January 2003 ECN-C--03-008

AN OVERVIEW OF BIOFUEL TECHNOLOGIES, MARKETS AND POLICIES IN EUROPE

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Acknowledgement

This report gives an overview of current developments with regard to biofuel technologies, the European biofuel market, and national and European biofuel policies. The authors would like to acknowledge the valuable comments from T.J. de Lange and P. Kroon (ECN Policy Studies), H. Boerrigter (ECN Biomass), F. Goudriaan (Biofuel), and B. Wagenaar (BTG).

The project is registered at ECN under project number 7.7449.02.01.

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Abstract

For fuels produced from biomass, various conversion routes are available that follow from the different types of biomass that can serve as a feedstock. These conversion technologies are discussed in both technological and economic terms. For each route, the fuel characteristics of the biofuel are described and compared to those of the fossil fuel it can replace, either petrol or diesel. Currently, the European biofuel market only consists of biodiesel (e.g. Rapeseed Methyl Ester, RME) and ethanol (and its derivative ETBE). The production and application of these biofuels is discussed for the most important biofuel countries in the European Union and the countries in which the use of biofuels is less developed. The report also describes national and European policies aimed at stimulating the production and application of biofuels. There is a special focus on two European Directive proposals on the promotion of the use of biofuels in transport and the process towards adoption of these Directives.

CONTENTS

SUMMARY

The use of biofuels in automotive engines has been known for a long time, but in Europe the production and use of these fuels has been developing more seriously only just the past five to ten years. This is partly due to European and national environmental policies aiming at the reduction of CO_2 emissions. Biofuels are an important technology for reducing the emissions in transport, as they do not lead to any additional CO_2 emissions released to the air, apart from the emissions due to production and transport of the biomass and biofuels.

For fuels produced from biomass, various conversion routes are available that follow from the different types of biomass feedstocks. These routes include direct conversion processes such as extraction of vegetable oils followed by esterification (biodiesel), fermentation of sugar-rich crops (ethanol), pyrolysis of wood (pyrolysis oil derived diesel equivalent), and HydroThermalUpgrading (HTU) of wet biomass (HTU oil derived diesel equivalent). Another possibility is to produce liquid biofuels (methanol, DME, Fischer-Tropsch liquids) from synthesis gas, which results from gasification of biomass. Most of these biofuels will not be commercially available on the short term. Although insights on technological and cost developments and the expected commercial availability of these biofuels are changing continuously, it can be stated that these biofuels will probably not be produced and applied on a commercial scale before 2010. Currently, only ethanol (and its derivative ETBE) produced from food crops and biodiesel (mainly Rapeseed Methyl Ester, RME) are applied on a commercial basis on the European market. They will remain the dominant biofuels in the coming decade, as alternative biofuel technologies are still in the development stage.

At present, the biofuel producing countries in the European Union only have a small share in global production of biofuels, namely a little less than 6%. Most of the global biofuel production consists of ethanol. The main ethanol producers are the USA and Brazil, whereas the share of Europe is rather small. However, Europe is the most important producer of biodiesel on the global market. As from the year 1993, the European production level of biodiesel increased by almost ten times, from 80,000 tons in 1993 to 780,000 tons in 2001. Germany is the leading European producer, followed by France, Italy and Austria. Throughout the European Union, biodiesel is applied in automotive engines in various blends with regular diesel. In Germany, Austria and Sweden, it is used in pure form in adapted captive fleet vehicles. The European production of ethanol for application as an automotive fuel grew by 4.5 times as from 1993, namely from 47,500 tons in 1993 to 216,000 tons in 2001. France, Spain and Sweden are the main players on the European ethanol market. Ethanol may be applied in blends with petrol or in pure form in adapted vehicles. In France, the produced ethanol is mainly converted to ETBE, which is used as an oxygenate for petrol. In the other nine EU Member States, the application of biofuels in still in an experimental phase.

Although the importance of the use of biofuels in transport has already been stressed in the EU White Paper on renewable sources of energy (1997) and the Green Paper on a European strategy for the security of energy supply (2000), this has not led to the development of concrete biofuel-specific national policies in many EU Member States. Some countries support the use of biofuel by exempting them from excise duties or environmental taxes. However, in June 2001, the discussion on biofuels did result in two EU Directive proposals on the promotion of biofuels. The first draft Directive obliges the EU Member States to sell a certain amount of biofuels on their national markets in the period 2005 - 2010. In order to support this, the second draft Directive provides the opportunity to the Member States to adjust their national excise duty systems for automotive fuels in favour of biofuels.

1. INTRODUCTION

The use of biofuels in automotive engines has been known for a long time, but in Europe the production and use of these fuels has been developing more seriously only just the past five to ten years. In the development of the engine in late nineteenth century biofuels (ethanol) were used for experiments (EurObserv'ER, 1999). During the twentieth century other fuels, namely petrol and diesel derived from crude oil, developed so strongly that biofuels were only used on a very small scale in the transport sector. A reason for the dominance of fossil fuels in this sector is the large and cheap supply of its main feedstock, crude oil. Nowadays, petrol and diesel are still the most common fuels used in vehicles but the (experimental) application of biofuels has been expanding, which is partly due to European and national environmental policies.

This report provides an overview of current developments with regard to biofuel technologies, the European biofuel market and national and European policies aiming at the promotion of the use of biofuels in transport. In this Chapter, first the reasons for the recent serious development of the production and use of biofuels will be given. Next, the different types of biofuels that will be discussed in this report will be marked out.

1.1 Drivers behind the renewed interest in biofuels

As it is common these days to use petrol or diesel as a transportation fuel, this was even more the case in the 1960s. In the 1970s, two Oil Crises and the Report by the Club of Rome on the depletion of certain (energy) resources created a growing awareness that natural resources, like oil and gas, are exhaustible and should be used with care. A second insight that arose in this period was that the countries that did not have a large supply of natural resources at their disposal were largely dependent on the countries that did have access to this large supply. Most of the countries belonging to the latter group are organised in the Organisation of Petroleum Exporting Countries (OPEC). At the other side, there is the International Energy Agency (IEA), in which the countries that do not have access to a large supply of natural resources are united. This Agency was founded in 1974 as a part of the OECD with the goal to reduce the dependency on energy imports from the OPEC countries. To realise this goal, the IEA set up IEA Bioenergy in 1978. This was to improve co-operation and information exchange between countries that had national programmes in bio-energy research, development and deployment (Internet source 21).

Biofuels are part of these research programmes, but the research and development activities with regard to biofuels were not only based on reducing the oil-dependency but also on product improvement and environmental issues. Concerning product improvement, biofuels have been used as additives to improve the quality of fuels applied in road vehicles. The increasing application of biofuels in transport was also stimulated by environmental goals on carbon dioxide (CO_2) emissions that were set by national governments and international agreements, such as the Kyoto Protocol (1997).

Despite energy efficiency improvements, the energy demand of the European transport sector is expected to grow substantially the next decades, thus leading to increasing CO_2 emissions. Biofuels can play an important role in reducing these emissions because their 'well-to-wheel' CO_2 emissions are much lower than those of fossil fuels. This is explained in Figure 1.1.

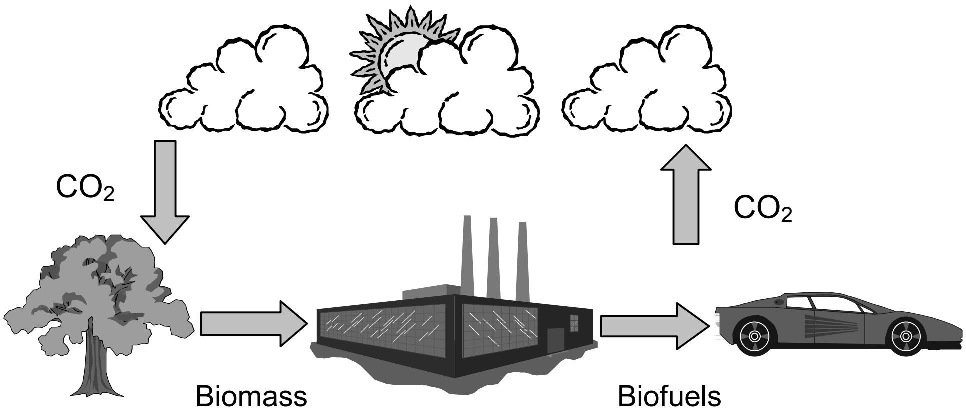

Figure 1.1 *Biofuels as 'climate-neutral' fuels*

Biofuels are produced from biomass. Biomass denotes plant materials that are part of the short carbon cycle. This means that the CO_2 that these crops take up from the air during their life for their growth by means of photosynthesis returns to the atmosphere when they are converted into energy. In order to be able to speak of a 'renewable' energy source, the stock of biomass must at least be kept constant. Because no net CO_2 emissions are released to the air - apart from the emissions due to production and transport of the biomass and biofuels - biofuels can be considered 'climate-neutral'.

1.2 Biofuel conversion routes

In this overview, only liquid biofuels that can be used as substitutes for petrol and diesel in combustion engines will be described. Figure 1.2 shows the conversion routes for the most important automotive fuels and the biofuels that will be discussed in this report.

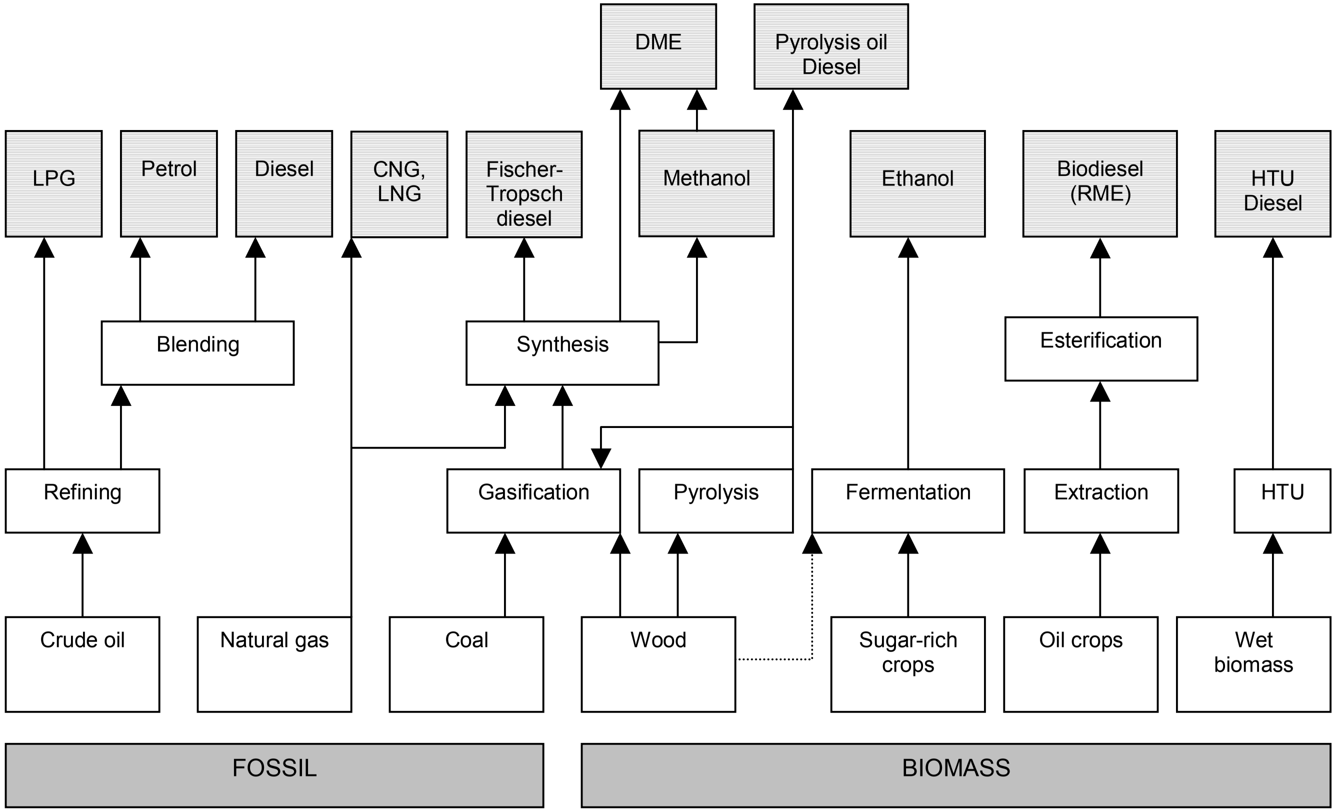

Figure 1.2 *Overview of automotive fuel conversion routes (based on figure from Internet source 1)*

As said in the introduction, petrol and diesel produced from crude oil are presently the dominant automotive fuels. LPG (Liquefied Petroleum Gas), a by-product of processing of crude oil, and natural gas, in the form of CNG (Compressed Natural Gas) or LNG (Liquefied Natural Gas), have lower CO_2 emissions but they are only applied on a small scale in most European countries.

For fuels produced from biomass, various conversion routes are available that follow from the different types of biomass feedstocks, i.e. woody biomass, sugar-rich crops, oil crops, and wet biomass. In the figure above, only those biofuels are indicated that will be discussed in this report. These conversion processes and the characteristics of the resulting biofuels will be described in more detail in the next Chapter. Although some biofuels may be suitable for application in fuel cell vehicles, this report will only deal with their use in combustion engines.

The final Chapter of this report will give an overview of the development of the European market for biofuels and describe the application of biofuels in the different Member States of the European Union. This Chapter will also deal with national and European policies aimed at the promotion of the production and use of biofuels.

2. BIOFUEL CONVERSION TECHNOLOGIES AND END-USE

2.1 Introduction

In this Chapter, the conversion technologies for the production of the biofuels indicated in the introduction will be discussed, in both technological and economic terms. First, the direct conversion routes will be described, followed by a discussion of the gasification routes. For each route, the fuel characteristics of the biofuel will be described and compared to those of the fossil fuel it can replace, either petrol or diesel. Finally, the engine and infrastructure adaptations - if required for the application of a specific biofuel - will be discussed.

2.2 Biodiesel (RME)

Biodiesel is produced from vegetable oils, which can be derived from oil crops. Vegetable oils have been used as a fuel for a long time already. The conversion of biomass into vegetable oils for automotive fuel applications is similar to the production of vegetable oils for the food industry, which is a well-established process. Since, in Europe, vegetable oils for the production of biodiesel are mainly derived from rapeseed, this section will focus on this type of biodiesel, Rapeseed Methyl Ester (RME).

2.2.1 Biomass input

The vegetable oils that are used for biodiesel production can be extracted from the seeds or the pulp of several oil crops. The most important sources for vegetable oil production are rapeseed, soybean, palm and sunflower. For the production of 1 ton of RME, about 2.5 tons of rapeseed are needed, which requires a land area of 0.77 hectares (IEA, 1996a).

2.2.2 Conversion technology

Conversion process

For the production of biodiesel, vegetable oils are extracted from oil seeds by mechanically pressing or extraction with a solvent, like hexane. The latter technology results in a higher yield.

Vegetable oils can be used directly as diesel engine fuels, but this requires engine modification because some of their properties are less advantageous for this application. Two major problems are their very high viscosity and poor thermal and hydrolytic stability. Moreover, the low cetane number of vegetable oils, which varies between 33 and 43, indicates that they have less favourable ignition qualities.

To overcome the problems mentioned above and make vegetable oils suitable for engines used in road vehicles, they must be adapted in such a way that they meet the requirements of the current diesel engines, especially with regard to the viscosity and cetane number. This can be done through esterification. This means that the large, branched molecule structures of the oils (triglycerides) are transformed into smaller straight-chained molecules (methyl esters) that are similar to fossil diesel components. The methyl ester produced from rapeseed vegetable oil is called Rapeseed Methyl Ester (RME).

The majority of the methyl esters is produced through catalytic transesterification of the oil with methanol. Here, the triglycerides of the vegetable oil react with methanol in the presence of a catalyst, resulting in the production of methyl esters (biodiesel). This process takes place in a simple reactor system at low temperature (range 50-66ºC) and pressure (around 1.4 bar). The general steps in this conversion process are indicated in Figure 2.1.

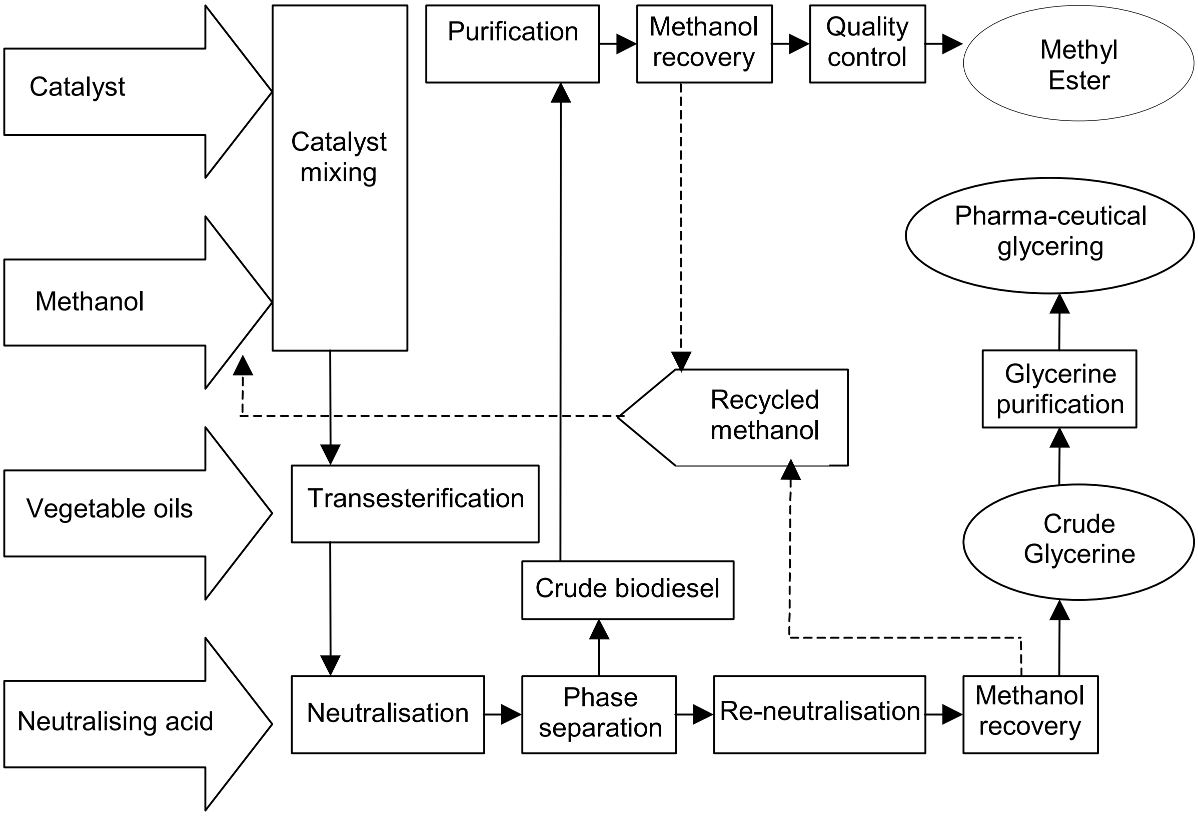

Figure 2.1 *General conversion process scheme for biodiesel production from vegetable oils (Internet source 5)*

The first step in this process is the mixing of methanol and the catalyst, which is usually sodium hydroxide (caustic soda) or potassium hydroxide (potash). Excess methanol is added to ensure the total conversion of the triglycerides into esters, because it first reacts with free fatty acids present in the oil, leading to soap formation. The catalyst/methanol mixture is fed into a closed reactor vessel, which prevents the loss of alcohol. Then the vegetable oil is added to the reactor. The reaction mixture is left to settle in the vessel for 1 to 8 hours. The concentrations of free fatty acids and water in the mixture must be monitored because if these are too high, this may cause problems with regard to soap formation and the separation of the glycerine by-product.

After the conversion of the vegetable oils into esters has taken place, the reacted mixture is neutralised first by adding acids. Then the methanol is removed and recovered for re-use in the process. The mixture now consists of two major products: methyl esters and glycerine. These have formed two layers in the reaction vessel, because glycerine is heavier than methyl esters. The glycerine is separated from the methyl esters and the soaps present in the glycerine are neutralised. The salts resulting from this neutralisation process are sometimes recovered for use as fertiliser. The crude glycerine can be used in the cosmetic and pharmaceutical industry.

After being separated from the glycerine, the methyl esters are purified. By means of a washing process, residual catalyst and soaps are removed. The purity of the esters produced in this way amounts to about 98%. This can be improved further by distillation. The end product is an amber-yellow coloured liquid with a strongly reduced viscosity. This biodiesel also has better long-term storage properties than the original vegetable oils and can be used as a fuel in diesel engines.

Status of the technology and economics

The production of biodiesel from vegetable oils by means of the conversion process described above is a well-established technology. It is applied on a large scale in several European countries (see Sections 3.2 and 3.3).

Current production costs of RME amount to approximately 0.50 €/litre (or 15 €/GJ). These costs depend on the prices of the biomass used and the size and type of the production plant. The short-term investment costs for a 400 MW_{th} plant are about 150 €/kW_{th}. On the long term, these costs may decrease by about 30% for a larger-sized plant with a thermal input capacity of 1000 MW_{th}, assuming economies of scale. Other important factors determining the production costs of RME are the yield and value of by-products of the biodiesel production process, such as oil seed cake (a protein rich animal feed) and glycerine (used in the production of soap and as a pharmaceutical medium). Longer-term projections indicate a future decrease in RME production costs by more than 50%, up to approximately 0.20 €/litre (or around 6 €/GJ). However, in order to provide the amount of energy equivalent to 1 litre of petroleum-derived diesel, a larger amount of RME is needed due to its lower energy content (Faaij, 2002; Faaij and Hamelinck, 2001; European Commission, 2001a; Internet source 19).

2.2.3 Biofuel end-use

Fuel properties

Esterified vegetable oils are suitable for application in automotive diesel engines, as the viscosity, density and cetane number of RME are similar to those of diesel. In Table 2.1, some fuel parameters are listed for RME and compared with those of fossil diesel.

Table 2.1 *Fuel properties of biodiesel (RME), compared to diesel (IEA, 1996b)*

Fuel properties	Biodiesel (RME)	Diesel
Chemical formula	Methyl ester	$C_{12}H_{26}$ [1]
Molecular weight [kg/kmol]	296	170 - 200
Cetane number	54	50
Density [kg/l] at 15ºC	0.88	0.84
Lower Calorific Value [MJ/kg] at 15ºC	37.3	42.7
Lower Calorific Value [MJ/l] at 15ºC	32.8 (at 20ºC)	35.7
Stoichiometric air/fuel ratio [kg air/kg fuel]	12.3	14.53
Oxygen content [wt-%]	9.2 - 11.0	0 - 0.6
Kinematic viscosity [mm^2/s] at 20ºC	7.4	4
Flash point [ºC]	91 - 135	77

As said before, the problems with regard to the application of neat vegetable oils in diesel engines (compression ignition engines) can be overcome to a large extent by converting the oils into esters. This process results in a remarkable reduction in viscosity, namely from 50 - 86 mm^2 for vegetable oils to 7.4 mm^2/s for RME. However, the viscosity of RME is still about twice the value of diesel fuel. This affects the atomisation of the fuel during the injection. Below a temperature of 0ºC, problems occur with the supply of biodiesel from the tank to the engine and the cold start behaviour of the engine. These problems can be solved by fuel heating or adding additives, like flow enhancers.

The table indicates a higher cetane number for RME compared to regular diesel. This denotes a good ignition quality, which leads to a higher engine efficiency and emission reduction. The stoichiometric air/fuel ratio is somewhat lower for RME, which indicates that less air is needed

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[1] Diesel is not one chemical compound but a mixture of a great number of different hydrocarbon compounds, which can include paraffins (or alkanes, linear and branched), olefins (linear and branched), naphthene and aromatics. It contains larger and heavier hydrocarbon molecules than petrol (IEA, 1996b).

to burn the same quantity of fuel. A disadvantage of combustion of RME is that it entails a specific smell that might cause inconvenience.

The density of RME is somewhat higher than that of diesel. This higher density compensates for the reduced energy content (gravimetric Lower Calorific Value) of RME to some extent. This lower value is due to the much higher oxygen content of RME compared to diesel. Because vehicles using RME have, on an energy basis, the same fuel consumption as those running on diesel fuel, this lower energy content leads to higher fuel consumption.

RME also differs from regular diesel with respect to some properties that are not related to engine performance. One of them is the fuel flash point, which is primarily important for the safe handling of a fuel. RME needs to be heated to a higher temperature than diesel to produce a vapour/air mixture that will ignite when a flame is applied.[2]

An ecologically favourable property of biodiesel is its high biodegradability. This is a significant advantage for use in niche markets where a high biological decomposability is an important feature, e.g. in environmentally endangered areas. However, high biodegradability also means that the fuel is less stable, which is disadvantageous with respect to storage.

Engine and infrastructure adaptations

Since RME has similar fuel properties compared to diesel, it can be mixed with fossil diesel in any proportion for application in conventional diesel engines. However, if 100% RME is to be used, a number of relatively minor changes in the engines are required. Material incompatibility with some engine components should be taken into account, because RME shows a high chemical aggressiveness towards metallic materials, rubber seals, coatings and elastomers. Although RME can be mixed with fossil diesel in any ratio, car manufacturers often recommend not to apply mixtures in their engines with a proportion of RME higher than, for example, 5%. A reason for this is that the certification level for the engine with regard to NO_x emissions can be exceeded when a large proportion RME is used. Moreover, the durability of the engine cannot be guaranteed if the engine is run with any other fuel than the one it is constructed, tested and certified for. Many diesel engine producers are working on an (improved) application of biodiesel. Some car manufacturers, for example PSA Peugeot - Citroën, have produced private cars especially for the use of pure RME. Another application of biodiesel is a mixture with ethanol to esterol, which is developed for regular diesel engines.

Because RME can be mixed with fossil diesel, the fuel can be distributed and marketed using the existing diesel fuel infrastructure. However, one should take into account that the lower volumetric energy content of RME results in a larger volume to be transferred. The limited compatibility with construction materials must be anticipated here too. Biodiesel-resistant materials should be used in fuel systems and storage tanks. When storing RME for longer periods, its low stability causes storage difficulties. Since RME degrades upon exposure to air, the fuel should be isolated from oxygen. Ingress of water should also be avoided, since water destroys the ester-linkage between alcohol and acid components in the methyl esters of biodiesel. This causes sludge formation in the fuel storage tank. RME can best be stored in a dark and cool place. However, at low temperatures, biodiesel starts to crystallise and solidify. When heated up to room temperature again, the oil resumes its original form. These adverse longer-term storage effects can be reduced by using additives.

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[2] The flash point of biodiesel is very sensitive to the alcohol content. It drops from 167ºC to 35ºC when the residual methanol concentration in RME is increased from 0% to 0.5% (IEA, 1996b).

When handling biodiesel, it should be taken into account that RME dissolves asphalt and makes it soft. The higher viscosity at low temperatures and the heavy foaming of RME may cause problems during refuelling. The foaming can be reduced by adding anti-foamants (IEA, 1996a, 1996b; Faaij, 2002; Faaij and Hamelinck, 2001; Novem, 2000a; Internet source 34; Internet source 5; Internet source 19).

2.3 Ethanol

Ethanol has been used on a large scale as a transportation fuel, for example in Brazil. Here, 60% of the produced ethanol is sold in hydrated form (93 vol-% ethanol and 7 vol-% water), which completely replaces petrol in vehicle engines. The remaining 40% ethanol is applied in water-free form in a mixture with petrol up to 24% (IEA, 1996b; Machado Filho, 2000). The predominant technology for converting biomass to ethanol is fermentation followed by distillation. Fermentation is a bio-chemical conversion process in which the biomass is decomposed using micro-organisms (bacteria or enzymes). This technology can be used for various types of biomass feedstocks. This section will discuss ethanol production from both food crops, which is the traditional feedstock, and woody biomass, which currently gains a lot of attention.

2.3.1 Biomass input

Currently, bio-ethanol is mainly produced from agricultural crops. Suitable raw materials for the production of ethanol are sugar-containing agricultural products such as sugar beet, sugar cane, molasses and sweet sorghum. These are the oldest and easiest-to-use feedstock. Crops that contain starch can also be used, but they have to be converted to sugars first. These include potatoes and various types of grains such as barley, corn, and wheat. Average ethanol yields per hectare differ between 2100 and 5600 litres, depending on the kind of crop used. For grains, this is about 2800 litres. A feedstock of around 3 tons of grains is needed for the production of 1 ton of ethanol (IEA, 1996a).

At present, research and development activities in the field of bio-ethanol are mainly focussed on using lignocellulosic or woody materials as a feedstock. These include short rotation energy crops (for example willow, popular, miscanthus and eucalyptus), agricultural residues (e.g. straw and sugar cane bagasse), forest residues, waste woods, and municipal solid wastes. About 2 - 4 dry tons of woody or grassy material is required for the production of 1 ton of ethanol (Internet source 35).

There are several reasons for shifting to ethanol production from lignocellulosic biomass. Lignocellulosic biomass is more abundant and less expensive than food crops, especially when it concerns a waste stream with very little or even negative economic value. Furthermore, it has a higher net energy balance, which makes it more attractive from an environmental point of view. However, these kinds of biomass are more difficult to convert to sugars due to their relatively inaccessible molecular structure.

2.3.2 Conversion technology

Conversion process

Bio-ethanol can be produced from various kinds of biomass feedstocks but only few crops contain simple sugars, which can easily be separated and made available to the yeast in the fermentation process. This separation is done by extraction or crushing. To obtain complete recovery of the sugar, this separation process must be repeated several times.

Other types of biomass, such as grain, contain larger and more complex carbohydrate molecules that have to be broken down first to simpler sugars by hydrolysis. Figure 2.2 presents an example of a conversion process scheme for ethanol production from grain, with dry milling as pre-treatment operation of the biomass[3].

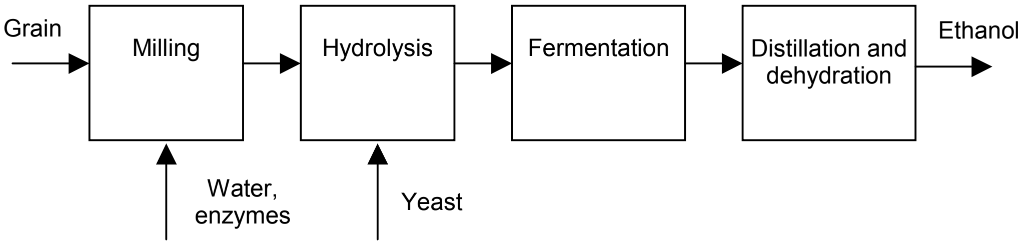

Figure 2.2. *Conversion process scheme ethanol production from grain (dry milling)(IEA, 1996a)*

The first step in this conversion process comprises milling or grinding of the grain to free the starchy material from the grain kernels. Then this material is diluted in water to adjust the amount of sugar in the mash. This is necessary to maintain the yeast and make the mash easier to stir and handle. Then this mixture is cooked to dissolve all the water-soluble starches. The starch is converted to sugars simultaneously. This can be done by enzymes or acid hydrolysis. All grains produce enzymes that are able to convert starch to a form of fermentable sugar. In the case of acid hydrolysis, dilute mineral acid is added to the grain slurry prior to cooking. The short carbohydrates resulting from these processing steps can be fermented by micro-organisms. For growing of the yeast needed for the fermentation process, the solution must be slightly acid, namely a pH between 4.8 and 5.0. During fermentation, ethanol is produced, which is diluted with water. This process also results in the formation of CO_2. Through a series of distillation and dehydration steps, the ethanol concentration can be increased.

The conversion process of lignocellulosic biomass to ethanol only differs from the process described above with respect to the break down, or hydrolysis, of the raw material to fermentable sugar. This hydrolysis process is more difficult than the hydrolysis of starch. Lignocellulosic biomass contains carbohydrate polymers called cellulose (40-60% of dry weight) and hemicellulose (20-40% of dry weight) that can be converted to sugars. Cellulose is composed of glucose molecules bonded together in long chains that form a crystalline structure. Hemicellulose consists of a mixture of polymers made up from xylose, mannose, galactose, or arabinose. It is much less stable than cellulose. Both materials are not soluble in water. The remaining fraction, a complex aromatic polymer called lignin (10-25% of dry weight) cannot be fermented because it is resistant to biological degradation. This material can be utilised for the production of electricity and/or heat.

Several technologies and process configurations have been developed the conversion of the fermentable fractions cellulose and hemicellulose. Figure 2.3 indicates the general pathways for conversion of lignocellulosic biomass to ethanol.

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[3] Another option for pre-treatment of the grain is soaking it in water and dilute acid, followed by grinding. This process is called wet milling.

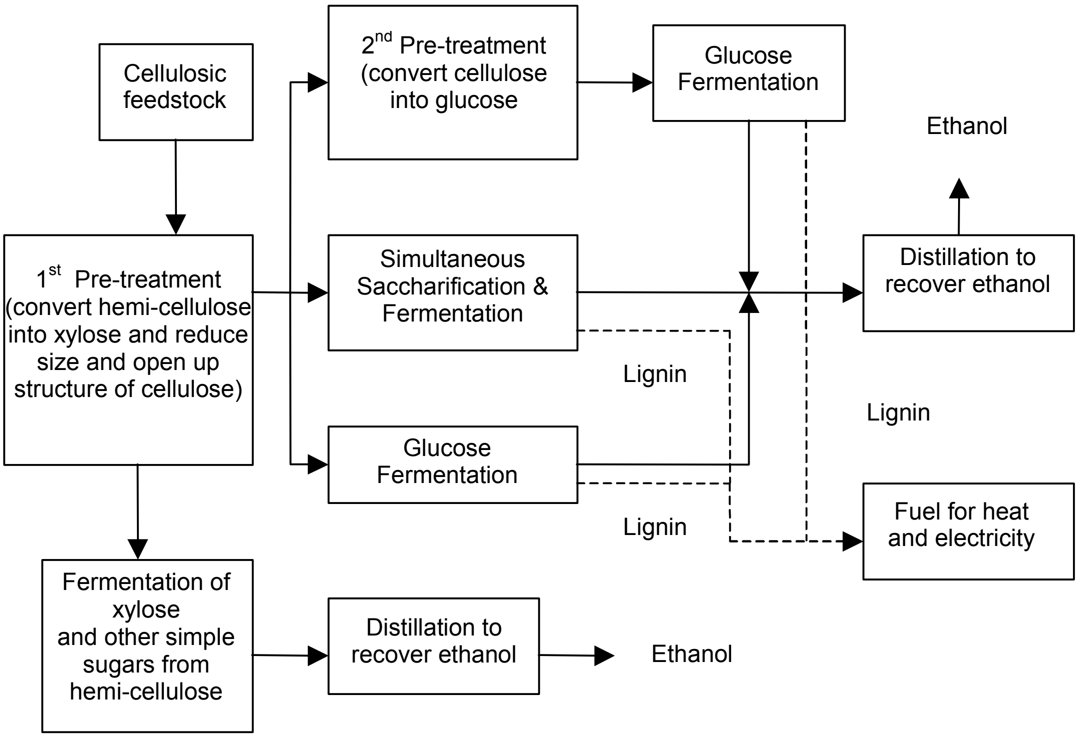

Figure 2.3 *General pathways for ethanol fermentation from cellulosic feedstock (Internet source 16)*

The oldest method is to convert the fermentable materials by dilute acid hydrolysis (first pre-treatment step). Here, low concentration acids (0.5%) break the hydrogen bonding between cellulose chains and decrystallise the material at a temperature of about 200ºC. This results in the conversion of hemicellulose into soluble C5- and C6-sugars (mainly xylose and mannose), which can directly be fermented into ethanol. The hydrolysis of hemicellulose can take place under relatively mild process conditions. The cellulose fraction is more resistant and requires more rigorous treatment. In this first pre-treatment step, the cellulose is exposed to hydrolysis by reducing its size and opening up its structure. Glucose, a C6-sugar, is produced from this fraction using an acid with a concentration of 2% and a temperature up to 240ºC (second pre-treatment step). Then the glucose can be fermented into ethanol.

Another possibility for converting cellulose into glucose is to use cellulase enzymes that are able to break down the cellulose. The first application of enzymatic wood hydrolysis in an ethanol process was to replace the cellulose acid hydrolysis step with a cellulase enzyme hydrolysis step. This is called separate hydrolysis and fermentation (SHF process). With this, the glucose yield from cellulose is increased. Later, simultaneous saccharification and fermentation (SSF process) was introduced. Here, the enzymatic hydrolysis and sugar fermentation processes take place at the same time in one vessel. This reduces the number of reactors needed for the conversion process. Moreover, cellulase enzymes and fermenting microbes are combined. This process was later improved to include the co-fermentation of the sugars glucose and xylose (SSCF technology). An advantage of this process is that sugars produced during hydrolysis are immediately fermented into ethanol, which avoids problems such as sugar accumulation and enzyme inhibition (Internet source 16; Reith et al, 2001).

For both sugar-containing and starch crops and lignocellulosic biomass, the fermentation and distillation steps are basically identical. The produced ethanol can be used as a transportation fuel in pure form or mixed with petrol. If it is applied in automotive engines, its water content must be close to zero to reduce the corrosive effect of the fuel. The additional purification by the extraction of water (dehydration) of the alcohol is an extra process step in ethanol production.

Ethanol can also serve as an oxygenating additive in petrol (3% mixed) for CO reduction and as a lead substitute, or as a raw material for the production of ETBE (ehtylbutylether). ETBE is an also oxygenate for petrol (15% mixed). It increases the octane number and thus improves the knock resistance of the fuel.

Status of technology and economics

Fermentation of sugars to ethanol is a mature technology, which is applied commercially on a large scale. There is a little chance of technological improvements that may significantly reduce the current production costs. These costs are largely determined by biomass feedstock prices, which can account for 55 - 80% of the final price of ethanol.

Current research and development activities mainly focus on the conversion of lignocellulosic biomass. This technology is not available on a commercial scale yet. Scaling up still proves difficult and commercially unattractive. An important issue is the development of cost-effective and environmentally sound pre-treatment and hydrolysis technologies. For example, the National Renewable Energy Laboratory (NREL), USA, is currently developing a process with steam pre-treatment combined with dilute sulphuric acid hydrolysis of hemicellulose, followed by enzymatic hydrolysis of cellulose. Iogen in Canada is working on combining steam explosion with dilute acid pre-treatment followed by enzymatic hydrolysis. A two-stage acid hydrolysis of hemicellulose and cellulose process is being developed by BC International Corporation (BCI), Canada. Problems that still need to be solved are insufficient separation of cellulose and lignin, the formation of by-products that inhibit ethanol fermentation, high use of chemicals and considerable waste production. With regard to enzymatic hydrolysis, the currently available cellulase enzymes are not cost effective yet.

Another research issue is the cost-effective fermentation of hemicellulose-derived sugars. The yeasts used in the ethanol industry are able to effectively ferment C6-sugars such as glucose, but they are not capable of converting C5-sugars such as xylose. For this, less costly and more effective enzymes need to be developed by genetic modification, which is difficult.

For fuel applications, the purity of the ethanol must be almost 100%. This means that the water content must be much lower compared to ethanol produced by current industrial technology. For this ‘deep’ dehydration of the ethanol several technologies are available, such as the use of molecular sieves and membrane separation, which can still be improved. The power and heat production from the non-fermentable fraction of the biomass and the overall process integration can also be developed further, which will lead to an increase of the energetic efficiency and economic performance of the process (Reith et al, 2001; Faaij, 2002).

Another technological option for the production of ethanol is gasification (more details about gasification can be found in Section 2.6). The resulting gas can be converted using anaerobic bacteria for fermentation. With this route, hydrolysis pre-treatment steps are eliminated. The feasibility of this technology has been demonstrated, and plans are being developed for a pilot production facility.

The short-term investment costs of a production facility for sugar-containing crops are estimated at 290 €/kW$_{th}$ (for a 400-MW$_{th}$ plant) by Faaij, Hamelinck and Tijmensen (2000). This is expected to decrease by 40% on the long term (1000 MW$_{th}$), although the fuel production efficiency will not be increased. If the ethanol is produced from wood, the investment costs will be higher, i.e. 350 €/kW$_{th}$ on the short term. Here, a cost decrease of about 50% is expected on the long term, taking into account economies of scale for all equipment concerned.

Present production costs for ethanol derived from sugar and starch crops are high: 20 €/GJ (corn, USA) and 15 - 25 €/GJ (sugar beet, North West Europe). This is about 0.32 - 0.54 €/litre (Daey Ouwens and Faaij, 2000; Faaij, 2002). Production costs for ethanol from lignocellulosic biomass are estimated at 5 - 15 €/GJ (or 0.11 - 0.32 €/litre), where the lower costs are for advanced technologies (Faaij, 2002). The National Renewable Energy Laboratory (NREL) gives an estimate of 0.27 €/litre, with a feedstock of 42 €/ton. If a feedstock is used with zero costs, the ethanol production costs can be as low as 0.17 €/litre. It should be taken into account here that a larger amount of ethanol is required to provide the same amount of energy compared to petrol due to the lower energy content of ethanol. This results in higher costs for 1 litre of petrol equivalent (Internet source 6).

2.3.3 Biofuel end-use

Fuel properties

Ethanol is best used in a spark ignition or Otto engine because of its high octane rating. Due to its poor ignition quality (low cetane number), ethanol is less suitable for diesel engines. Technical solutions for this problem include the injection of small quantities of diesel oil, fumigation of the alcohol, and the use of an electrical ignitions system (spark or glow plug) or additives. In Table 2.2, the fuel properties of ethanol (and its derivative ETBE) are listed, in comparison with those of petrol.

Table 2.2 *Fuel properties of ethanol, compared to petrol (IEA, 1996b; personal communication P. Kroon, ECN)*

Fuel properties	Ethanol	ETBE	Petrol
Chemical formula	C_2H_5OH	C_4H_9-OC_2H_5	C_8H_{15}[4]
Molecular weight [kg/kmol]	46	102	111
Octane number (RON)	109	118	97
Octane number (MON)	92	105	86
Cetane number	11		8
Reid Vapour Pressure [kPa] at 15ºC	16.5	28	75
Density [kg/l] at 15ºC	0.80	0.74	0.75
Lower Calorific Value [MJ/kg] at 15ºC	26.4	36.0	41.3
Lower Calorific Value [MJ/l] at 15ºC	21.2	26.7	31
Stoichiometric air/fuel ratio [kg air/kg fuel]	9.0		14.7
Boiling temperature [ºC]	78	72	30-190

The octane number of ethanol appears to be higher than that of petrol, so ethanol has better anti-knock characteristics. This better quality of the fuel can be exploited if the compression ratio of the engine is adjusted accordingly. This increases the fuel efficiency of the engine. The oxygen content of ethanol also leads to a higher efficiency, which results in a cleaner combustion process at relatively low temperatures.

The Reid Vapour Pressure, a measure for the volatility of a fuel, is very low for ethanol[5]. This indicates a slow evaporation, which has the advantage that the concentration of evaporative emissions in the air remains relatively low. This reduces the risk of explosions. However, the low vapour pressure of ethanol, together with its single boiling point, is disadvantageous with regard to engine start at low ambient temperatures. Without aids, engines using ethanol cannot be started at temperatures below 20ºC. Cold start difficulties are the most important problem with regard to the application of alcohols as automotive fuels.

The density of ethanol is a little higher than that of petrol. However, this cannot compensate for the lower energy content (Lower Calorific Value) of ethanol, which is about two-third of that of

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[4] Like diesel, petrol is not one chemical compound but a blend of a great number of different hydrocarbon compounds. It contains smaller and lighter hydrocarbon molecules than diesel. Most of the hydrocarbons in petrol have four to nine carbon atoms. Petrol consists of aromatics, olefins and paraffins (IEA, 1996b).

[5] It should be noted here that the RVP of automotive fuels is manipulated in refineries by mixing with additives in accordance with the season and the country in which the fuel is to be used. The appropriate volatility of fuels is different depending on the specific climate where it is applied.

petrol. Ethanol requires a lower air/fuel ratio than petrol, which indicates that less oxygen is needed for the combustion of ethanol.

Engine and infrastructure adaptations
Ethanol can be used in current spark ignition engines and the existing infrastructure for petrol without any adaptations, if it is mixed with petrol up to 20% (Novem, 1999).

The most important problem with respect to the use of pure methanol in vehicle engines is that, at low temperatures, its evaporation is too slow for use in combustion engines. The ignitability of ethanol can be improved by mixing with additives (such as petrol) or heating the alcohol with an electrical heating element at the inlet of the engine.

Another difficulty concerns the lower volumetric energy content of ethanol. This entails that larger fuel flows are needed compared to the original engine design to get the same engine performance. Moreover, less oxygen is needed for combustion. This means that the combustion chamber, the valve timing, the location of the spark plug and the fuel system need to be adjusted to be able to use pure ethanol. Because the octane number of ethanol is higher than that of petrol, the compression ratio of the engine can be increased which results in a higher engine performance.

Moreover, ethanol is incompatible with some materials used in engines. If ethanol is mixed with petrol in a high proportion or applied in pure form, it affects certain kinds of plastics, elastomers and metals like steel, aluminium and magnesium. When water is dissolved in the alcohol, the aggressiveness towards metals increases. Special plastics and corrosion and wear resistant metals, e.g. stainless steel, must be used for engine components.

The application of ethanol as a transportation fuel requires some adaptations of the petrol distribution infrastructure and refuelling facilities. First of all, the energy content of ethanol is lower, which means larger storage tanks are needed. On-board of the vehicle, one can also choose a larger fuel tank. If the same tank volume is used, the vehicle range is strongly reduced. For tankers and storage tanks, the materials used should be compatible with ethanol, just like the engine components. Storage tanks should be watertight because ethanol is soluble in water. Furthermore, they must be equipped with fixed roofs and internal floating covers.

Other infrastructure issues concern the safety of ethanol handling. For extinguishing an ethanol flame, water can be used. However, for mixtures with petrol one should use CO_2 or foam instead, because by adding water, the petrol is expelled from the mixture and washed away. As ethanol burns with a visible flame, no special measures have to be taken to improve the luminosity of an ethanol flame. It should be taken into account that ethanol can form a vapour above the fuel in the tanks, even at ambient temperatures. This should be avoided because it may cause an explosion and because it may negatively influence the driving ability. This can be done by installing vapour barriers in the fuel system of the car and in the fuel dispenser and by adding volatile additives, like petrol. Ethanol is biodegradable, so that there is less risk for soil and water pollution from spill compared with the use of fossil fuels (Reith et al, 2001; IEA, 1996a, 1996b; Machado Filho, 2000; Internet source 27;Internet source 22; Internet source 16; Internet source 35).

2.4 Pyrolysis oil derived diesel equivalent

Pyrolysis oil is produced by conversion process called flash pyrolysis. Pyrolysis means that biomass is thermally converted in the absence of oxygen. With this process, a liquid is produced as an intermediate for a wide variety of applications, for example as a raw material for the production of a diesel substitute.

2.4.1 Biomass input

Any type of biomass can be used for pyrolysis processes, but lignocellulosic biomass is preferred. Before the material can be added to the process, it must have a particle size smaller than 6 mm and a moisture content below 10 weight-%. This entails that the biomass must be dried and grinded first in most cases.

2.4.2 Conversion technology

Conversion process

As no oxygen is present in the process, the biomass is not burned, but the chemical bonds between the molecules in the biomass are broken at high temperatures to form the final reaction products char, bio-oil and gases. The amount and composition of pyrolysis products depends on pyrolysis temperature, heating rate and residence time and on the composition of the biomass. There are several types of pyrolysis processes, with different heating rates. This report will focus on the very rapid flash pyrolysis process, because this is the most relevant for pyrolysis oil production. Because this process takes place at very high temperatures, the production of gaseous components is maximised compared to other types of pyrolysis processes. A liquid fuel is produced by cooling these gases.

Slow pyrolysis, which takes place at temperatures around 400°C, has a very low heating rate and a long residence time, even up to days. The main product is charcoal. At somewhat higher temperatures, conventional pyrolysis processes take place, resulting in the production of gas, oil and char in equal proportions. Fast pyrolysis takes place at temperatures from 500 to 650°C and the residence times are very short, namely 0.5 up to 5 seconds. Under these conditions, organic vapours, pyrolysis gases and charcoal are produced. The vapours are condensed to bio-oil.

In flash pyrolysis processes, even higher temperatures are applied (700 to 1000°C). The residence time is below one second. Flash pyrolysis processes have a very high heating rate of the particles - higher than 10,000°C per second - and a rapid cooling of the produced vapours to produce mainly liquids. The flash pyrolysis reactor is therefore used to convert biomass into a liquid. Figure 2.4 presents the general process scheme for flash pyrolysis.

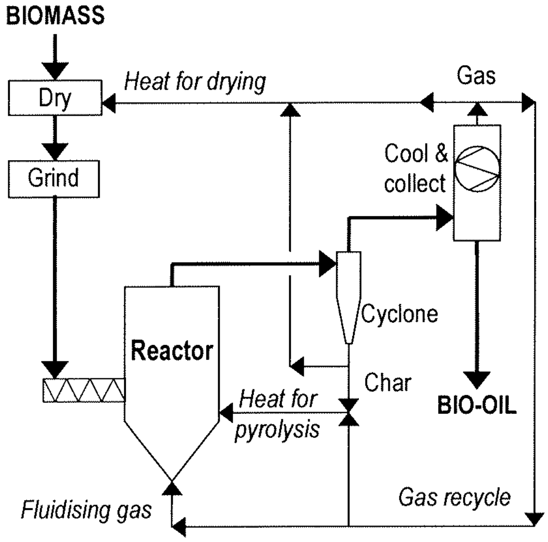

Figure 2.4 *General process scheme flash pyrolysis (with a fluid bed reactor)(Novem, 2000a)*

First, the biomass must be dried and grinded in order to meet the size and moisture content requirements for the pyrolysis process. Then it is fed into the reactor. Several types of reactors can be used, such as fluid bed reactors. In this type of reactor, the fine biomass particles are fed to a reactor with a bed, made of an inert component, e.g. sand. The heating of the biomass particles is done by means of blowing hot gas through them, from the bottom to the top. When the velocity of the carrier gas is high enough, the bed become voluminous, which causes the reaction to take place in the entire reactor volume.

Another possibility is the rotating cone technology. Here, the biomass is mixed with hot sand particles. The particles are fed to the bottom of the cone where they are transported upwards along the hot conus wall by the rotating action of the cone. A carrier gas is not needed here, unlike the fluid bed reactor, because the whirling in the reactor is already caused by the motion of the rotating cone. The absence of carrier gas simplifies the collection of the pyrolysis products after the reaction has taken place, because they are undiluted. Another favourable characteristic of this technology is that the reactor has a compact design. The rapid heating and a short gas phase residence time in this type of reactor result in a relatively high bio-oil yield (for wood 75-80 weight-%). A disadvantage of this technology is that the wood particle size should be below 2 mm. The pyrocycling technology does not have this unfavourable characteristic, because here relatively large biomass particles can be used, up to 13 mm. The moisture content is also allowed to be relatively high, about 15%. The biomass particles are transported via a number of heat exchangers, where a part of the biomass is split into smaller molecules and the residue remains as charcoal.

After the biomass particles have been pyrolysed, the reaction products are transported to a cyclone, where they are separated. The char, containing aromatic chemical structures, can be burned with air to provide heat for drying of the biomass or the pyrolysis process. The gaseous components are transported to a cooler. Here, they are mainly condensed to bio-oil. The part of the non-condensable gases mainly consists of CO, CO_2, CH_4 and H_2. These can be recycled, e.g. for drying of the biomass or as fluidising gas. Application in a gas engine is also a possibility.

Pyrolysis oil contains many valuable components that can be used for a wide variety of non-energetic purposes, namely the production of chemicals. They can be separated through extraction. The main components of bio-oil are phenol, water, levoglucosan and hydroxyacetaldehyde. Phenol is used in the production of plywood and of nylon and epoxy resins. Other uses of phenol are as a disinfectant, slime-killing agent, and in some medicines. Levoglucosan is a sugar derivative, which may be used for pharmaceutical synthesis, pesticide synthesis, specialty polymers and resins, and surfactants. Hydroxyacetaldehyde is another sugar derivative. It can be applied for example as brightening agent for paper production and for the browning of foods.

As the conversion of biomass to liquid pyrolysis oil increases the volumetric heat content compared to solid biomass and thus decreases transportation costs, flash pyrolysis is considered a good conversion route. The energy production can be decentralised according to demand. Bio-oil can be applied as a fuel for co-firing in an electric power plant or as a raw material for synthesis gas production, where it is gasified with (enriched) air and pure oxygen. If desired, it can then be converted to automotive fuels such as methanol or Fischer-Tropsch fuels. For direct application as a diesel substitute in vehicle engines, pyrolysis oil needs to be upgraded and stabilised first. Pyrolysis oil can also be used as a replacement for fossil oil or diesel in stationary applications, such as boilers, ovens or engines.

Status of the technology and economics

Research and development activities in the field of pyrolysis of biomass are mainly focussed on the development of several types of reactors for fast pyrolysis processes. Compared to combustion and gasification, the technology is still at an early stage of development, the pilot/demonstration phase. The current bottlenecks of pyrolysis technologies concern the upscaling of the reactors and meeting the desired oil quality through condensation and treatment of the tar fraction, product cleaning and modification, and upgrading techniques. For pyrolysis oil there is no market yet, despite the fact that the research and development on this topic is going on now for about 20 years. The technological development is mainly focussed on the production of fine chemicals (non-energetic applications).

The energetic efficiency of conversion of biomass to raw bio-oil is currently about 60-70% (Higher Heating Value). This is reduced significantly when hydrogenation[6] technologies are used for upgrading of the oil. Faaij, Hamelinck and Tijmensen (2000) expect that short-term efficiency for a pyrolysis hydrodeoxygenation will amount to 67%. However, the Utrecht Centre for Energy research et al (2000) estimates that (partially) upgraded bio-oil may be produced on the longer term with an overall efficiency of only about 50%.

Due to the small number and limited scale of existing pyrolysis oil production units, the economics of a commercial scale unit can only be estimated. Faaij, Hamelinck and Tijmensen (2000) give estimates for the investment costs of a pyrolysis plant on the short term of about 1,000 €/kW_{th}, assuming a 400 MW_{th} (input) plant. For the long term, this will decrease by 20%, based on a plant with a thermal capacity of 1000 MW_{th}. For the concept of pyrolysis hydrodeoxygenation, the investment costs for a 400 MW_{th} plant on the short term are estimated at around 350 €/kW_{th}. On the long term, this will decline by 15% for a 1000 MW_{th} plant.

Besides the investment costs depending on plant scale and type of pyrolysis technology, the costs of bio-oil production is also largely influenced by the feedstock (pre-treatment) costs. Studies indicate that production costs for pyrolysis oil can be between 75 and 300 €/ton oil (4 - 18 €/GJ or 0.06 - 0.25 €/litre[7]), assuming feedstock costs between 0 and 100 €/ton (0 - 1.9 €/GJ) (Internet source 9).

2.4.3 Biofuel end-use

Fuel properties

Pyrolysis oil is typically a liquid, almost black-coloured, depending on its chemical composition. It is different from fossil oil in many respects. First of all, the density of bio-oil of 1.2 kg/litre is much higher than that of fossil oil. However, the energy content is much lower, namely 16 - 19 MJ/kg (Higher Heating Value), compared to 42 - 44 MJ/kg for conventional fuel oils. This is due to its high content of organically bound oxygen. This entails that the oil has a polar nature and does not mix with hydrocarbons. However, it is soluble in water, unlike fossil oil. It contains less nitrogen than petroleum products, and almost no metal and sulphur components. Pyrolysis oil shows many viscosity changes, from 0.025 up to 1.0 Pascal per second at a temperature of 42ºC, which is due to, among other things, the water content (15 - 35 weight-%) and the extent to which the oil has aged. Especially at high temperatures, the oil is quite unstable and starts to degrade. During this 'aging' process, chemical reactions, like polymerisation, take place. Organic acids are formed, which makes the oil very acid, with a pH value of about 2 to almost 4. Furthermore, the oil has a specific smell and it contains several components that are carcinogenic.

Due to the characteristics mentioned above, pyrolysis oil cannot be used as an energy carrier directly. For use as a transportation fuel, it needs to be upgraded and stabilised to diesel quality first. This can be done using, for example, catalytic upgrading or hydrogenation processes. Although this is technically feasible, the chemical upgrading of pyrolysis oil to transportation fuel is currently too expensive due to the hydrogen needed for this process. The technology is still in the laboratory/pilot phase and needs to be developed further. Technical problems that still need to be solved concern the removal of contaminants from the produced products. The final quality of pyrolysis oil diesel will always remain lower than that of fossil diesel.

Up till now, the direct application of bio-oil in diesel engines has proved unsuccessful. During tests, problems occurred with the acidity of the oil, which caused corrosion of the engine (personal communication B. Wagenaar, BTG) However, pyrolysis oil may be used as input for a gasification process combined with further synthesis to methanol or Fischer-Tropsch liquids

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[6] In this reaction hydrogen adds across a double or triple bond of carbon atoms.

[7] Assuming a density of 1.2 kg/litre and a HHV of 16 - 19 MJ/kg, see Section 2.4.3.

(see Sections 2.7 and 2.9). The gasification of pyrolysis oil and the subsequent cleaning and conditioning of the gas produces synthesis gas with the same characteristics as syngas produced from other sources that is fed to the Fischer-Tropsch synthesis process. According to Calis et al (2002) this route results in lower logistics costs than direct gasification of biomass due to higher calorific value of pyrolysis oil compared to moist wood. However, this cost advantage is offset by higher feedstock costs due to a lower overall thermal efficiency and higher capital costs due to two thermal conversion steps, of which pyrolysis is carried out on a much smaller scale than the gasification step.

Engine and infrastructure adaptations

For engine design, it must be taken into account that pyrolysis oil is chemically aggressive towards steel. Moreover, since the oil is very acid, storage facilities should be equipped with acid proof materials. Since pyrolysis oil degrades when stored at temperatures higher than 50ºC, heat and contact with light and oxygen must be avoided. Because pyrolysis oil diesel is not mixable with fossil diesel, the existing diesel infrastructure cannot be used for gradually introducing this biofuel (Novem, 2000a, 2000b; UCE et al, 2000; Daey Ouwens and Faaij, 2000; Faaij and Hamelinck, 2001; Internet source 9; Internet source 13).

2.5 HTU oil derived diesel equivalent

During the 1980s, the Shell Laboratory in Amsterdam carried out research on the Hydro Thermal Upgrading process. Here, the biomass is decomposed in water to produce a crude oil-like liquid called ‘bio-crude’. Objectives of this process were to concentrate the energy of the biomass into an (automotive) fuel with a higher energy density. However, due to unfavourable economic conditions, the experiments were stopped. As bio-energy received renewed interest in the 1990s, the technology was then developed further by a Dutch company, Biofuel, founded by former employees of Shell.

2.5.1 Biomass input

The HydroThermalUpgrading (HTU) process can be used for the conversion of a broad range of biomass feedstocks, which is an advantageous characteristic of this technology. Possible feedstocks include municipal solid wastes and agricultural wastes. The process was especially designed for wet biomass such as beet pulp, sludge or bagasse. So the biomass does not have to be dried first. Very wet mixtures with 10-30% of organic material are a suitable feedstock.

Conversion process

In the HTU process, dry or wet biomass reacts in liquid water at a high pressure and a relatively low temperature. The main product of the HTU conversion process is ‘biocrude’, a transportable energy carrier similar to fossil oil. The conversion process is shown in Figure 2.5.

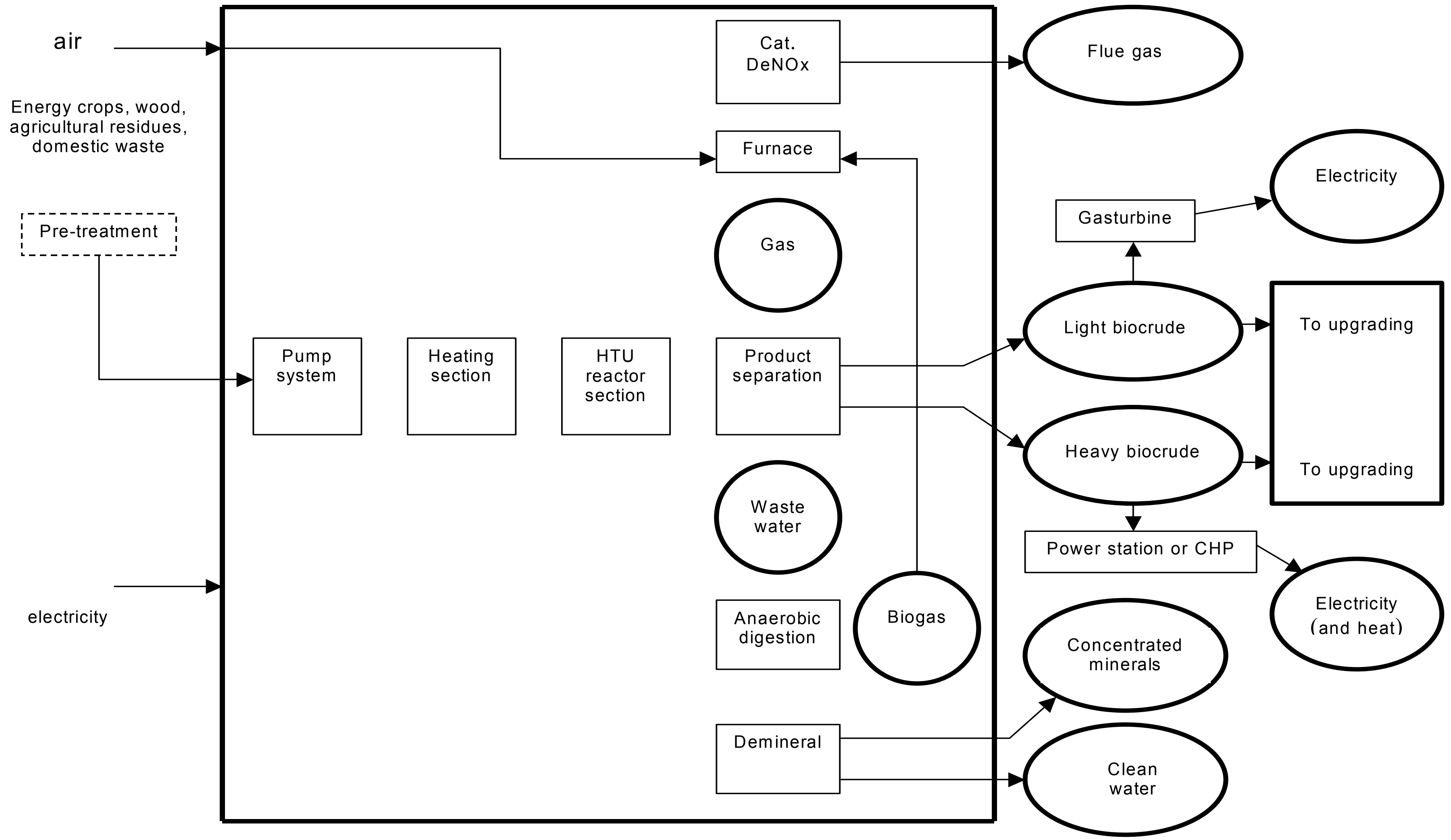

Figure 2.5 *HydroThermalUpgrading (HTU) conversion process scheme (Novem, 2000b)*

The first step in the conversion process is the pre-treatment of the biomass feedstock. Because the HTU process is especially designed for wet materials, dry types of biomass need to be soaked in an aqueous environment first. This takes place at a temperature of ca. 200 - 250ºC and a pressure of often 30 bar. The presence of water significantly influences the properties of the biomass feedstock and the final product.

Then the wet biomass is transported to the heating and subsequently the reaction section. The conversion process takes place at a pressure of about 120 - 180 bar and a temperature of ca. 300 - 350ºC. In a pilot facility in Apeldoorn, the Netherlands, the HTU conversion reaction takes 5 to 10 minutes. The energy consumption of the process is relatively high.

Besides the 'biocrude', the main product of the reaction (50%), the HTU process also produces gases (30%). About 70 - 90 weight-% of the gas consists of CO_2 and 20 - 30 weight-% of H_2. It also contains methane and CO. Another by-product is a water solution (15%) with 5% organic compounds. This waste water can be used in an anaerobic digestion process to produce biogas. Both the biogas and the gases from the HTU process are fed to a furnace.

The biocrude is a viscous black organic liquid, a mixture of various kinds of hydrocarbons. It is not mixable with water and due to its relatively low oxygen content (10 - 15% bound oxygen), it is more stable than pyrolysis oil. It contains very low concentrations of nitrogen and sulphur and has a Lower Heating Value (LHV) of 30 - 36 MJ/kg.

The biocrude can be separated into light and heavy biocrude, which can serve as energy carriers for various purposes. The heavier fractions, which contain all minerals from the biocrude, can be used for co-firing in coal-based electric power plants. It can also be used as naphtha for the production of chemicals. The lighter fractions, which are very clean, can be used for the production of diesel fuel components. In order to convert the biocrude into a traditional transportation fuel of diesel quality, it must be upgraded by means hydrogenation techniques, e.g. catalytical HydroDeOxygenation. In this process oxygen is removed from the biocrude by adding hydrogen. Because a large amount of hydrogen is needed for this process, this is an energetically and economically unfavourable aspect of this conversion and subsequent upgrading technology.

Status of the technology and economics

The HTU technology currently only exists on a pilot scale. In Apeldoorn, a continuous test plant was built in 1999 on the site of TNO in Apeldoorn. The conversion technology has not been demonstrated for all feedstocks yet. After a shut-down period of two years, the operation of the pilot plant has recently been continued. This pilot plant aims at providing information about design parameters for a larger demonstration plant. A demonstration plant (with an output of 3,000 tons per year) is to be built by the year 2006. A large commercial production facility will not be built before 2008/2009.

Research on the HTU conversion process concentrates on the complex chemical properties of the reactions of the HTU process and the testing of several feedstock types. Moreover, technical problems such as the removal of contaminants from the produced products still need to be resolved. Other critical aspects are the introduction of the feed, the heating of the reactants, and the treating of the waste water. The HydroDeOxygenation technology must also be developed further. It is a well-know refinery process but for this application the best process conditions are still a research topic. So far, the technology has been proven at an experimental scale by Shell.

The thermal efficiency of the HTU process, from biomass to raw biocrude is estimated at ca. 80% (Faaij and Hamelinck, 2001; UCE et al, 2000). Upgrading by means of hydrogenation processes such as HydroDeOxygenation results in significant efficiency penalties. UCE et al (2000) estimates that (partially) upgraded bio-crude may be produced on the longer term with an overall efficiency of about 60%.

Faaij, Hamelinck and Tijmensen (2000) estimate that the investment costs of HTU production plant on the short term are about 95 €/kW$_{th}$ for a 400 MW$_{th}$ (input) plant. For the long term, this will decrease by 25%, based on a plant with a thermal capacity of 1000 MW$_{th}$. If HydroDeOxygenation is applied, this will lead to a more than five-fold increase of the investment costs, namely about 535 €/kW$_{th}$ (for 400 MW$_{th}$). This will also decrease by almost 25% on the long term.

The production costs of HTU diesel depend not only on the investment costs but are very sensitive to biomass feedstock costs as well. Depending on the type of biomass used, the Dutch company Biofuel estimates the production costs for HTU diesel at around 5 - 7 €/GJ (or ca. 0.16 - 0.24 €/litre[8]), for a large-scale production plant (Personal communication Goudriaan, Biofuel).

2.5.2 Biofuel output

Fuel properties

Developments of the HTU conversion technology aim at producing a diesel fuel with similar fuel properties to those of conventional diesel. These characteristics are determined by the C/H ratio of the fuel, which can be adjusted by the process conditions of the HydroDeOxygenation process. The fuel qualities of HTU diesel are expected to be very good. The cetane number is higher than that of conventional diesel, which denotes better ignitability. The fuel is clean and does not contain any oxygen.

Engine and infrastructure modifications

HTU diesel will be produced in such a way that it meets the fuel specifications for fossil diesel. This means that HTU diesel can be mixed with conventional diesel in any proportion and that it can be applied in the existing diesel engines and distribution infrastructure. HTU diesel is expected to be compatible with materials applied in engines and the infrastructure, such as plastics and metals (Personal communication Goudriaan, Biofuel; Novem, 1999, 2000a, 2000b; Internet source 12).

2.6 Gasification routes

Biomass can be converted by means of a gasification process. Any type of biomass can be used as a feedstock, including lignocellulosic such as cellulosic materials from agricultural crops (straw, molasses) and grasses and trees from forest plantations. Wet biomass, like municipal solid waste and agricultural residues can be used as well but this results is a lower efficiency.

Gasification of biomass results in a mixture of combustible gases. This is called synthesis gas or syngas. A broad range of liquid biofuels can be produced by synthesis from this gas, depending on the process conditions. In this section, a general description of the gasification and synthesis process will be given. The steps of this process are indicated in Figure 2.6. In the subsequent sections, details of the production processes of methanol, DME and Fischer-Tropsch hydrocarbons will be discussed.

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[8] Assuming the density of HTU diesel is the same as that of fossil diesel.

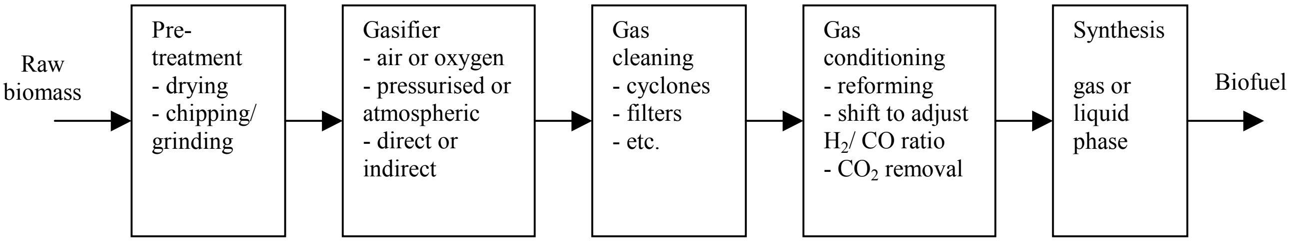

Figure 2.6 *General conversion scheme biomass gasification and synthesis (Faaij and Hamelinck, 2001; Faaij, 2002)*

Gasification denotes the partial oxidation of biomass by addition of a sub-stoichiometric[9] amount of oxygen, which exothermally reacts with the biomass at a high temperature, approximately 900ºC. In the case of a direct gasification process, the necessary heat for the process is produced by burning part of the biomass feed in the gasifier. Both air-blown and oxygen-blown biomass gasifiers can be used for direct gasification. If oxygen is used, a nitrogen-free synthesis gas can be produced. However, the production of oxygen for this process leads to higher energy use and investment costs. Indirect gasification processes use heat that is generated by burning part of the biomass or of the produced gas outside of the gasifier. The heat is subsequently fed to the gasifier. An advantage of this type of gasification process is that it produces an almost nitrogen-free gas without the use of oxygen anywhere in the process. However, indirect gasification consists of more steps and is more complex. Moreover, it produces two gas streams that must be cleaned (Den Uil et al, 2001).

Different types of reactors are suitable for gasification of biomass, such as fixed beds, fluid beds and entrained beds. Fixed beds operate at temperatures between 700 and 1200ºC. They are categorised according to the direction of the gas flow through the reactor (upward, downward or horizontal) or by the flow directions of the solid flow and the gas stream (co-current, counter-current or cross-current). Co-current reactors are able to produce a relatively clean gas (low tar content), in contrast with the counter-current gasifier type. This is favourable, as additional gas cleaning is avoided. However, the counter-current gasifier type is less critical with respect to the biomass feedstock and it has a better scale-up potential. Fluidised beds contain a mixture of biomass with a hot material, for example sand. The reaction takes place in the whole reactor volume. The temperature, which is uniform throughout the bed, can be controlled by changing the air-biomass ratio. Fluidised bed reactors are more tolerant regarding the biomass used compared to fixed bed gasifiers, but the produced syngas always contains some tar (more than the co-current fixed bed), which requires removal. Entrained beds operate at a very high temperature (1500ºC) and produce tar-free syngas. However, the process is very difficult to control and it requires very small biomass particles as input. Circulated fluidised bed (CFB) gasifiers are currently most widely used. It is a robust and fuel-flexible technology, which can be applied for scales ranging from one to several hundreds of megawatts. These gasifiers are generally operated at near atmospheric pressures with air as gasification medium (Boerrigter et al, 2002).

The synthesis gas resulting from the reaction in the gasifier mainly contains carbon monoxide, carbon dioxide, hydrogen, methane, water, and nitrogen. The composition of syngas varies depending on for example raw biomass composition and operating conditions. It usually contains a certain amount of CO_2. The gas also contains contaminants like e.g. small char particles, chlorides, sulphur, alkali metals, nitrogen compounds and tars. These contaminants can decrease the catalyst activity in the gas reformer, the shift and synthesis reactor, and cause corrosion in heat exchangers and the gas turbine (if one is applied). Tar can cause serious problems in biomass

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[9] Stoichiometric combustion implies that the fuel is combusted with exactly enough air to oxidise all carbon and hydrogen. (IEA, 1996b) Biomass conversion with a super-stoichiometric amount of oxygen is called combustion (Novem, 2000c).

gasification systems, like wear and corrosion due to soot formation as a result of partial combustion of tar or polymerisation reaction of tar compounds at high temperatures. Moreover, tar can interact with other contaminants in the syngas, such as fine particles. Tar is removed by cleaning devices aimed at particle removal like fabric filters. For the reasons mentioned above, the gas must be cleaned thoroughly (and cooled if needed), under 'wet' cold or 'dry' hot conditions. The impurities can be removed using, for example, cyclones and ceramic filters. The resulting gas can be used in boilers, engines and gas turbines for electricity and/or heat generation or as a raw material for the chemical industry.

After cleaning of the syngas, the gas is conditioned, which includes process steps like CO_2 removal and reforming. During of conditioning of the gas, hydrocarbons are converted to H_2 and CO, which are needed for the synthesis. H_2 and CO must be available in a certain ratio. This ratio differs for various final products. For the production of methanol, H_2 and CO are used in a ratio of 3:1. For Fischer-Tropsch liquids, this is 2:1. However, in the gas resulting from biomass gasification, the proportion of hydrogen is usually lower than needed. Therefore, the proportions of these two components must be shifted in the syngas via a water-gas shift (WGS) reaction. Here, CO reacts with water to produce CO_2 and H_2. The CO_2 is removed afterwards by means of chemical or physical absorption. The synthesis gas is compressed and transported to the final synthesis reactor. The synthesis reaction takes place under influence of a catalyst. The composition of the final product depends on the catalyst used and other process conditions. The final products are extracted by distillation of the reactor effluent. Biofuels produced by gasification and synthesis processes are always very clean, as the syngas has been cleaned thoroughly before it is fed to the synthesis reactor.

2.7 Methanol

Like ethanol, methanol has also been used as a transportation fuel for quite a long time, especially in the USA. Methanol can be produced from synthesis gas, which results from the gasification of biomass (see Section 2.6).

2.7.1 Biomass input

For the production of 1 ton of methanol, a little over 2 dry tons of wood is required. This corresponds with a yield of 550 litres of methanol per ton of wood. The estimated methanol yield from grassy materials is somewhat lower, namely about 450 litres per ton (Internet source 35).

2.7.2 Conversion technology

Conversion process

Conventional methanol reactors use fixed beds of catalyst pellets and operate in the gas phase. Processes under development are mainly slurry technologies, which have a higher conversion per pass. An example of this is the liquid phase process. Here, the reactants H_2 and CO, the product methanol and the catalyst are suspended in a liquid. The heat transfer between the solid catalyst and the liquid phase is very efficient, which results in high conversions per pass and eliminates the need for a gas recycle loop, in contrast to conventional methanol reactors. Several reactors can be used in this type of process, for example, the slurry bubble column reactor of the Liquid Phase Methanol (LPMEOH) process, developed by Air Products and Chemicals. This process uses catalysts in powder form, slurried in an inert mineral oil. An advantage of this liquid phase process is that it is more suitable to overcome process variations due to the liquid inventory, which acts as a temperature buffer. However, in order to protect the copper catalyst, the biomass-derived synthesis gas must be cleaned thoroughly to meet the (very) stringent process requirements. This process is able to reach a methanol conversion of 95%. The process can be combined with a gas and/or steam turbine where the purge gas is utilised for electricity generation.

The produced methanol has a broad range of possible applications, besides use as a transportation fuel, such as a chemical feedstock, extractant, or solvent. It can also be used for the production of methyl tertiary butyl ether (MTBE), a petrol additive that improves the anti-knock quality of the fuel.

Status of the technology and economics
The technology of biomass gasification has not reached the commercial phase yet. For this, the gasifier and (high temperature) gas cleaning need to be developed further. Areas of improvement include the development of ‘new’ catalysts with a higher methanol production capacity at lower temperature and pressure, and lower sensitivity syngas contaminants. Furthermore, research and development focuses on the optimisation of operating pressure and minimisation of oxygen consumption and high syngas yield by maximum carbon conversion and low residual concentrations of hydrocarbons in the syngas.

Costs for biomass gasification and methanol are dependent on the investment costs and operational costs, including biomass costs. On the short term, the investment costs for a methanol production facility of 400 MW_{th} are estimated at 700 €/kW_{th}. On the longer term, larger installations will be used, which may lead to a decrease of the investment costs by 25-30%. The short-term efficiency is about 50-55%. For a larger plant, for example 1000 MW_{th}, this is expected to be 60-65% on the longer term, assuming partial electricity production (Faaij and Hamelinck, 2001; UCE, 2000). Investment costs for liquid phase methanol production processes are 5-23% less than for gas phase processes of the same methanol capacity (Faaij and Hamelinck, 2001).

Short term production costs for methanol are estimated at approximately 0.14 - 0.20 €/litre (or 9 - 13 €/GJ). In the future, production costs may decrease up to 0.10 €/litre (or 7 €/GJ). Like ethanol, methanol has a lower volumetric and gravimetric energy content compared to petrol, which results in a higher fuel need for supplying the same amount of energy. This leads to higher costs per litre petrol equivalent (Faaij and Hamelinck, 2001; UCE, 2000; Faaij, 2002).

2.7.3 Biofuel end-use

Fuel properties
Methanol can be applied in almost any vehicle type and can be used as a neat fuel or mixed with hydrocarbons. However, methanol has a low cetane number (5 compared to 50 for fossil diesel), indicating poor ignition quality. This means that its use in compression ignition engines (diesel engines) will be difficult.[10] However, since methanol has a high octane rating, application of the fuel as a petrol substitute in a spark ignition or Otto engine is preferred. The following table sums up the fuel properties of methanol (and its derivative MTBE), compared with those of fossil petrol.

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[10] Technical solutions for this have already been mentioned in Section 2.3.3.

Table 2.3 *Fuel properties of methanol, compared to petrol (IEA, 1996b; personal communication P. Kroon, ECN)*

Fuel properties	Methanol	MTBE	Petrol
Chemical formula	CH_3OH	C_4H_9-OCH_3	C_8H_{15}
Molecular weight [kg/kmol]	32	88	111
Octane number (RON)	110	116	97
Octane number (MON)	92	100	86
Cetane number	5		8
Reid Vapour Pressure [kPa] at 15ºC	31.7	57	75
Density [kg/l] at 15ºC	0.79	0.74	0.75
Lower Calorific Value [MJ/kg] at 15ºC	19.8	35.2	41.3
Lower Calorific Value [MJ/l] at 15ºC	15.6	26.0	31
Stoichiometric air/fuel ratio [kg air/kg fuel]	6.5		14.7
Boiling temperature [ºC]	65	55.3	30 -190

First of all, the octane number of methanol is higher than that of petrol, which means that it has better anti-knock qualities. Moreover, it can potentially reach a higher fuel efficiency if the compression ratio in the engine is properly adjusted.

The Reid Vapour Pressure is much lower for methanol compared to petrol, which entails a slower evaporation of the fuel. This leads to the occurrence of cold start difficulties, just like ethanol, which can be solved with the same kind of technical measures (see Section 2.3.3). Pure methanol shows starting problems at a temperature of 10ºC and lower.

The density of methanol is somewhat higher than that of petrol. However, the calorific value is half that of petrol. Methanol has an even lower air/fuel ratio than ethanol, which indicates that even less oxygen is needed for the combustion of methanol.

Methanol is a water-clear liquid with a mildly spirituous odour. It is nearly tasteless. Because it is poisonous, additives must be used to give it a nasty smell and taste to distinguish it from other fuels and prevent accidental intake. Contact with skin and eyes should be avoided. Methanol can penetrate the skin and enter the bloodstream.

Engine and infrastructure adaptations

Methanol can be used in regular spark ignition engines and the existing infrastructure for petrol without any adaptations in mixed form with petrol up to 15% (Novem, 1999). For the application of methanol in higher proportions or in pure form, the necessary adjustments of the engine and infrastructure are the same as those for ethanol (see Section 2.2.3) due to the similar characteristics of both alcohol fuels.

With regard to safe handling of methanol, additional measures need to be taken as pure methanol burns with an invisible flame, unlike ethanol. This causes problems when a methanol fire needs to be extinguished. The flame can be made visible by adding additives. Furthermore, extra precautions need to be taken for people who are working with methanol vehicles everyday because the fuel is toxic and poisonous (IEA, 1996a, 1996b; Novem, 2000c; Boerrigter et al, 2002; Specht et al, 1999; Internet source 9; Internet source 17; Internet source 35; Internet source 27).

2.8 DME

Dimethylether (DME) is currently being used mainly as a propellant in spray cans. Research on the use of DME as a transportation fuel has only started recently. A reason for this was that in the beginning of the 1990s, a new method for producing DME was accidentally discovered during attempts to produce synthetic petrol from synthesis gas. Before that, DME had only been used in the cosmetics industry and no one ever tried to apply it as a diesel fuel. It proved to be an attractive diesel substitute due to its ability to reduce the exhaust emissions of NO_x. Moreover, it can be produced from different feedstocks, such as biomass and natural gas. Like bio-methanol, bio-DME is produced by means of biomass gasification followed by synthesis.

2.8.1 Biomass input

A feedstock of around 3 tons of woody materials is required for the production of 1 ton of DME. This corresponds with a yield of 500 litres of DME per ton of wood (SNEA, 2002).

2.8.2 Conversion technology

Conversion process

DME, the simplest ether, can be produced directly from synthesis gas, a mixture of CO and H_2, for example in a slurry phase reactor. This is similar to the production process of methanol (see Section 2.6 and 2.7).

DME can also be produced from pure methanol. This is done by means of a process called catalytic dehydration. This denotes a process where water is chemically separated from the methanol. First, the methanol is heated to a temperature of 250ºC by means of a heat exchanger before it is fed to the reactor. In the reactor, an exothermic reaction takes place and DME is formed. The reaction products are heated to ca. 365ºC before leaving the reactor. After the reactor effluent is cooled down, the DME is separated from the other components, methanol and water. The final product quality is determined in a purification process. Often, the production of methanol and DME is combined in one process.

Before being used as a fuel, DME was mainly used as a substitute propellant for chloro-flouro-carbons (CFCs) in spray cans. This is still its primary application, comprising 90% of the globally produced DME. It is also used as an ignition improver in methanol engines. Other energy purposes besides as transportation fuel are as power generation fuel and household fuel for cooking and heating. However, these markets do not exist yet. The International DME Association (IDA) expects large, economical supplies of (natural gas-derived) DME for power generation, as a transportation fuel and for domestic cooking uses to be available by 2005 (Internet source 1).

Status of the technology and economics

World wide, there are several small-scale facilities for the production of DME from pure methanol. Direct DME synthesis from synthesis gas is still under development. Some pilot plants have been built for this type of process. However, at present, DME is mainly produced from synthesis gas derived from natural gas, naphtha, heavy oil or coal. The technology for producing DME from biomass as a raw material is still in the development phase. Research and development activities with regard to gasification of biomass and syngas cleaning and conditioning have already been described for methanol production in Section 2.4.2. The synthesis process and processing of the reactants for DME derived from biomass is identical to those for natural gas.

The production costs are DME from biomass are largely determined by the costs for the feedstock and investment costs. In the Bio-DME project of the Swedish National Energy Administration (2002), the investment costs for a commercial scale plant with an annual production of 200,000 tons of DME are estimated at € 390 million, or around 2,000 €/ton.

The International DME Association (IDA) states that natural gas-derived DME can be delivered to the customer at a cost that is competitive with conventional diesel from crude oil priced at about 23 US dollar per barrel.[11] DME production from biomass is more expensive, because the raw material and capital costs are twice as high and the operating and maintenance costs are 75% higher (Internet source 32). The Swedish National Energy Administration estimated that the production costs of DME from biomass are around 0.27 €/litre (or 14 €/GJ). Because the energy content of DME is much lower than that of diesel, the costs for 1 litre of diesel equivalent are around € 0.50 (SNEA, 2002).

2.8.3 Biofuel end-use

Fuel properties

DME is a suitable as a diesel engine fuel on account of its low self-ignition temperature and appropriate cetane number. Table 2.4 lists the fuel properties of DME in comparison with those of fossil diesel.

Table 2.4 *Fuel properties of DME, compared to diesel (IEA, 1996b; Internet source 1)*

Fuel properties	DME	Diesel
Chemical formula	CH_3OCH_3	$C_{12}H_{26}$
Molecular weight [kg/kmol]	46	170 - 200
Cetane number	55-60	50
Density [kg/l] at 15ºC	0.67 (at 20ºC)	0.84
Lower Calorific Value [MJ/kg] at 15ºC	28.4	42.7
Lower Calorific Value [MJ/l] at 15ºC	18.8	35.7
Stoichiometric air/fuel ratio [kg air/kg fuel]	9.0	14.53
Auto-ignition temperature [ºC]	235	250

The cetane number of DME is somewhat higher than that of fossil diesel, which implies shorter ignition times and for that reason cleaner combustion in diesel engines. Another favourable quality of DME is that it burns without producing soot. Moreover, engines using DME produce less noise. A disadvantage is that the energy content of DME is lower than that of diesel.

The physical properties of DME are very similar to those of LPG. DME is gaseous at ambient temperature and pressure, but at 20ºC and a pressure above 5 bar, it is a liquid. Its boiling point at atmospheric pressure is - 25ºC. DME is mixable with most organic solvents and it has high solubility in water. It is very clean and does not contain sulphur, nitrogen or metals.

Engine and infrastructure adaptations

DME cannot be mixed with diesel, but retrofitting diesel engines for the use of DME is relatively simple. The geometry of the fuel system must be modified because DME has a lower energy content and density. This means that a higher fuel volume must be supplied for the same amount of energy compared to diesel. However, the fuel injection pressure can be decreased when DME is used. This leads to a smoother combustion process and thus lower NO_x emissions. DME does not cause any cold start problems, due to its high volatility, in contrast to alcohol fuels such as methanol and ethanol.

Because DME has lower lubricating properties than diesel, application of DME may lead to more wear formation on fuel system components. This is especially important for moving components in the engine, such as the fuel pump. Although DME does not corrode metals, unlike alcohol fuels, it may affect certain kinds of plastics, elastomers and rubbers after some time. This should be taken into account in the selection of sealing materials for the fuel system.

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[11] Assuming that world-scale manufacturing plants are built in locations with ample supplies of low-cost natural gas, using new LPG tankers and new LPG unloading and storage facilities (Internet source 1).

For the distribution and refuelling of DME, the fossil diesel infrastructure cannot be used. However, the infrastructure for DME can be very similar to that of LPG. Up till now, a distribution network for DME has not been developed yet, but due to the similarities to LPG, the same distribution concept can be used for DME.

Because DME is a gas at ambient temperature and pressure, it needs to be handled under pressure. It can be stored in liquid form at 5-10 bars at ambient temperature. This means that pressure tanks are needed both in the vehicle and in the distribution infrastructure, e.g. the refuelling stations. Because the pressure in the tanks is somewhat higher than that for LPG, the fuel tanks for DME are heavier. Moreover, due to the incompatibility of DME with some materials, other seals and hoses must be used for the fuel tanks compared to LPG. DME should be stored in dry, well-ventilated tanks. Contact with ignition or heat sources, such as sunlight, should be avoided. Furthermore, it should be taken into account that the fuel pressure in the fuel supply pump between vehicle tank and engine has to be increased to 12 - 30 bar in order to avoid vaporisation of DME. However, DME vapour is heavier than air, so it sinks when it is released, just like LPG.

DME is safer compared to methanol, because it burns with a visible flame and because it is not poisonous. However, contact with DME may cause irritation of the eyes and respiratory system and frost-bite when in contact with the skin. Due to its similarities with LPG, the same safety measures can be used for handling DME (IEA, 1996a, 1996b; Tornevall, 1998; SNEA, 2002; Holwerda, 1997; Internet source 32; Internet source 29; Internet source 25; Internet source 1).

2.9 Fischer-Tropsch diesel

The Fischer-Tropsch process was initially developed in Germany in the 1920s and produced synthetic fuels in the 1930s. Originally, fossil fuels were used as a feedstock for the process. Current developments focus on producing clean Fischer-Tropsch fuels based on biomass. Like the conversion processes for methanol and DME, the Fischer-Tropsch route also starts with gasification of the biomass, which is followed by a synthesis process.

2.9.1 Biomass input

Fischer-Tropsch liquids can be produced from several types of biomass (see Section 2.6). For the production of 1 ton of Fischer-Tropsch diesel about 8.5 tons of wood are needed. The yield of liquid fuels is thus about 150 litres per ton of wood[12] (Boerrigter and Den Uil, 2002). Another option is to feed the conversion process with bio-oil, e.g. pyrolysis oil (see Section 2.4).

2.9.2 Conversion technology

Conversion process

For the production of Fischer-Tropsch liquids, usually a slurry reactor or a fixed bed reactor is used as synthesis reactor. Here, iron or cobalt catalysts can be used. Cobalt catalysts have a higher conversion rate, a longer life, and a higher reactivity, while the iron catalyst type has a higher tolerance for impurities and a lower price. Moreover, iron-based catalysts show considerable water-gas shift (WGS) activity and the H_2/CO ratio is adjusted in the synthesis reactor.

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[12] If 1 ton of wood is gasified, this results in 2 $m_n{}^3$ of bio-syngas. From this gas, 175 litres of Fischer-Tropsch wax (long-chain hydrocarbons) can be produced, which is converted to 150 litres of Fischer-Tropsch diesel by means of a cracking process (Boerrigter and Den Uil,2002).

However, if a cobalt-based catalyst is used, the water-gas shift needs to be modified prior to the synthesis reaction.[13] In the synthesis reactor, the syngas is converted into a broad range of hydrocarbon chains, which includes light hydrocarbons (C_1 - C_2), LPG (C_3 - C_4), naphtha (C_5 - C_{11}), diesel (C_9 - C_{20}) and wax ($> C_{20}$) fractions (Den Uil et al, 2001; Boerrigter et al, 2002).

The resulting product composition depends on the process temperature and pressure, the catalyst and the reactor type. Typical process conditions for Fischer-Tropsch synthesis when aiming for long-chain products (waxes) are temperatures of 200 - 250ºC and pressures of 25 - 60 bar (Boerrigter et al, 2002). If the process is operated at higher temperatures it mainly produces lighter hydrocarbons, which can be refined to petrol and diesel, solvents and olefins. For the production of Fischer-Tropsch diesel, a higher yield is achieved for the route of production of waxes followed by selective hydrocracking, compared to direct production of diesel fractions from synthesis gas.

The unconverted off-gas remaining after the synthesis can be recycled and fed to the synthesis reactor again to maximise the production of liquids. In a simplified system, a so-called 'once-through' Fischer-Tropsch synthesis, the gaseous by-products are utilised for electricity and heat generation in a combined heat and power plant (CHP). A favourable aspect of the latter system is that investments are lower due to elimination of gas recycling and the accompanying synthesis gas production (Den Uil et al, 2001).

Fischer-Tropsch diesel is a very suitable transportation fuel. Fischer-Tropsch liquids in general can also be used as an energy carrier and for storage purposes and for electricity and/or heat generation. Petrol components produced by the Fischer-Tropsch process cannot be applied in the existing spark ignition engines. In contrast with petroleum-derived petrol that contains aromatics, Fischer-Tropsch petrol consists of straight hydrocarbon chains, whose octane number is too low for application in current engines. Therefore, straight-chain Fischer-Tropsch petrol can only be used in these engines in a mixture with fossil petrol, up to 15%.[14] For this reason, the section about biofuel end-use (Section 2.9.3) will only discuss the application of Fischer-Tropsch diesel (Novem, 1999).

Status of the technology and economics

So far, large-scale Fischer-Tropsch conversion installations only use fossil fuels for the production of synthesis gas, for example, the Shell installation in Malaysia, which produces Fischer-Tropsch liquids derived from natural gas. In South-Africa, Sasol has a production plant using coal as a raw material. The use of biomass as input for Fischer-Tropsch processes is still in the development phase. Possibilities for gasification of biomass or bio-oil (produced by pyrolysis of biomass) for the production of synthesis gas are currently being investigated. The integration of biomass gasification and Fischer-Tropsch synthesis has not yet been demonstrated.

Current research and development activities are focused on cleaning and conditioning of synthesis gas, development of several types of catalysts, reducing the amount of inert components in the feed gas, and the utilisation of by-products such as electricity, heat and steam. The production of Fischer-Tropsch liquids in combination with electricity and heat seems a promising option.

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[13] The reaction for iron catalysts for the production of Fischer-Tropsch fuels is: $2\,CO + H_2 \Rightarrow -CH_2- + CO_2$. Here, a prior shift to a H_2/CO ratio of 2:1 (WGS reaction: $CO + H_2O \Rightarrow CO_2 + H_2$) is not needed. However, this shift is necessary before synthesis takes place using a cobalt catalyst because here the reactants are needed in a ratio of 2:1: $CO + 2\,H_2 \Rightarrow -CH_2- + H_2O$ (Boerrigter et al, 2002).

[14] These straight chains can be converted by means of catalytic reforming into CO and H_2, which can be recycled to the Fischer-Tropsch reactor (personal communication H. Boerrigter, ECN).

Whether improved performance of advanced longer-term systems can be achieved is partly determined by the possibilities of application of high-performance high-temperature gas cleaning, high temperature gas separation and single pass synthesis gas processing.

Besides the raw material costs, the capital investment costs are important factors that determine the production costs of Fischer-Tropsch fuels. A typical breakdown of investment costs for a Fischer-Tropsch process indicates that the largest part of the investment costs is for the preparation of the synthesis gas (66%). The Fischer-Tropsch synthesis process costs account for 22% of the total investment costs. The remaining part of the capital costs is for upgrading and refining of the products. This division of capital costs may change if an electricity generation unit is taken into account (Novem, 2000c).

The total short-term investment costs are estimated by Faaij, Hamelinck and Tijmensen (2000) at around 720 €/kW_{th} for a 400 MW_{th} plant. Den Uil et al (2001) mention investment costs of approximately 770 €/kW_{th} for a system of the same size. For the longer-term, this will decrease by 25 - 35%, based on a 1000 MW_{th} installation, as a result of efficiency improvements, technology development and increase in scale (Faaij, Hamelinck and Tijmensen, 2000; Den Uil et al, 2001).

Different studies provide various production cost ranges for Fischer-Tropsch hydrocarbons. They can be as low as 11 - 13 €/GJ (UCE, 2000; Novem, 2000c; Den Uil et al, 2001), or even 8 - 11 €/GJ (Daey Ouwens and Faaij, 2000) for large tri-generation plants. However, sometimes, higher numbers are given, such as 18-19 €/GJ. On the longer term, production costs are expected to decrease to below 9 €/GJ (Faaij, 2002; UCE, 2000). Currently, production costs of Fischer-Tropsch fuels are higher than those of fossil automotive fuels. They may have a higher market value due to their good fuel properties and clean composition. Depending on the future contaminant limitation of petrol and diesel, their market value can increase. But with the normal range of crude oil prices, the production and cleaning of fossil automotive fuels will remain less expensive than the production of 100% Fischer-Tropsch fuels.

2.9.3 Biofuel end-use

Fuel properties

Fischer-Tropsch diesel is a high quality and clean transportation fuel with favourable characteristics for application in diesel engines. Its fuel properties are listed below, in comparison with those of petroleum-derived diesel.

Table 2.5 *Fuel properties of Fischer-Tropsch diesel, compared to diesel (IEA, 1996b; Fanick, 2001; Norton et al, 1998)*

Fuel properties	Fischer-Tropsch diesel	diesel
Chemical formula	Paraffins	$C_{12}H_{26}$
Molecular weight [kg/kmol]		170 - 200
Cetane number	> 74	50
Density [kg/l] at 15ºC	0.78	0.84
Lower Calorific Value [MJ/kg] at 15ºC	44.0	42.7
Lower Calorific Value [MJ/l] at 15ºC	34.3	35.7
Stoichiometric air/fuel ratio [kg air/kg fuel]		14.53
Oxygen content [wt-%]	~ 0	0 - 0.6
Kinematic viscosity [mm^2/s] at 20ºC	3.57	4
Flash point [ºC]	72	77

Fischer-Tropsch diesel is similar to fossil diesel with regard to its energy content, density, viscosity and flash point. It is also in liquid phase at ambient conditions. The fuel has some characteristics that are more favourable than those of regular diesel. First of all, Fischer-Tropsch diesel has a higher cetane number, which indicate better auto-ignition qualities. Moreover, it has a very low aromatic content, which leads to cleaner combustion. This means that the particle and NO_x exhaust emissions are lower. Furthermore, sulphur emissions are avoided, because Fischer-Tropsch diesel is sulphur free (May et al, 2001).

Another advantage of Fischer-Tropsch diesel is that its chemical composition can be engineered to meet most or all engine manufacturer requirements for diesel fuel quality. Special formulations or additive packages may be necessary to meet standards to fuel lubricity, cold flow, and elastomer compatibility (May et al, 2001).

Engine and infrastructure adaptations

Fischer-Tropsch diesel is mixable with conventional diesel. Therefore it can be applied in current diesel engines and the existing diesel distribution infrastructure without any modifications. If applied in regular diesel engines, Fischer-Tropsch diesel already leads to emission reductions but if the diesel engine is optimised to exploit the favourable properties of Fischer-Tropsch diesel, this may even be improved further. Adaptations of the engine include for example the revision of the combustion system to utilise the better self-ignition qualities (higher cetane number) and the use of sulphur-intolerant after-treatment devices, which can be applied here without problems because Fischer-Tropsch does not contain any sulphur (May et al, 2001; Boerrigter and Den Uil, 2002; Daey Ouwens and Boerrigter, 2000; Novem, 2000c; Daey Ouwens, Faaij and Ruyter, 2001; UCE, 2000; Den Uil et al, 2001; Boerrigter, 2002).

2.10 Outlook

Table 2.6 presents an overview of short-term and long-term investment costs and production costs for the biofuels described earlier in this chapter. It should be noted here that cost estimates may vary among data sources due to the use of different assumptions. For example, assumed biomass costs may diverge if different studies are compared. Feedstock costs are a very important component in biofuel production costs, even up to 50% (Den Uil et al, 2001). Moreover, there are differences in the specific designs of the conversion systems. In estimating future cost reductions, there are uncertainties about the results of efficiency improvements, technology development and scaling-up. For details about underlying assumptions for the data given in this compilation, the original data sources can be consulted. These have been indicated in the respective sections in this chapter.

Table 2.6 *Overview of investment costs and production costs (data sources are indicated in Chapter 2)*

Biofuel	Investment costs short term [€/kW_{th}]	Investment costs long term [€/kW_{th}]	Production costs short term [€/litre]	Production costs long term [€/litre]	Production costs short term [€/GJ]	Production costs long term [€/GJ]
RME	150	110	0.50	0.20	15	6
Ethanol (sugar crops)	290	170	0.32 - 0.54		15 - 25	
Ethanol (wood)	350	180	0.11 - 0.32		5 - 15	
Methanol	700	530	0.14 - 0.20	0.10	9 -13	7
DME			0.27		14	
Fischer-Tropsch diesel	720 - 770	500 - 540	0.31 - 0.45		9 -13	
Pyrolysis oil[15]	1,000	790	0.06 - 0.25		4 -18	
HTU diesel	535	400	0.16 - 0.24		5 -7	

From the preceding discussion in this chapter, it appears that most biofuels will not be commercially available on the short term. Although insights on technological and cost developments

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[15] Production costs for pyrolysis diesel are much higher than those for pyrolysis oil because of the expensive process for upgrading of the oil.

and the expected commercial availability of these biofuels are changing continuously, it can be stated that these biofuels will probably not be produced and applied on a commercial scale before 2010 (Van Thuijl, 2002; Novem, 1999).

Currently, only ethanol (and its derivative ETBE) produced from food crops and biodiesel (mainly RME) are applied on a commercial basis on the European market. They will remain the dominant biofuels in the coming decade, as alternative biofuel technologies are still in the development stage. Therefore, the next chapter dealing with the European and national markets for biofuels will only discuss the production and application of these types of biofuels.

3. EUROPEAN BIOFUEL MARKETS AND POLICIES

3.1 Introduction

This Chapter will first describe the development of the European market for biofuels. Only the production and use of ethanol/ETBE and biodiesel (RME) will be discussed, since these are the only biofuels presently available on a commercial basis. Subsequently, this Chapter will discuss the production and use of biofuels in the most important biofuel countries in the European Union and the countries in which the use of biofuels is less developed. Finally, this Chapter will outline the national policies of the EU Member States specifically aiming at the promotion of biofuels and biofuel policy developments on the European level. As an introduction, first an overview is given of the market parties and governmental bodies involved in the biofuel product chain from biomass cultivation to biofuel end-use.

The agricultural sector mainly takes care of the production of the biomass. The biomass feedstock includes residuals from agriculture, forestry and cattle farming and so-called energy crops. Residuals are, for example, straw from cereals, plant residuals from the flower sector, wood residuals from forestry, fertilisers and animal waste. But organic fractions from municipal and industrial wastes can serve as resources for biofuel production as well. Furthermore, energy crops that are grown especially for bio-energy purposes can be applied for both biofuels production and electricity and heat generation. These crops include perennial plants, such as trees (e.g. willow, poplar) and grasses (e.g. miscanthus). So producers of biomass can be found in a broad range from cattle farmers to wood companies, from households to industries, from flower producers to specialised crop farmers (ATLAS, 1997).

For the production of biodiesel, the biomass feedstock (e.g. rapeseed, sunflowers) is processed at specialised sites (see Section 2.2.2). In 2000, there were 15 commercial esterification sites throughout the commercially producing EU Member States, namely six in Germany, four in France, two in Italy, and one in Austria, Belgium and Sweden. These producers extract oil from rapeseed and sunflower seeds and transform it into Rapeseed Methyl Ester (RME) or Sunflower Methyl Ester (SME), respectively. The final product is sold to oil companies, which distribute it via their automobile service station network (EurObserv'ER, 2001). For the production of ethanol (see Section 2.3.2), several small production companies obtain their feedstock (corn, wheat, beets or barley) from farmers. They process it in such a way that sugar is extracted, which eventually will be transformed into ethanol. A second step in this process may be conversion of the ethanol into ETBE by the oil companies.

National and European governments together with the large oil companies are involved in the production, marketing and end-use of biofuels. The European government creates an incentive for the production of biofuels with its policy aimed at increasing the use of biofuels in the transport sector in the coming decade (see Section 3.4). This European policy affects the national governments of the EU Member States, which have to develop national policies in order to realise the European targets. These policies influence the whole market from biomass producer, to biofuel producer, to biofuel seller. The national governments as well as the oil producers influence the economic feasibility by their policies and process developments, respectively.

The European and national policies also provide incentives for research institutes to investigate the recent and future developments in the market of biofuels. Oil companies also do this to find out what their opportunities are in this new fuel market. These companies take care of the marketing of biofuels to their customers at their service stations. Besides this, they are in contact with car and engine manufacturers. This collaboration is very important since the engine and the fuel used in the engines have to be compatible. The car manufacturers have to communicate the use of cars with these engines to their customers.

3.2 Development of the European biofuel market

The production of biofuels expanded during the 1980s, before it developed more seriously in the 1990s. The present global production level is estimated at about 15 million tons per year. The producing countries in the European Union only have a small share in this global production level, namely a little less than 6% (890,600 tons in 2000). (EurObserv'ER, 2001) Most of the global biofuel production consists of ethanol, namely 14.6 million tons (in 2000). The main ethanol producers are the USA and Brazil, whereas the share of Europe is rather small. However, Europe is the most important producer of biodiesel on the global market.

As from the year 1993, the European production level of biodiesel increased by almost ten times, from 80,000 tons in 1993 to 780,000 tons in 2001. Figure 3.1 presents the development of the total biodiesel production in Europe for this period.

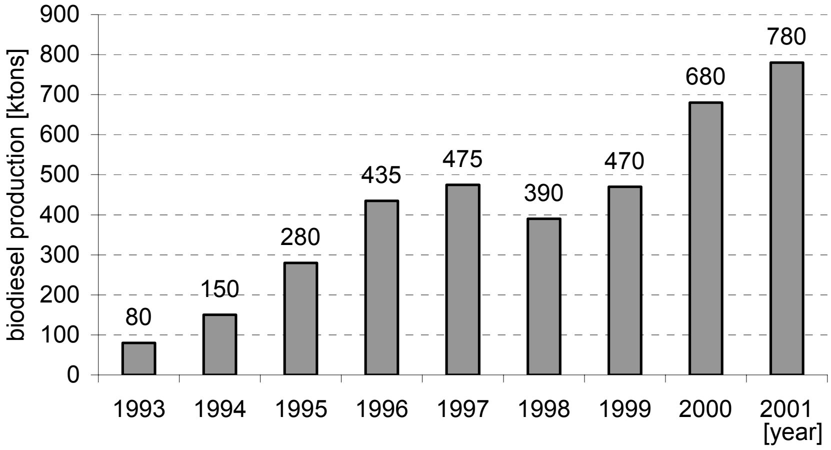

Figure 3.1 *Biodiesel production of the European Union (1993 – 2001; Internet source 2)*

The European production of ethanol for application as an automotive fuel grew by 4.5 times as from 1993, namely from 47,500 tons in 1993 to 216,000 tons in 2001. Figure 3.2 gives an overview of the development of the total European ethanol production in this period.

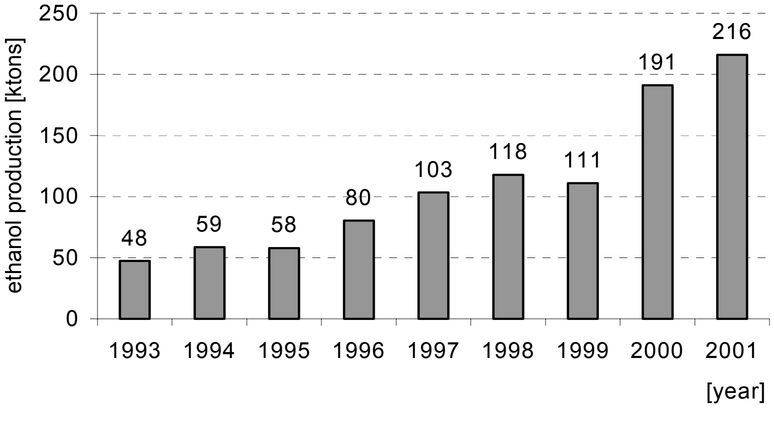

Figure 3.2 *Ethanol production of the European Union (1993 – 2001; EurObser'ER, 2001; Internet source 2)*

It appears that the European production of biofuels, both biodiesel and ethanol, increased remarkably, especially the past three years. In the next section, the current biofuel production will be discussed for all individual EU Member States.

3.3 Current production and application of biofuels in Europe

This section will deal with the current production and application of biodiesel (mainly RME) and ethanol/ETBE (produced from food crops) within the European market. A distinction is made between the most important biofuel countries and those countries in which the production and application of biofuels is less developed. The first category contains the following countries: France, Germany, Austria, Sweden, Italy and Spain. The other nine EU Member States are in the other group: Belgium, Denmark, Finland, Greece, Ireland, Luxembourg, The Netherlands, Portugal and the United Kingdom.

Figure 3.3 and 3.4 indicate the shares of the most important biofuel countries in total European production of biodiesel and ethanol, respectively.

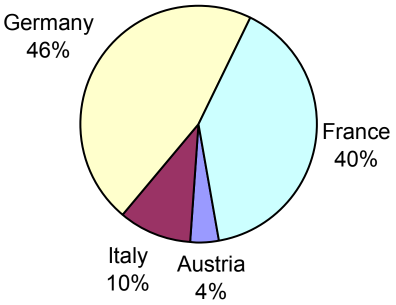

Figure 3.3 *Shares of main producing countries in the total European production of biodiesel for 2001 (total production 780,000 tons). (Internet source 2)*

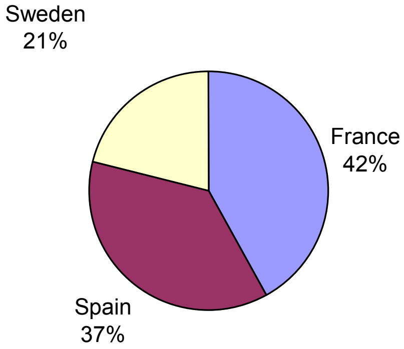

Figure 3.4 *Shares of main producing countries in the total European production of ethanol for 2001 (total production 216,000 tons). (Internet source 2)*

3.3.1 The main players on the European biofuel market

In this section, the national markets for biodiesel are described, for the main players on the European biofuel market, in order of importance.

France

France has already had a long history concerning biofuels. As from the end of the Nineteenth Century and the beginning of the Twentieth Century, France has been producing crops for the production of biofuels. This is not surprising, considering the agricultural heritage of the country. The country's agricultural sector is able to produce a large amount of raw material for the production of biofuels. Therefore, France has always been one of the dominant European producers of biofuels.

In 2001, the total French production of biofuels was about 403,000 tons. This amount comprises a biodiesel production of 312,000 tons and around 91,000 tons of ethanol production. Besides this, the country produces ETBE, a derivative of ethanol, as well. In 2000, the production of

ETBE amounted to 193,000 tons.[16] There is one large biofuel producer, namely Diester Industries (EurOberv'ER, 1999). The biodiesel produced in France consists mainly of RME and SME. Both types of biodiesel are mixed with regular diesel. SME is also used as a domestic fuel blender. Biodiesel is applied in a 30-% mixture in captive fleets. For regular diesel, there are blends with 5% of biodiesel. In France, the produced ethanol is not used in pure form but it is rather converted to ETBE, which is used as an additive to petrol.

The application of the different blended fuels can be found in a lot of urban captive fleets. Throughout the past decade, a lot of French cities used for example biodiesel in their public transport system. There were even captive fleets that were using biodiesel in pure form but this was only temporary.

Germany

In Germany, the production of biofuels is focused on biodiesel. The production of ethanol for automotive fuel purposes is negligible compared to that of biodiesel. Germany is the leader on the European biodiesel market. In 2001, the production rate amounted to almost 360,000 tons. This is a substantial increase compared to the year 2000, in which 246,000 tons of biodiesel were produced. This makes Germany the fastest growing producer with a growth rate of almost 50%. Looking at the future, Germany also has the largest expected production potential of all current EU Member States, namely a production capacity of 780,000 tons of biodiesel (EurObserv'ER, 2001). Figure 3.4 shows the expected growth of biofuel production in Germany.

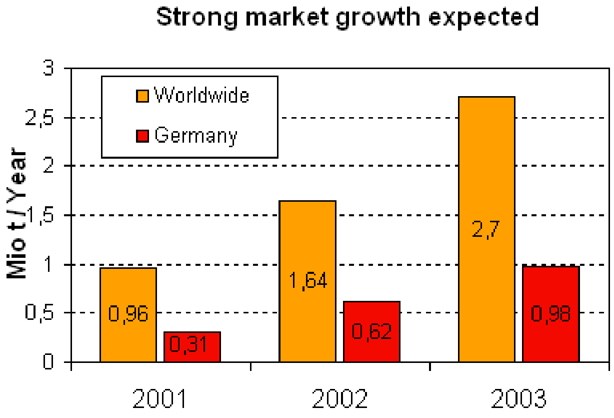

Figure 3.4 *Expected growth of biofuel production [million tons per year] world-wide and in Germany Source (Internet source 18)*

Currently, there are several production sites in Germany with a capacity of more than 60,000 tons per year. There are also three smaller production units with a capacity of less than 5,000 tons (Internet source 30). The two principal German biofuel producers, Conneman and Cognis, are situated in other countries besides its own, for example, in France.

There are about 100 refuelling stations throughout Germany where biodiesel is sold, namely oil from rapeseed, soy or other plants. No engine changes were necessary for the use of these fuels (Internet source 30). Generally, RME is used in pure form in all kinds of vehicles in Germany. Germany is also one of the three countries that use 100% pure biodiesel in adapted vehicles (Internet source 2). This is also done in Austria and Sweden, which will be described later in

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[16] The Swiss Alcohol Board EAV (Eidgenössische AlkoholVerwaltung) published a production rate of 127 million litres of ETBE in 2001 (Internet source 14). It is not completely clear how the rates for ethanol and ETBE should be separated. The ADEME website makes note of the fact that France does not use ethanol in its pure form but that it transforms it into ETBE. It has been decided that only the production rates for biodiesel and ethanol are added in order to determine the total production rate of biofuels in France. This is done because ethanol is the basic biofuel. (Internet source 2).

this section. Obviously, Germany is one of the most active countries in the European Union concerning the production and use of biofuels.

Spain

Spain mainly produces ethanol and ETBE. France and Spain are the only commercial producers of ETBE within the European Union. In 2001, the production rate of ethanol was almost 80,000 tons. For the year 2000, Spain produced about 170,000 tons of ETBE.[17] (Internet source 2). The crops used for biofuel production were grown on 43,500 hectares of land, of which 36,000 hectares were used for grain. The remaining 7,500 hectares were used mainly for growing sunflower (Internet source 10). SME is also used in Spain but no production rates have been found for this type of biofuel (Internet source 2).

It is not clear whether ethanol is used in project form, for example captive fleets, or whether ETBE is used by petrol industries for mixing in regular petrol, as no information about the specific application of ethanol or ETBE as automotive fuels has been found for Spain.

Italy

The production of biofuels in Italy mainly comprises biodiesel, namely RME and SME. With a production rate of 78,000 tons, it is the second smallest European producer[18] (Internet source 2). No production figures for ethanol have been found for Italy. The ENER IURE report states that there is one ETBE production plant with a capacity of 90,000 tons per year.[19]

The crops used for biodiesel production are mostly traditional crops, like rape and sunflower. The crops are cultivated on more than 9,500 hectares of land of which 9,000 hectares are used for sunflowers and only 550 hectares for rape. The crops are converted into biodiesel in eight plants (Internet source 7). The annual production capacity is expected to decrease to 500,000 tons per year in the period 2008 - 2012, which is determined in the Italian White Paper for the valorisation of renewable energy sources (ENER IURE). The two principal biofuel producers are Bakelite and Novaol (EurObserv'ER, 1999).

As from 1991, biodiesel has been distributed in Italy to municipalities, individual municipal transport firms and local municipal departments. SME is mainly applied as a pure fuel or as a blend with 20% diesel fuel, in thermal uses for public and private heating. In Italy, biodiesel is also blended at 5% in regular diesel fuel.

Sweden

Sweden is one of the three European countries that mainly produce ethanol. However, unlike France and Spain, Sweden is not producing ETBE. The production of ethanol was in an experimental phase until 2001. In 2000, the production rate amounted to about 20,000 tons of ethanol. In the spring of 2001, a new distillery was opened with a capacity of 40,000 tons. This directly explains that the ethanol production in Sweden more than doubled within one year, namely to 45,000 tons in 2001 (EurOserv'ER, 2002). The principal biofuel producer is Ekobränsle (EurOserv'ER, 1999).

The ethanol produced in Sweden is used in pure and blended form in automotive engines. Biodiesel is also applied on a small scale, for example, pure RME in adapted fleet vehicles (Internet source 2). Car company Saab is working on this by developing engines that are also adapted to the use of these alternative fuels (Internet source 31). Volvo is also working on car models in different ranges, whose engines are able to run on pure biodiesel. Sweden also participates in the ZEUS project, which aims on a broad popularisation of energy-efficient, environmentally

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[17] There is no production rate for 2001 found for ETBE.

[18] Another source, the ENER IURE Phase III Agriculture Italy report, gives a different biodiesel production rate for 2001, namely 125,000 tons.

[19] The exact production rate for this plant is not mentioned.

friendly vehicles. Stockholm is one of the eight project cities of this project (Internet source 36). Other activities with regard to biofuels include research programmes by the Swedish Energy Agency (SEA) aimed at obtaining more knowledge on the possibilities of biofuels for sustainable development.

Austria

Austria is the smallest European biofuel producer with a production rate of 31,000 tons of biodiesel (2001). In accordance with the development of the global production of biofuels, the production of biofuels in Austria increased enormously in the 1990s. This development is shown in Figure 3.5.

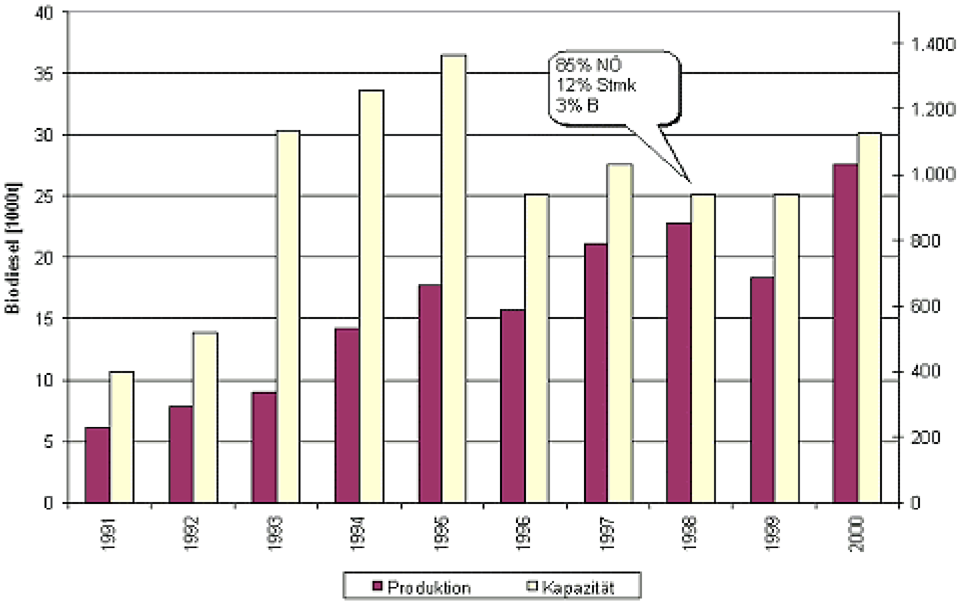

Figure 3.5 *Production and capacity of biodiesel (x1000 litres) 1991 - 2000 (Internet source 18)*

This increase was partly due to the fact that in Aschach, in Upper Austria, one of the world's first industrial biodiesel production plants started operating in 1991. Nowadays, there are two industrial biodiesel plants in Austria, besides several small plants that are owned by agricultural co-operative societies. Most of the fuel produced consists of RME. The shares of SME and used-oil methyl esters are relatively small (Internet source 18). A principal biofuel producer is Ölmühle (EurObserv'ER, 1999). There is no production of ethanol in Austria.

In Austria, RME is used mixed with regular diesel and, as already has been said earlier, 100% pure biodiesel is being used in adapted vehicles (Internet source 2). In the city of Graz, a pilot project for the application of pure biodiesel has been running since 1994. Between 1994 and 1997, two public transport buses were running on biodiesel. In 1999, the city continued this project with ten buses and now there are about 40 buses that are driving in Graz and its surroundings (Internet source 11). Nowadays, there are more than 50 ECOdiesel stations in Austria, which can only be used by adapted vehicles (Internet source 18).

3.3.2 The other countries

In this section, the countries that are less active in the field of biofuels are discussed. These are Belgium, Denmark, Finland, Greece, Ireland, Luxembourg, The Netherlands, Portugal and the United Kingdom. In most of these countries, the application of biofuels is still in an experimental phase. For these countries, examples of experimental applications of biofuels will be given.

Belgium

Belgium is an interesting story and a little bit of a mystery as far as biofuels are concerned. Production figures are given up to the year 2000. In this year, there was a modest production rate of 20,000 tons. This was less than 3% of the total production in the EU and therefore Belgium was the smallest producer within the EU. This is much less than the 19% of the total Belgian biodiesel production in 1998 (EurObserv'ER, 1999). The reason for this fall in production is not exactly known. There was a production site in Feluy with a capacity of 30,000 tons of biodiesel. Furthermore, there was a Belgian biofuel producer named Sissas (EurObserv'ER, 1999).

During the 1990s, there were several experiments going on in Belgium. For example, in Engies (Mons), 15 buses were running on biodiesel during eight months in 1991 and 1992. The Ministry of Technology and Development of the Walloon Region funded the experiment. The research department of oil company TotalFinaElf, as it is called now, was involved in this project as well.

Denmark

The Danish city of Copenhagen is trying and testing DME for the application on buses. Besides this Copenhagen is one of the eight project cities of the ZEUS project (see Section 3.3.1 on Sweden). In Copenhagen, this project resulted in the replacement of some of the petrol-driven cars in the municipal fleet by electric cars. This was in order to reduce traffic pollution and to promote the use of environmentally friendly vehicles. Another initiative was the introduction of a 'Green Card' for lorries over 3,5 tons in order to reduce pollution and traffic congestion in the city centre (Internet source 36).

Finland

There is not much information found on biofuel production in Finland. There are several studies from the first half of the 1990s stating that biodiesel production based on rapeseed oil was too expensive in order to be economically viable. If sales of biodiesel were exempt from taxes, then biodiesel might be able compete with fossil diesel (Internet source 7).

The first Finnish biofuel production plant came into operation in October 2001. From the start, this plant has been one of the world's largest biofuel plants with a commercial production (Internet source 37). However, this plant is not producing biofuels for use in cars but for the production of electricity on a competitive basis, for the production of steam for forest industry and for producing district heat for the municipality (Internet source 33).

Greece

Greece is active in the field of pilot tests for biofuels. There has not been any commercial production of biofuels so far. Resources for these pilot tests are sunflower, maize, olive and frying oils. Moreover, sweet sorghum (a tropical plant) is used for the production of bioethanol (Internet source 7).

Ireland

There are some developments going on in Ireland but they are all in an experimental phase. For example, there are pilot tests running for the use of RME. The application of used frying oil engines is also researched. There has also been a successful test of four commercial trucks running for 42,000 km over a period of three months. Another project aims at exploring the production of biodiesel from vegetable oil by growing potential energy crops, including rapeseed, in trials. One company has investigated the idea of setting up a biofuel production plant, processing sugar beet, but this has not been made concrete yet (Internet source 20).

Luxembourg

Two developments can be described for the grand duchy of Luxembourg. Firstly, fuel is produced from wood chips as an important alternative energy source. Secondly, RME is applied in about 40 buses in the city of Luxembourg. The city of Luxembourg is one of the eight project cities of the ZEUS project (see Section 3.3.1 Sweden).

The Netherlands

There are two projects to be mentioned here for the Netherlands. The first one is called OPEK Netherlands, which stands for Organisation of Plant-oil and Ecological Energy sources. This is a private initiative aiming at finding out whether the production and application of biofuel produced from rape is economically feasible. The main goal of the organisation is to stimulate the use of biofuels. Therefore, they want to prove that the use of this biofuel is not only environmental friendly but also technically feasible, namely that the use will not damage the engine of the vehicle. In the beginning of 2003, OPEK will start to produce oil from rape crops. Then 15 trucks will be used for the experiment, which will run for eight years (Didde, 2002; Internet source 26).

The other project is the plan of the municipality of Venlo, a city in the Southern part of the Netherlands, to use biodiesel for its car fleet, which consists of 80 vehicles. The project will start with the application of this fuel in one cleaning vehicle. Later on, another vehicle will be used. If the results of these tests are positive, then the other vehicles will start using biodiesel too (Internet source 4).

Portugal

In Portugal, SME is used in captive fleets, blended in mixtures of 30% and 5% with diesel (Internet source 2). It is remarkable that there is only the use of SME and no production or use of RME, while RME is the most important biodiesel on the commercial European biofuel market. This is because the main oleaginous culture in terms of cultivation area in Portugal is the production of sunflower oil (ENER IURE, 2002b).

United Kingdom

In the United Kingdom, domestic biodiesel is currently produced from waste oils.[20] Furthermore, several pilot projects using hydrogen, ethanol, methanol, and biogas were to be introduced during the course of 2001, as a result of national legislation (ENER IURE Agricultural Report).

Like in the Netherlands, there is an organisation dedicated to the promotion of automotive fuels and oils from renewable sources. This is the British Association for Biofuels and Oils (BABFO). This organisation is not producing biofuels, like the OPEK in the Netherlands will do, but it is more focused on a political field and on providing information. In this way, the BABFO wants to modify the tax on biodiesel in the UK and try to establish a biodiesel plant. A pilot plant is being planned.

3.3.3 International biofuel trade

Currently, international trade in biofuels has not developed yet. It seems unlikely that European countries import biofuels from other countries outside the European Union, for example the USA and Brazil, since the utilisation of their own fallow land and/or agricultural residues is an important reason for EU Member States to produce biofuels, besides CO_2 emission reduction objectives. In order to be able to let imported automotive fuels qualify as biofuels, the origin of the fuels and the feedstock used must be known exactly. A system of certificates of origin has not been established yet, so this cannot be ensured to biofuel importing countries. At present, most of the biofuels produced within the European Union seem to be consumed within the EU Member States as well, who may mutually trade these fuels. There is one example known for import of biofuels from the European Union to Brazil. At some time, a shortage of ethanol oc-

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[20] This comes from a research ECN has done in order to measure the stimulation of biofuels (Personal communication P. Kroon, ECN).

curred in this country. To overcome this, ethanol was imported and methanol was used to substitute ethanol in a blend with petrol. The result of the insecurity of the ethanol supply led to an enormous decrease of the sales of adapted vehicles running on pure ethanol, from 60% to almost zero (Personal communication P. Kroon, ECN).

3.4 National and European biofuel policies

3.4.1 Development of biofuels policy in Europe

In the White Paper for a Community Strategy and Action Plan, entitled ‘Energy for the Future: Renewable Sources of Energy’(1997), the need for increasing the share of liquid biofuels has already been mentioned. It is stated that, at present, biofuels are not competitive due to the relatively low price of crude oil. Still, it is important to secure an increasing part of alternative fuels on the market, because of unpredictable oil prices and long-term fossil resource depletion.

The first priority that is identified in the White Paper is a decrease of production costs of biofuels. Other focus areas of focus are tax exemption and subsidised biomass growing initiatives. The first proposals by the Commission for making large-scale tax exemption measures possible date from this time. The small-scale incentives that are in force to stimulate pilot projects seem to be too limiting; market initiatives tend to go beyond the experimental stage. Whereas most activities in the biofuel sector took place in France, Austria and Germany, the explicit goal has been to promote biofuels in all Member States. To this end, the White Paper announces to release additional directives in the years to come.

The Green Paper called ‘Towards a European Strategy for the Security of Energy Supply’ (2000) stresses the importance of biomass in relation to supply security. Whereas the entire energy supply is at stake, all usage is promoted: generation of heat and electricity using biomass and the production of biofuels. It is stated that “the enormous potential of forest and agricultural residues has so far not been exploited”. Advantages concern the emission of greenhouse gases (“between 40 and 80 % less than fossil fuels”), local environment (“less particulate and carbon monoxide and hydroxide”), and social aspects (“job creation in rural areas”). It is also stressed that intense agricultural production forms are undesirable.

Moreover, it is emphasised that the current Community legislation is working counterproductive to the need for security of supply, for tax exemption for biofuel is not allowed other than in pilot projects. The final report on the Green Paper (2002) adds that in the longer term it might be technically possible to replace 20% of the petrol and diesel used for road transport by the year 2020, if a proper framework of incentives is set up.

A number of 13 ‘guidelines for debate’ are listed, of which two are directly linked to biofuels and the transport sector. The first question is whether co-ordinated EU action is required for a share of 20% in total fuel consumption by the year 2020. Several viewpoints are mentioned in the final report on the Green Paper, generally putting the matter in a broader perspective, pointing out several aspects of large-scale biomass growing and proposing to use demand growth control measures to reduce energy demand of the transport sector. The second question addresses the way corrective action can be taken for energy saving in the transport sector by substituting road haulage by rail transport.

The discussion on the use of biofuels in the EU in both the White Paper and Green Paper mentioned above did not lead to the development of concrete biofuel-specific national policies in many EU Member States. However, in June 2001, it did result in two EU directive proposals on the promotion of biofuels. The first draft directive obliges the EU Member States to sell a certain amount of biofuels on their national markets in the period 2005 - 2010. In order to support this, the second draft directive provides the opportunity to the Member States to adjust their national excise duty systems for automotive fuels in favour of biofuels. Before these directives are discussed in more detail, the current national biofuel-specific policies will be described first for all EU Member States.

3.4.2 Current national policies for the promotion of biofuels

In this paragraph, the current national policies concerning biofuels in the different EU Member States will be discussed. The order of the countries is the same as in Section 3.3 about the national biofuel markets.

France

France is one of the leading countries concerning the production and use of both biodiesel and ethanol. Liquid biofuels is one of the four bio-energy fields in France. During the past years there has not been significant progress in this field. This is because France was confronted with protests against its state of production. The problem was that the state of production was commercial to an extent that it was not conform to European Legislation on biofuels. This legislation from 1992 allowed a tax exemption on biofuels for pilot projects. France was giving a tax exemption of 100% for biodiesel and of 80% for ethanol but it was not possible to talk about ‘pilot projects’ anymore, considering the production of about 420.000 tons of biofuels in 2000. The protests led to a prohibition by the EU on subsidy measures for France. The French government requested for adjusted measures and this was honoured in May 2002 by maximum duty exemption on biodiesel and ethanol (Internet source 28). Besides the outcome of this request, the French government was and is waiting for the approval of the proposed EU directive on biofuels in order to expand the production of biofuels (see Section 3.4.3) (Internet source 24).

Another reason for the stagnating production rates is that France is one of the four EU Member States that are confronted with an EU authorisation for the annual biodiesel production. However, only two of them, France and Italy, have been imposed a limitation on their annual biodiesel production. For France, this was 317,500 tons at the end of 2000. This quota is linked to the desired level of tax exemption, which is necessary because of the guarantee of equitable competition between different countries in the EU (EurObserv’ER, 2001).

The national programme for biofuels in France comprises a 100-% tax exemption for biodiesel production and an 80-% tax exemption for ethanol production, which was already mentioned. This is in conformance with the ‘biofuel production programme’ administrated by the ‘Agence de l’Environnement et de la Maitrise de l’Energie’ (ADEME). This mechanism of fiscal incentives aims at developing investments for biofuel production but a limit has been imposed now due to European legislation. These incentives will be reduced in 2005 (ENER IURE, 1998). When the proposed EU directive is accepted, a new legal and fiscal frame is expected for France (ENER IURE, 2002b).

Germany

Germany is one of the six Member States that produce biofuels on a commercial basis. It is also one of the four countries that is confronted with EU authorisation on the annual biodiesel production. However, Germany, together with Austria, does not have any restriction on this production rate (EurObserv’ER, 2001), unlike France and Italy.

The Law on the Excise Tax on Oil and Oil Products, the so-called ‘Mineralölsteuergesetz’, regulates national policy on biofuels in Germany. But this is indirect legislation for biofuels, since the law does not have a specific part focusing on biofuels. Alcohol and vegetable oil fuels are not mineral oils so they do not fall within the scope of this law. The only thing covered by this law is that alcoholic and vegetable oil fuel with no or up to a maximum concentration of 3% of hydrocarbons is exempt from fuel taxation. This together with the lack of concrete legislation on biofuels is considered a tax exemption. This is to support the use and market penetration of biofuels (ENER IURE, 2002c). However, in legal terms, biofuels are not exempt from any taxation. This is about to change as the government decided to extend the so-called tax exemption on all biofuels within the framework of the planned amendment of the Law on the Excise Tax on Oil and Oil Products (ENER IURE, 2002a).

Besides this unregulated tax exemption for biofuels, there are different so-called permissibility assessments coming from the Federal 'Immission' Control Act ('Bundesimmissionsschutzgesetz'). This Act provides the protection of environment through influences by air pollution, noise, earthquakes and similar events. Permission is needed for hazardous fuels from wood with an installed capacity of 100 kW to 1 MW, as well as for biofuels with a capacity of less than 100 kW, whereas the operation of rapeseed-oil, straw, corn and miscanthus, is generally prohibited. There is no permissibility assessment for biofuels, straw and other organic material with a burning-heat capacity from 100 kW to 1 MW[21] (ENER IURE, 2002c).

Spain

In Spain, policy for biofuels can be divided into national policy and regional policy. On a national level not too much regulation is found for a country that is producing biofuels on a commercial basis. There is a fiscal measure that guarantees a state deduction for investments made in new tangible fixed assets that are intended for the use of renewable energy sources.[22] The deduction will be 10% of the investments made. The treatment of agricultural materials, forestry or oils used for its transformation into biofuels (bioethanol or biodiesel) is one of the investments qualified for this deduction (ENER IURE, 2001b).

The development of biofuels is also influenced by the Royal Decree 1165/95 for the application of financial exemption. This decree ensures a reduced rate of excise duty. Besides this decree there is the Royal Decree 1728/99 on Fuel Quality, which should approve the quality of the biofuel. Currently, this Decree only applies to fossil fuels. Standards of quality for biofuels have not been established yet.

Another incentive on a national level for the production of biofuels can be found in subsidies and is appointed in the Royal Decree 615/1998. Within the framework of the Spanish Energy Saving and Efficiency Plan (Order PAEE), credits are available for projects concerning fuel production from forestry, agriculture and industry residues. This includes the production of biofuels. The subsidy rate of these activities has been fixed at 30% of the subsidisable costs (ENER IURE, 2001d).

Finally, there is a subsidy that is generated by ICO-IDEA.[23] ICO-IDAE has a financing rule containing a discount of the interest for renewable energy and energy efficiency projects. The projects can be financed op to 70% and the reduction will be five points of the interest rate. Biofuels projects are qualified for this discount as well (ENER IURE, 2002h).

Italy

Italy has already been actively producing biofuels since 1991. As from that year, biodiesel was distributed to municipalities, individual transport firms and the local municipal departments (Internet source 7). It is therefore not surprising that the 'Italian White Paper for the valorisation of Renewable Energy Sources' (1999) describes the aim to promote the use of biodiesel for heating purposes and for public transportation. Besides this promotion, Italy also wants to be active in the drafting of the European policy on biofuels (ENER IURE, 1999). The promotion and the active attitude partly led to the position Italy now has on the commercial biodiesel market.

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[21] § 19 BImSchG, annex 1.3 of the 4th Bundesimmissions-schutzgesetz (BimSchV).

[22] This is regulated by Law 24/2001, of 27 December, of Fiscal, Administrative and Social-Order Measures Article 35.4 of the Corporation Tax Law.

[23] ICO-IDEA is a combination of the Official Credit Institute (Instituto de Crédito Oficial) and the Institute for Diversification and Saving of Energy (Instituto para la Diversificacíon y Ahorro de la Energía).

Italy is one of the four countries that is authorised for a certain level of annual biodiesel production by the EU. The country has a quota of 125,000 tons and it also has an authorisation rise to 320,000 tons at the end of 2001 (EurObserv'ER, 2001).

Furthermore, the EU also allowed Italy to reduce excise duties on fuels containing biodiesel until the end of June 2004. The proposal applied to mixtures containing 5% or 25% of biodiesel. Italy had requested an exemption from excise duties for a three-year programme that started in July 2001. This exemption is valid until the annual quota of 300,000 tonnes of biodiesel is reached. The current level of excise duties on diesel is € 381,70 per 1,000 litres. The effective duty rate to final products would be € 362.60 per 1,000 litres for biodiesel used as a diesel additive in quantities of less than 5%, and € 286.30 per 1,000 litres for biodiesel used as a motor fuel mixed with diesel in a proportion of approximately 25% (Internet source 28). On a national level of law, this means that Legislative Decree of 26 October 1995 (number 504) concerning the taxation on production and consumption of among other things mineral oils, alcohol and electricity is adjusted for the production of biofuels. This is done by article 21 of the Legislative Decree. Because there is a limit of exemption the distribution is also regulated. This is done by specific ministerial decrees, which has been confirmed by the decree of the Finance Ministry of 22 May 1998 (number 219) (ENER IURE, 2002d).

Besides the policy incentive for biodiesel, there is legislation for ethanol and ETBE as well. This can be found in the Legislative Decree 280 from 1994, which regulates the blending of ethanol and ETBE with gasoline. This decree is in line with the EU directive on crude-oil savings through the use of substitute fuel components in petrol[24] (Internet source 7). The BioBase report for Italy also notes the existence of Law 173 (1998), which provides financial incentives for non-food production. In other words, non-food production is stimulated in order to provide raw materials for, among other things, production of biofuels.

Sweden

The Swedish government has a policy, which aims at the reduction of the use of fossil fuels and the promotion of the use of renewable energy sources such as biofuels. This is done by taxation and administrative measures. The most important policy measure for biofuels in Sweden is that biofuels are exempt from energy taxes, environmental taxes and fees (ENER IURE, 2001c). There are two concrete fiscal measures of which biofuels are exempt. These are the Carbon Dioxide Tax and the Sulphur Tax. Both taxes belong to the Act of Energy Taxation (Act 1994:1776) (ENER IURE, 2001f).

Besides these direct energy taxations, the production and use of biofuels is promoted in an indirect way by so-called green taxes. For example, the carbon dioxide tax has resulted in an increased use of biofuels (website Swedish Environmental Protection Agency). These fiscal measures seem to have a very positive effect on the production and use of biofuels. But it should also be mentioned that this implies mainly the use of biofuels in the district-heating sector, and not specifically in the transport sector. There are no subsidies provided for the use of biofuels in Sweden.

Austria

Austria is one of the four biodiesel producing EU Member States. Austria does not have a restriction on its annual biodiesel production. The production of rape was decreasing in the second part of the 1990s but this trend was ended due to new policy. This policy named ÖPUL[25] strongly focused on renewable materials, which led to an increase in the production of these ma-

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[24] Council Directive 85/536/EEC of 5 December 1985.

[25] ÖPUL means "Österreichisches Programm zur Förderung einer Umweltgerechten, extensiven und den natürlichen Lebensraum schützenden Landwirtschaft" (http://www.noel.gv.at/service/LF/LF3/OEPUL.htm).

terials. An example of an ÖPUL-measure is that contributions are paid to farmers that use fallow land for growing renewable material (Internet source 11).

Besides this policy, that supports the production of for example rape, the Austrian government also aims at supporting the production of biofuels, which is not only to act in conformance with the planned EU directive but also for national reasons. Namely, the production and use of biofuels will create employment, less dependency on the import of diesel and it will lighten the balance of trade (Internet source 11). Therefore, the production of biofuels is also supported by tax reductions. The basis of this tax reduction can be found in the regulation of fuel from 1992 (Kraftstoffverordnung BGBI 1992/123). This regulation states that only fuels that comply with the standards are allowed. So, the standards for RME, for example, are established in a pre-standard (ÖNORM Vornorm C1190).

There is also regulation concerning the taxation of mineral oils (Mineralölsteuergesetz 1995, BGBI 1995/630). To support the production and the use of biofuels there is a tax reduction. Austria is only producing biodiesel so the tax reductions are as follows:

- if biodiesel is used in pure form the tax exemption is 100%,
- if the content of biogenous fuels in a blend is up to 5%, there is a tax exemption of the entire biogenous share,
- if the content of biogenous fuels in a blend is higher than 5%, there is no tax exemption.

Besides this, the production of biodiesel in small-scale plants from agricultural co-operatives is completely free of mineral oil tax, under the condition that the fuel is exclusively used in farms (ENER IURE , 2001d).

Belgium

It seems as if there is not much happening with regard to biofuels in Belgium. No current commercial production rates were found for this country. This may be the result of a lack of clearly defined and specific policy for biofuels. This starts with the fact that the legal regime that applies to the production of oil seeds that are destined for other than human consumption or animal feed purposes, for example biofuels, is not defined clearly. Eventually, it seems logical that these production activities are a part of agricultural activities (ENER-IURE, 2002b). This should mean that the production of biofuels is a part of the agricultural legislation of the country but there is no specification for biofuels in this legislative area..

More concrete regulation for biofuels is found in the form of the following fiscal measure: the Royal Decree 22.07.1993 - Levy on Energy. This is a form of indirect taxation that is translated into an additional levy on the sales of certain types of fuels and of electricity. The goal of this national decree is to create revenues that are necessary to finance measures aimed at promoting competitiveness of enterprises and employment. Fuels other than mineral oil products are excluded (ENER IURE, 2002e). So this indicates a levy exemption for biofuels, since these are not mineral oil products.

Denmark

Energy 21 is the name of the long-term policy programme of Denmark. Biomass has a very important position in this policy programme in order to increase the contribution from renewable energy. It is expected that (renewable) energy crops will contribute to the energy system from the year 2005 (Internet source 8).

The Danish government does not have any biofuel-specific policies.[26] One of the reasons for the lack of policy was the fact that tax exemption for biofuels was not allowed because they should be taxed as fossil fuels, according to the EU Mineral Oil Directive. The situation has now

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[26] The most recent source for this dates from October 2001. This means that the developments after the publishing of the proposal of the EU Directive in November 2001 have not been taken into account.

changed as a result of the proposal for an EU directive but it is not clear whether Danish policy has already changed with regard to, for example, tax exemption for biofuels. The government has been willing to work for the proposal for an EU directive on the promotion of the use of biofuels for transport and it will change its national policy. Assuming the old situation is still active, biofuels are imposed to the Danish CO_2, SO_2 and energy tax (ENER IURE, 2001d). Another reason for no policy for biofuels is the fact that the production costs are 1.5 to three times higher compared to fossil fuels.

Subsidies can be used for the utilisation of biofuels, according to Act Number 3 (1992). The goal of this Act is to promote the use of biomass in Denmark through subsidies for installations. The maximum amount of subsidy is 50% but usually there is a support up to 10 to 25% of installation costs (ENER IURE, 2001e).

Finland

In Finland there is a lot of development in the field of bio-energy. A result is a well-developed scheme of legislation. This is completely different for biofuels, which might explain the fact that Finland is not yet producing biofuels on a commercial basis. The only thing that is concrete for liquid biofuels is a proposal for households for a lower petrol tax for a certain period of time. This proposal aims at promotion of renewable energy sources in Finland in the future (ENER IURE, 2002d).

Greece

Greece is not too active in the field of biofuels. However, the Greek government has set some goals with regard to Renewable Energy Sources (RES). The ENER IURE Fiscal Measures Report states that "the prime goal of a national RES development programme should not be the equivalent (equally funded) development of all RES types and applications, but rather the priority support of those ones that exploit in an optimal way (high benefit-to-cost ratio), both for the national economy and for the society, the available public financial resources" (ENER IURE, 2002f). Translated to biofuels, this means that biofuels will only be supported if exploitation is economically viable. This is not yet the case despite the production of liquid automotive biofuels was one of the main points in the Greek Action Plan for Climate Change of 1995. This plan, supported by other national programmes, described the national policies for the promotion of RES-related investments for the period from 1996 to 2000. One of the supporting programmes is the Operational Programme for Energy (OPE). In the first round of this programme (1996), capital subsidies could be provided to projects associated with the production of bioethanol (to be used as an automotive fuel). A production of 50,000 tons of bioethanol was expected in 2000 but there were only few investors found due to the disadvantageous (or lack of) EU policy on biofuels. In the second round of the OPE (1997), a more modest target was adopted with less capital subsidy. Because of the lack of interest in projects there were only a few pilot projects reacting on this programme (ENER IURE, 2002b). These modest projects were supported also to stay in line with the existing European provisions for the tax exemption of liquid biofuels. The Greek petroleum supply company ELINOIL took advantage of the European rules and started a pilot project in 1999. RME was used as a substitute for diesel oil initially in five of its petrol stations in the Greek Region of Thrace. The RME was imported from Austria and was used as a substitute in heavy-duty trucks and vehicles. The European Commission financially supported this pilot project (ENER IURE, 2002b).

Now there are two projects for biofuels going on in Greece. These projects are a part of the so-called PENED-project, which is a programme supporting the development of the Greek research potential (academic institutions and laboratories). The government funds this project (ENER IURE, 2002b).

Ireland

Ireland is the most import-dependent energy economy of the EU Member States. The country is importing 90% of its fuel. As described in the preceding section on production and application, Ireland only has a few research projects running but more needs to be done to reach the targets set in the EU directive.

However, the Irish government did introduce legislation in order to reduce excise duty on the use of biofuels. This kind of legislation was introduced in 1995 in the Finance Act. A certain governmental group was established making qualifying conditions but it seemed that this legislation was never activated, as the Department of Finance refused to reduce excise duty to a business proposing to develop a liquid biofuels plant (ENER IURE, 2002f).

Now, with a clear EU target on biofuels in sight, the importance for creating policy concerning biofuels is high. A clear position in favour of biofuels is needed. Its energetic and environmental possibilities should be recognised and there should not only be attention for the economic criteria for the implementation of biofuels in the market. (ENER IURE, 2002g) This not only applies to Ireland, but to the other less active EU Member States as well.

Luxembourg

In Luxembourg, there does not seem to be a clear biofuels policy. The only thing that is mentioned in the ENER IURE General Report for Luxembourg (ENER IURE, 2002h) is that “the use of agricultural raw material for the manufacturing of fuels for transport is being strengthened, since, (…) the colza (rape) crops are used for the production of biodiesel (…).”

The Netherlands

In the Netherlands, two motions[27] were proposed in 2001 to promote the use of biofuels in engines. The first motion requests the government to propose a complete tax exemption for cold pressed vegetable oils as a long-term experiment in diesel engines of cruises, agricultural vehicles and a selection of the road vehicles (motion Hofstra, Kamerstukken II, 2000-2001, 27 400 IXB, number 32). The second motion requests the government to propose a tax exemption for refined biofuels and lubricants that will only be valid for cruises and navigation and for applications in nature and agriculture[28] (Internet source 23).

In 1997 and 1998, there were legislative measures for biofuels but this is not specific policy, as biofuels are not explicitly mentioned. These measures are found in the Energy Programme Order (52) Programme number 3 (1998) and Programme number 5 (1997). Both programmes aim at stimulating the use of biomass and waste as an energy source, which should lead to a maximum saving of fossil fuels. These programmes were funded by the Ministry of Economic Affairs for the amount of almost € 4.1 million and almost € 227,000, respectively (ENER IURE, the Netherlands).

Portugal

The only concrete policy that is found for Portugal concerns a tax reduction for biofuels used in Research and Technological Development projects certified by the Ministry of Economy and the Ministry for the Environment (Internet source 3).

United Kingdom

The United Kingdom has implemented policy for biofuels relatively recently. The goal of the British government is to reduce CO_2 emissions and improve air quality. Initially, this led to the promotion of less polluting fossil fuels, like LPG. This was done in the so-called Powershift programme (ENER IURE, 2001a). Eventually, this has led to policy support for fuel efficiency measures and for renewable automotive fuels. The support resulted in the legislative measure called the Green Fuel Challenge, which can be considered a framework for commissioning innovative bids for green fuels (from ECN Questionnaire). This Green Fuel Challenge is also

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[27] These motions were proposed in a letter of the State Secretary of the Ministry of Finance at the time on October 28th, 2001.

[28] Motion Crone c.s., Kamerstukken II, 2000-2001, 27 400 IXB, number 33.

known on the administration level as the March 2001 Budget. In the Budget, a duty reduction was announced of 20 pence per litre on biodiesel, which is 20 pence below the duty rate of Ultra Low Sulphur Diesel. This will balance the additional production costs of biodiesel. This reduction was confirmed in the Budget 2002. The budget also gives the opportunity for legislation that will benefit the production and use of other biofuels like ethanol. This may eventually lead to the introduction of duty reductions or exemptions for pilot projects to evaluate the feasibility and/or environmental benefits (ENER IURE, 2001a). Besides the fiscal measure, there are no subsidies in the UK for the consumption of renewable energy sources.

3.4.3 European biofuel policy developments

As mentioned earlier, the European Commission proposed a new EU policy to promote the use of biofuels in the transport sector in 2001. The "Communication from the Commission on alternative fuels for road transportation and on a set of measures to promote the use of biofuels" includes two proposals. The first draft directive aims at promoting the use of biofuels for transport by setting biofuel sales targets for the EU Member States. The second proposal, amending the Directive 92/81/EEC, allows the Member States to apply a reduced rate of excise duty on certain mineral oils containing biofuels and on biofuels (European Commission, 2001 a,b,c).

The Communication from the European Commission on these two draft directives poses that the challenge as formulated in the Green Paper is unparalleled in history. Typical problems are identified, for example, the large number of advantages of today's car as experienced by a large population. The road transport sector's strong competition imposes economical challenges on the use of alternative fuels. These arguments led to the definition of four supply-side possibilities that each could reach a level of 5% or more of the total automotive fuel market by the year 2020, and one demand-side option:

1. Motor vehicle fuel efficiency
2. Biofuels
3. Natural Gas
4. Hydrogen
5. Other fuels and technologies.

In Table 3.1, a rough guideline of an introduction scheme for alternative fuels in the EU is presented. The paper stressed the importance of continuous monitoring of any alternative fuel strategy against developments in motor fuel efficiency. Namely, a successful implementation of a strong fuel efficiency regime makes high substitution percentages less necessary and may offer the most cost-effective CO_2 emission reduction together with an improved security of supply.

Table 3.1 *Rough guideline of introduction scheme of alternative fuels in the EU (European Commission, 2001a)*

Year	Biofuel [%]	Natural gas [%]	Hydrogen [%]	Total [%]
2005	2			2
2010	6	2		8
2015	(7)	5	2	(14)
2020	(8)	10	5	(23)

Furthermore, as part of the strategy to reduce emissions and improve fuel economy, the Commission dictates herself a plan of action, in which the following issues have been put forward. First of all, two proposals for directives are made, which will be discussed below. Secondly, a contact group of important stakeholders will be formed, which will report to the Council and the Parliament on further possibilities regarding the introduction of alternative fuels, in particular for natural gas and hydrogen. Also, the Commission will monitor developments in the field regarding other alternative fuels and technologies. Finally, the aim is to keep consumers involved in the matter of biofuels.

The first proposal: directive on the promotion of the use of biofuels in transport

In the Explanatory Memorandum of the directive proposal on the promotion of the use of biofuels in transport,[29] the objective and the scope of the directive are illustrated. This document also mentions a definition of the different types of biofuels and the current situation in Europe and the potential for biofuels in Europe. Moreover, the production costs and benefits in terms of CO_2 emission avoidance and increased security of supply are discussed and quantified. Impacts on other policies are also discussed, i.e. agriculture, employment, fiscal policy, environmental considerations. Some interesting quotes regard, for example, vehicle exhaust emission ("little, if any, emission advantage"),[30] groundwater contamination ("Member States should apply widely best available techniques for the construction and operation of underground storage tanks at service stations") and land use agricultural practice ("Environmental advantages from growing crops for biofuels should be promoted through sustainable farming and afforestation"). Furthermore, it is stated that attention needs to be paid to production and refining. Finally, opportunities are identified for third and developing countries.

The action at Community level is justified by referring to the EU strategy for sustainable development as presented by the Commission to the Gothenburg European Council of 15 and 16 June 2001. Here, the promotion of biofuels is addressed: "limiting climate change and increasing the use of clean energy, addressing threats to public health, managing natural resources more responsibly and improving the transport system and land use". International events as the UN Framework Convention on Climate Change of 1992 and the Kyoto Protocol of 1997 are mentioned. Other policy documents are also referred to, notably the previously discussed White and Green Papers.

Finally, it is stated that the approach as proposed aims at creating a level playing field for all sectors involved, and that particularly the Accession Countries can be key players in the biofuel industry.

The actual directive proposal obliges the Member States to establish a minimum percentage of 2% by 31 December 2005 by volume of biofuels to be sold in their respective national markets. This amount is to increase every year by 0.75% to 5.75% in the year 2010. The biofuels that are taken into consideration as such are defined in the Annex: bioethanol, biodiesel, biogas, biomethanol, bio-DME, bio-oil, bio-ETBE. For bio-ETBE the share originating from biomass-input is defined as 45%.

State of affairs regarding directive proposal on promotion of the use of biofuels for transport

The draft directive has been criticised from several sides. The EU Energy ministers opposed to the mandatory market penetration rates and prefer them to be indicative and optional. In the European parliament, only Austria, Spain and Italy seemed to be in favour of binding targets. (Environmental Daily 1232 10/06/2002). Biofuel developers opposed to the draft's emphasis put on bioethanol and biodiesel. (Environmental Daily 1236 14/06/2002) Environmental NGOs strongly condemned the draft as a "highly dubious environmental policy" (Internet source 15) The NGO Transport and Environment pleaded for softer targets (Environmental Daily 1232 10/06/2002).

On 12 September 2002, a modified directive proposal[31] is released, in which amendments have been adopted. Important additions regard the public reporting of environmental and financial effects, for which, among others, a discussion of the use of pesticide, the energy efficiency and the CO_2-emmission during the production are mandatory. Hereto, a uniform environmental im-

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[29] 2001/0265(COD).

[30] Note, that this statement does not correspond to the local environment improvements claimed in the Green Paper. Unfortunately, emission levels of biofuels are indeed expected to be equivalent to those of fossil fuels.

[31] COM(2002)508 final 2001/0265(COD).

pact assessment is to be developed by the Commission, including a full life cycle analysis of the use of biofuels.

Furthermore, biodiesel is subject to European quality standards and could possibly be subject to different tax regimes, depending on the biodiesel origin. Moreover, a biofuel with a favourable environmental effect can be given preference by specific tax exemptions. The list of possible biofuels has been adopted. Firstly, it has been stressed that the list is not binding, and biofuels can be added. The explicit mention of bio-oil has been expunged, and the entry of bio-hydrogen has been added.

The biofuel penetration rates will remain to be mandatory, but in case of specific difficulties a Member State has the right to apply once and well founded, for a dispensation of maximum two years. The minimum amount of biofuel sold until the year 2010 has remained unchanged.

In the original proposal, Member States were obliged to blend a minimum percentage of biofuel in fossil petrol and diesel, as from the year 2009. This has been removed in the modified proposal. However, it remains possible for Member States to comply with the obligation of a minimum percentage of biofuels sold on their national automotive fuel markets by introducing a minimum blending percentage. In the modified proposal, it is stressed that, in order to comply with the obligation more quickly, Member States should give priority to the promotion of the use of biofuels by public and collective transportation vehicles. They should also inform consumers about the possibilities of biofuels.

The second proposal: directive amending the Directive for a reduced rate of excise duty on biofuels

This proposal for a Council Directive sets out a new framework of taxation for biofuels. It is explained that within the taxation framework on energy products, automotive fuels are taxed in three ways: excise duties (proportional to the physical quantity of the product), dedicated taxes and duties and VAT (proportional to the selling price of the product). Presently, there is no Community framework for energy products other than mineral oils nor for taxes other than excise duty and VAT.

In this matter, two other EU Directives, namely one on the harmonisation of the structures of excise duties (92/81/EEC) and the other on the approximation of the rates of excise duties (92/82/EEC) are at stake. These two directives set a minimum rate of tax for each mineral oil, but in practice, excise duty is often far in excess of the minimum Community rates, which have not been adjusted since 1992, and differs enormously from one Member State to another. Some exemptions however are allowed, notably for reasons of competitiveness, fiscal reforms, environment-related pilot projects, or public passenger transport.

The framework embedding the proposal indicates the Member States’ space for interpretation. Firstly, the reduction of excise duties should be proportional to the percentage of biofuel incorporated in the fuel or end product. Secondly, the actual amount of tax on the end product may not be less than 50% of the normal rate of excise duty for the corresponding propellant. Thirdly, transitory measures are foreseen in favour of products solely made up of biofuels, which have been totally exempt from excise duty on 1 January 2001.

Furthermore, Member States are asked to set up excise reduction mechanisms, which take account of changes in raw material prices in order to prevent over-compensation for the extra cost of manufacturing biofuels. In this way, competition is guaranteed, as is the incentive of a reduction in costs for producers and distributors of biofuels.

State of affairs regarding the directive for a reduced rate of excise duty on biofuels

In September 2000, the Court of First Instance annulled the Commission decision of April 1997, which established the compatibility of the state aid scheme 15 in France involving the reduction of excise duty on ETBE. The production of ETBE in France had gone beyond the pilot project phase. For this reason, France firmly supports the amending directive on tax reduction.

France, on the contrary, is averse of a European energy tax, which is supported by other members. Despite unanimous agreement on the principle of tax breaks for biofuels, the United Kingdom blocks the adoption of the biofuel directives in order to augment political pressure on France to accept the energy tax (Environmental Daily 1232 10/06/2002).

3.5 Outlook

At the European Parliament sitting of 22 October 2002, the Parliament called on the Council of the European Union to adopt both proposed biofuels directives described above “without any delay”. It is emphasised that the objective of the entire strategy should be the achievement of a low- to zero-emission transport sector. Finally, the legislative resolution on the Commission communication on alternative fuels for road transportation and on a set of measure to promote the use of biofuels was forwarded to the Council and the Commission of the European Union.

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APPENDIX A GLOSSARY OF TERMS

Additive
Additives are added to the fuel in small amounts to improve the properties of the fuel.

Air/fuel ratio
Mass ratio of air to fuel inducted by an engine.

Alcohol
Group of organic compounds, derived from hydrocarbons, which have one or more hydrogen atoms replaced by hydroxyl (OH) groups.

Aromatics
Hydrocarbons with a ring structure (benzene ring), e.g. benzene, toluene, xylene.

Auto-ignition temperature
The minimum temperature at which a mixture of air and fuel ignites spontaneously without the application of an ignition source.

Catalyst
Substance that influences the speed and direction of a chemical reaction without itself undergoing any significant change.

Cetane number
A measure for the ignition quality of diesel fuel based on ignition delay in a compression ignition engine (also called diesel engine). The ignition delay is the time between the start of the injection and the start of the ignition. The higher the cetane number, the shorter the ignition delay and the better the ignition quality. The cetane number is based on the ignition quality of cetane (high cetane number) and heptamethylnonane or (a)-methyl naphthalene (low cetane number).

Compression ratio
The ratio of the combustion chamber at the beginning of the compression stroke and the volume of the chamber at the end of the compression stroke.

Compression ignition engine (diesel engine)
Internal combustion engine with an ignition caused by the heating of the fuel-air mixture in the cylinder by means of compression. This compression causes a rise in temperature and pressure, which makes possible the spontaneous reaction between fuel and oxygen.

Flash point
The temperature to which the fuel has to be heated to produce a vapour/air mixture that will ignite when a flame is applied.

Heating value
The amount of energy released when a fuel is burned completely in a steady-flow process and the products are returned to the state of the reactants. The heating value is dependent on the phase of water/steam in the combustion products. If water is in liquid form, the heating value is called the Higher Heating Value (HHV). When it is in vapour form, one speaks of the Lower Heating Value (LHV).

Hydrolytic stability
The extent to which a substance can withstand its degradation in the presence of water.

Knock
Uncontrolled combustion in a spark ignition engine.

Motor Octane Number (MON)
Octane number that is measured under relatively severe driving conditions that may occur under full throttle, i.e. when the inlet mixture temperature in the engine and the engine rotational speed are both relatively high.

Octane number
A measure for the tendency of a fuel to detonate, when it is combusted in the cylinder of a combustion engine (spark ignition engine or Otto engine). This is also named knock resistance of the fuel. Knock can lead to severe engine damage. The higher the octane number of the fuel, the lower the tendency to detonate and the higher the knock resistance. A higher knock resistance results in a higher compression ratio that can be used in the engine, increasing the engine efficiency. According to the definition of the octane number, iso-octane has an octane number of 100 and n-heptane has an octane number of 0. The octane number can be expressed in a MON or RON value. The difference between these two values is called the sensitivity of the fuel: the ability to deal with the changes in engine load. The MON is usually about 10 points lower than the RON value.

Research Octane Number (RON)
Octane number, which is measured by a special one cylinder laboratory test engine. This is the most frequently mentioned octane number. It is measured during rather mild circumstances.

Reid Vapour Pressure (RVP)
Measure for the vapour pressure and volatility of fuels.

Spark ignition engine (Otto engine)
Internal combustion engine with an ignition of the fuel/air mixture by means of a spark.

Stoichiometric air/fuel ratio
The exact air/fuel ratio required to completely combust a fuel to water and CO_2.

Viscosity
Measure of the resistance to flow of a liquid.

Volatility
Fuel property that determines the behaviour of the engine during the starting up and warming up. A fuel with a higher volatility generates less pollution in the engine during use (IEA, 1996b).