Market analysis biofuels

Implications for the armed forces in the Netherlands

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Acknowledgement/Preface

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Abstract

Commercial road fuels are increasingly blended with biofuels. These biofuel blends impose risks for the specific application in the military environment. Therefore the Ministry of Defence has commissioned ECN to provide a market analysis of biofuel (blends) projected to become available up till 2030, with a focus on diesel fuels for ground use.

We conclude that the percentage of conventional biodiesel (FAME) in the EU is likely to increase up to around 7% until 2020. It is unlikely that the share of FAME in commercially available diesel blends will increase above 10%. Hydrogenated vegetable oil (HVO) is expected to gain an increasing market share, especially in the time window 2015-2020. After 2020, the fraction of biogenic diesel in blends may further increase. However, this additional demand will most likely be met by the production of advanced high quality 2nd generation BTL diesel, thereby not reducing the fuel quality, also not for military applications.

From a global perspective, it is most likely that up to 2030 biodiesel blends will only contain a minor average fraction of diesel from biological origin (~below 3%). The main reason is that biofuel substitutes for petrol are expected to maintain their market share of about 80% of the total biofuel production. However, in addition to the EU, biodiesel blends up to 10% may also be introduced in regions with a large biodiesel feedstock supply potential, such as South East Asia, Latin America or Sub-Sahara Africa.

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FAME	Fatty Acid Methyl Ester
HVO	Hydrogenated Vegetable Oil
PVO	Pure Vegetable Oil
DME	Dimethyl Ether
SNG	Synthetic Natural Gas
MGO	Marine Gas Oil
MDO	Marine Diesel Oil
BTL	Biomass to liquids
GTL	Gas to Liquids
IEA	International Energy Agency
EIA	Energy Information Administration (US)
SECA	Sulphur Emission Control Area
EEA	European Environmental Agency
ACEA	European Automobile Manufacturers’ Association
ASTM	American Society for Testing and Materials
Mtoe	Million tons oil equivalent
(M)boe	(Million) barrels of oil equivalent

Summary

The application of biofuels is an option that helps to reduce greenhouse gas emissions in transport, provided that a number of crucial sustainability criteria are fulfilled. For the ministry of defence, the introduction of biofuels in conventional blends raises new questions for their fuel purchase, distribution and stocking activities. For the specific application in the military environment, the fuel requirements are more stringent than in civil applications, especially regarding long term stability, viscosity, corrosive behaviour and lower energy density. Therefore, the Ministry has commissioned ECN to provide an overview of the possible future role of biofuels in global transport fuel supply. The present study focuses on a market analysis of biofuels and the related fuel blends projected to become available on the market up till 2030. An extensive overview of the technical specifications of these new fuel (blends), especially related to the stringent military requirements, is provided in a complementary study performed by the Netherlands Organization for Applied Scientific Research (TNO).

The key biofuels currently available are: (1) biodiesel, mostly fatty acid methyl esters (FAME) with a small share of hydrotreated vegetable oils (HVO), produced from oil crops such as rapeseed and soy, that can be blended with conventional diesel fuel, and (2) bioethanol, produced from cereals and sugar crops, that can be blended with conventional gasoline. These biofuels are increasingly blended with conventional road transport fuels of fossil origin, since low blends (below about 7%) can be applied with limited changes to fuelling points and vehicles. Nevertheless, first generation biofuels and their blends do have several characteristics that critically differ from fossil fuels.

The study concentrates on diesel and its biogenic substitutes, since diesel and comparable middle distillate fuels are the predominantly used fuels by the armed forces. First generation FAME biodiesel blends impose by far the largest risks for application in the military environment because: (1) diesel (and other middle distillates) are the fuels that are predominantly used by the armed forces for ground use; (2) the commercially available FAME blended diesel has several characteristics that do not meet the strict fuel requirements for military applications, especially regarding long term stability, viscosity, corrosive behaviour and lower energy density; (3) blend percentages of FAME biodiesel in commercially available fuels are increasing, thereby increasing the risks for military application.

We conclude that the percentage of conventional biodiesel (FAME) in the EU is likely to increase up to around 7% until 2020. It is unlikely that the share of FAME in commercially available diesel blends will increase above 10%. After 2020, the fraction of biogenic diesel in blends may further increase, but this additional demand will most likely be met by the production of advanced high quality 2nd generation biomass to liquids fuels (BTL). BTL fuels have comparable or better specifications than conventional diesel and other middle distillates, but are not expected to be blended in substantial quantities before 2020.

As a first generation alternative to FAME biodiesel, hydrogenated vegetable oil (HVO) is expected to gain an increasing market share, especially in the time window 2015- 2020. HVO has much better specifications than FAME and can be blended with fossil diesel at higher volumes. However, HVO is still dependent on vegetable oils as feedstock.

From a global perspective, it is most likely that up to 2030 biodiesel blends will only contain a minor average fraction of diesel from biological origin (~below 3%). The main reason is that biofuel substitutes for petrol are expected to maintain their market share of about 80% of the total biofuel production. However, in regions with large biodiesel feedstock supply potentials,

such as South East Asia, Latin America or Sub-Sahara Africa, higher blends may be introduced. In general, these local biodiesel blends are not expected to exceed 10%.

The superior physical-chemical characteristics of second generation Fischer-Tropsch middle distillates also imply that, with minor modifications, these fuels can be safely applied in aviation. Currently, because of the risks related to FAME, road diesel fuel is strictly separated from jet fuels. Since the global availability of future advanced middle distillate biofuels suitable for aviation, will be limited compared to total demand, the potential introduction of biofuels in aviation will largely depend on economical and political factors.

At present no biodiesel is blended into marine diesel fuels. Given the limited global availability of biofuels worldwide, especially in the diesel segment, it is unlikely that biofuel blending in shipping diesel will emerge rapidly. If biodiesel will be blended through shipping fuels at all it will probably be blended with the ‘lightest’ type that is most comparable to road diesel: marine gas oil (MGO). Locally, it is however possible that FAME biodiesel blends will be commercially available for shipping, especially in some high FAME production regions in SE Asia.

With the increasing growth rates and ambition levels, the societal debate on biofuels is also becoming increasingly strong. Issues like feedstock availability, competition with food, environmental impacts and implementation issues can strongly influence the long-term perspectives for biofuels.

1. Introduction

1.1 Background

The transport sector is responsible for about half of the world's oil consumption and emits about one quarter of the global CO_2 emission (Ribeiro, 2007). In Europe (EU-27) the share of transport in total greenhouse gas emissions is approximately 22% (EEA, 2008). Road transport accounts for 72% of all transport-related CO_2 emissions, a fraction that has increased by 32% between 1990 and 2005 (DG TREN, 2008). As economies continue to grow, the demand for transportation tends to increase correspondingly. Based on projected economical growth the global transport volume is expected to double approximately till 2050.

Many studies on energy and climate change indicate that drastic greenhouse gas emission reductions need to be realised in the coming decades. For example, the Stern Review on the Economics of Climate Change (Stern, 2006) indicates that the developed world, including the Netherlands, needs to achieve emissions reductions of 60-80% by 2050 in order to prevent excessive climate change. This reduction target is relative to the year 2000. With such high overall greenhouse gas emission reduction targets, the transport sector will also need to reduce it emissions. If, for example, the required CO_2 reduction is to be divided equally over all sectors, and the transport sector growth is taken into account, this sector has to cut CO_2 emissions by about 70-90% compared to 2000.

Besides the global warming issue, policy makers are also concerned about a possible future oil scarcity. Of all fossil energy resources, oil has the lowest reserve-to-use ratio. In addition policy makers want to decrease the oil dependency from unstable and/or hostile countries. To meet the climate change challenge, and to improve the security of supply, the transport sector will have to implement radical changes, including:

- Substantial vehicle and engine efficiency improvements, e.g. by a shift to electric engines and hydrogen fuel cells.
- Decoupling of economic growth and transport intensification, e.g. by further optimization of logistics and a new perspective on spatial development.
- A switch to renewable and carbon-neutral fuels; electricity and hydrogen provide good long-term perspectives for this. In the short term biofuels are among the few options available.

The application of biofuels is an option that helps to reduce CO_2 emissions provided that a number of crucial sustainability criteria are fulfilled. Compared to other sustainable transport options, such as the electric or fuel-cell powered vehicle, biofuels have the advantage that they can be applied without fundamental changes in fuel distribution and end use: most biofuels can be blended with gasoline or diesel and used with limited changes to fuelling points and vehicles. Currently available examples of biofuels are bioethanol, produced from cereals and sugar crops, that can be blended with conventional gasoline, and biodiesel, produced from oil crops such as rapeseed and soy, that can be blended with conventional diesel fuel (see Chapter 4 for details). However, first generation biofuel(blends) do have several characteristics that critically differ from fossil fuel. Especially long term stability and a lower energy content remain a critical issue for biopetrol (alcohol) as well as for (FAME) biodiesel. Nevertheless biofuels are increasingly blended with conventional transport fuels of fossil origin; i.e. in diesel and petrol (not in aviation fuels).

For the Ministry of Defense, the introduction of biofuels in conventional blends raises new questions for their fuel purchase, distribution and stocking activities. For the specific application in the military environment, the fuel requirements are more stringent than in civil applications, especially regarding long term corrosive behavior of fuels and stability against biological or chemical decomposition. Therefore, the Ministry has commissioned ECN to provide an overview of the possible future role of biofuels in global transport fuel supply.

1.2 Objectives

For the reasons explained in the previous paragraph, the armed forces (Ministry of Defence) need additional information on:

1) The market outlook of present and future biofuels, including an evaluation of how this will affect the future fuels for the armed forces in the Netherlands. The present study, carried out by the Energy research Centre of the Netherlands (ECN), focuses on the market analysis of biofuels and the related fuel blends projected to be on the future market.

2) Technical specifications of these new fuel (blends), especially related to the stringent requirements on vehicles to be ready for operation under all conditions. This key aspect is *not* addressed in depth in the present report, since it is extensively reported in a parallel study performed by the Netherlands Organization for Applied Scientific Research (TNO).

The studies carried out by TNO and ECN have been conducted in cooperation and are complementary to each other. In addition TNO and ECN reviewed their mutual studies.

1.3 Scope and outline of the report

This report presents our findings on the expected developments in the international biofuel market. The study is based on a literature review and ECN's years of experience with policy studies on biofuels. We address the impact of biofuels on the armed forces, thus including the army, the air force and the royal navy. The main focus of the study, however, is the impact on the army. The study concentrates on biofuels that can be classified as middle distillates, including road diesel, most jet fuels as well as marine gas oil. These latter two fuels have characteristics that are relatively close to the 'road' diesel. In addition, most of their production routes are also comparable to biodiesel production routes (see Chapter 4). Application of fuels in aviation, evidently, involves the most stringent requirements regarding fuel specifications.

The armed forces hardly use light distillates like petrol (gasoline), nor heavy fuels, such as heavy fuel oil (see overview in Paragraph 2.4). Consequently our study focuses on middle distillates and their (potential) substitutes from biological origin. Nevertheless the developments of biofuels substituting petrol (especially bioethanol), are also evaluated, since the bioethanol and biodiesel market are strongly interrelated. In addition, both fuels in part compete for the same feedstock, especially regarding future production routes of biofuel (second generation biofuels; see also Chapter 4). The time frame of our study covers the expected developments from present until approximately 2030.

Following this introduction, Chapter 2 describes the current global status of biofuel use. Chapter 3 describes the most relevant current and future biofuels, as well as their production technologies and feedstocks. Chapter 4 gives the regulations on biofuels and policies on promoting biofuels in the Netherlands, the European Union and globally. Based on the policy ambitions and resource potentials in different parts of the world, Chapter 5 provides an overview of the expected developments in biofuel production and its geographical distribution, as well as some trends in geographical variations. Chapter 6 provides a synthesis of the main factors underlying future biofuel demand and production, resulting in a projection of the most likely developments in the diesel fuel segment (diesel and comparable distillates are the dominant military fuels). Finally, in Chapter 7 the main findings are summarized and conclusions presented.

2. Current global status of biofuel use

2.1 Current and expected growth of biofuel blending

At present, the average global share of biofuels in the global use of transport fuels is still limited (see Figure 2.1; Fulton, 2008). Locally, however, biofuel shares can already be much higher, especially in niche markets or demonstration projects. Over the last decade the production and use of biofuels has been rapidly growing since governments are promoting biofuels and support them by introducing policies (see also Chapter 3). Apart from reducing greenhouse emissions governments also promote biofuels as a way of increasing the security of supply, as well as to economically stimulate rural areas. It is very likely that the trend of blending fossil fuels with biofuels will continue and that these fuels will further penetrate the global fuel markets. Since in most cases, no alternative (unblended) fossil fuels will be available, the increasing market penetration of biofuels will affect the fuel supply to the armed forces in the Netherlands.

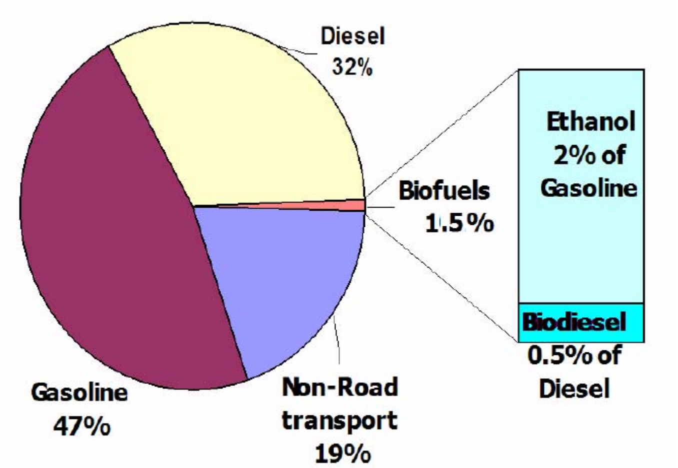

Figure 2.1 *Global transport fuel shares, 2007*
Note: graph taken from Fulton, 2008.

2.2 Potential risks of biofuels in military applications

The armed forces in the Netherlands (army, navy, air force) use a relatively small fraction of the total fuel consumption. As a consequence, the armed forces have to buy the regular fuels on the market, which do not necessarily meet the specific requirements for military application. Over the past decades fuel specifications have been rather stable. The new developments in blending increasing amounts of biofuels to fossil fuels, however, do have a relatively strong impact on fuel specifications, that are important for military application. For example, conventional biofuel (blends), including first generation biodiesel (see also Chapter 4), have been reported to be less stable to biological and chemical decomposition and/or more corrosive. Many studies report field problems, especially related to biological stability (e.g. McCormick and Westbrook, 2007; Abdullah et al. 2007; Takei 2007). The long-term stability of biodiesel is limited by deterioration via hydrolytic and oxidative reactions, related to its high degree of unsaturation (Meher et al, 2004). This may lead to the formation of insoluble products that cause problems within the fuel system. While biodiesel is generally considered to be insoluble in water, it actually takes up considerably more water (as much as 1500 ppm) than fossil diesel (Fernando et al., 2007). In long-term storage, condensed water in the fuel tank can support the growth of bacteria and molds that use bio-diesel as the food source. These hydrocarbon-degrading microorganisms will grow as a film or slime that can accumulate as sediment over longer periods of time. The microbial slime can subsequently detach from the wall of the tank and clog fuel filters.

Long-term storage in partially filled containers should be avoided as condensation in the container can contribute to the long-term deterioration of the biodiesel (www.biodiesel.com). Consequently, when storing biodiesel over longer periods of time it is important to fill tanks and containers as full as possible, with a minimal head space of air remaining. The containers should be away from direct sunlight while the storage temperature should be sufficiently low to avoid oxidative or hydrolytic degradation problems. Biocides are available to treat biodiesel fuel, and with their use at very dilute concentrations, they can inhibit the growth of microbes over a long period of time (www.biodiesel.org, 2009). In conclusion, when long-term storage of bio-diesel is necessary, several extra precautions should be taken which however may conflict with military fuel storage and handling procedures, especially during field operations.

In addition, biodiesel also acts as a solvent which can dissolve sediments in diesel fuel tanks and consequently clog fuel filters (www.biodiesel.org, 2009). This problem often occurs when shifting from conventional diesel to biodiesel(blends) using the same fuel system. Polymerization of certain biodiesel components can result in the formation of insoluble deposits. Thus, if biodiesel blends are applied in the military environment special attention should be paid to the risk of fuel line clogging .

The operation of military vehicles, planes and ships has to be ultra reliable, also under extreme conditions, including strong temperature changes, and long periods of not using vehicles, with fuel stored in the tank. Jet fuel is the commodity with limited scope for product differentiation. Consistency in fuel supplied is essential. Consequently, especially for application in aircrafts, biofuels must meet all the specifications of the default fossil fuel, as failure on specific aspects might have catastrophic implications. Apart from problems related to fuel stability, the energy content is also an important issue, especially in aviation. For example, the energy content of Jet A1 is 48 MJ/kg, whereas the energy content of typical first generation biodiesel is only 37.5 MJ/kg. The lower energy content could significantly affect aircraft range. (Appadoo, 2009).

Currently, the blending of biofuel with road diesel, and the related change in fuel characteristics, already impact the fuel distribution of the armed forces. The present biofuel blended road diesel has been reported to be less stable regarding biological degradation, and related formation of flocks or aggregates, resulting in potential clogging of fuel filters and/or related failure of engines. Biodiesel blend tests with 3% FAME have shown severe pumpability concerns at low temperatures. The main issues related to the risks of biofuel use in aviation, and guidelines and procedures to minimize these risks are reported in Appendix C of this report. In line with these procedures, the extensive pipeline network for jet fuels, operated by DPO (Defensie Pijplijn Organisatie), is currently only used for jet fuel transport. In the past the pipeline from Rotterdam to Markelo, for example, was also used for road diesel transport.

Text box on the viewpoints of auto manufacturers on biodiesel (ACEA et al., 2006).

Especially at levels above approximately 5%, potential problems include:

- Biodiesel may be less stable than conventional diesel fuel, so precautions are needed to avoid problems linked to the presence of oxidation products in the fuel. Some fuel injection equipment data suggest such problems may be exacerbated when biodiesel is blended with ultra-low sulphur diesel fuels.
- Biodiesel requires special care at low temperatures to avoid an excessive rise in viscosity and loss of fluidity. Additives may be required to alleviate these problems.
- Being hygroscopic, biodiesel fuels require special handling to prevent high water content and the consequent risk of corrosion and microbial growth.

- Deposit formation in the fuel injection system may be higher with biodiesel blends than with conventional diesel fuel, so detergent additive treatments are advised.
- Biodiesel may negatively impact natural and nitrile rubber seals in fuel systems. Also, metals such as brass, bronze, copper, lead and zinc may oxidize from contact with biodiesel, thereby creating sediments. Transitioning from conventional diesel fuel to biodiesel blends may significantly increase tank sediments due to biodiesel's higher polarity, and these sediments may plug fuel filters. Thus, fuel system parts must be specially chosen for their compatibility with biodiesel.
- Neat (100%) biodiesel fuel and high concentration biodiesel blends have demonstrated an increase in NO_x exhaust emission levels.
- Biodiesel fuel that comes into contact with the vehicle's shell may be able to dissolve the paint coatings used to protect external surfaces.

2.3 Limited market share of fuels for military application

The armed forces in the Netherlands (army, navy, air force) all use a relatively small fraction of the total fuel consumption. In 2007 the annual fuel use by the army, air force and navy was 30, 76, 46 million liters of diesel (ground fuel), kerosene, and gas oil, respectively (see Table 2.1). For comparison, the total fuel sales in 2007 for road transport in the Netherlands amounted to approximately 5800 and 8400 million liters for petrol and diesel fuel, respectively (CBS, 2008). Consequently, the military ground fuel diesel use amounts to only 0,35% of total diesel sales in the Netherlands. This amount is too low to allow affordable production by refineries of dedicated military fuels. Instead the armed forces depend on procurement of the regular fuels on the market, that are increasingly blended with biofuels. Although these commercially available fuels have to meet specific fuel specifications, following the national and EU guidelines (EN-228 for petrol, EN-590 for diesel), that does not necessarily mean that these fuels will also meet the specific requirements for military applications. Over the past decades fuel specifications have been rather stable. The new developments in biofuel blending, however, especially regarding so called first generation fuels (see Chapter 4) may have a relatively strong impact on fuel specifications.

2.4 Fuel types and consumption for military applications

The key requirement for all fuels for the armed forces is that they allow very reliable operation under all circumstances. This implies that fuel needs to be stable over long storage times (months to years), and suitable for application over a wide temperature range (-50 °C / + 50 °C). Preferably the fuels should also be suitable for so called 'Single Fuel Policy' (SFP) operations.

The armed forces in the Netherlands predominantly use middle distillates. More specifically:

- The army (land forces) use F-54 diesel fuel, i.e. commercially available road diesel (quality standard EN-590). In Europe, this implies low sulfur diesel fuel (less than 10 ppm S, although locally purchased diesel fuel applied during missions abroad may contain sulphur levels up to 8000 ppm. In addition the army uses small amounts of F-67 (commercial petrol EN-228), amounting to only 0.3% of the total military fuel use.
- The Royal Dutch navy predominantly uses middle distillate fuel, especially F-76 and sometimes DMA, i.e. commercially available marine gasoil. Marine gasoil (MGO) and marine diesel oil (MDO) are two different types of distillates, where MGO is of a better quality. DMA is a marine gasoil, and the most commonly used distillate. It is of better quality than DMB (containing more sulphur) and DMC (containing fractions of residual fuels), and thus most vessels can burn DMA. In addition to regular DMA, DMA 0.1 is the low sulphur version of this fuel, i.e. it has a sulphur content of max. 0.1%. It is mandatory to burn low sulphur distillates in the SECA areas and off the coast of California

(www.maerskoiltrading.com, 2009). Naval ships are usually operating on F-76 diesel fuel, a NATO specified diesel fuel that is available worldwide.

- The air force predominantly uses F-34, a fuel based on civil JET-A1 plus additives. Military airplanes have no fuel heating systems, so fuel additives need to be added such as fuel system icing inhibitor and corrosion inhibitors. Aviation fuel additives are compounds added to the fuel in very small quantities, usually measurable only in parts per million, to provide special or improved qualities. The quantity to be added and approval for its use in various grades of fuel is strictly controlled by the appropriate specifications. See also Appendix B for an overview of fuel additives in common use. For helicopter use on ships a different fuel is applied: F-44 fuel (flashpoint 60 °C).

Table 2.1 *Overview of the current fuel use by the armed forces in the Netherlands Annual fuel use, and fuel type used by the Netherlands army, air force and navy.*

Fuel type	Army	Air force	Navy
Main fuel	*Diesel:* F-54 (Commercial diesel EN-590). In addition small amounts of F-67 (commercial petrol EN-228)	*Kerosine:* F-34 (based on civil JET-A1 plus additives) In addition F-44 for helicopters on ships (flashpoint 60 °C)	*Gas Oil:* F-76
Fuel consumption (million liter/year)	ca. 30	ca. 76	ca. 46

Source: Zijderveld, 2009; Defensie Milieurapportage 2007.

3. Fuel types and production technologies

3.1 What are biofuels?

Biofuels are renewable liquid fuels produced from plant material[1]. Plants store their energy as sugar, starch or oil. These have a high-energy value and can be converted to (first generation) liquid biofuels with relatively simple techniques. The remaining parts of the plant also contain energy, which however requires advanced technologies to convert into (second generation) biofuels. Currently, the two main types of liquid biofuels are: (1) biodiesel, produced from plant oil; and (2) bioethanol, produced from plant derived sugar or starch. Most biofuels can be blended - to a certain extent - with conventional fossil fuels without the need for major modification of vehicles or refueling infrastructures. In addition, biofuels can in certain applications completely substitute fossil fuels, although in this case modifications are required to the engine and the fuel system. The different types of biofuels, their characteristics, feedstocks and production processes are presented in the next paragraphs.

3.2 Overview of biofuels, characteristics and technologies

A variety of fuels can be produced from biomass resources including liquid fuels, such as ethanol, methanol, biodiesel, Fischer-Tropsch diesel and gasoline, and gaseous fuels, such as hydrogen and methane. Biofuels are primarily used to fuel vehicles, but can also fuel engines in stationary applications or can be burned in power plants or furnaces. Generally, somewhat arbitrary, biofuels are divided in two main categories: (1) conventional or first generation biofuels; and (2) advanced or second generation biofuels.

3.2.1 First generation biofuels

First generation, or conventional, biofuels are generally made from food crops, using existing refining and fermenting technologies. First generation biofuels are currently produced at a commercial scale. The most important first generation biofuels are: biodiesel (or fatty acid methyl ester, FAME), hydrogenated vegetable oil (HVO), pure vegetable oil and bioethanol (from sugar and starch crops).

Biodiesel (FAME)

This type of biofuel is currently by far dominant in the biodiesel(blend) on the market. Commercially available biofuel in Europe currently contains up to a few percent of FAME, but this percentage may rise towards 10% in the next decade, depending on EU policies and international developments (see Chapters 4 and 5).

Because FAME biodiesel is the key biofuel that may cause problems by application in the military environment (see Paragraph 2.2), the production process and the fuel characteristics of FAME are most extensively described here. FAME biodiesel can be made from most vegetable oils, animal fats, waste vegetable oils, or microalgae oils. Soybeans and rapeseed (canola) oils are the most common vegetable oils used today. Biodiesel consisting of fatty acid methyl esters (FAME) can be produced by a variety of esterification technologies, though most processes follow a similar basic approach (IEA, 2004). First the oil is filtered and pre-processed to remove water and contaminants. If free fatty acids are present, they can be removed or transformed into biodiesel using pre-treatment technologies. The pretreated oils and fats are then mixed with an

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[1]: Biodiesel can also be produced from (residual) animal fats. However, given the limited availability of this material this is a negligible route.

alcohol (usually methanol) and a catalyst (usually sodium or potasium hydroxide). The oil molecules (triglycerides) are broken apart and reformed into esters and glycerol, which are then separated from each other and purified. The resulting ester fuel is called ‘biodiesel’. These biomass-derived ethyl or methyl esters can be blended with conventional diesel fuel or used as a neat fuel (100% biodiesel).

FAME biodiesel fuels also require special treatment at low temperatures to avoid an excessive rise in viscosity and loss of fluidity (ACEA, 2006). Moreover, the production of biodiesel with full compliance with ASTM D6751-07 or EN 14214:2003 is a very challenging task (Abdullah et al, 2007). The European standards organization, CEN, has published an automotive FAME standard (EN 14214) that establishes specifications for biodiesel use as either: (i) a final fuel in engines designed or adapted for biodiesel use; or (ii) a blendstock for conventional diesel fuel. Similarly, the international section of the American Society for Testing and Materials (ASTM International) has established specifications for neat biodiesel (ASTM D 6751) but only for use as a blending component, not as a final fuel (ACEA et al, 2006). However, as described in Paragraph 2.2, despite these standards FAME biodiesel (blends) do differ from 100% fossil fuels based diesel. These differences also regard some characteristics that are vital for military application, especially long term stability, and low temperature viscosity. In several regions in the world, including the EU, in specific market segments fossil fuel may even be substituted by pure biofuels. The use of pure bio-diesel fuels however, cannot occur without adopting a series of precautions. Unless the proper precautions are taken, biodiesel fuels can cause a variety of engine performance problems including filter plugging, injector coking, piston ring sticking and breaking, seal swelling and hardening/cracking and severe lubricant degradation

Hydrogenated vegetable oil (HVO)

HVO is produced from vegetable oils, and therefore should be classified as first generation biofuel. Hydrogenating of vegetable oils produces a much higher quality product than first generation (FAME) biodiesel. HVO can be blended with fossil diesel at higher volumes. However, this product is still dependent on vegetable oils as feedstock and therefore is not as attractive as second generation biofuels which can be produced from wastes and residues.

The hydrogenation process would normally be integrated within an oil refinery to avoid having to construct a dedicated hydrogenation production unit. The process can be integrated with hydrotreaters, and make use of hydrogen, already used in a refinery to remove sulphur. The process is in the early commercial stage of development and there are several companies with technologies that use this process. The company which is furthest on with this technology is probably Neste Oil. The Neste NExBTL process has been producing 170,000t/yr at its Porvoo plant in Finland and has plans for other plants to come on stream in the near future. Other companies are developing this process as well and have plans to built or expand plants. Neste Oil claims that their hydrotreated biodiesel has similar properties to BTL or GTL, being a 100% hydrocarbon type paraffinic biobased diesel fuel, characterised by high cetane numbers (up to 99), good cold properties (-30 °C), and a good stability without problems (Neste Oil, 2006; Linhardt, 2009).

One of the most important issues is that like first generation biofuel, the production of this fuel is currently limited by the need for food based feedstocks (vegetable oils) which are becoming increasingly expensive with concerns about global food shortages. To be economically viable hydrogenation needs to be closely coupled to a refinery operation. One of the components leading to high costs is the additional hydrogen stream that is needed, especially if not coupled to a refinery. With demand for biodiesel expected to continue, processes which produce a good quality diesel which can be blended at higher levels and at similar costs are likely to be attractive (E4Tech, 2008).

Pure vegetable oil

Pure vegetable oil (PVO) is produced from vegetable oils that are derived from oil seeds by mechanical pressing or solvent extraction. Rapeseed is by far the most used feedstock in Europe, followed by sunflower. Outside the EU also soybean and palm derived oils are used. Pure vegetable oil can be used as automotive fuel, but is not suitable for use in regular diesel engines, due to unfavourable fuel properties, such as its very high viscosity, its poor thermal and hydrolytic stability, and its less favourable ignition qualities (low cetane number), and its high injector fouling tendency (ACEA, 2006). Nevertheless, pure vegetable oil can be used in diesel engines that are adapted specifically for this application. PVO is currently being used on a small scale (Refuel, 2009).

Ethanol (first generation)

Ethanol is the most widely used biofuel today with in 2008 an annual production capacity of about 3 billion liters, based on starch crops, such as corn (DOE, 2009). In addition in tropical regions, especially Brazil large amounts of alcohol are produced from sugarcane. The 2008 global production of fuel ethanol amounted to about 65 billion liters (AMFI, 2009)

Ethanol can be produced from any biological feedstock that contains appreciable mounts of sugar or materials that can be converted into sugar such as starch or cellulose. Sugar beets and sugar cane are obvious examples of feedstock that contain sugar. Corn, wheat and other cereals contain starch (in the seeds) that can relatively easily be converted into sugar (IEA 2004).

Two key reactions convert biomass to bioethanol:

- Hydrolysis, a chemical reaction that converts the starches in the raw feedstock to simple sugars. Acids and enzymes are used to catalyze this reaction.
- Fermentation, a series of biochemical reactions that convert sugars to ethanol. Industrial fermentation of sugars to ethanol is performed by yeast. The fermentation process, resulting in the production of ethanol and carbon dioxide, is similar to brewing beer.

The enzymes for starch conversion and ethanol fermentation and distillation technology at a commercial scale are readily available. Nearly all ethanol in northern countries is made from widely-available grains such as wheat or barley or from sugar beet or molasses. In the tropics (e.g. in Brazil) sugar cane is the dominant feedstock that already contains sugar, thereby making the hydrolysis step superfluous.

3.2.2 Second generation biofuels

Second-generation biofuels, also referred to as advanced biofuels are made from non-food feedstocks, such as wood and straw (lignocellulosic biomass). The production process uses the whole plant, rather than just the plant oils, starches or sugars that are used to make first-generation biofuels. This means that waste materials from agriculture and forestry can also be used as feedstocks. Using advanced fuel production technologies, these low-value agricultural crops and residues can be converted into fuels. There are two main technologies to convert whole plant biomass to liquid biofuels: gasification and conversion through a combination of physico-chemical and biochemical conversion steps. These fuel production technologies are not yet available on a fully commercial scale. Consequently, large scale market introduction of second generation biofuels is not expected in the coming decade. The most important second generation biofuels are: Fischer-Tropsch biodiesel, and bioethanol (from lignocellulosic biomass). Other potentially interesting fuels are: dimethylether (DME) and Synthetic Natural Gas (BIO-SNG).

Fischer-Tropsch biodiesel

Fischer-Tropsch diesel, FT-diesel, or BtL (Biomass-to-Liquids) is a full substitute of diesel. Fuel specifications are excellent and comparable to other high quality fuels, such as Gas-to-

Liquid (GTL) transportation fuels. These characteristics make FT-biofuels also suitable for application in aviation. Lignocellulosic biomass is gasified to produce syngas which is in turn transformed into liquid hydrocarbons, mostly diesel and kerosene and a range of other liquid and gaseous fuels, such as synthetic gasoline, methanol, ethanol, dimethylether (DME), methane, and hydrogen. Such production has the advantage of being chemically essentially the same as petroleum-based fuels. Thus modifications to existing engines and fuel distribution infrastructure are not required. In the production process biomass is gasified to produce a syngas, consisting mainly of carbon monoxide and hydrogen. The syngas is then reacted in a catalytic process (the Fischer-Tropsch process) under certain temperature and pressure conditions to produce one or more products. (Petroleum Economist, 2006)) The key feedstock ultimately being considered for this route is waste (agricultural wastes, waste wood residues and municipal solid waste) for economic reasons, but energy crops could also potentially be used as feedstocks for this process. Gasification has been proven to work on a wide range of feedstocks. However, gasifiers and gasification systems are generally designed to operate with feedstocks with narrow physical and chemical property ranges. The quality of the fuels that can be obtained, the range of fuel products and co-products, and the potential for producing biofuels with low GHG intensity, make syngas-based systems particularly attractive. There is strong interest in developing this route, in Europe in particular (E4tech, 2008)

Biomass gasification technologies are commercially available, at different scales and with different designs. Similarly, syngas conversion technologies have been demonstrated at commercial scale for synthetic diesel and gasoline, methanol, ethanol, DME, methane and hydrogen. Synthetic fuels are produced commercially today mainly from natural gas or the gasification of coal e.g. Sasol plants in South Africa and Qatar. However, there is very limited commercial experience in integrating biomass gasification with downstream processes for the production of liquid or gaseous transport fuels. The only experience involves the gasification of mixed feedstocks, including biomass, at the Schwarze Pumpe plant in Germany for the production of methanol and in the Choren pilot plant. Despite the fact that both biomass gasification and the Fischer-Tropsch process for fuel production from syngas being demonstrated technologies already used at scale, further R&D, and demonstration is needed to determine plant configurations that will be technically and economically viable using biomass (E4tech, 2008). For BTL production the IEA (2008) report as key challenges: (1) improvement biomass gasification technologies and increase their scale to the levels at which the FT-synthesis process becomes financially viable; and (2) improvement of the cleaning and conditioning technologies.

Bioethanol (from lignocellulosic biomass)

It is also possible to convert lignocellulosic feedstock into alcohol, although this process is more complex. Trees and grasses are largely made up of cellulose and hemicellulose, which can also be converted to sugars (though with more difficulty than conversion of starch) through a combination of physico-chemical pre-treatment and enzymatic hydrolysis. Cellulose can thus be converted to glucose which can be readily fermented to ethanol using standard industrial yeasts. The hemicellulose fraction can be hydrolyzed to a mixture of mainly C5 sugars (e.g. xylose) and some C6 sugars. Ethanol fermentation of C5 sugars requires modified yeasts or other organisms for complete fermentation. This technology is not yet available. For cellulosic ethanol production to become commercially viable the IEA (2008) reports as essential barriers to be solved: (1) pretreatment of lignocellulosic biomass, degrading the closed structure of the material so that the cellulose becomes mobilized; and (2) improvement of performance (and reduction of costs) of the enzymes that hydrolyse cellulose into glucose (that can subsequently be fermented into ethanol).

Dimethylether (DME)

Bio-DME (Dimethyl Ether) is a fuel that can be used in diesel vehicles with limited adaptations. Lignocellulosic biomass is gasified to produce syngas which is then converted into methanol in the presence of a catalyst (usually copper-based). The methanol undergoes subsequent dehydration in the presence of a different catalyst resulting in the production of DME.

Synthetic Natural Gas (BIO-SNG).
Biogas, or biomethane, is a fuel that can be used in gasoline vehicles with limited adaptations. It can be produced through anaerobic digestion of manure and other digestible feedstock. Bio-SNG (Synthetic Natural Gas) is a fuel that can similarly be used in gasoline vehicles with limited adaptations. To produce SNG lignocellulosic biomass is gasified to produce syngas which is in turn catalytically converted into methane.

3.2.3 Third generation biofuels

Sometimes the name ‘third generation biofuels’ is used for (future) fuels derived from feedstocks produced in aquatic environments (microalgae) or from crops produced at marginal land (Jatropha).

Microalgae produce chemicals and substances that have a number of uses, including the production of transport fuels. The use of high oil yielding micro-algae as a feedstock for biodiesel production has the potential for efficient land and resource use, as the ponds or reactors in which they are grown can be sited on unproductive land. There are a large number of companies starting up in this area which quote high yields for algal oil production and who release press statements saying that they will be producing large quantities of algal biodiesel in the coming months or years. None of these companies have yet produced algal biofuels at scale and none have produced evidence of the GHG intensity of this fuel (E4tech, 2008).

3.2.4 Energy density of biofuels

Most biofuels have several characteristics that for most aspects unfavorably differ from fossil fuels. Apart from critical issues as long term stability, corrosion and viscosity, as already addressed in the previous sections, the energy density is an important issue as well. Apart from high quality second generation GTL biofuels (see Paragraph 3.2.2), biofuels have a lower energy density than the fossil fuel that they substitute. Furthermore it is important to note that blends of biofuels are expressed in percentage by volume (per litre). For example E5 refers to a 5 vol% blend of ethanol per litre gasoline. The current and proposed EU-policy targets (5.75% in 2010 and 10% in 2020) however refer to a percentage expressed by energy content. Since the energy content of biofuels is typically lower than that of fossil gasoline and diesel, a larger percentage of biofuels blends by volume is needed to reach these biofuels targets by energy content. Figure 3.1 gives an overview of the energy density of biofuels compared to fossil fuels and other energy carriers.

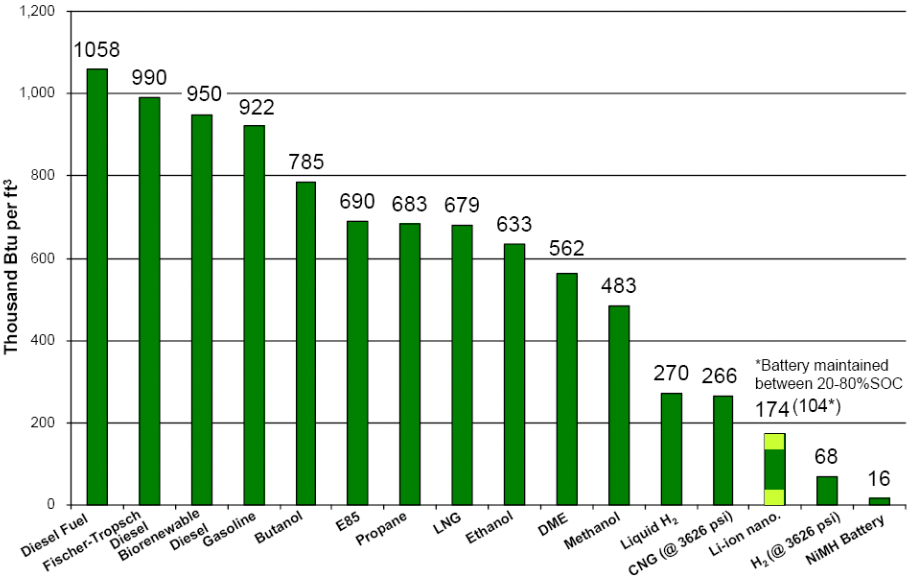

Figure 3.1 *Energy density of biofuels compared to fossil fuels and other energy carriers*
Source: Eberhardt et al., 2006.

3.3 Most relevant biofuels for military application

As described in more detail in Paragraph 2.4, currently the armed forces predominantly use middle distillates. The army (land forces) use commercially available road diesel (quality standard EN-590). The navy predominantly uses middle distillate fuel, especially F-76 and occasionally DMA, i.e. commercially available marine gas oil. The air force predominantly uses F-34, a fuel based on civil JET-A1 plus additives.

Army biofuels

As explained in Chapter 5, a plausible scenario is that commercial road diesel towards 2020 will be increasingly blended with first generation biodiesel, towards a maximum percentage of about 10%. Most of the first generation biodiesel blended will be FAME. However, with the increasing production capacity of HVO, it is possible that around 2020 a few % of the blend will constitute of HVO, thereby improving the overall quality of the diesel blend compared to FAME biodiesel (see also Paragraph 3.2.1). If the relative share of biodiesel in diesel blends will continue to increase after 2020 (depending on international developments, see Chapter 5), most likely further increase in the biofuel share in the diesel segment will be based on Fischer-tropsch biodiesel, providing a high quality substitute, with characteristics that are equal or better than the fossil diesel alternative.

Navy biofuels

Currently no biodiesel is blended into marine diesel fuels, following national, EU and international guidelines, biofuels are predominantly blended into road fuels.

Given the limited global availability of biofuels woldwide - especially diesel that even in ambitious biofuel scenario’s will not increase above global average blend percentages of 2-3 percent for road transport (see Chapter 7) - it is unlikely that biofuel blending in shipping diesel will emerge rapidly. However, from a technical viewpoint, the rather robust diesel shipping engines are expected to be less sensitive to (first generation) biodiesel related problems. On the other hand, potential engine troubles or even engine blackouts at sea can be very dangerous.

If biodiesel will be blended through shipping fuels at all it will probably be blended with the ‘lightest’ type that is most comparable to road transport diesel i.e. marine gas oil (MGO). MGO is currently used in medium to high speed 4-stroke engines, especially in inland navigation and some categories of marine vessels. MGO is a distillate of better quality than the diesel oil used in shipping (MDO) and has a sulphur content of 0.1% in the EU since 2008.

Currently civil sea shipping uses predominantly heavy fuel oil (HFO) also frequently referred to as bunker oil. HFO largely consists of the viscous residue that remains from the refining process after the light products have been separated from crude oil by means of distillation. This fuel is mostly burned in big slow speed 2-stroke diesel engines. Since the engines are robust and capable of burning the 'complicated' viscous HFO, it is unlikely that biodiesel blending will result in many operational problems. However, given the low price of HFO it is highly unlikely that biodiesel will be blended in this market segment. Nevertheless it is possible that even at present blending with marine bunker fuels occurs of unspecified biofuel (waste) that is not suitable for road application.

Aviation biofuels

The characteristics of the present FAME type biodiesel, impose a large risk for aviation, even in concentrations of only a few %. Therefore, currently FAME is strictly separated from jet fuels (see also Appendix C) so it is highly unlikely that military aircrafts will be fueled with kerosene, containing more than trace quantities of FAME. On the contrary, the expected second generation biofuels, especially fuels produced by the Fischer-Tropsch process (see Paragraph 3.2.2) will most likely be perfectly suited for application in the aviation sector. The Fischer Tropsch process allow the production of dedicated fuels with tight specifications. So the question weather or not these fuels will be applied in aviation will be rather a matter of politics or economics than of fuel specific issues. Again, it is important to realize that the global availability of middle distillate type of biofuels will be limited, compared to total demand for this type of fuels. As explained in chapter 7, even in the ambitious biofuel scenario's, the global middle distillate biofuel production by 2030 is not expected to increase above a level that will allow a 2-3 percent blending with road transport diesel.

3.4 CO_2 performance and sustainability issues

Like all biomass-based options, the CO_2 that is emitted when combusting biofuels has shortly before been stored in organic matter. However, the greenhouse gas performance and overall sustainability of biofuels are currently in the centre of an intensive scientific and social debate. Several key issues are presented here.

Overall greenhouse gas reduction

- The net energy balance and GHG emissions of the biofuels supply chain. Along the biofuels production chain, inputs are required that lead to greenhouse gas emissions. While 2nd generation biofuels usually lead to more substantial greenhouse gas emission reductions than 1st generation biofuels, these emissions still differ greatly between different specific biofuels chains, crop cultivation being a critical step. Particularly emissions of N_2O by fertiliser application are a critical but still very uncertain factor (Crutzen et al. 2008). Figure 3.2 gives an overview of the greenhouse gas emission savings of bio-ethanol and biodiesel produced form several feedstocks, both first and second generation. Clearly, the different feedstocks are characterized by rather different greenhouse gas emission savings. For first generation biofuels, ethanol from sugarcane shows the best greenhouse gas saving. For second generation biofuels both ethanol from lignocellulose and FT-diesel from lignocellulose, show the highest greenhouse gas reduction.

- Apart from production chain emissions, biofuels from agricultural crops can cause greenhouse gas emissions by changes in soil organic carbon content due to land use change. This can occur directly in the field where the crop is cultivated, but also indirectly. For example, corn for ethanol on US farmland formerly used for growing cereals for food may induce new cereals production for food elsewhere in the world, causing conversion of forests into arable land and thereby soil carbon losses. A well-known analysis of this effect is the study of Searchinger et al. (2008). However, the extent to which such effects occur depends on a manifold of uncertain relations (see also Sylvester-Bradley (2008). One of the most critical factors is whether farmers will respond to increasing demand for arable crops by taking more land into production (causing GHG emissions) or by increasing the productivity of existing cropland.

Fuel versus food discussion

- Related to this issue is the ‘fuel versus food’ discussion: conventional biofuels use food crops as their feedstock. Although such demand is still relatively small compared to crop demand for food and feed (Bole and Londo 2008), there is concern that biofuels development may lead to growing food prices and induce poverty, especially in urban areas (Gallagher et al. 2008; Oxfam 2008). Especially in developing countries, production of biofuels and their feedstocks entails both opportunities and risks in terms of economic development and social welfare. A crucial factor appears to be local farmers’ security of land tenure (Cotula et al. 2008), an issue in which several developing countries have particularly bad track records.
- Second-generation biofuels, which commonly use low-grade material as feedstock (e.g. woody materials and residues, straw and other agricultural residues), induce less soil carbon impacts and affect food prices less strongly than today’s 1st generation biofuels.

Biodiversity

- The growing demand for biofuels can be met by taking more land into production an/or by intensification of the productivity of existing cropland. Both options generally will result in loss of biodiversity. Crops for second-generation biofuels, cultivated outside the tropics, are expected to have a lower impact on biodiversity.

Although the topic remains highly controversial, many studies argue that biofuels can deliver a positive contribution to greenhouse gas emission reduction, improvement of energy security and rural economic development, as long as they are introduced gradually and at the same time implemented with stringent additional measures to minimise adverse effects. The biofuel development scenarios on which this study is based usually aim at development pathways that meet these criteria. However, major fundamental breakthroughs and setbacks, e.g in the development of global agricultural productivity, can still make or break the future scope for sustainable biofuels.

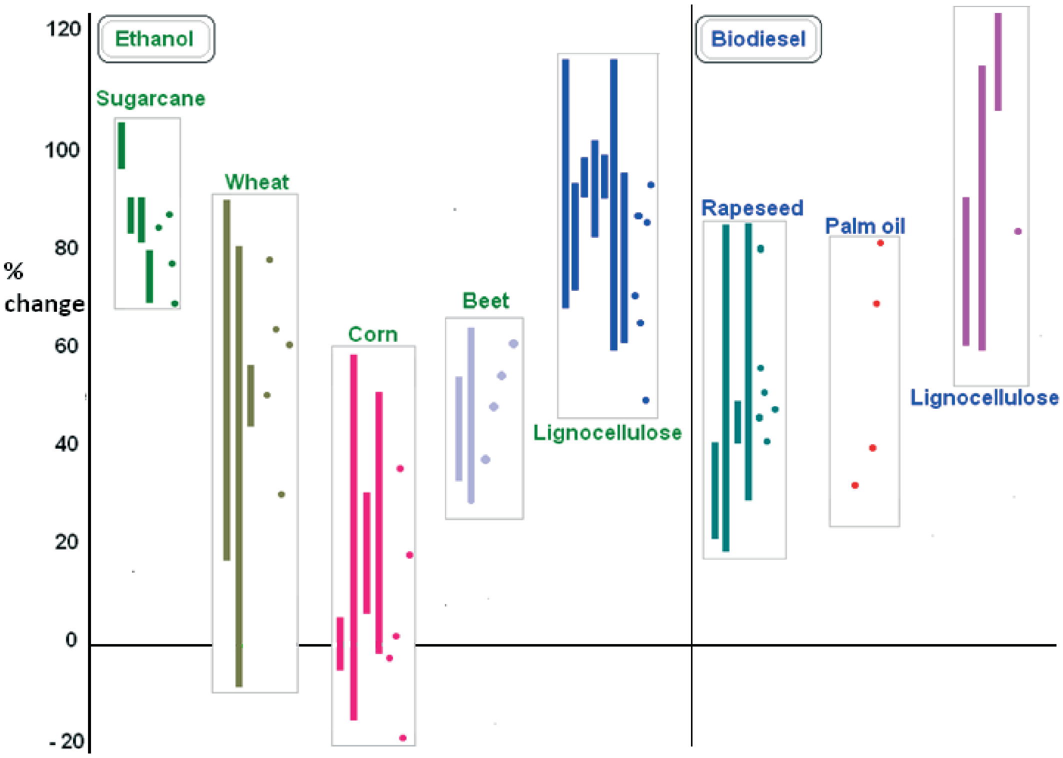

Figure 3.2 *Greenhouse gas emission savings for several biofuels based on crop and fuel production chains, for both first and second generation feedstocks, as reviewed by the IEA (2008). Lignocellulose (wood, grasses etc.) is the feedstock for second generation biofuels.*

4. Regulations and policies

As biofuels are not yet competitive with fossil fuels today and in the short to mid term in most regions in the World, the deployment of biofuels is primarily dependent on policy support (with, until the recent drop of oil prices, bioethanol in Brazil as the key exception today). Such policy is usually motivated by the role biofuels play in reducing greenhouse gas emissions in transport, reducing the dependency of fossil oil, and creating domestic (rural and industrial) development (Londo and Deurwaarder, 2007).

In this chapter, we briefly go into the policy targets for biofuels that are presently in place (or in preparation) in the European Union (4.1), the Netherlands (4.2), and in other regions in the world (4.3).

4.1 The EU biofuels policy

Current EU biofuels policy is the Biofuels Directive (EP/EC, 2003), in which an indicative target for member states has been formulated of 5,75% in 2010. The Renewable Energy (RES) Directive (EP, 2008) sets a mandatory target to member states of 10% in 2020 to renewable energy in transport. In addition to biofuels, the mandatory target covers renewable electricity in transport (e.g. in electric vehicles) and renewable hydrogen (in fuel cell vehicles). However, it is likely that biofuels will still need to provide the bulk of this 10% target:

- For electricity in transport, key uncertainty is the development rate of electric vehicles (both the plug-in hybrid and all-electric vehicles). In a recent analysis, ECN projected several development pathways for electricity in transport (Hanschke et al., 2009), with penetration rates from several promilles to maximally 2% of total energy demand for Dutch transport. Taking into account an ambitious 40% average share of renewables in total electricity production by 2020, applying the calculation rules specified in the directive, and assuming that a Western-European country such as the Netherlands would probably be a front-runner in electric propulsion, this leads to a maximum foreseeable share of renewable electricity in the target of ca 1% by 2020 in the EU27.
- For hydrogen, even the ambitious HyWays road map (Anonymous, 2007) projects that hydrogen vehicles will amount to only 1 to 3 percent of the passenger vehicle fleet by 2020 (and none in the trucks segment); accelerated penetration is expected after 2020. Furthermore, the hydrogen applied will only partly be produced from renewable sources, coal and natural gas being the more conventional production routes in the short term. Assuming an identical efficiency factor of 2.5 for hydrogen, the renewable hydrogen share in the 10% target will probably not exceed 0.5% by 2020.

Next to the 10% target in the RES directive, several other EU policy aspects may either be a driver for biofuels, or may dampen it to lower levels:

- The overall 20% target for renewables in the RES directive has been differentiated among the member states (see Figure 4.1). Several countries (circled in red) have low 2005 shares for renewables but high targets for 2020, such as the UK, the Netherlands and Germany. These countries might face problems meeting this target with a mix of renewable power, heat and biofuels in which the transport sector only reaches to its 10% directive target, given e.g. the inherently low flexibility of the power generation sector and the difficulty that member states experience in further developing renewable heating and cooling. One of the options would be to increase the share of renewables in transport. However, this would require sustainability issues relating to biofuels to become better manageable.

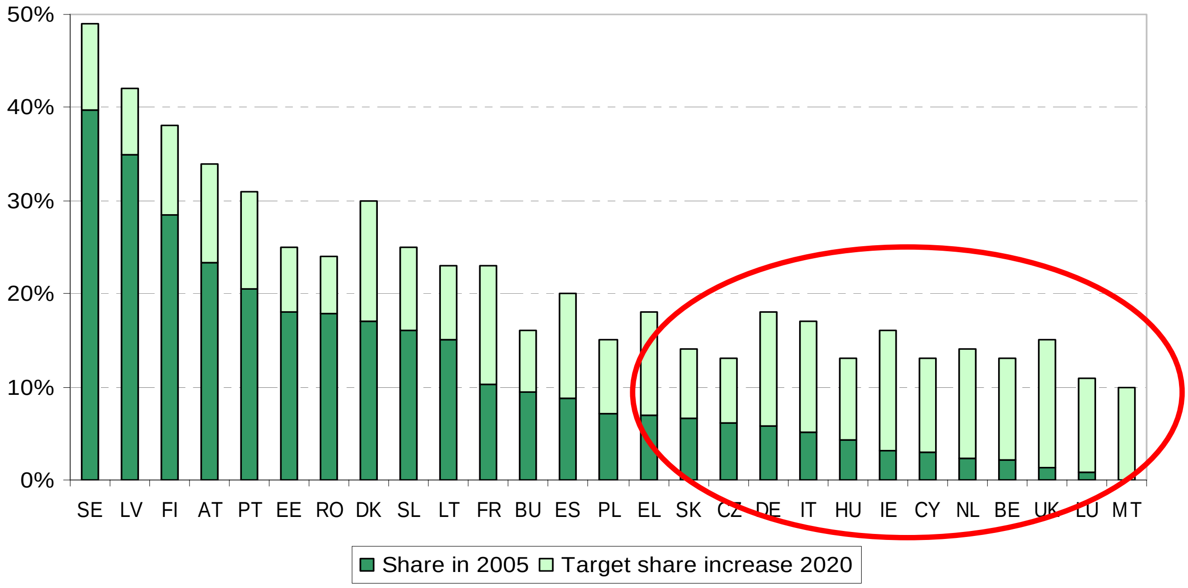

Figure 4.1 *Allocation of the overall 20% objective for renewables among the EU member states. Based on Annex 1 of the Renewables Directive*

Source: EP, 2008.

- Along with the adoption of the RES directive, the Fuel Quality Directive was recently updated, now involving a 6% mandatory target for greenhouse gas emission reductions to fuel suppliers. Member states have to implement the RES directive in their national legislation before the end of 2010. As the minimum greenhouse emission reduction limit for biofuels after 2017 will be 50 to 60% (see below), this corresponds to a maximum biofuels target of 10-12% when completely met by biofuels. So in short, this directive provides an additional driver for reaching a biofuels share close to 10%.
- The RES directive states that biofuels produced from residues, wastes and lignocellulosic materials (such as wood or grasses) count twice towards the obligation. This may have a dampening effect on the ambition level: if the EU would be able to introduce a 20% share of these types in the total biofuels mix, an 8.6% biofuels share would suffice to meet a 10% target.
- The RES directive also introduces several criteria relating to sustainability (greenhouse gas balance, exclusion of nature reserves and other sensitive areas) with which biofuels should comply to be eligible for supportive policies. These criteria may provide a barrier for further growth of biofuels, particularly for the conventional ones that use agricultural crops, as these criteria have not been specified fully yet. Particularly the indirect land use changes that biofuels production may induce are still subject of debate. For example: If European rapeseed is increasingly used for biofuels production, this may lead to rising prices of vegetable oils, thereby causing forest land to be taken into agricultural production in e.g. Brazil (for soy) or South-East Asia (for palm oil). The issue whether (and how) greenhouse gas emissions from this land use change should be taken into account in the greenhouse gas profile of the rapeseed-based biodiesel is still unsolved.

4.2 The Netherlands biofuels policy

Current biofuels policy has mainly been inspired by the EU Biofuels Directive (EP/EC, 2003). For 2009, fuel distributors are obliged to blend 3,75% of biofuels into their average fuel sales, and 4% in 2010 (SenterNovem, 2009). As such, the Dutch obligation for 2010 is lower than the 5,75% indicative target that the EU provided; this has been mainly motivated by concerns about the sustainability of current biofuels. Fuel distributors can meet this aggregate obligation with varying shares of biofuels over the time of the year, and can also differentiate between the biofuels share in gasoline and diesel. Also, there is a system of ‘bio-tickets’: tradable certificates for the distribution of biofuels that fuel distributors can trade among each other.

Dutch biofuels policy until 2020 has not yet been formalized, but will most probably align with the 10% target for 2020 that has been adopted by the European Parliament in the Renewable Energy Directive (EP, 2008); see Paragraph 4.1.

Any biofuels target does not exempt fuel distributors to comply with fuel quality standards, such as EN590 for diesel and EN228 for gasoline. However, with the update of the Fuel Quality Directive, the maximum share of biodiesel in fossil diesel will be increased from 5% to 7% (on volume basis) and for gasoline the average fuel volatility has been adapted to allow for higher share of bioethanol.

Although biofuel blends have to meet the above mentioned fuel quality standards it is likely that biofuel blending nevertheless affects fuel characteristics that are important for military applications. Especially long time fuel stability, against biological or chemical degradation, as well as corrosiveness is a critical issue. These issues are evaluated in depth in the parallel study carried out by the Netherlands Organization for Applied Scientific Research (TNO).

4.3 Policies and targets for biofuels around the world

In the past years, many countries have developed biofuels policies and introduced specific blending targets. In contrast with the EU, where climate change is one of the main motivations for biofuels, energy security and rural development seem to be the main policy drivers in other parts of the world. Figure 4.2 gives an overview of selected national targets.

- In the US, the Renewable Fuels Standard provides the basis for a target pathway for biofuels starting with 9 billion gallons in 2008, increasing up to 36 billion gallons in 2022 (RFA, 2009), roughly equal to 20% of total transport fuel consumption by then. This pathway includes sub targets for advanced lignocellulosic biofuels, and an ambitious R&D programme to develop the required technologies is linked to the RFS.
- Brazil is the country with probably the longest-lasting and most successful biofuels policy in the world. Starting in 1975 with the Proalcool programme, long-term policy support has led to the establishment of a bioethanol industry that is competitive against fossil fuels (IEA, 2009). With recent policy initiatives, the country is developing a biodiesel industry as well, mainly with soy bean oil as a feedstock.
- Many Asian countries have relatively recently developed biofuel programmes. However, food security issues, as well as concerns about deforestation are still on the table, and there are fundamental doubts whether the set ambitions will be met (Elder and Romero, 2008).

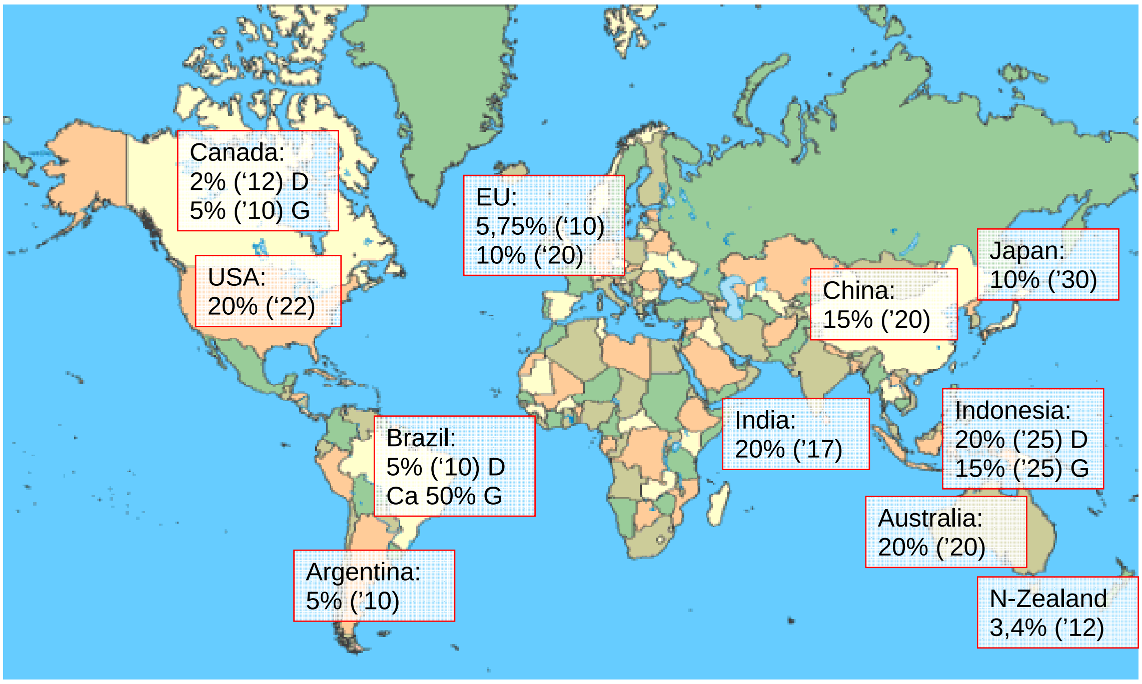

Figure 4.2 *Overview of biofuels blending targets in different countries in the world. Given in percentage on energy basis, target year given in brackets ('12 meaning 2012, etc). 'D' signifies a diesel substitute subtarget, 'G' one for gasoline substitutes.*
Based on: Elder and Romero (2008), Anonymous (2008), Reuters (2008), Forge (2007) and RFA(2009).

4.4 Aviation in EU Emissions Trading Scheme

On 27 June 2008 the European Parliament and the European Council reached an informal second-reading agreement on the inclusion of aviation in the EU Emissions Trading Scheme ('EU ETS'). Pursuant to the Aviation Directive, greenhouse gas emissions from flights to, from and within the EU will be included in the EU ETS as from 1 January 2012. Similar to industrial companies already covered by the EU ETS, aircraft operators will be allocated an emissions cap. If their emissions increase, they will be obliged to buy additional emission allowances. And if they reduce their emissions, they may sell their surplus allowances.

From 2012 on every international airline with flights from and to the EU area will have to participate in the mandatory EU CO_2 Emissions Trading Scheme. The European Parliament voted in favour of the Aviation Directive during a plenary session on 8 July 2008. The European Council is expected to give its formal approval within the foreseeable future. All EU Member States will then have 12 months to implement the Aviation Directive into national legislation (De Brauw et al., 2008).

There are several reasons for implementation of the aviation in the EU ETS (Zaman, 2008). Firstly, aviation causes about 2% to 3% of global emissions and about 3% of EU emissions - but may have a disproportionately greater effect on climate change than ground-level emissions. In addition, the overall emissions in the EU decreased from 1990 to 2005 (-1.5 to 2% in the EU15, - 7.9% in the EU27), whereas aviation emissions increased by about 90%. Furthermore, flights departing from or arriving in an EU country are now responsible for half of global aviation emissions. For the above reasons the legislation scope applies to every operator of an aircraft which lands at or takes off from an airport within the EU (with a few exceptions). Whether or not the flight is wholly within the EU. Whether or not the operator is licensed within the EU. The legislational scope also apply to the owner of an aircraft in respect of a flight where the operator is not known or is not identified by the owner.

The implementation of the EU ETS will be an incentive for the aviation sector to reduce their greenhouse gases. One of the options to reduce the emissions is the use of low carbon fuels. This may lead to the application of (advanced) biofuels in aviation, especially second generation BTL fuels. However the global availability of these fuels will be limited compared to total demand. As explained in chapter 6 it is most likely that up to 2030 the average global share of biogenic substitutes for middle distillates will be below 3%, whereas the large road transport sector will have a high demand for the same type of fuels. Consequently, the question to what extend these fuels will be applied in aviation will be rather a matter of politics and economics.

5. Biofuels development scenarios

This chapter aims to provide an overview of the expected developments in biofuel production in the Netherlands, the EU and globally. Given policy ambitions and resource potentials in different parts of the world, several studies have proposed scenarios for the development of biofuels in the coming decades. In this section we discuss several of these projections, on the EU/Dutch level and on the global level. The armed forces predominantly use diesel fuel and comparable middle distillate fuels. Nevertheless, the developments in the production of bio-gasoline (alcohol) are also important, since they have a strong impact on the developments in the biodiesel production. Therefore we focus not only on the projected consumption volumes of biofuels but also on the split between use in gasoline and in diesel.

5.1 Scenarios for the EU and the Netherlands

In the preparation of the renewables directive, the EU has commissioned several scenario analyses for attainable levels of biofuels production and consumption in the EU. The ‘Scenarios for energy efficiency and renewables’ (Mantzos and Capros, 2006) contain a high renewables scenario, in which ca 15% of road transport fuel demand by 2020 can be covered by biofuels (with equal shares in gasoline and diesel), increasing to 20% by 2030. This can be considered an upper limit: in the corresponding ‘baseline’ scenario, biofuels reach up to 7% in 2020 and 8% in 2030, again with equal shares in gasoline and diesel.

Other studies indicate that potentially, the EU is capable of producing substantially more biofuels than this. On the basis of trend extrapolations in EU agricultural productivity, and assuming that agriculture in Eastern Europe can reach Western levels of productivity in the coming decades, the REFUEL project states that vast areas of agricultural land will become available for energy crops (Wit et al., 2007). When crops for conventional, first-generation biofuels are cultivated on this land, this area suffices to meet a 10% biofuels target in 2020. However, for higher ambition levels either imports or more land-efficient biofuels are necessary. For example, when advanced, 2nd generation biofuels are introduced, the resource base has been estimated to be sufficient to meet a more than 30% share of biofuels by 2030 (Wit et al., 2007; Londo et al., 2008).

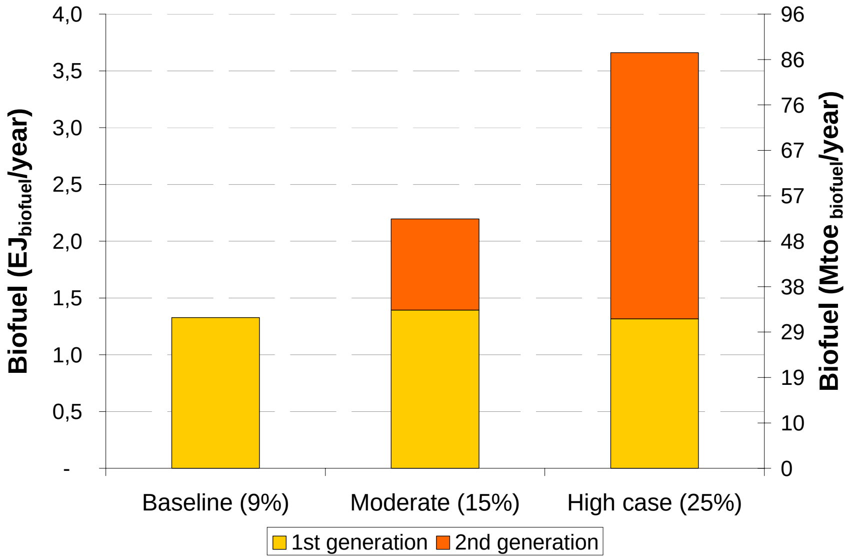

Figure 5.1 *Most cost-effective ways to meet different biofuels targets by 2030. The graph illustrates that higher targets require more land-efficient 2nd generation biofuel production chains.*

Source: Londo et al (2008).

For the Netherlands, the study ‘Welvaart en Leefomgeving’ provides mid- to long-term scenarios for the energy economy (WLO, 2006). The scenarios in this study are roughly in line with the IPCC SRES scenarios, in which globalization versus regionalization and market versus public governance are the distinguishing factors. Within the bandwidth of these scenarios, the study projects a biofuels share in the Netherlands between 2 and 6% by 2040. However, these scenarios did not yet take into account the EU 10% biofuels obligation for 2020.

5.2 Global biofuels scenarios

For projections of the global growth of biofuels, two key sources were consulted: (1) several authoritative publications by the International Energy Agency (IEA, 2008, 2008, 2008), and (2) the most recent global and US projections from the US Energy Information Administration (EIA, 2008, 2009). Both projections are described in detail in the next two paragraphs.

5.2.1 The IEA assessments

The reference scenario in the IEA World Energy Outlook 2008 (IEA, 2008) projects an introduction of biofuels up ca 120 Mtoe (5 EJ) globally by 2030 (see Figure 5.2). The dominant part of almost 100 Mtoe is covered by ethanol, while ca 20 Mtoe of biodiesel is produced and consumed. On average, this corresponds to a global share of biofuels in road transport fuel consumption of just over 5%. Given the ratio between ethanol and biodiesel, the share in gasoline will be substantially higher than for diesel.

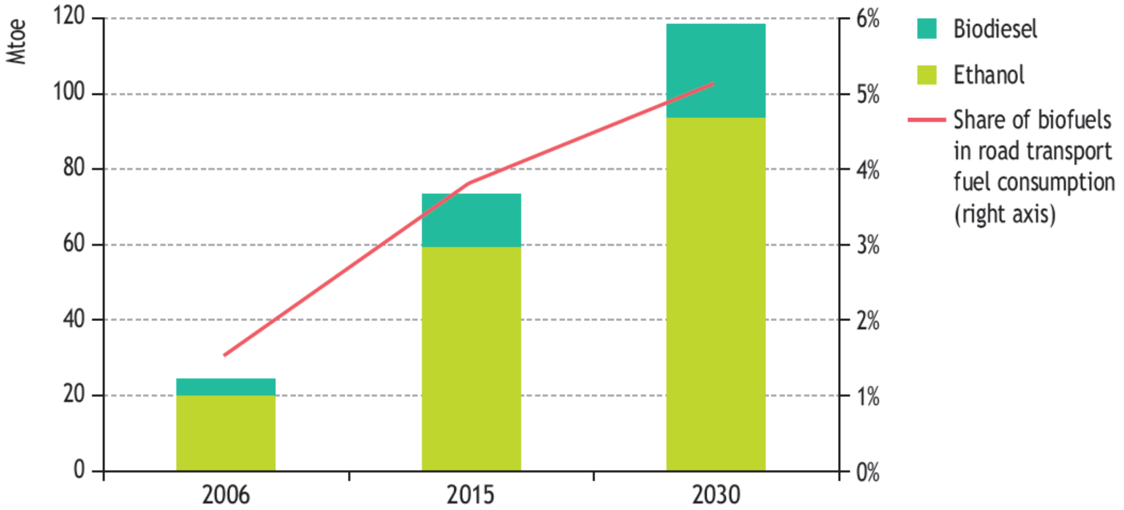

Figure 5.2 *Global biofuels development up to 2030 according to the reference scenario in the IEA World Energy Outlook*

Source: IEA, 2008.

The World Energy Outlook has also analysed two scenarios in which the world agrees on climate change mitigation efforts. In the most ambitious of the two, the ‘450 ppm scenario’, overall greenhouse gas emissions are strongly reduced, and also the share of biofuels increases significantly. This scenario projects an overall biofuels production and consumption of 240 Mtoe (or 10 EJ) by 2030. The additional growth of biofuels is mainly coming from 2nd generation biofuels (IEA, 2008). As total fuel consumption growth in road transport is also dampened by climate constraints, the overall share of biofuels in road transport reaches a level between 10 and 15%.

Comparable biofuel shares can be derived from the IEA Energy Technology Perspectives (IEA, 2008). In this study, the agency further elaborates road maps for the penetration of energy technologies that are essential in a low-carbon future. Its baseline scenario roughly corresponds to the reference scenario in the World Energy Outlook, and this study also assesses two climate-active alternative scenarios. In the ACT map and BLUE map scenarios, 2nd generation biofuels penetrate strongly, particularly after 2030, leading to an overall biofuels production of more than 600 Mtoe (25 EJ) by 2050 (see Figure 5.3 for projected use biomass-based fuels in transport). The balance between 1st and 2nd generation technologies and between gasoline and diesel substitutes is indicated in Figure 5.4: the projection clearly shows that 1st generation technologies are not expected to penetrate strongly: the bulk of long-term biofuels growth comes from advanced, 2nd generation, whole plant conversion processes (cellulosic ethanol production and biomass to liquids (BTL) processes; see Chapter 4 for additional information)

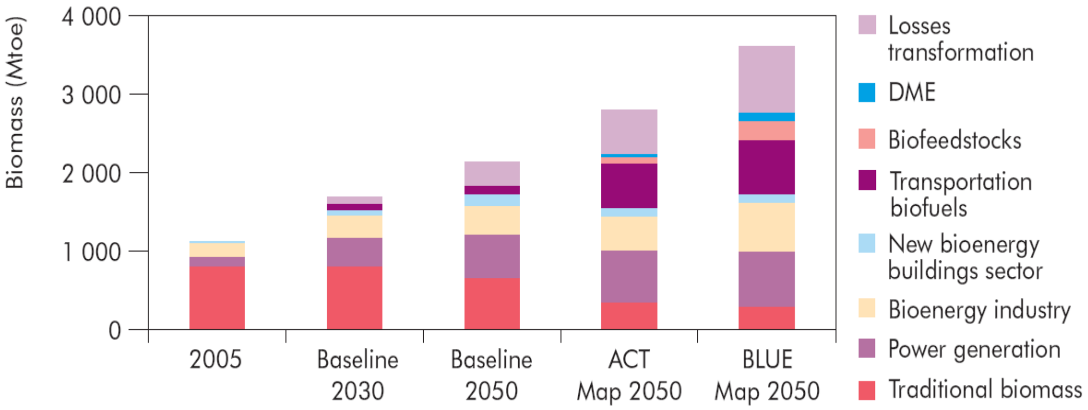

Figure 5.3 *Biomass-based energy applications in different scenarios in the IEA Energy Technology Perspectives*

Source: IEA, 2008

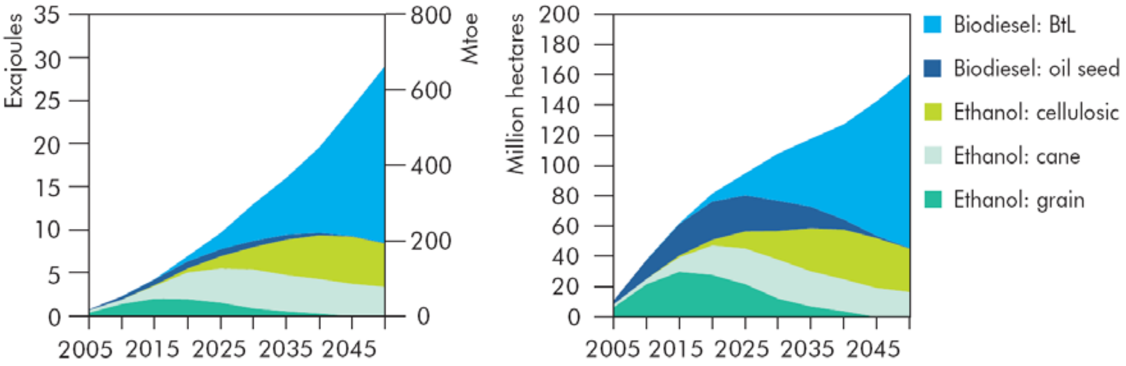

Figure 5.4 *Biofuels demand in the BLUE map scenario (left graph) and corresponding land demand (right column).*

Source: IEA, 2008

The crucial factor in the future development of 2nd generation biofuels is the related conversion technologies being successfully introduced and becoming commercially viable. Currently, both main routes still have their technological challenges (for further details see Chapter 4). For cellulosic ethanol production to become commercially viable, the essential barriers are in (IEA, 2008):

- Pretreatment of lignocellulosic biomass, degrading the closed structure of the material so that the cellulose becomes mobilized.
- Improvement of performance (and reduction of costs) of the enzymes that hydrolyse cellulose into sugars (that can subsequently be fermented into ethanol).

For BTL production, key challenges are to:

- Improve biomass gasification technologies and increase their scale to the levels at which the FT-synthesis process becomes financially viable.
- Improve the cleaning and conditioning technologies.

Nevertheless, several studies (IEA, 2008, 2008; Londo et al., 2008) indicate that 2nd generation biofuels can become commercially viable, not only in competition with 1st generation biofuels but in the long term even in competition with fossil fuels, provided oil prices are around 100 US$ per barrel (see Figure 5.5). Note, however, that biofuel *prices* will not go below the price of fossil oil, as this will remain the dominant (and thereby price-setting) product in the liquid fuel market.

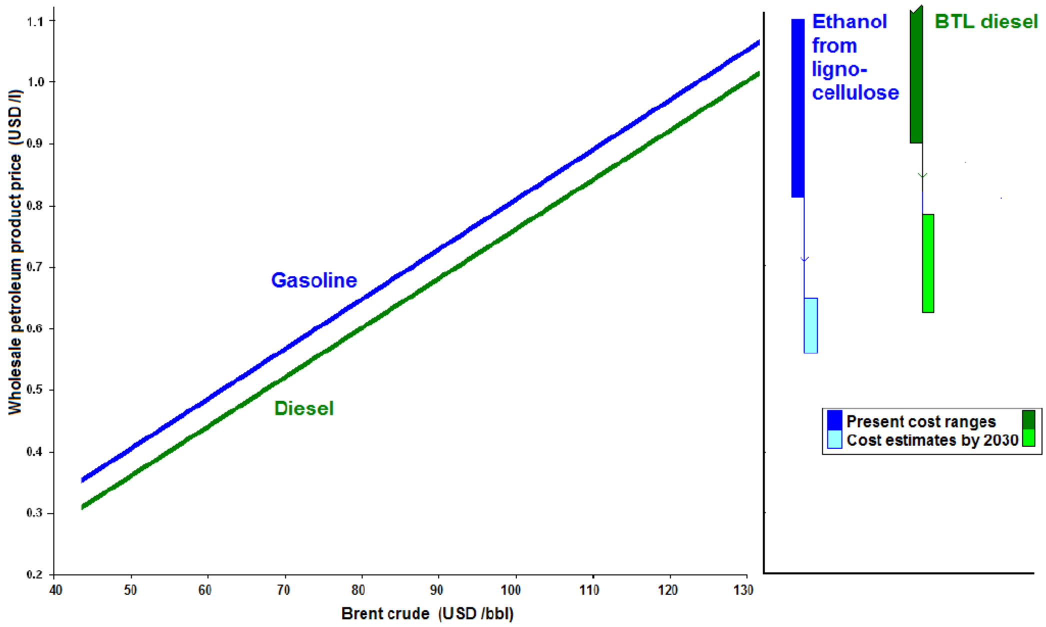

Figure 5.5 *Projected production cost decreases for 2nd generation biofuels, and their future competitiveness against fossil-based liquid fuels*
Note that at oil prices around 100 US$ per barrel 2nd generation biofuels (ethanol and BTL-diesel) are expected to become commercially viable.
Source: IEA, 2008.

5.2.2 The EIA assessments

The Energy Information Administration (EIA) of the United States annually issues an international energy outlook (in autumn) as well as a national energy outlook (in spring). Their most recent international energy outlook (EIA, 2008) projects biofuel developments in the same order of magnitude as the International Energy Agency IEA (see the previous paragraph). In its reference case, the international energy outlook projects biofuels to reach a production volume of 2.7 million barrels oil equivalent per day, corresponding to a 4% share in energy demand for road transport. The study also indicates that future developments in fossil energy prices influence this projection. In the US for example, projected biofuel consumption may range between 27 and 40 billion gallons, depending on optimistic or pessimistic assumptions in future oil prices (EIA, 2008).

The recently published annual energy outlook 2009 (EIA, 2009) projects substantially higher productions of biofuels to be reached, up to a production volume of 5.4 million barrels per day by 2030 in its reference case, or almost 10% of road transport fuels (provided all liquid biofuels are applied in this sector). Again, lower or higher oil price assumptions lead to higher or lower biofuels shares (see Table 5.1), partly due to changing biofuel production, partly due to changing total liquid fuel demand in transport. These higher projections apparently express new policy initiatives in e.g. the EU, in which the 10% renewable fuels obligation was formally adopted in December 2008.

Table 5.1 *Biofuel production volumes and shares in total fuel consumption in road transport by 2030 as producted in the EIA Annual Energy Outlook 2009* (EIA, 2009)

Scenario	Biofuels production [million boe/day]	Total liquid fuel consumption in transport [million boe/day][1]	Biofuels share in road transport energy[2] [%]
Reference	5.4	58	9
Low oil price	3.3	66	5
High oil price	7.7	49	16

[1] Assuming that 55% of total liquid fuel production is applied in road transport (IEA, 2008); boe = barrel of oil equivalent.

[2] Assuming all biofuels are applied in road transport.

Text box : Diesel crunch

Diesel vehicles have a better fuel economy and, therefore, lower CO_2 emissions per kilometre, than petrol vehicles. Over the last two decades, the performance of diesel engines in terms of acceleration and engine power has increased enormously. Present diesel engines have a performance that is comparable to petrol engines. In addition, diesel engines offer better fuel economy and a high torque. Over the past years, the number of diesel-powered vehicles in road transportation, in Europe, has increased enormously and, consequently, so has the demand for diesel fuel.

While petrol demand in the United States is growing, in Europe it has actually declined, since 2000 (See Figure 5.6), at an average of 2.1 percent per year, and the diesel demand has increased by 2.0 percent.

The increasing demand for diesel within the European Union means that there is intense competition for this fuel on the world market. This phenomenon is often called the ‘diesel crunch’. In the short term, additional increased demand for diesel from the Asian developing countries imposes further strains. In Asia, diesel demand has grown at the rate of 2.7 percent, since 2000.

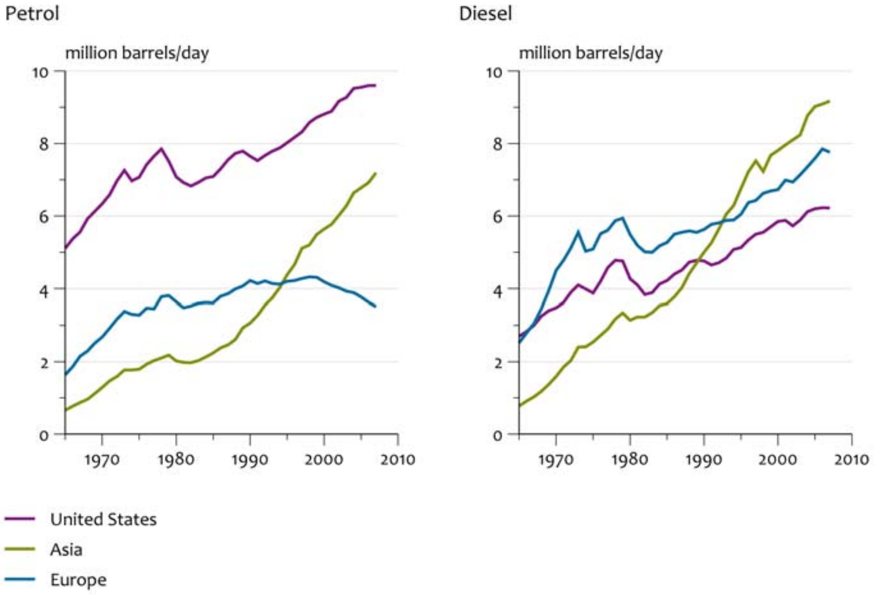

Figure 5.6 *Trends in petrol and diesel demand in the United States, Europe, and Asia (1995-2004)*

Source: BP, 2005.

During the distillation process, refineries produce a full spectrum of refinery products, including light distillates, such as naphtha, LPG and petrol, as well as middle distillates, especially road diesel and jet fuel (see also appendix A). The product mix from the basic refinery process of distillation, cannot be changed. Depending on the crude type, 35 to 60% in residuals remain after distillation. The residual stream can be converted into lighter products, which, to some extent, enables changing the product mix and to increase the diesel production relative to the other refinery products. This diesel increase can be achieved by: (1) increasing the ratio of hydrocracking (diesel production) over cat cracking (petrol production); (2) conversion of heavy residues combined with hydro-treatment; and by (3) producing it from natural gas (gas to liquids). Volumes of this production route are still low, but gradually increasing. The production of more biodiesel would also reduce the diesel crunch.

The European refinery sector has already stretched the diesel production substantially, because of the diesel shortages in Europe. A further increase of the diesel production, thus reducing CO_2 emissions in the transport sector by increasing the share of fuel-efficient diesel cars, can only be achieved at a loss in efficiency and an increase in CO_2 emissions from the refineries.

Some basic calculations with the ECN refinery model Serum indicate that the production of additional diesel by secondary conversion processes will require about twice as much energy, and related CO_2 emissions, compared to the primary distillation process.

This means that a CO_2 saving effect on the road through further dieselisation of vehicles, can be substantially reduced by the increase in refinery emissions, related to the secondary refinery processes for the additional diesel demand. A demand which could not be met by primary conversion processes. Roughly estimated, taking the additional refinery emissions into account, about half of the CO_2 reduction from, increased dieselization would remain (Kroon, 2008).

5.3 Regional variations in production capacity and consumption

The current and expected production and consumption of biofuels are both characterized by large regional variations. The biofuel production varies on a regional and global scale, because of differences in many factors including: agricultural circumstances and related feedstock production (land availability, soil fertility, water availability, climate, food demand etc.); economical conditions; biofuel promoting policies; geopolitical influences etc. The demand for biofuels is influenced by the local production, global markets, as well as by local or regional policies that may boost demand when mandatory biofuel targets have been set, such as in the EU (see paragraph 4.1). As a consequence, the biofuel blending shares can differ greatly between world regions (see Figure 5.7 and Table 5.2). In this respect, potentially higher-blend regions, particularly for FAME biodiesel, could be SE Asia (palm oil, possibly Jatropha), Latin America (soy, although ethanol from cane will be dominant in this region), Sub-Sahara Africa (palm oil, possibly Jatropha). But the odds of blends higher than 10% are relatively small.

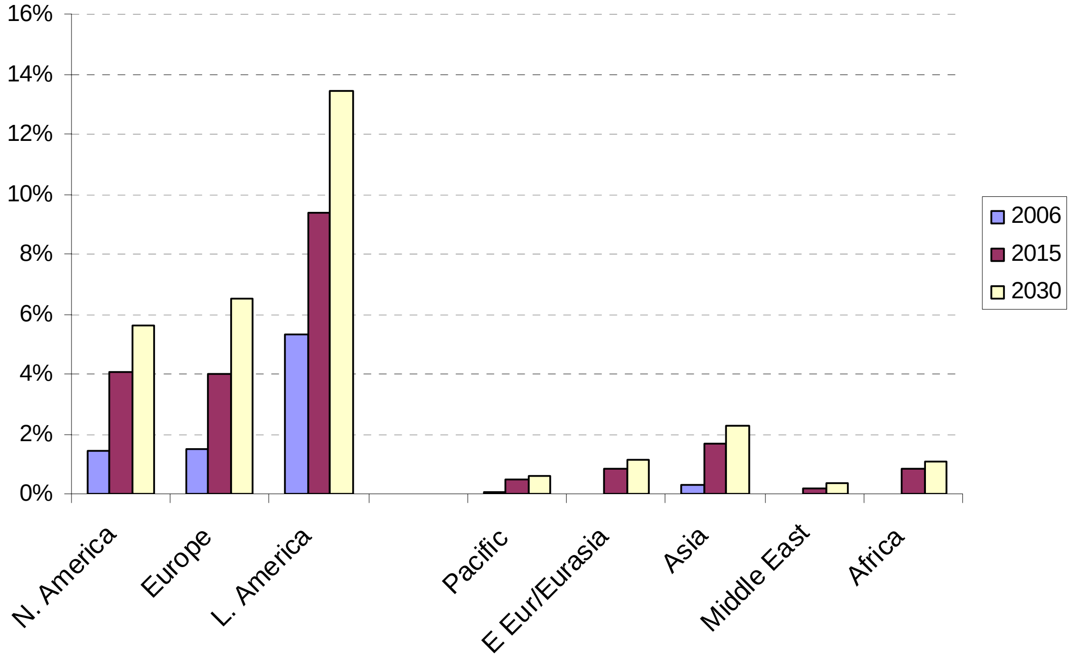

Figure 5.7 *Projected production of biofuels by for various regions*
Source: IEA, 2008

Table 5.2 *Final consumption of biofuels by region in the IEA (2008) Reference Scenario in Mtoe, for the years 2006, 2015, and 2030.*

	2006	2015	2030	2006-2030*
OECD	**16.9**	**49.5**	**72.5**	**6.3%**
North America	11.3	32.9	46.8	6.1%
Europe	5.5	15.8	24.7	6.5%
Pacific	0.1	0.8	0.9	10.3%
Non-OECD	**7.5**	**24.0**	**46.0**	**7.9%**
E. Europe/Eurasia	0.0	1.1	1.5	16.8%
Asia	0.8	7.6	17.9	14.0%
Middle East	0.0	0.3	0.8	n.a.
Africa	0.0	0.7	1.1	n.a.
Latin America	6.6	14.4	24.7	5.6%
World	**24.4**	**73.5**	**118.5**	**6.8%**
European Union	*5.5*	*16.6*	*25.9*	*6.7%*

* Annual average rate of change.

6. Synthesis and projection of future biofuel blends

In the previous chapters it has become clear that the development of both biofuel demand and production depend on many underlying factors that are characterized by large uncertainties. As a result the various projections span a large range. The next two paragraphs provide a synthesis of the main factors underlying future biofuel demand and production, resulting in a projection of the most likely developments in the diesel fuel segment.

6.1 Factors influencing the future global fuel demand

- A key factor, underlying fuel demand, is the expected growth in transport demand for both passengers and freight transport, for all transport modalities. Most scenarios project a rather linear growth of total transport demand, of about 15% per decade, resulting in an approximate doubling of global transport demand by 2050 (e.g. King, 2007).

- At the same time, the fuel demand per transport km will decrease since more fuel efficient technologies are being developed and implemented. This trend is stimulated by policy measures, such as the increasingly stringent EU CO_2 legislation for cars.

- In the short to medium term (up to 2030), corresponding to the time horizon of the present study, the internal combustion engine will likely remain the dominant propulsion source in transport (see e.g. King, 2007 and Figure 6.1). Further incremental improvements of conventional ICE technologies and additional fuel saving technologies, could result in maximum efficiency gains in the order of 50%. These improvements are expected to be most effective in fuel savings in the passenger transport segment. On balance, improved efficiency in the transport sector could at best result in a stabilization of the fuel demand for the next two decades, compared to the present situation. Consequently, it is highly unlikely that the global demand for transportation fuels will decrease till 2030. More likely demand will still steadily increase, especially due to strong increase in demand by rapidly developing countries such as India and China, in line with many scenarios, such as the World Energy Outlook scenario’s from the IEA (2008).

- In the long term (2040 and beyond), the transport sector faces the major climate change challenges, in order to prevent excessive global temperature rise. Taking an equal share in greenhouse gas reductions, compared to other sectors, the transport sector should reduce its emissions with 65 to 95%, compared to 2000 levels, especially since the transport volume is expected to double between 2000 and 2050[2]. This reduction can only be achieved with drastic changes on several fronts, including: (1) substantial changes in travel behaviour, travel demand and public acceptance; (2) availability of zero-carbon or low-carbon fuels; and (3) availability of advanced vehicle technology. The low carbon technology will be very important. For passenger car transport, both electricity and hydrogen - in combination with Battery Electric Vehicles (BEVs) and Fuel Cell Electric Vehicles (FCEVs) - have the potential to substantially reduce the demand for transportation fuels and will therefore also strongly influence the global demand for biofuels. However, the main impact of these developments is expected after 2030 (see Figure 6.1), thus outside of the main scope of the current study.

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[2] The global CO_2 reduction targets for 2050, required to keep the temperature increase below two degrees as advised by Stern (2006) and IPCC (2008), respectively, results in emission reductions of 65-95% for the transport sector; taking into account the expected doubling in transport volume (King 2007), and assuming an equal share of emission reductions over all sectors.

- As described in the previous chapters, and in the complementary study by TNO, the first generation (FAME) biodiesel constitutes the main risk factor for military operations. Since petrol is hardly used for military purposes, operational problems to the use of alcohol as a petrol substitute are much less important. It is important however to realize that the (future) split in demand for diesel fuels vs. petrol, also affects the demand for their biofuels substitutes. Over the last decade, especially in Europe and Asia, the demand for diesel is rising, and this trend is expected to continue (see also textbox on Diesel Crunch). Consequently this trend will also increase the relative demand for biodiesel over bio-petrol (alcohol). On a regional scale these effects may be important. On the global scale, however, the shift in demand will be less severe, and most scenario's do not project a major shift in the production ratio of biodiesel versus bio-alcohol. Ethanol/diesel ratio's are projected to shift only slightly from the present ratio of about 4:1.

In summary, we conclude that the global fuel demand for both diesel and petrol is expected to increase gradually up till 2030, with the diesel demand projected to grow slightly faster than the petrol demand.

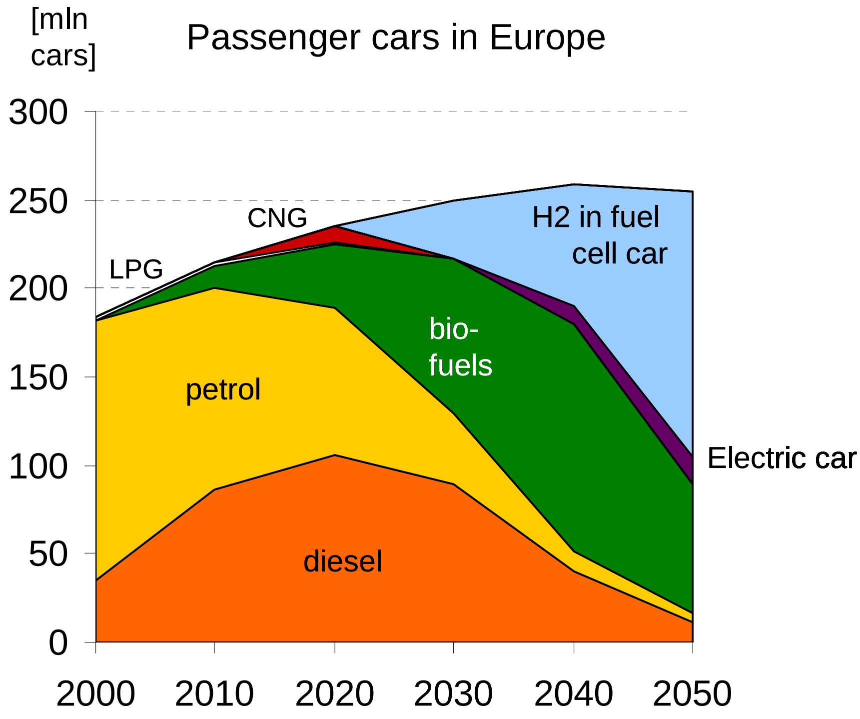

Figure 6.1 *Projected development of vehicle types in Europe in a scenario with intensive climate policy and high oil prices.*

Source: Uyterlinde et al (2007).

6.2 Factors influencing the future global biofuel production:

Currently, on a global scale, less than 2% of the fuel demand in transport is met by biofuels. North America is the world's largest consumer of biofuels, given its huge increase in demand over the past few years, followed by Latin America and the EU. More than 80% of the global biofuel production (on an energy basis) is met by bio-alcohol, whereas less than 20% is met by biodiesel. This means that the current global average biodiesel blend percentage is less than about 0,5%. On a global scale, the ratio of bioethanol over biodiesel over the next two decades is expected to only marginally change towards more biodiesel (IEA, 2008).

Key scenarios projecting biofuel production up to 2030 (IEA, 2008; EIA, 2008) indicate that the global biofuel production until 2030 will increase by a factor of 3 to 4, towards about 120 Mtoe (Mton Oil equivalents; about 5 EJ). This biofuel production is by that time still expected to be divided over 80% bioethanol and 20% biodiesel (on an energy basis). Even in the most ambitious scenario for biofuels, the so called '450 ppm scenario[3]' (see Paragraph 5.2.1), the overall projected biofuel production and consumption of 240 Mtoe (or 10 EJ) by 2030, will not equal more than 10 to 15%[4]. Also in this scenario the projected relative share of biodiesel is only about 20%, equaling an overall global share of biodiesel in blends of only about 2-3%. The gradual increase in biodiesel production is after 2020 expected to be predominantly met by 2nd generation Fischer Tropsch Diesel, characterized by superior fuel specifications. After 2020 the global production capacity of FAME is expected to remain roughly constant, implying that the relative share of FAME will gradually decrease as a result of increasing total fuel consumption.

The above paragraph focuses on the global average situation. However, with especially the US consuming large amounts of bio-ethanol, the relative share of biodiesel will be larger in other regions of the world. Consequently, locally, higher blends of biodiesel could develop, due to local production and/or by imports sustained by policy measures. As already explained in the previous chapters, the EU is projected to have a relatively high biodiesel share. Up to 2020 the biodiesel fraction in commercially available diesel in the EU is likely to grow from a few % at present, up to about 7-10%. It is highly unlikely, however, that the FAME concentration will increase above 10%; most likely the average FAME % in biodiesel blends will not increase above 7% (Verbeek et al, 2008). In addition, the gradual expansion of HVO (first generation biodiesel of much higher quality than FAME; see Paragraph 3.2.2) may further reduce the relative share of FAME in biofuels blends. After 2020, the expected further growth in biodiesel production will be met by advanced 2nd generation BTL diesel, which will not negatively impact the quality of the diesel blend. On the contrary, BTL diesel will have superior specifications for most applications, as compared to fossil diesel fuel. Given the low biodiesel availability on a global scale, compared to the global diesel demand, it is unlikely that many 'hotspots' of locally high FAME concentrations in diesel(blends) will develop. As explained above, the EU can actually be regarded as a local hotspot. It is therefore unlikely that FAME concentrations in many other parts of the world will be higher for the foreseeable future. The only exception may some regions in SE Asia, were the FAME percentage in locally available biodiesel blends may become higher than 10%, especially resulting from local production.

In summary we conclude that the fame percentage in the EU is likely to increase up to around 7% till 2020. It is unlikely that the percentage of FAME in commercially available biodiesel blends will increase above 10%. After 2020 the biodiesel fraction in blends may further increase, but this demand will most likely be met by the production of advanced high quality 2nd generation BTL diesel, thereby not reducing the fuels quality, also not for military applications. The relative share of FAME in biodiesel blends is expected to decrease gradually after 2020, as a result of increasing total fuel consumption, at constant or declining global production capacity.

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[3] The BLUE scenarios in the IEA's Energy Technology Perspectives publication of 2008 describe pathways to reach a long-range CO_2 concentration of 450 ppm in the atmosphere.

[4] Note that the relative share of biofuels in the transport sector in the 450 ppm scenario increases more than linear with production, since the total fuel consumption in this 'ambitious' greenhouse gas reduction scenario is also dampened by climate constraints and associated additional fuel savings.

7. Conclusions

Ground fuels

First generation FAME (fatty acid methyl ester) biodiesel blends impose by far the largest risks for application in the military environment because: (1) diesel (and other middle distillates) are the fuels that are predominantly used by the armed forces for ground use; (2) the commercially available FAME blended diesel has several characteristics that do not meet the strict fuel requirements for military applications, especially regarding long term stability, viscosity, corrosive behaviour and lower energy density; (3) blend percentages of FAME biodiesel in commercially available fuels are increasing, thereby increasing the risks for military application.

We conclude that the FAME percentage in the EU is likely to increase up to around 7% until 2020. It is unlikely that the share of FAME in commercially available biodiesel blends will increase above 10%. After 2020 the biodiesel fraction in blends may further increase, but this demand will most likely be met by the production of advanced high quality 2nd generation BTL diesel, thereby not reducing the fuel quality, also not for military applications.

As a first generation alternative to FAME biodiesel, hydrogenated vegetable oil (HVO) is expected to gain an increasing market share, especially in the time window 2015- 2020. HVO has much better specifications than FAME and can be blended with fossil diesel at higher volumes. However, HVO is still dependent on vegetable oils as feedstock.

In contrast to FAME, advanced second generation biomass to liquids Fischer-Tropsch diesel has comparable or even better specifications than conventional diesel. This superior fuel is however not expected to be blended in substantial quantities before 2020.

The global fuel demand for both diesel and petrol is expected to increase gradually up till 2030, with the diesel demand projected to grow slightly faster than the petrol demand.

From a global perspective, it is most likely that up to 2030 diesel blends will on average only contain a minor fraction of 1st or 2nd generation biodiesel (~below 3%). The main reason is that biofuel substitutes for petrol are expected to maintain their substantially larger market share (~80% of total biofuel production), compared to diesel substitutes.

Aviation and shipping fuels

The superior physical-chemical characteristics of second generation Fischer-Tropsch middle destillates, also imply that these fuels, with minor modifications, can be safely applied as kerosene substitute in aviation. Currently, because of the risks related to FAME blending, diesel fuel is strictly separated from jet fuels. Since the global availability of future advanced middle distillate biofuels, suitable for aviation, will be limited compared to total demand, the potential introduction of biofuels in aviation will largely depend on economical and political factors.

At present no biodiesel is blended into marine diesel fuels. Given the limited global availability of biofuels worldwide, especially in the diesel segment, it is unlikely that biofuel blending in shipping diesel will emerge rapidly. If biodiesel will be blended through shipping fuels at all it will probably blended through the ‘lightest’ type that is most comparable to road diesel: marine gas oil (MGO). Locally, it is however possible that FAME biodiesel blends will commercially available for shipping, especially in some high FAME production regions in SE Asia.

Other considerations

With the increasing growth rates and ambition levels, the societal debate on biofuels is also becoming increasingly strong. Issues like feedstock availability, competition with food, environmental impacts and implementation issues can strongly influence the long-term perspectives for biofuels.

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Appendix A Basic information on oil refinery

A refining diagram is presented as Figure A.1 (taken from De Wilde et al, 2007). Crude oil enters the atmospheric distillation process, where it is heated. Lighter products, such as petrol and diesel fuel, evaporate because they have a lower boiling point and are, in this way, separated from the heavy products. The heavy residue (atmospheric residue) can then be: (1) used directly as heavy fuel oil or (2) distilled a second time under low pressure (vacuum distillation). During vacuum distillation, a part of the residue will then be evaporated (vacuum gas oil) and another part will remain in the bottom of the tower (vacuum residue). Atmospheric residue and vacuum residue are the raw materials for heavy fuel oil (HFO), otherwise known as bunker oil.

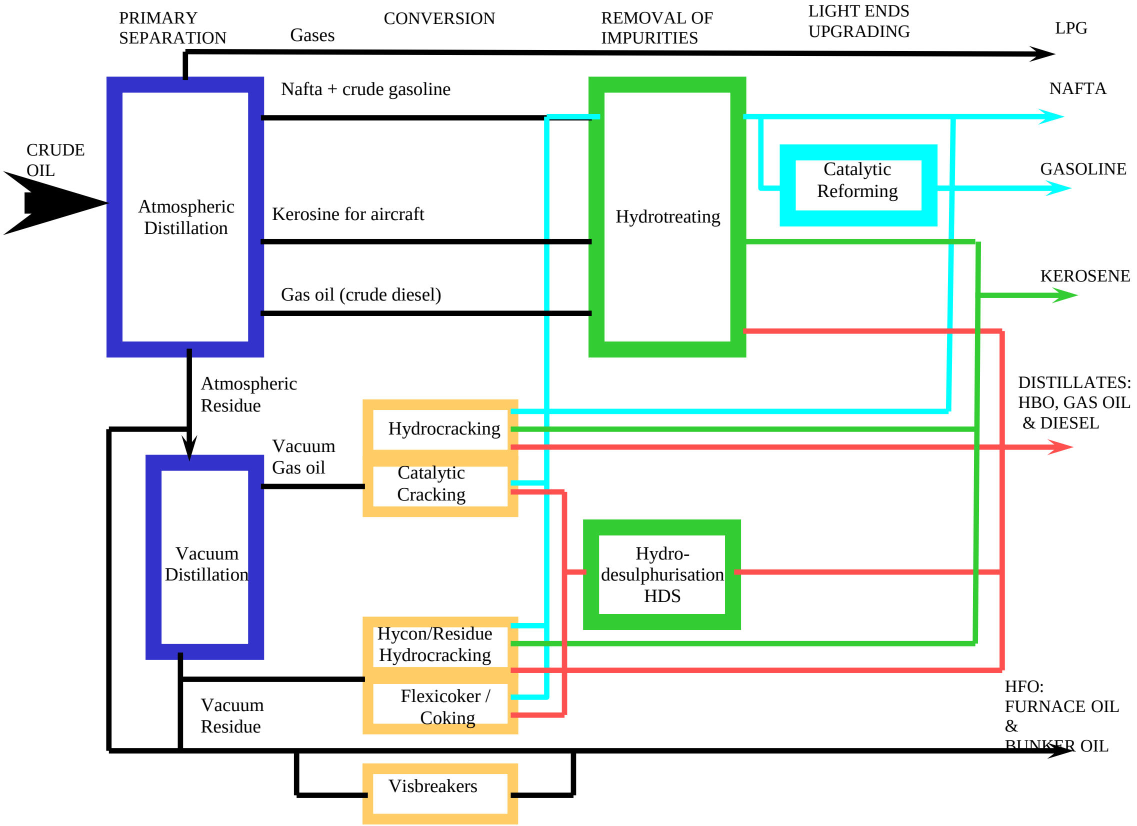

Figure A.1 *Diagram of the refining process*

The intermediate products form the distillation process need to be further upgraded. Hydrocrackers are used to make a good quality diesel fuel by adding hydrogen. There has been a great deal of investment in hydrocrackers in Europe. Catalytic crackers (otherwise known as ‘catcrackers’) are used to make petrol from (vacuum) gas oil. A part of the vacuum gas oil can also be used directly as distillate fuel for ocean-going vessels.

It is also possible to convert vacuum residues, characterised by a high carbon/hydrogen ratio, into lighter products. This involves processes in which heavy residues are transformed by: (1) separating out carbon, as done in the flexicoker procedure at Exxon Mobil, or (2) adding hydrogen, as is the case in the hycon procedure at Shell. Both procedures not only produce distillate/gas oil but also other products, such as kerosene and petrol.

Refining capacity in the Netherlands

As of 1 January 2005, the worldwide refining capacity was 82 million barrels per day (Oil & Gas Journal, 2006; BP gives a higher figure on its site: 85.7 million barrels per day). The Dutch share amounted to approximately 1.6%. The VNPI (Vereniging Nederlandse Petroleum Industrie; Netherlands Petroleum Industry Association) expects 3% annual growth until 2010/2012. Of the 66 million tons of refining capacity, 58 million are located in the Rotterdam port area (see also Figure A.2).

Refining capacity is geared to volume of 'regional demand'

In Europe, there is both a shortage of kerosene, which is imported from the Middle East, and a shortage of diesel fuel, which is imported from Russia, the US and other countries. A surplus of petrol is exported to the US. The shipment of products is, in most cases, more expensive than the transportation of crude petroleum because smaller ships are used. For this reason, primary capacity and throughput in refineries are partly determined by local demand.

In Europe, bio-fuels are on the upswing. In principle, this will decrease the growth in demand for petroleum-based fuels in our region. This will also curtail the readiness to invest in new capacity. If refineries nevertheless invest in capacity expansion, the result will likely be a surplus of capacity, making it less attractive for others to do the same. Guaranteed regional sales across the entire spectrum of light products (including petrol) will make expansion into strong growth markets, such a Southeast Asia, more appealing to refining companies than enlargement of their facilities in the Netherlands. Conversely, refineries will, to a large extent, be able to focus on maximising production of diesel fractions for which there is a large demand in Europe. This will, however, require additional investment in such items as hydrocracking capacity and possible divestment of the existing capacity in catcrackers.

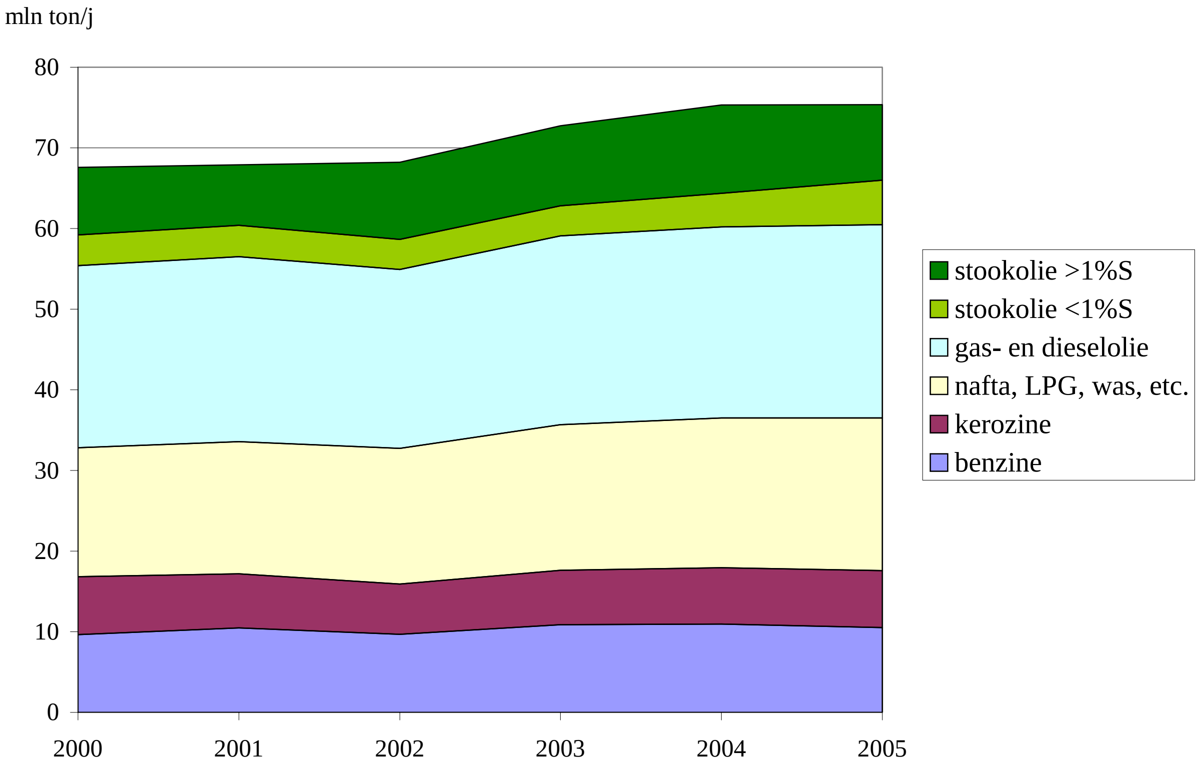

Figure A.2 *Gross production of Dutch refineries until 2005.*

Source: De Wilde et al., 2007.

Appendix B Overview of aviation fuel additives in common use

The website www.csgnetwork.com, visited in May 2009, provides the following overview of fuel additives in common use:

1. Anti-knock additives reduce the tendency of gasoline to detonate. Tetra-ethyl lead (TEL) is the only approved anti-knock additive for aviation use and has been used in motor and aviation gasolines since the early 1930s.

2. Anti-oxidants prevent the formation of gum deposits on fuel system components caused by oxidation of the fuel in storage and also inhibit the formation of peroxide compounds in certain jet fuels.

3. Static dissipater additives reduce the hazardous effects of static electricity generated by movement of fuel through modern high flow-rate fuel transfer systems. Static dissipater additives do not reduce the need for `bonding' to ensure electrical continuity between metal components (e.g. aircraft and fuelling equipment) nor do they influence hazards from lightning strikes.

4. Corrosion inhibitors protect ferrous metals in fuel handling systems, such as pipelines and fuel storage tanks, from corrosion. Some corrosion inhibitors also improve the lubricating properties (lubricity) of certain jet fuels.

5. Fuel System Icing Inhibitors (Anti-icing additives) reduce the freezing point of water precipitated from jet fuels due to cooling at high altitudes and prevent the formation of ice crystals which restrict the flow of fuel to the engine. This type of additive does not affect the freezing point of the fuel itself. Anti-icing additives can also provide some protection against microbiological growth in jet fuel.

6. Metal de-activators suppress the catalytic effect which some metals, particularly copper, have on fuel oxidation.

7. Biocide additives are sometimes used to combat microbiological growths in jet fuel, often by direct addition to aircraft tanks; as indicated above some anti-icing additives appear to possess biocidal properties.

8. Thermal Stability Improver additives are sometimes used in military JP-8 fuel, to produce a grade referred to as JP-8+100, to inhibit deposit formation in the high temperature areas of the aircraft fuel system

Appendix C Potential contamination of jet fuel with biodiesel

This appendix provides information on the potential contamination of jet fuel with biodiesel, based on two literature sources from the UK.

Background

The shipment of biodiesel fuel through multiproduct distribution systems - pipelines, ships, barges, etc. - is now a common occurrence in Europe and is increasing in other parts of the world. Pipeline trials have shown that the bio-component, FAME (Fatty Acid Methyl Ester), can adhere to metal surfaces and be subsequently desorbed by a following jet fuel parcel, thus contaminating it with low levels of FAME. Thus, fuel handling operations need to be carefully controlled and measures introduced to ensure that such cross-contamination is avoided as far as is practicably possible. However, it is recognised by the industry that trace levels of FAME will inevitably find their way into jet fuel and, as its presence in jet fuel is not approved by the aircraft engine and airframe manufacturers (OEMs), a programme of work is required to demonstrate that the presence of FAME in jet fuel will not compromise aircraft safety nor adversely affect aircraft operation.

To avoid supply disruption at airports, fuel supply companies, via the Joint Inspection Group Product Quality Committee, have been working with the OEMs (including GE, Pratt & Whitney, Rolls Royce, Honeywell, Snecma, Airbus and Boeing) to establish and conduct a testing programme aimed at the approval of 100 mg/kg FAME in aviation turbine fuel. This work has been formalised as an Energy Institute Joint Industry Project, established at the request of the members of the JIG PQ committee, to provide the framework to facilitate the testing required by the OEMs and progress it to conclusion (Joint Inspection Group, 2008)

Carryover of FAME in multi product pipelines

Information Statement on the Carryover of FAME (Fatty Acid Methyl Ester) In Trace Quantities During Transportation Through Multi Product Pipelines (Ministry of Defence, 2008)

Biodiesel containing FAME was first introduced into Multi Product Pipelines (MPPs) in the UK cotransporting jet fuel in 1995. Initially, the available analytical methods at that time indicated no detectable trail back of the FAME component into following jet fuel batches and consequently pipeline sequencing operations were not altered based on these data.

However, with significant advances in experimental analytical techniques, was detected in interface samples in 2006 prompting both refinement of the analytical methods and a further controlled pipeline trial in 2007. This controlled trial demonstrated that low level trail back of the FAME component from biodiesel into a following jet fuel batch can occur at detectable levels. In the absence of reliable data on historical trace level FAME carryover in MPPs, the initial fuel supply industry advice required revision of the sequencing of batches of biodiesel and jet fuel by employing a non-aviation buffer material between the products.

Subsequently the Joint Inspection Group Ltd. (JIG) issued a detailed guidance bulletin (Number 15) (www.jointinspectiongroup.org) in November 2007 for the fuel supply and distribution industry. Careful control of a combination of sequencing, batch size and interface management can be used to ensure the level of FAME trail back into jet fuel is below this detection limit.

Operators of multiproduct handling systems should also verify that bulk contamination, even at very low levels (e.g. 0.01%), cannot occur.

Whilst pipeline operators and fuel distributors will need to go through a management of change activity that will involve some testing for low level FAME using the new analytical tests, it is not envisaged that routine testing of every batch will be required for two primary reasons. Firstly, the general consistency of bulk fuel distribution operations provides surety that once initial conditions have been tested and shown to provide the necessary control of FAME, only periodic confirmatory testing should be needed. Secondly, management of change systems shall be employed to ensure that any significant alteration to the distribution operation is appropriately controlled and further FAME testing is triggered to verify the new mode of operation. The sophisticated analytical techniques used to detect the low levels of FAME are neither simple to run and interpret nor readily available. There are currently no precision data for these methods.

Based on learning from an incident in the UK, it is important to note that testing activities conducted to verify the effectiveness of QA procedures should focus on the final batch tanks where jet fuel leaves a multiproduct handling system. The handling system downstream of the tested tank should be completely segregated from diesel containing FAME and there must be no risk of any other contamination mechanism. If this is not the case and downstream segregation cannot be guaranteed then FAME testing to verify downstream operations should be performed. See JIG Bulletin 16 for further details and guidance.

The less than 5 mg/kg approval is granted on the basis that the aviation petroleum industry is working towards an approval of 100 mg/kg FAME in jet fuel under the guidance of the engine and airframe OEMs and that the ASTM protocol for additive and alternative fuel approval shall be followed.

Appendix D Background information ECN

ECN : Innovations for Sustainable Energy

The Energy research Centre of the Netherlands (ECN), one of the leading energy R&D institutes in Europe, is the largest research centre in the Netherlands in the field of energy. At this moment ECN employs about 900 people. ECN is at the cutting edge in the development of new technologies that meet tomorrow's energy demands and ECN brings this high standard knowledge and technology to the market.

The aim of the research program is threefold: a substantial lowering of the energy demand through energy conservation, a rapid growth of the use of renewable energy and the efficient and clean use of the remaining fossil fuels.

On the subject of energy conservation ECN is working on separation technology, heat storage, heat pumps and heat management, process intensification and building energetics. The research on renewables focuses on solar, wind and biomass, while the clean fossil fuels subjects are carbon capture, hydrogen and fuel cell research. The activities cover the whole range from fundamental research in collaboration with universities till applied development together with industry.

ECN is partner in large European projects and executes contract research for government and industry. The turn over is about € 75 mln of which 50% is from international origin. At this moment ECN employs about 630 highly qualified people.

How can we provide the world with sustainable energy? The Energy research Centre of the Netherlands works continuously to address this problem. ECN is active within the transition area between fundamental research carried out by universities and the application of knowledge within the market. And it is successful, as reflected in the growing number of assignments we receive from the government and industry.

At ECN the researchers move between fundamental research at universities and appliance of knowledge and technologies in practice. This work has a huge impact on daily life. For example, solar systems are placed on roofs of houses and modern wind mills are spinning in the field by means of technology developed by ECN. With this the institute exerts an important function for the society of today and tomorrow.

ECN focuses on the knowledge and information required by the government to develop and evaluate policies and to achieve policy objectives in the field of energy, the environment and technological innovation.

ECN works together with national and international industry in the development and implementation of products, processes and technologies important for the transition to a sustainable energy system.

ECN closely cooperates with Dutch and foreign universities and research institutes and performs a bridging function towards implementation by carrying out technological research.