel blends achieved through the use of HVO and next generation biodiesel	If 10%vol FAME is required in the fuel specification to ensure the annual average is 7%vol FAME, then this may cause issues for older vehicles in the diesel parc

Source: Ricardo

Scenario 2	**Biodiesel Blend Option B** **B100 (100%vol FAME)**

Blends for 2020

Grade 1:

B100

Diesel	0	%vol
FAME	100	%vol
HVO	0	%vol
Next Generation Biodiesel	0	%vol

Grade 2

B7

Diesel	90.0	%vol
FAME	4.0	%vol
HVO	2.8	%vol
Next Generation Biodiesel	0.2	%vol

Split by grade:

Grade 1	**3**	**%vol**	**Grade 2**	**97**	**%vol**

Blends for 2030

Grade 1

B100

Diesel	0	%vol
FAME	100	%vol
HVO	0	%vol
Next Generation Biodiesel	0	%vol

Grade 2

B15

Diesel	85	%vol
FAME	4	%vol
HVO	9	%vol
Next Generation Biodiesel	2	%vol

Split by grade:

Grade 1	**4**	**%vol**	**Grade 2**	**96**	**%vol**

Consequences

If some of the available FAME stock is used to create a B100 blend, then the FAME content of the commodity blend can be reduced to <5%vol (annual average). This is equivalent to EN 590:2004, which allowed up to 5%vol FAME. Therefore, the commodity blend (Grade 2) would be suitable for older diesel vehicles in the vehicle parc.

A relatively small portion of the diesel stock would be required to be B100 FAME (3% in 2020 and 4% in 2030). However this would require 3-4% of the diesel vehicle parc to be B100 compatible by 2020. OEMs would need to develop B100 vehicles, and for the market penetration of these vehicles would have to ramp up to 10-15% of new diesel vehicle sales by 2020.

This would also require Europe-wide development of a refuelling infrastructure for B100.

Heavy goods vehicles, buses or other fleet vehicles would be a good target sector for B100 vehicles. In this case, infrastructure development could be restricted to major trunk routes, or fleet depots. It would also limit the development effort required to ensure there are sufficient B100 vehicles, since HGVs and buses consume significantly more fuel than passenger cars.

It is likely that suitable government incentives would be required to ensure the development of the B100 infrastructure and the market uptake of B100 vehicles.

Changes to fuel specifications would be minor, focusing on the increased content of HVO and next generation biodiesels

Advantages

- The commodity grade (B7 in 2020 and B15 in 2030) contains <5%vol FAME, which means there will be no compatibility issues for older vehicles in 2020 or 2030
- Fuel specification for B100 already exists
- The existing fuel specification allows for up to 7%vol FAME (EN 590:2009)

Disadvantages

- Requires infrastructure development for B100
- Requires the portion of B100 compatible vehicles in the vehicle parc to increase rapidly up to 2020
- Requires OEMs to develop more B100 compatible vehicles (although this could be limited to heavy duty applications)
- Requires strong political will to ensure B100 infrastructure development and market uptake of B100 vehicles
- Modifications to fuel specifications required to allow for higher levels of HVO and next generation biodiesel

Source: Ricardo

Scenario 2

Biodiesel Blend Option C

Protection biodiesel blend

Blends for 2020

Grade 1:				Grade 2			
	Diesel	90.0	%vol		Diesel	90.0	%vol
	FAME	7.0	%vol		FAME	7.0	%vol
	HVO	3.0	%vol		HVO	2.0	%vol
B10	Next Generation Biodiesel	0.0	%vol	**B10**	Next Generation Biodiesel	1.0	%vol

Split by grade:

Grade 1	**75**	**%vol**	**Grade 2**	**25**	**%vol**

Blends for 2030

Grade 1				Grade 2			
	Diesel	90.0	%vol		Diesel	80.0	%vol
	FAME	7.0	%vol		FAME	7.0	%vol
	HVO	3.0	%vol		HVO	11.0	%vol
B10	Next Generation Biodiesel	0.0	%vol	**B20**	Next Generation Biodiesel	2.0	%vol

Split by grade:

Grade 1	**25**	**%vol**	**Grade 2**	**75**	**%vol**

Consequences

In 2020, the biofuel mix of the second grade is also B10 with ≤ 7%vol FAME. Therefore, for this scenario and this option, there is no discernible difference between the two grade options.

In 2030, although the second grade has higher biofuel content (20%vol), the FAME content remains ≤ 7%vol, which implies the second grade would also be suitable for older vehicles.

Advantages

- Older vehicles are protected
- The FAME content remains within the current fuel specification (7%vol)
- Higher biofuel blends achieved through the use of HVO and next generation biodiesels

Disadvantages

- Two diesel grades with different bio contents, yet both are suitable for the diesel parc

Source: Ricardo

Scenario 2 — Biogasoline Blend Option A

One Commodity Blend

Blends for 2020

Grade 1:

E20

Gasoline	80	%vol
Ethanol	20	%vol

Split by grade:

Grade 1	**100**	**%vol**

Blends for 2030

Grade 1

E40

Gasoline	60	%vol
Ethanol	40	%vol

Split by grade:

Grade 1	**100**	**%vol**

Consequences

Up to 20%vol ethanol in 2020 is higher than the assumed ethanol tolerance for Euro 4, Euro 5 and Euro 6 gasoline vehicles. Therefore E20 in 2020 would not be suitable for most gasoline vehicles in the vehicle parc.

If gasoline in 2030 will be E40, then Euro 6 gasoline engines will need to be designed for this ethanol content. This will require similar modifications as for flex-fuel vehicles.

Advantages	Disadvantages
⊕ Only one gasoline grade required	⊖ E20 is not suitable for Euro 4 and Euro 5 gasoline vehicles ⊖ Euro 6 gasoline vehicles will need to be E20 and E40 compatible ⊖ New European fuel specifications for E20 and E40 required

Source: Ricardo

Scenario 2	Biogasoline Blend Option B E85

Blends for 2020

Grade 1:				Grade 2			
E85	Gasoline	25	%vol	E10	Gasoline	90	%vol
	Ethanol	75	%vol		Ethanol	10	%vol

Split by grade:

	Grade 1	**15**	**%vol**		**Grade 2**	**85**	**%vol**

Blends for 2030

Grade 1				Grade 2			
E85	Gasoline	25	%vol	E10	Gasoline	90	%vol
	Ethanol	75	%vol		Ethanol	10	%vol

Split by grade:

	Grade 1	**45**	**%vol**		**Grade 2**	**55**	**%vol**

Consequences

As for Scenario 1, if approximately one third of the ethanol is used to produce E85, then the remaining commodity grade is suitable for the rest of the gasoline vehicle parc in 2020 and 2030 (10%vol ethanol, which is inline with the proposed changes the current fuel specification).

In 2020, E85 would represent at least 15% of the gasoline stock, which would require >15% of the gasoline vehicle parc to be E85 compatible by 2020. This would require a rapid introduction of new E85 compatible flex-fuel vehicles, with market penetration reaching 40-50% of new gasoline vehicles by 2020.

Beyond 2020, FFVs would need to retain or grow market share of 40-50% of new gasoline vehicles to ensure >45% of the gasoline vehicle parc was E85 compatible by 2030.

This option also requires the Europe-wide development of a refuelling infrastructure for E85.

Changes to fuel specification would not be required, beyond the proposed change to increase the ethanol content to 10%vol.

Advantages	Disadvantages
+ A protection grade for older vehicles is available in 2020 and 2030 + No changes in current (and proposed) fuel specification required	− Two gasoline grades required − Requires development of E85 refuelling infrastructure throughout Europe − Requires OEMs to development more E85 compatible flex-fuel vehicles, with rapid introduction of new models to achieve 40-50% market share of new gasoline vehicles by 2020 − Requires strong political will to ensure development of E85 refuelling infrastructure and rapid market uptake of E85 vehicles

Source: Ricardo

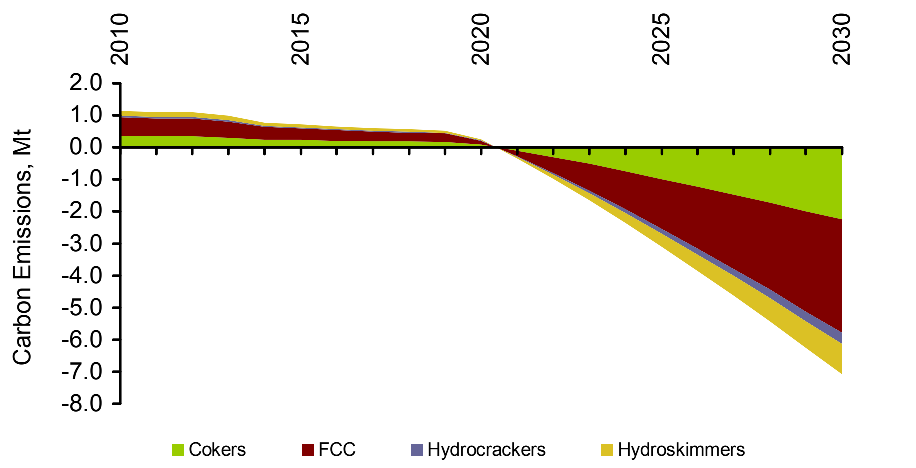
12.5 Scenario 3 Implications

In Scenario 3 there is an increasing role for both biodiesel and biogasoline in the transportation fuel pools. Their role however is restricted, particularly post 2020, by a rapid expansion in sales of electric vehicles. The low content of biogasoline in the gasoline pool, relative to our mid-cycle position, initially creates a small increase in European demand for refinery gasoline leading to a slight increase in and European gasoline prices. European refineries margins increase slightly and refineries respond by increasing production. Post 2020 the combination of increasing electric vehicle sales and continued rise in both biogasoline and biodiesel consumption starts to reduce demand for refined oil products. Gasoline price falls result and refinery margins drop with marginal refineries reducing their production.

12.5.1 Scenario 3 Carbon Emission Implications

A low content of biogasoline in the gasoline pool out to 2020 creates a small increase in refinery gasoline demand out to 2020. Refineries increase their production which results in slightly higher carbon emissions (see Figure 138) Post 2020 increasing content of biogasoline in the gasoline pool and a rapid rise in electric vehicle sales gradually reduces demand for refinery gasoline and as prices and margins are squeezed refinery production falls reducing refinery carbon emissions.

Figure 138: Scenario 3 Carbon Emissions Change



Source: Wood Mackenzie

NB - These are nominal emissions based on our previously explained benchmark configuration emissions and do not take account of any potential changes in refinery emissions per barrel processed.

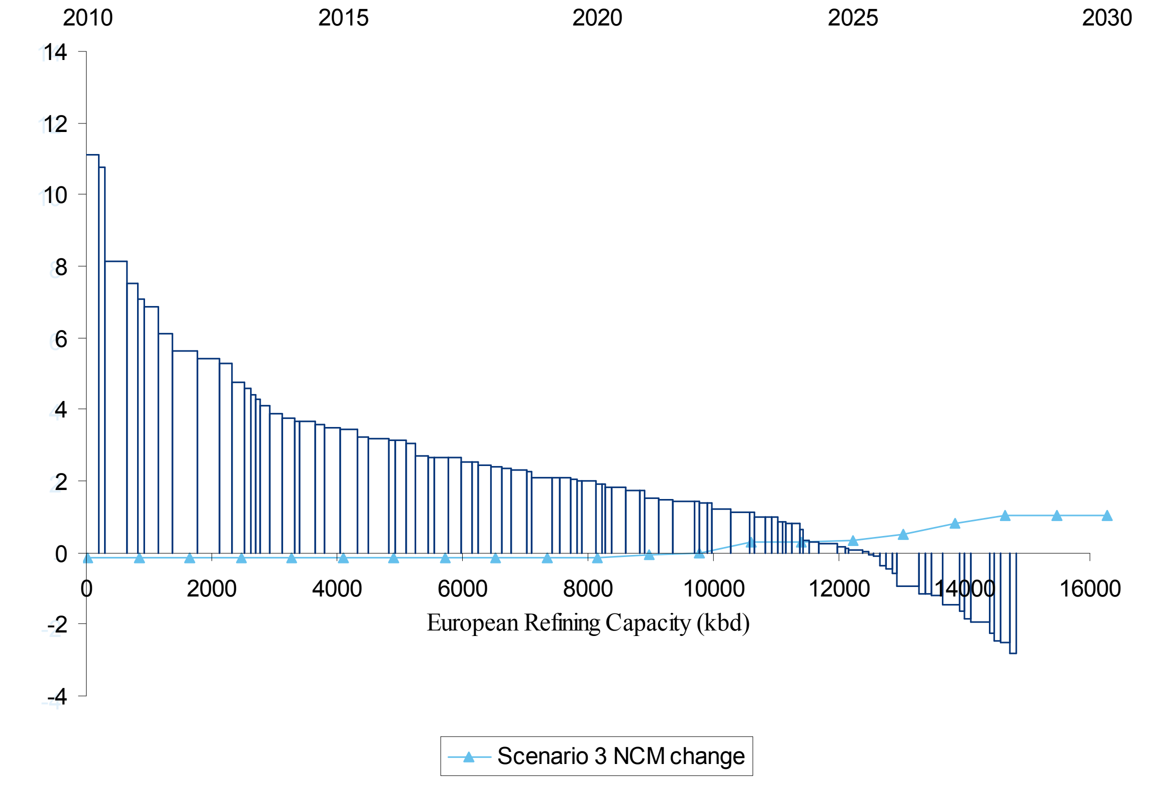
By 2030 carbon emissions under this scenario are almost 7.5 Mt less than under the mid cycle refining year. The FCC refinery type accounts for half of the changes in carbon emission whilst cokers account for approximately one third of the emission differences.

12.5.2 Scenario 3 Refinery Economics Implications

The small increase in demand for refinery gasoline supports a slight increase in European gasoline prices and a similarly slight improvement in European refining margins out to 2021(see Figure 139). Post 2021 the combined impact of increasing electric vehicle sales and rising biogasoline in the gasoline pool starts to erode at refinery gasoline demand. Prices for refinery gasoline fall and refinery margins gradually drop. Europe continues to remain short middle distillates with middle distillate pricing movement expected to remain almost unchanged.

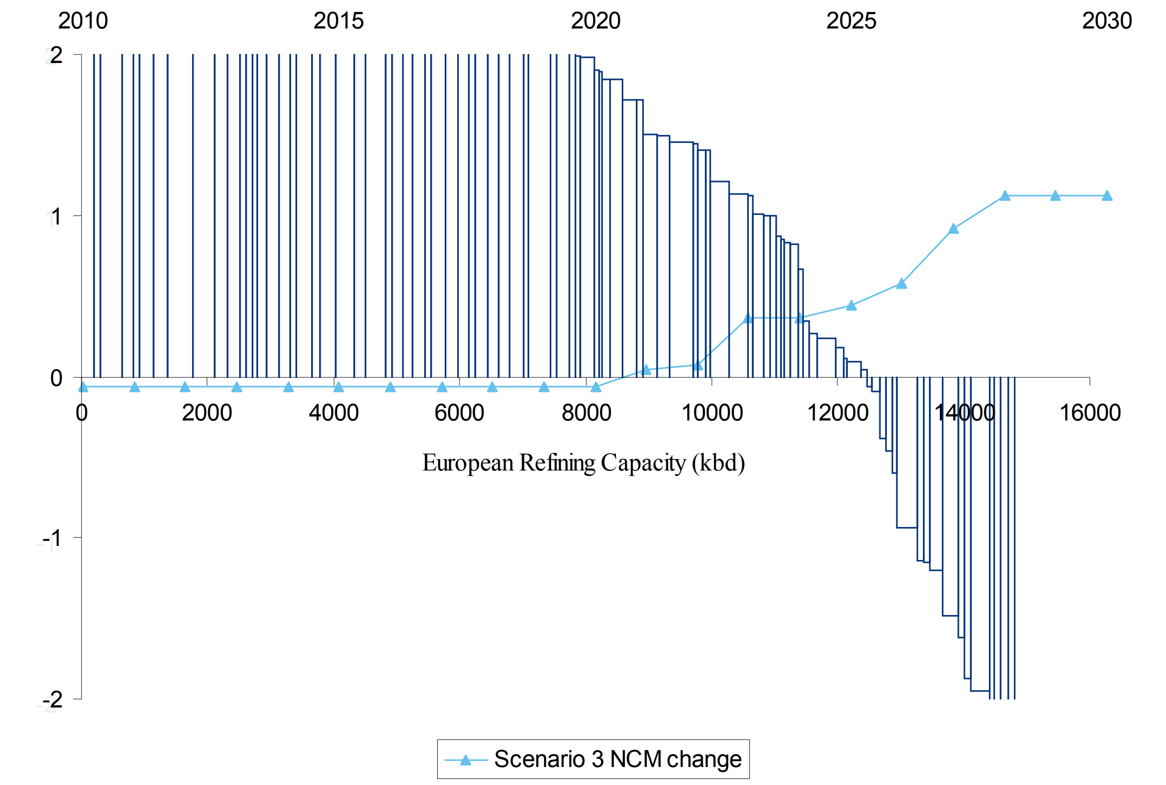
Margin declines for European refineries start to occur post 2020 but are initially small as a close up view of the NCM results shows in Figure 140. In 2023 there is the first major negative movement in refining margins with margins falling by 0.38 $/bbl. Then there is a continual fall in refining margins and by 2028 refining margins have fallen by 1.14 $/bbl.

Figure 139: Scenario 3 – Refinery NCM Changes vs Mid Cycle Position



Source: Wood Mackenzie

Figure 140: Scenario 3 – Refinery NCM Changes vs Mid Cycle Position (Close Up)



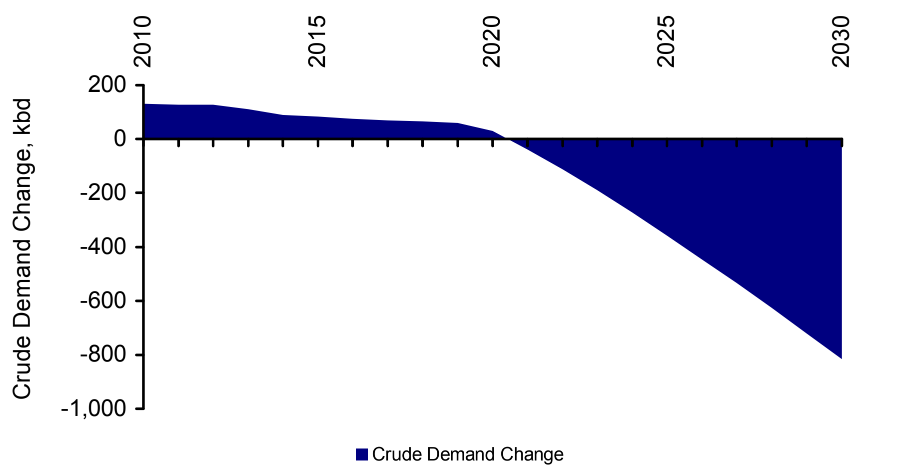
Source: Wood Mackenzie

The reduced refining margins results in an increased threat of further refinery closures. As margins start to decline by 2023 seven European refineries develop negative net cash margins due to the increased content of biofuels in the gasoline and diesel pools. By 2027 twelve European refineries have negative NCMs which rises to sixteen by 2030.

12.5.3 Scenario 3 Crude Demand Implications

In scenario 3 a low content of biogasoline in the gasoline pool out to 2020 creates a small increase in refinery gasoline demand out to 2020. Refineries increase their production which results in a slightly higher crude demand (see Figure 141). Post 2020 increasing content of biogasoline in the gasoline pool and a rapid rise in electric vehicle sales gradually reduces demand for refinery gasoline and as prices and margins are squeezed refinery production falls reducing refinery carbon emissions. In 2020 crude demand remains relatively unchanged but demand starts to fall rapidly and is down almost 900 kb/d by 2030.

Figure 141: Scenario 3 – Reduced Crude Oil Demand



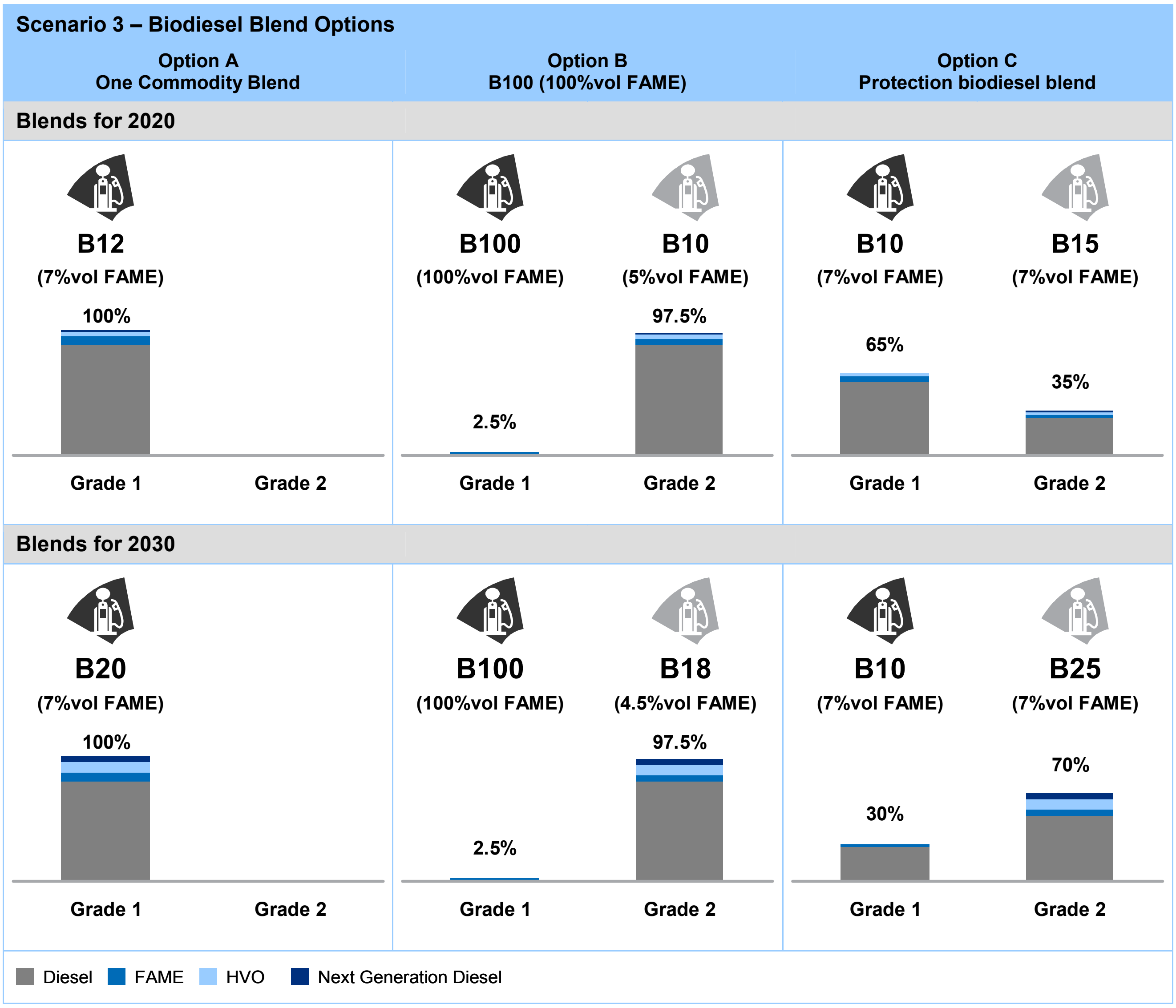
Source: Wood Mackenzie

12.5.4 Scenario 3 Biofuel Blend Implications

Figure 142 contains a summary of the three biodiesel blend options in 2020 and 2030 for Scenario 3. All three options are feasible for this scenario. However, since FAME accounts fro 7%vol in 2020, fuel specifications for Option A (B12) and Option C (B15) may need to allow the FAME content to be greater than 7%vol to allow for regional and seasonal differences. Depending on the FAME upper limit, these fuels with higher FAME content may not be suitable for older vehicles in the vehicle parc in 2020.

Option B is the least preferred option since it requires the rapid ramp up in B100 vehicles and the development of a small, but wide spread, B100 infrastructure throughout Europe.

Figure 142: Scenario 3 – Overview of the Biodiesel Blend Options

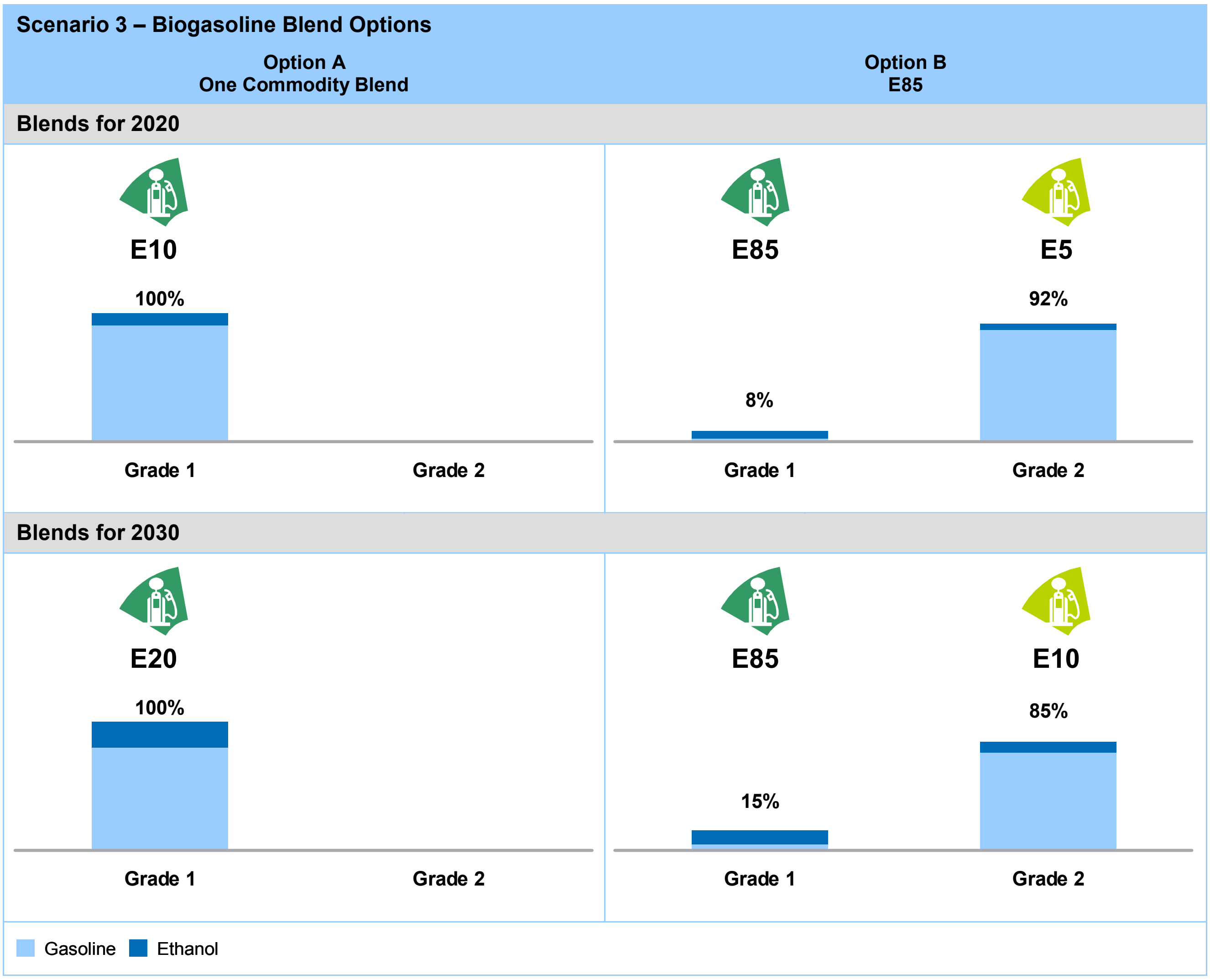


Source: Ricardo

Figure 143 contains a summary of the two biogasoline blend options in 2020 and 2030 for Scenario 3. As for Scenario 1, Option A is preferred, since one commodity blend of E10 in 2020 and E20 in 2030 requires the least investment in infrastructure and flex fuel vehicles.

Further information on the grade combinations for each option is provided in the pages following the summary tables.

Figure 143: Scenario 3 – Overview of the Biogasoline Blend Options



Source: Ricardo

Scenario 3

Biodiesel Blend Option A

One Commodity Blend

Blends for 2020

Grade 1:

B12

Diesel	88.0	%vol
FAME	7.0	%vol
HVO	4.0	%vol
Next Generation Biodiesel	1.0	%vol

Split by grade:

Grade 1	**100**	**%vol**

Blends for 2030

Grade 1

B20

Diesel	80.0	%vol
FAME	7.0	%vol
HVO	8.5	%vol
Next Generation Biodiesel	4.5	%vol

Split by grade:

Grade 1	**100**	**%vol**

Consequences

Although the biodiesel increases from 12%vol in 2020 to 20%vol in 2030, the FAME content remains constant at 7%vol annual average. This is at the limit of the assumed tolerance to FAME of Euro 4 and Euro 5 diesel engines, which suggests that all diesel vehicles in 2020 and 2030 will be able to run on these two biodiesel blends.

However, to ensure that the annual average of 7%vol FAME is achieved, the fuel specifications may need to allow for higher FAME content, possibly up to 10%vol FAME. If this occurs, then there may be some issues with running older vehicles on this biofuel blend.

Since HVO and next generation biodiesel (e.g. BTL) have similar chemical and physical properties to conventional diesel, it is assumed that future vehicles will be able to tolerate 5-15%vol content of these biofuels.

New fuel specifications will be required for 2020 and 2030 to allow for higher contents for HVO and next generation biodiesel.

Advantages	Disadvantages
+ Only one diesel grade required + FAME content remains constant between 2020 and 2030	− Modifications to fuel specifications required to allow for higher levels of HVO and next generation biodiesel − If 10%vol FAME is required in the fuel specification to ensure the annual average is 7%vol FAME, then this may cause issues for older vehicles

Source: Ricardo

Scenario 3

Biodiesel Blend Option B

B100 (100%vol FAME)

Blends for 2020

Grade 1: **B100**

Diesel	0	%vol
FAME	100	%vol
HVO	0	%vol
Next Generation Biodiesel	0	%vol

Grade 2 **B10**

Diesel	90.0	%vol
FAME	5.0	%vol
HVO	4.0	%vol
Next Generation Biodiesel	1.0	%vol

Split by grade:

Grade 1	**2.5**	**%vol**
Grade 2	**97.5**	**%vol**

Blends for 2030

Grade 1 **B100**

Diesel	0	%vol
FAME	100	%vol
HVO	0	%vol
Next Generation Biodiesel	0	%vol

Grade 2 **B18**

Diesel	82.0	%vol
FAME	4.5	%vol
HVO	9.0	%vol
Next Generation Biodiesel	4.5	%vol

Split by grade:

Grade 1	**2.5**	**%vol**
Grade 2	**97.5**	**%vol**

Consequences

If nearly half of the available FAME stock is used to create a B100 blend, then the FAME content of the commodity blend is reduced to < 5%vol (annual average). This is equivalent to the previous fuel specification EN 590:2004 which allowed up to 5%vol FAME. So the commodity blend (Grade 2) would be suitable for older diesel vehicles in the vehicle parc.

A relatively small portion of the diesel stock would be required to be B100 FAME (2.5% in 2020 and 2.5% in 2030). This would require ~2.5% of the diesel vehicle parc to be B100 compatible by 2020. This means OEMs would need to launch new B100 compatible vehicles, with market share reaching ~7% of new diesel vehicle sales by 2020. B100 vehicles would need to retain market share of 2-3% beyond 2020 to maintain vehicle parc share.

The introduction of B100 on this scale would also require Europe-wide development of a refuelling infrastructure for B100 fuel.

Heavy goods vehicles, buses or other fleet vehicles would be a good target sector for B100 vehicles. Since HGVs and buses consume proportionally more fuel than passenger cars, the required number of B100 vehicles would be reduced. Infrastructure development could be restricted to major trunk routes, or fleet depots.

It is likely that suitable government incentives would be required to ensure the development of the B100 infrastructure and the market uptake of B100 vehicles.

Advantages

- The commodity grade (B10 in 2020 and B18 in 2030) contains < 5%vol FAME, which means there will be no compatibility issues for older vehicles in 2020 or 2030
- Fuel specification for B100 already exists
- Existing fuel specification EN 590:2009 allows for up to 7%vol FAME, implying no change in fuel specification required
- Higher biodiesel contents achieved in commodity grade diesel by using HVO and next generation biodiesel

Disadvantages

- Requires infrastructure development for B100
- Requires the portion of B100 compatible vehicles in the vehicle parc to increase rapidly up to 2020
- Requires OEMs to develop more B100 compatible vehicles (although this could be limited to heavy duty applications)
- Requires strong political will to ensure B100 infrastructure development and market uptake of B100 vehicles

Source: Ricardo

Scenario 3

Biodiesel Blend Option C

Protection biodiesel blend

Blends for 2020

Grade 1: B10			Grade 2 B15		
Diesel	90.0	%vol	Diesel	85.0	%vol
FAME	7.0	%vol	FAME	6.0	%vol
HVO	3.0	%vol	HVO	7.0	%vol
Next Generation Biodiesel	0.0	%vol	Next Generation Biodiesel	2.0	%vol

Split by grade:

Grade 1	**65**	**%vol**	**Grade 2**	**35**	**%vol**

Blends for 2030

Grade 1 B10			Grade 2 B25		
Diesel	90.0	%vol	Diesel	75.0	%vol
FAME	7.0	%vol	FAME	7.0	%vol
HVO	3.0	%vol	HVO	12.0	%vol
Next Generation Biodiesel	0.0	%vol	Next Generation Biodiesel	6.0	%vol

Split by grade:

Grade 1	**30**	**%vol**	**Grade 2**	**70**	**%vol**

Consequences

In 2020, approximately two thirds of the vehicle parc will be Euro 4 and Euro 5 vehicles. The projection grade with ≤ 7%vol FAME ensures these vehicles will remain operational beyond 2020.

Although the second grade has higher biofuel content (15%vol in 2020 and 25%vol in 2030), FAME remains ≤ 7%vol, which implies the second grade would also be suitable for older vehicles. However the fuel specification for these fuels may set the FAME limit to 10%vol FAME to ensure the annual average is 7%vol.

Advantages	Disadvantages
⊕ Older vehicles are protected ⊕ The FAME content remains within the current proposed fuel specification (7%vol)	⊖ Two diesel grades with different bio contents, yet both are suitable for the diesel parc ⊖ A new fuel specification allowing up to 10%vol FAME may be required to ensure the annual average is 7%vol

Source: Ricardo

Scenario 3

Biogasoline Blend Option A

One Commodity Blend

Blends for 2020

Grade 1:

Gasoline	90	%vol
Ethanol	10	%vol

E10

Split by grade:

Grade 1	**100**	**%vol**

Blends for 2030

Grade 1

Gasoline	80	%vol
Ethanol	20	%vol

E20

Split by grade:

Grade 1	**100**	**%vol**

Consequences

Up to 10%vol ethanol in 2020 is inline with the assumptions regarding ethanol tolerance for Euro 4, Euro 5 and Euro 6 gasoline vehicles.

However, if gasoline vehicles will be operating on E20 by 2030, then Euro 6 gasoline vehicles will need to be designed for 20%vol ethanol content. This could potentially double the development effort for OEMs, since the current reference fuel is only 5%vol ethanol. OEMs would need to repeat work for the E20 fuel.

Advantages

- Only one gasoline grade required
- E10 in 2020 is inline with the current proposals for future fuel specification

Disadvantages

- Euro 6 gasoline vehicles will need to be E20 compatible
- New European fuel specification for E20 required

Source: Ricardo

Scenario 3

Biogasoline Blend Option B

E85

Blends for 2020

Grade 1:			**Grade 2**		
Gasoline	25	%vol	Gasoline	95	%vol
Ethanol	75	%vol	Ethanol	5	%vol
E85			**E5**		

Split by grade:

Grade 1	**8**	**%vol**	**Grade 2**	**92**	**%vol**

Blends for 2030

Grade 1			**Grade 2**		
Gasoline	25	%vol	Gasoline	90	%vol
Ethanol	75	%vol	Ethanol	10	%vol
E85			**E10**		

Split by grade:

Grade 1	**15**	**%vol**	**Grade 2**	**85**	**%vol**

Consequences

Since Scenario 3 Gasoline Option A is E10, for Option B the split between E85 and the commodity grade in 2020 has been selected so that the commodity blend is E5, since this is the current fuel specification. As for Scenario 1 and Scenario 2, this results in approximately one third of the ethanol being used to produce E85.

In this scenario, >8% of the gasoline vehicle parc will need to be E85 compatible by 2020. This will require OEMs to develop more E85 compatible flex-fuel vehicles. Market penetration of these FFVs will need to ramp up to 20-25% of new gasoline vehicle sales by 2020 (assuming market introduction around 2015).

Beyond 2020, FFVs would need to retain market share of 15-20% of new gasoline vehicles to ensure >15% of the gasoline vehicle parc was E85 compatible by 2030.

This option also requires the Europe-wide development of a refuelling infrastructure for E85.

Changes to fuel specification would not be required, beyond the proposed change to increase the ethanol content to 10%vol.

Advantages

- A protection grade for older vehicles is available in 2020 and 2030
- No changes in current (and proposed) fuel specification required

Disadvantages

- Two gasoline grades required
- Requires development of E85 refuelling infrastructure throughout Europe
- Requires OEMs to development more E85 compatible flex-fuel vehicles
- Requires strong political will to ensure development of E85 refuelling infrastructure and suitable market uptake of E85 vehicles

Source: Ricardo

12.6 Scenario Impacts on Fuel Oil Specification

Following the assessment of biofuel blend options for each Scenario (see sections 12.1 – 12.5), the purpose of this section is to discuss the impact of the selected Scenarios and biofuel blends on future specifications for final oil products (octane, cetane etc.).

This study has concluded that, for most of the Scenarios considered, one commodity blend for diesel and one commodity blend for gasoline should be sufficient to meet the Renewable Energy and Fuel Quality Directive targets in 2020, as long as the content of FAME in diesel is kept below 7%vol and the content of ethanol in gasoline is kept below 10%vol. However, since some of the blend options considered are at the limit of these thresholds, it may be necessary for the fuel specifications to allow for higher biofuel content (e.g. up to 10%vol FAME). Studies will need to be commissioned to ensure that 7-10%vol FAME blends will be suitable for Euro 4, Euro 5 and Euro 6 diesel vehicles in 2020, and to identify what modifications, if any, are required to ensure the biofuel blends are suitable for the older vehicles within the fleet.

Figure 144 to Figure 147 contain tables which compare the changes to future fuel specifications required for each scenario in 2020 and 2030, based on the selected preferred blend options for diesel and gasoline. These future fuel specifications are compared to the current fuel specifications EN 590:2009 and EN 228:2008.

For diesel, the assumed baseline fuel is RF06-03. The future fuel specifications have been developed by linearly blending the properties of the diesel and biodiesel products in the ratios stated in sections 12.1 – 12.4. As discussed in these sections, in reality it may be necessary for the fuel specification to allow higher volumes of FAME, HVO and next generation biodiesel to account for regional and seasonal variations in the fuel mix.

Figure 144: Changes To Diesel Specification In 2020 As A Consequence Of The Selected Scenario Blend Options

2020 Fuel Specifications	Scenario 1	Scenario 2	Scenario 3	EN 590:2009
Grade	**Option A B13 (7%vol FAME)**	**Option A B10 (7%vol FAME)**	**Option A B12 (7%vol FAME)**	**B7**
Density @ 15°C [kg/m^3]	835.1	836.8	835.6	845 (max)
Viscosity @ 40°C	2.9	2.9	2.9	2.0-4.5
Cetane Number [-]	54.6	53.8	54.3	51.0
Distillation 10%	218.7	216.9	218.1	
Distillation 50%	281.3	281.1	281.3	245.0
Distillation 90%	334.9	336.0	335.5	
Cloud point [°C]	-10.0	-9.7	-9.9	-10 to -34
Lower Heating Value [MJ/kg]	43.0	42.9	42.9	
Polycyclics	3.5	3.6	3.5	
Oxygen [%wt]	0.6	0.6	0.6	
Sulphur [ppm]	3.7	3.8	3.8	10
FAME content (max) [%vol]	7	7	7	7

Source: Ricardo, IFCQ

In 2020 (Figure 144) the specification properties of the scenario diesel fuels are very close to those of the baseline fuel, suggesting no major differences since the FAME content remains at 7%vol. The cetane number is higher, due to the addition of HVO and next generation biodiesel products. However, in reality, the increase in cetane number from 51-53 to 54-55 may not be realised, except for premium products, if the oil industry decide to use a lower specification of baseline diesel for the commodity fuel.

The T10 (front-end volatility) is higher, but it is anticipated that this would be addressed in the refining of the baseline diesel, since it is mainly a consequence of adding FAME, although it could also be addressed by including some lighter fatty acid feedstocks. Any issues regarding oxidation stability are likely to be resolved by use of additives.

Figure 145: Changes To Diesel Specification In 2030 As A Consequence Of The Selected Scenario Blend Options

2030 Fuel Specifications	Scenario 1	Scenario 2	Scenario 3	EN 590:2009
Grade	Option A B23 (7%vol FAME)	Option A B17 (7%vol FAME)	Option A B20 (7%vol FAME)	B7
Density @ 15°C [kg/m^3]	829.6	832.9	831.2	845 (max)
Viscosity @ 40°C	2.9	2.9	2.9	2.0-4.5
Cetane Number [-]	57.2	55.6	56.4	51.0
Distillation 10%	224.7	221.1	222.7	
Distillation 50%	281.9	281.6	282.1	245.0
Distillation 90%	331.5	333.6	333.4	
Cloud point [°C]	-11.0	-10.4	-10.7	-10 to -34
Lower Heating Value [MJ/kg]	43.0	43.0	43.0	
Polycyclics	3.1	3.3	3.2	
Oxygen [%wt]	0.6	0.6	0.6	
Sulphur [ppm]	3.3	3.6	3.5	10
FAME content (max) [%vol]	7	7	7	7

Source: Ricardo, IFCQ

In 2030 (Figure 145) there do not appear to be any drastic changes to the blend properties from 2020. Again the cetane is high and the sulphur low. T10 has increased further and the lower heating value has decreased by less than 1%.

Figure 146: Changes To Gasoline Specification In 2020 As A Consequence Of The Selected Scenario Blend Options

2020 Fuel Specifications	Scenario 1	Scenario 2		Scenario 3	EN 228:2008
Grade	Option A E10	Option B E85	Option B E10	Option A E10	E5
RON [-]	98	109	98	98	95
MON [-]	86	89	86	86	85
RVP [kPa]	70	33	70	70	45-70 according to class
Ethanol (max) [%vol]	10	85	10	10	5

Source: Ricardo, BP, IFCQ

In 2020, the main differences in specification properties of the scenario gasoline fuels (Figure 146) compared to the current specification is the increased octane rating and changes to vapour pressure caused by the additional ethanol content. As the ethanol blends increase to 20%vol in 2030 (Figure 147), the octane ratings continue to increase, while the vapour pressure reduces slightly. However, it should be noted that, as for biodiesel, the benefits of higher octane through the additional of ethanol may not be realised if the oil industry decide to use a lower specification of baseline gasoline for the commodity fuel.

Figure 147: Scenario 3 – Changes To Gasoline Specification In 2030 As A Consequence Of The Selected Scenario Blend Options

2030 Fuel Specifications	Scenario 1	Scenario 2		Scenario 3	EN 228:2008
Grade	**Option A**	**Option B**		**Option A**	**E5**
	E20	**E85**	**E10**	**E20**	
RON [-]	100	109	98	100	95
MON [-]	87	89	86	87	85
RVP [kPa]	65	33	70	65	45-70 according to class
Ethanol (max) [%vol]	20	85	10	20	5

Source: Ricardo, BP, IFCQ

In addition to specifying the maximum limits for content of biofuel products in diesel and gasoline, future fuel specifications may include requirements for fuel additives to help mitigate some of the negative impacts of the biofuels, such as the additional deposits resulting from the use of FAME.

Alongside changing the fuel specifications to allow for higher levels of biofuel content, it is important to ensure that the specifications of the reference fuels used for homologation are also updated to be in line with the fuels that will be available to European consumers.

As discussed in the second paragraph, this study has concluded that one commodity blend for diesel and one commodity blend for gasoline should be sufficient for most of the scenarios considered. Single commodity blends have been preferred by the consortium since this option does not require dedicated vehicles for higher biofuel contents, such aa B100 or E85. Although the introduction of dedicated and flex fuel vehicles is one method for increasing the use of biofuels in road transport, this approach requires strong political will backed with appropriate incentives and legislation, to ensure a suitable uptake of these technologies within the market place and the development of the refuelling infrastructure needed to fuel these vehicles.

13 Conclusions

This report has isolated and compared how three different biofuel scenarios impact four key criteria of the downstream sector:

- Carbon Emissions
- Refining Economics
- Crude Demand
- Biofuel Blend Options

A comparison of the results of the three scenarios is shown in Figure 148 through to Figure 151.

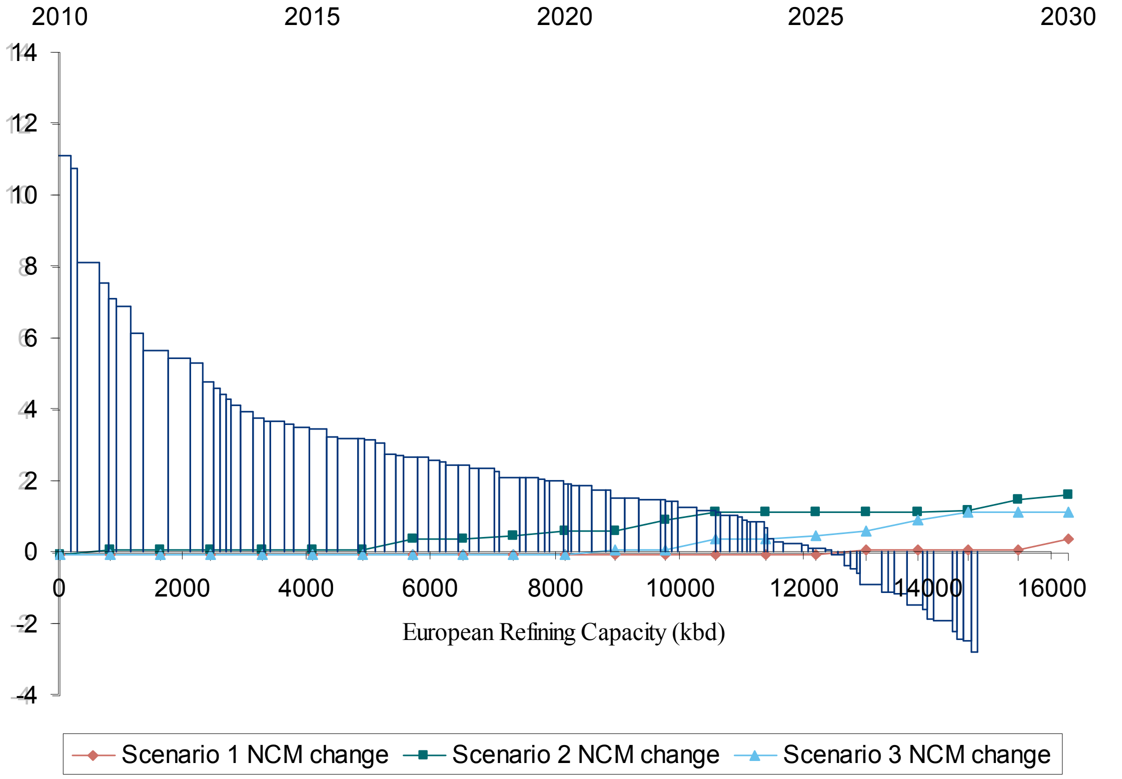
Scenario 1 which has the highest increase in the volumes of biodiesel in the diesel pool has been shown to have a limited effect on each of the downstream criteria identified above due to the large European diesel deficits. Only once the biodiesel volumes close these deficits sufficiently to narrow the European diesel import parity pricing environment will refining carbon emissions, refining economics and European crude demand be affected. Since the volume of FAME is less than 7% in 2020, it is likely that one commodity grade for diesel would be acceptable, with minimal changes required to the current diesel fuel specification. The volume of ethanol is less than 10% in 2020, suggesting no change to gasoline fuel specification beyond the FQD requirements for 2020.

Scenario 2 which has the highest increase of biogasoline into the gasoline pool has the greatest effect on the downstream criteria due to the large European gasoline surplus. For every barrel of biogasoline which enters the gasoline pool European gasoline prices will move downwards and so reduce the net cash margin for European refiners. They can be expected to respond to these price signals by reducing their supply. As refineries reduce their production their carbon emissions will fall in line with the reduction in crude demand. Ethanol represents nearly 20% by volume in 2020, which would not be acceptable for older vehicles. Therefore a combination of E85 and E10 blends would be required throughout Europe to fulfil this scenario. As for Scenario 1, the volume of FAME remains less than 7%vol, suggesting only minor changes to the current diesel fuel specification to allow for blending HVO and next generation biodiesel with diesel.

Scenario 3 where an increase in biofuels is complemented by a large rise in electric vehicle registrations sits between the two other scenarios. A large rise in electric vehicle registrations takes time to filter through and start reducing gasoline demand due to the large existing gasoline vehicle parc. However a rise in electric vehicle registrations combined with the increasing biogasoline content in the gasoline pool results in gasoline prices moving downwards with similar impacts on the downstream criteria as seen in Scenario 2. As for Scenario 1 and Scenario 2, the volume of FAME is less than 7%, suggesting minor changes only to future diesel fuel specifications. Scenario 3 projects the volume of ethanol to gasoline to increase to 10% in 2020 and to 20% in 2030. This suggests little change to gasoline fuel specifications for 2020, although fuel specifications beyond 2020 would need to allow for higher ethanol contents.

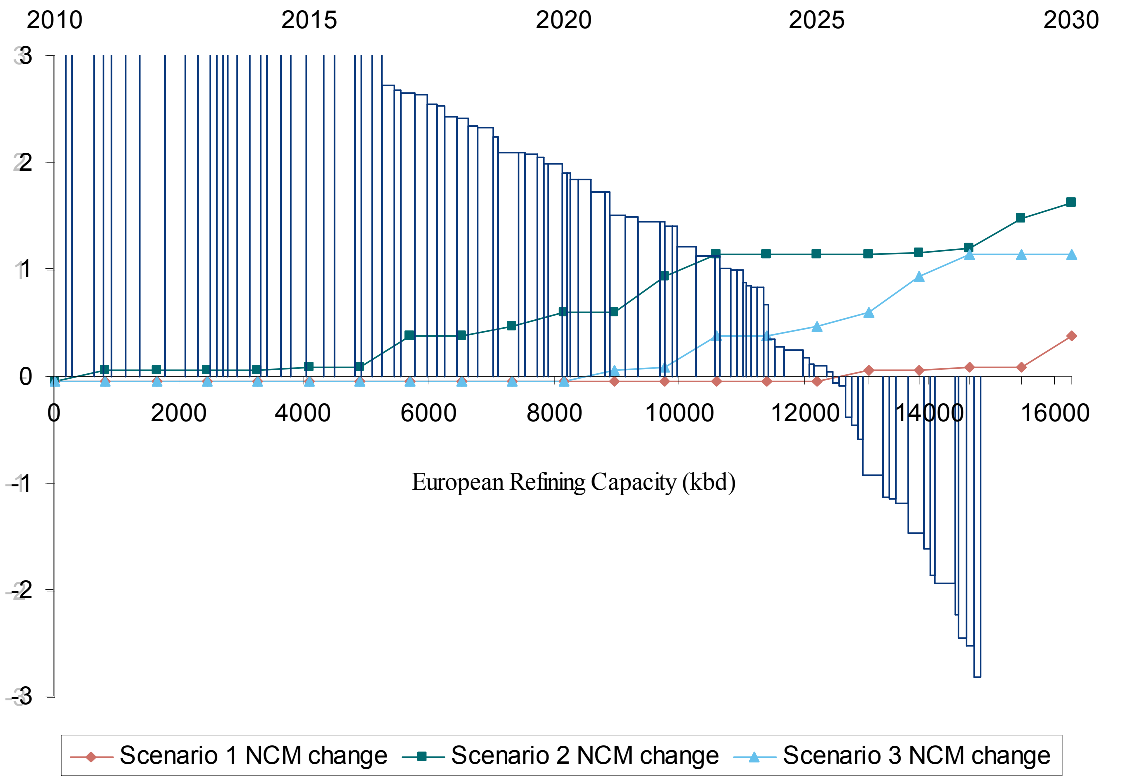
In conclusion for every barrel of biogasoline entering the gasoline pool European gasoline prices are expected to move downwards and so reduce the net cash margin for European refiners. European refiners can be expected to respond to these price signals by reducing their supply. As refineries reduce their production their carbon emissions will fall in line with the reduction in crude demand. However for biodiesel, only once the biodiesel volumes close the large European diesel deficit sufficiently to narrow the European diesel import parity pricing environment will refining economics, carbon emissions and crude demand alter. Whilst electric vehicles are expected to reduce gasoline demand the time it takes for them to do so initially reduces the impact on European refineries

Figure 148: Scenario Comparison On NCM Changes



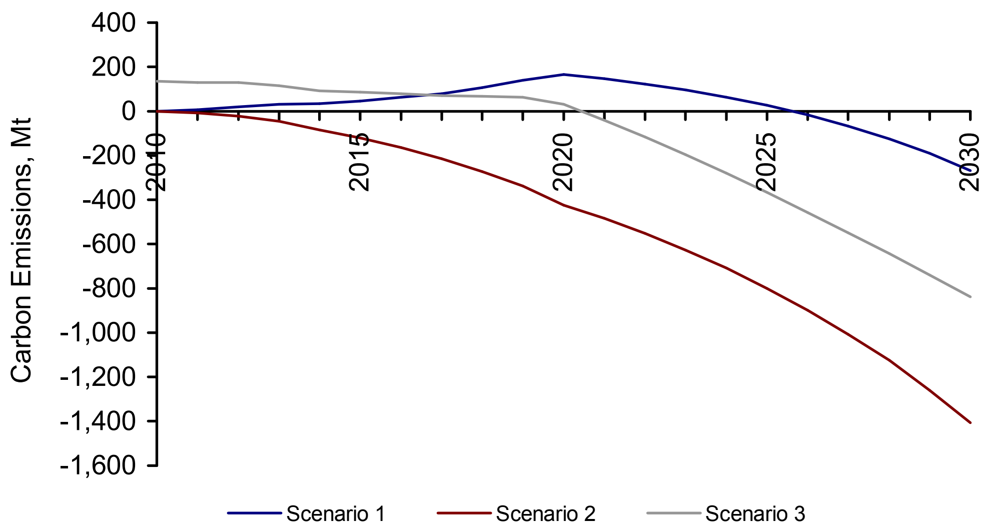
Source: Wood Mackenzie

Figure 149: Scenario Comparison On NCM Changes



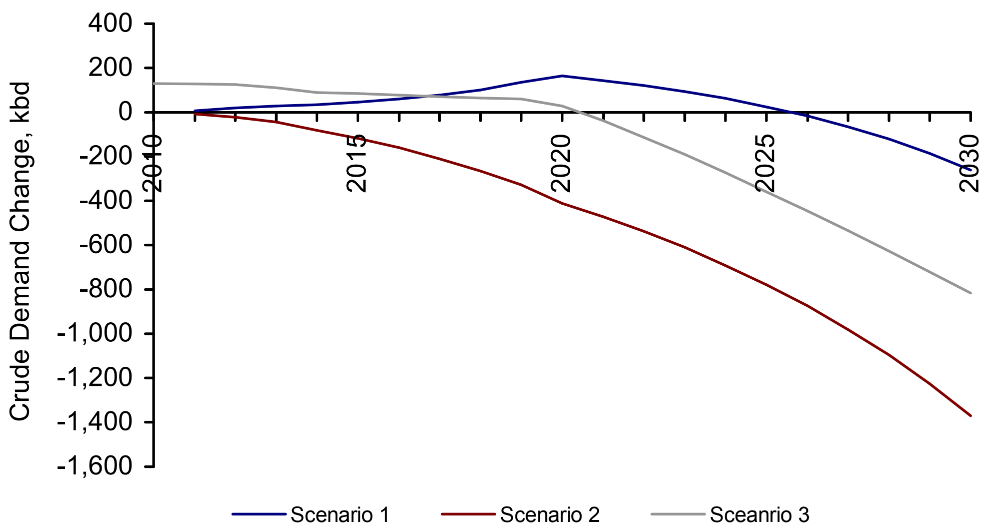
Source: Wood Mackenzie

Figure 150: Scenario Comparison On Carbon Emission Changes



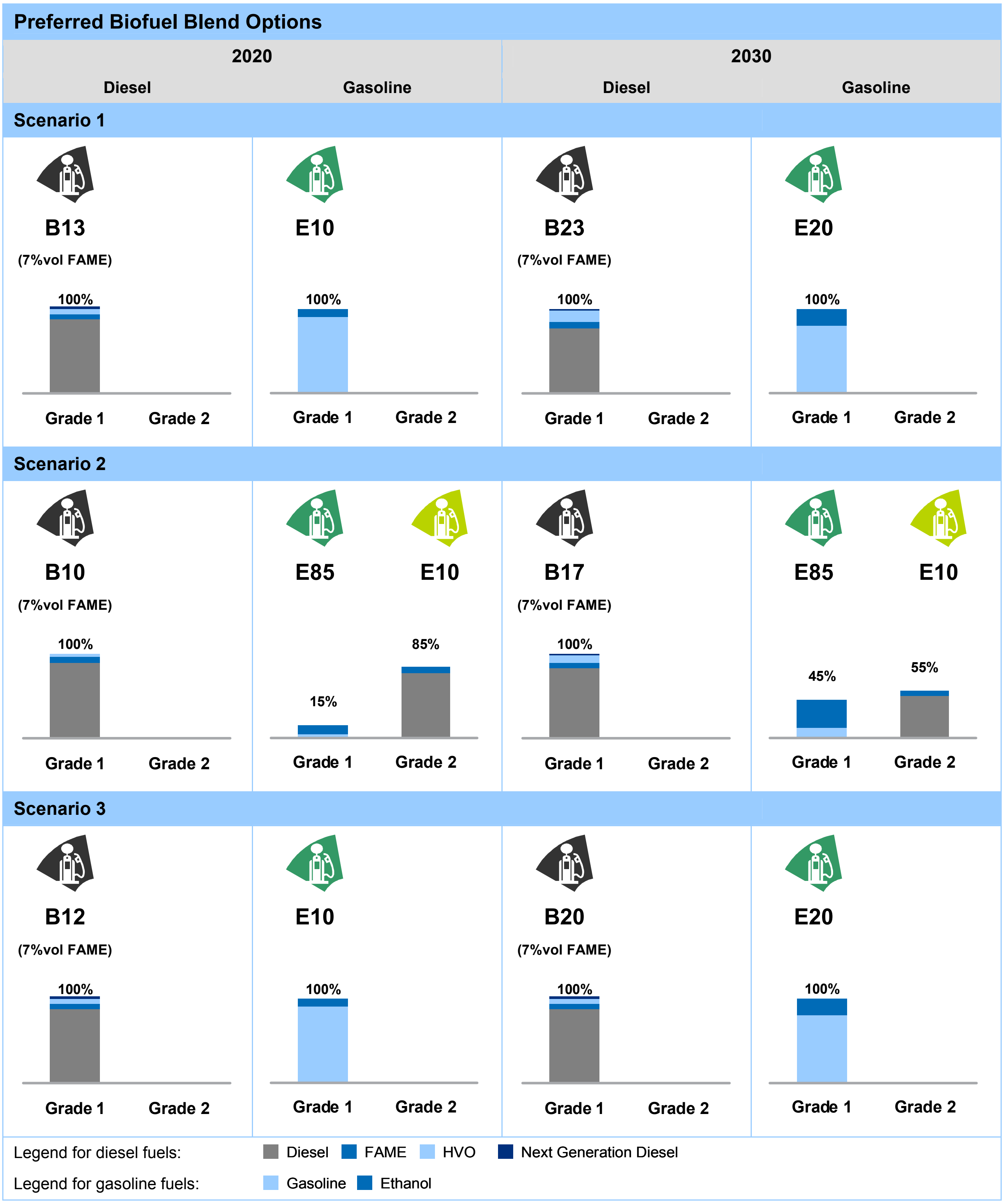
Source: Wood Mackenzie

Figure 151: Scenario Comparison On Crude Demand Changes



Source: Wood Mackenzie

Figure 152: Preferred Biofuel Blend Options for each Scenario



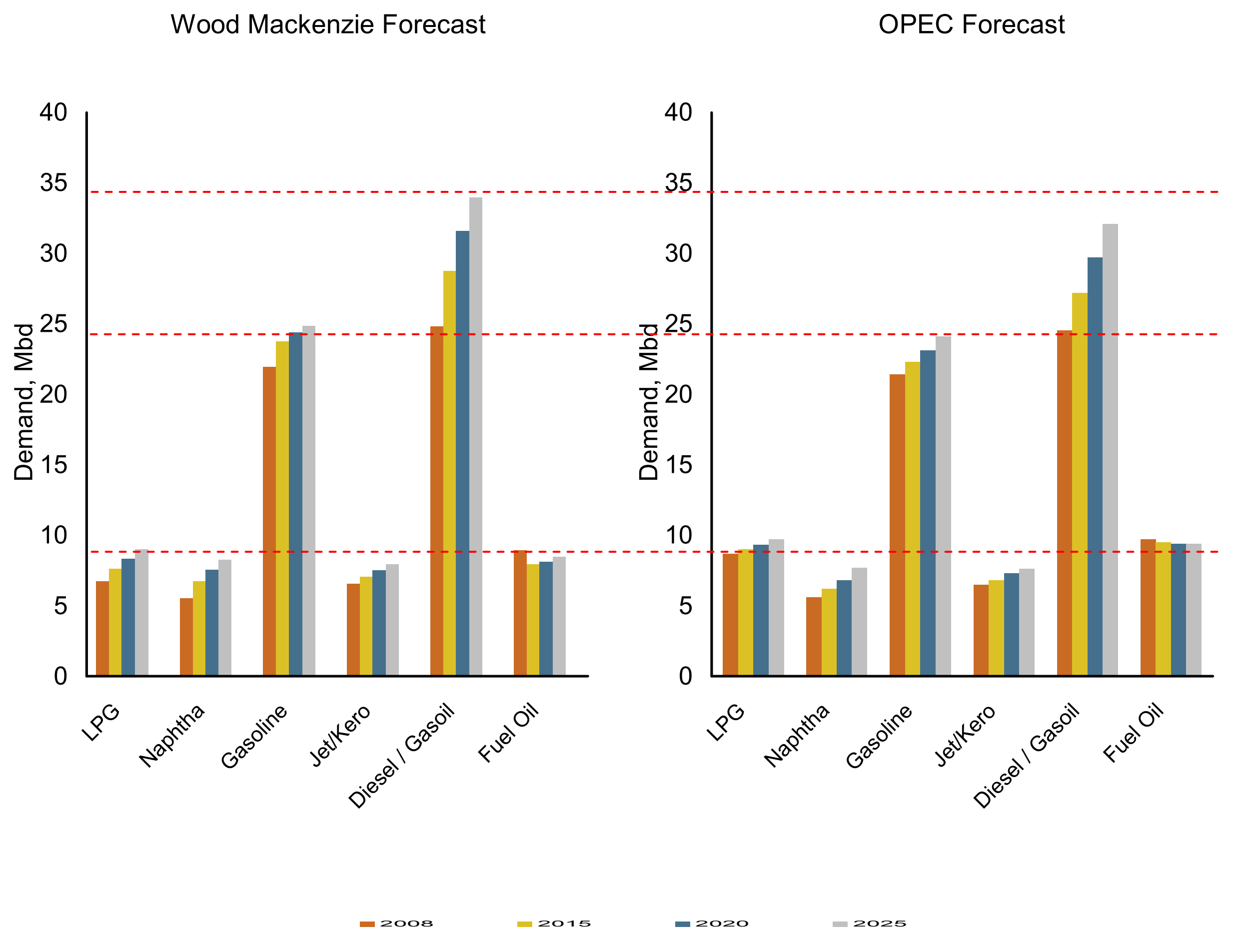
Source: Ricardo

Appendix A. Regional Review Of Supply and Demand for Oil Products

Appendix B. Demand Comparison

Figure 153 presents a comparison between the Wood Mackenzie demand forecasts and those of the OPEC World Oil Outlook 2009. Wood Mackenzie is slightly more bullish for oil product demand growth. Since the OPEC data was published the global economic circumstances have improved and Wood Mackenzie's latest demand forecasts include this.

Figure 153: Wood Mackenzie – OPEC World Demand Projection Comparison (Mb/d)

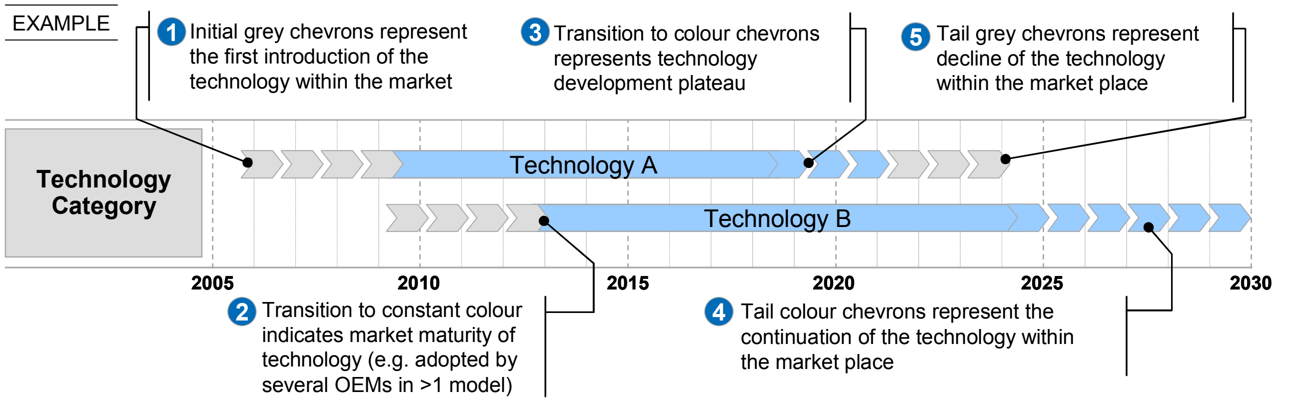


Source: Wood Mackenzie

Appendix C. Understanding the Technology Roadmaps

The Technology Roadmaps contained within this report aim to identify trends in automotive technology developing within the European market place up to 2030. Figure 154 contains descriptions to explain the use and meaning of the colours, shading and symbols that can be found in these Roadmaps.

Figure 154: Guide to understanding the Technology Roadmaps



Source: Ricardo

Appendix D. Fuel Specifications

European Diesel Fuel Specifications

EN 590:2009 Diesel Fuel Specification

	Europe – Diesel B5		Europe – Diesel B7	
Year of implementation	January 2005		October 2009	
Spec Name	EN 590:2004		EN 590:2006	
Grade	Diesel		Diesel	
	Temperate	Arctic & Severe Winter	Temperate	Arctic & Severe Winter
Additional Comment	Previous specification		Current specification	
Source	EN 590:2004		EN 590:2009	
Property				
Cetane number, min	51	47-49	51	47-49
Cetane index, min	46	43-46	46	43-46
Sulphur, ppm, max	10	10	50	50
Polyaromatics, wt%, max	11	11	11	11
Density @ 15°C, kg/m3, min	820	800	820	800
Density @ 15°C, kg/m3, max	845	840-845	845	840-845
Viscosity @40°C, cSt, min	2	1.2-1.5	2	1.2-1.5
Viscosity @40°C, cSt, max	4.5	4	4.5	4
Distillation				
T10, °C, min	Report		Report	
T10, °C, max	Report		Report	
T50, °C, min	Report		Report	
T50, °C, max	Report		Report	
T90, °C, min	Report		Report	
T90, °C, max	Report		Report	
T95, °C, max	360		360	
E180, vol%, max	10		10	
E250, vol%, max	65		65	
E340, vol%, max	95		95	
E350, vol%, max	85		85	
Flash Point, °C, min	55		55	
Carbon residue 10%, wt%, max	0.3		0.3	
Cold Filter Plugging Point (CFPP), °C, max	+5 to -44		+5 to -44	
Cloud Point (CP), °C, max	-10 to -34		-10 to -34	
Water, vol%, max	0.02		0.02	
Ash, wt%, max	0.01		0.01	
Total contamination, ppm, max	24		24	

	Europe – Diesel B5	Europe – Diesel B7
Lubricity, HFRR wear scar diam@60°C, micron, max	460	460
Copper corrosion, 3hr@50°C, merit (class), max	class 1	class 1
Oxydation stability, mg/100ml, max	2.5	2.5
Stability		
Oxydation stability (Induction period), minutes	1200	1200
Dye content, g/100L, max	allowed	allowed
Use of Additives	allowed	allowed
FAME content, vol%, max	5	7

Source: IFQC

EN 14214:2008 Biodiesel Fuel Specification

	Europe- Neat Biodiesel
Year of Implementation	May-09
Spec Name	EN 14214:2008
Grade	FAME
Additional Comment	
Source	EN 14214:2008
Property	
Cetane number, min	51
Ester Content, wt%, min	96.5
Sulfur, ppm, max	10
Density @ 15 °C, kg/m3, min	860
Density @ 15 °C, kg/m3, max	900
Viscosity @20°C, cSt, min	3.5
Viscosity @20°C, cSt, max	5
Flash Point, °C, min	101
Carbon residue 10% (CCR), wt%, max	
Water, %vol, max	0.05
Sulfated Ash, wt%, max	0.02
Total contamination, ppm, max	24
Copper corrosion, 3hr@50°C, merit (class), max	Class 1
Total acid number, mg KOH/g, max	0.5
Alcohol	
Methanol, vol%, max	0.2
Glycerides	
Monoglycerides, wt%, max	0.8
Diglycerides, wt%, max	0.2
Triglycerides, wt%, max	0.2
Glycerol	
Free Glycerol, wt%, max	0.02

Total, wt%, max	0.25
Linolenic acid methyl ester, wt%, max	12
Polyunsaturated methyl esters, wt%, max	1
Iodine number, g/100g, max	120
Phosphorous, ppm, max	4
Alkali, Group I (Na, K), ppm, max	5
Alkali, Group II (Ca, Mg), ppm, max	5
Oxidation stability @110°C, hour, min	6

Source: IFQC

European Gasoline Fuel Specifications

EN 228 Gasoline Fuel Specifications

	Europe – Gasoline E5	Europe – Gasoline E10
Year of implementation	January 2009	January-09
Spec Name	EN 228:2008	Directive of 2009 amending Directive 98/70/EC(1)
Grade	Unleaded Petrol	Petrol
Additional Comment		Directive of 2009 amending Directive 98/70/EC must be transposed by 27 EU Member States by December 2010
Source	EN 228:2008	Final compromise text of the Directive adopted in December 2008 by the Council of the EU and the European Parliament
Property		
RON, min	95	95
MON,min	85	85
Sulphur, ppm, max	10	10
Lead, g/L, max	0.005	0.005
Benzene, vol%, max	1	1
Aromatics, vol%, max	35	35
Olefins, vol%, max	18	18
RVP @ 37.8°C (100° F), kPa, min	45-70 according to class	
RVP @ 37.8°C (100° F), kPa, max		
VLI, calculated, max	1050-1250 according to class	
Density @ 15°C, kg/m3, min	720	
Density @ 15°C, kg/m3, max	775	
Distillation		
E70, vol%, min	48-50 according to class	
E70, vol%,max	20-22 according to class	

	Europe – Gasoline E5	Europe – Gasoline E10
E100, vol%, min	46	46
E100, vol%,max	71	
E150, vol%,max	75	75
FBP,°C,max	210	
Residue, vol%, max	2	
Oxygen, wt%, max	2.7	3.7
Oxygenates		
Methanol, vol%, max	3	3
Ethanol, vol%, max	5	10
Iso-propyl alcohol, vol%, max	10	12
Iso-butyl alcohol, vol%, max	10	15
Tert-butyl alcohol, vol%, max	7	15
Ethers (5 or more C atoms), vol%, max	15	22
Others, vol%, max	10	15
Phosphorous, g/L, max	0	
Oxidation stability (Induction period), minutes, min	360	
Existent gum (solvent washed), mg/100ml, max	5	
Copper corrosion, 3hr @ 50°C, merit (class)	class 1	
Appearance	Clear & Bright	
Dye content, g/100L, max	Allowed	
Use of additives	Allowed	To be assessed

Source: IFQC

EN 15376:2007 Neat Ethanol Specification

	Europe - Ethanol
Year of Implementation	January 2008
Spec Name	EN 15376:2007
Grade	Ethanol
Additional Comment	
Source	EN 15376:2007
Property	
Ethanol, vol%, min	98.7
Water, vol%, max	0.3
Chloride, inorganic, ppm, max	20
Copper, ppm, max	0.1
Methanol, vol%, max	1
Acetic Acid, g/l, 100%EtOH, max	0.007
C3-C5 alcohols, ppm, max	20,000
Non-volatile matter, g/100mL, max	0.01

Denaturant, vol%, min Denaturant, vol%, max	ETBE, MTBE, TBA, isoButOH, iso PropOH
Sulphur, ppm, max	10
Appearance	Clear and Bright
Acidity, wt%, max	0.007
Phosphorous, g/L, max	0.0005

Source: IFQC

CWA 15293 E85 Fuel Specification

	Europe - E85
Year of implementation	In progress
Spec Name	CWA 15293
Grade	E85
Additional Comment	
Source	CWA 15293
Property	
RON, min	95
MON,min	85
Methanol, vol%, max	1
Higher alcohols (C3-C8), vol%, max	2
Ethers (5 or more C atoms), vol%, max	5.2
Phosphorous, mg/L, max	not detectable
Oxidation stability (Induction period), minutes, min	360
Existent gum (solvent washed), mg/100ml, max	5
Copper corrosion, 3hr @ 50°C, merit (class)	class 1
pHe, min	6.5
pHe. max	9
Appearance	Clear & Bright
Acidity, (as CH3COOH), wt%, max	0.005
Water content, vol%, max	0.3

Source: IFQC

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Appendix G. Oil Product Conversion Factors

Conversion Factors	Tonnes to barrels
LPG	11.6
Naphtha	8.9
Gasoline	8.5
Kerosene	7.9
Diesel/Gasoil	7.5
Fuel Oil	6.5
Other products	7.1
Refinery Fuel & Loss	6.1
Ethanol	7.9
Biodiesel	7.1

Appendix H. Stakeholders Consultation

June through to September 2010 Wood Mackenzie and Ricardo contacted a variety of stakeholders to obtain feedback on the proposed scenarios and input to the review of how biofuels could impact their business. The precise consultation varied according to the nature of the stakeholders business but typical subjects covered included the following:

- Proposed assumptions used for the energy demand analysis
- Implications and opportunities of increased biofuel volumes
- Stakeholder awareness to biofuels and biofuels legislation
- Stakeholders view on how biofuel mandates could be met
- Technology Roadmaps
- Technical constraints of using Biofuels including current warranty limits
- The likely impact of different biofuel blend ratios on Euro 4, Euro 5 and Euro 6 engine technology
- Biofuel grade options that may be available in European fuelling stations in 2020 and 2030
- Cost implications for the future vehicle fleet of higher biofuel blends.

Stakeholder Consultation packs were prepared and distributed to stakeholders by email and telephone consultations were encouraged and conducted with key stakeholders wherever possible. Stakeholders were encouraged to openly comment on the topics discussed and to raise other issues relating to the subject area of biofuels in general. The feedback received from the stakeholders was consolidated and used to update the information presented in this report.

The following organisations were invited to take part in this consultation:

ACARE	International Association for Stability & Handling of Fuel (IASH)
ACEA	International Maritime Association
AECC	Interpipeline
Afton	Intertanko
AGQM	Iveco/FPT
ASTM Aviation Fuels Sub-committee	Japan - METI
ATC	Joint Inspection Group (oil company sellers of jet fuel)
BioFRAC	Maersk
BioJet Corporation	MAN Diesel
BMW	MAp Airports Group
Bosch	MOL
BP	Neste
British Airports Authority	Nissan
CARB	Nu Star
Caterpillar	OilTanking GmbH
CEPSA	OMV
Chevron	Peel Holdings
CLEPA	Perkins
CLH (Spanish Oil Pipeline and Terminals company)	Petroplus
Commercial Aviation Alternative Fuels Initiative	Preem
CONCAWE	PSA
Conoco Phillips	Renault
Cummins	Renault truck
Daimler	Repsol
Delphi	Rolls Royce
Denso	Rolls Royce
Energy Institute Aviation Committee	Scania
Eni	Shell
ERRAC	SMMT
ERTRAC	Statoil
EUCAR	Suzuki
European Community Shipowners Association	Swedish EPA (naturvaardverket)
European Oxygenated Fuel Association (EFOA)	Swiss EPA
Federation of European Tank Storage Associations (FETSA)	Total
Fiat	Toyota
Ford Europe	UK Department for Transport - DfT
Fraport AG	US Department of Energy - DoE
GE Marine	US EPA
General Motors Europe	Vesta Teminals (division of Mercuria)
German UBA	Vitol
Glencore	Vitol Tank Terminals International B.V
HBG Hydranten-Betriebs-Gesellschaft	Volvo car
Hellenic	Volvo truck
HMC	Vopak
Honda	VW Audi
IATA	Wartsila
ICAO (International Civil Aviation Organization)	Waterborne
Ineos	World Shipping Council
Infineum	