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# *Background Paper*

*on*

# **Biofuel Production Technologies**

WORKING DOCUMENT

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prepared by

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## Preface

One of the key issues of sustainable industrial development is the transition from fossil feedstocks to renewable ones in various sectors, such as energy and fuel, chemical and related industries. Bio-resources represent an important part of available renewable resources. The always increasing attention towards sustainable use of bio-feedstocks in energy and chemical/material production is driven by several factors, namely: fossil feedstock depletion, need of diversification of feedstocks-fossil and renewable, abundance of renewable resources in many countries of the world, CO<sub>2</sub> “neutrality” of renewable feedstocks, concerted potential development of both industry and agriculture, new openings for green chemistry and related industries development, etc.

There are many problems to be solved on the way towards a global acceptance of bio-renewables. Among those, there is a need of further development of suitable technologies including next generations of bio-fuels. Other issues include availability of feedstocks, risk of misconception in designing of bio-fuels strategies, etc. Therefore, further development and assessment of various technological options and of various scenarios of bio-fuels exploitation is highly needed.

The International Centre of Science and High Technology of the United Nations Industrial Development Organization (ICS-UNIDO) has been promoting programmes on capacity building and knowledge transfer in developing countries in several selected areas, including renewable resources. Due to the importance of bio-feedstocks exploitation and bio-fuels production, especially for developing countries, UNIDO has recently elaborated “UNIDO Bio-fuels Strategy”. In synergy with this effort, ICS-UNIDO has been providing a technical expertise on bio-fuel production technologies, especially on those for the next generation of biofuels upon the agreement with the UNIDO/PTC/ECB branch.

The present paper provides a survey of current technologies for the production of bio-fuels and places a particular emphasis on the aspects of evaluation of these technologies. In addition, this background document presents some data on the existing capacity of biofuel production in Europe with special attention on Central and Eastern European (CEE) countries. This document is being presented to the discussion and further elaboration at the *Regional Workshop on Promoting Sustainable Biofuels Production and Use in Central and Eastern Europe* organized by UNIDO in cooperation with the Energy Institute Hrovoje Pozar in Cavtat-Dubrovnik, Croatia on 12-13 November 2007. It is expected that the existing data reported herein will contribute to the development of the relevant UNIDO programmes in these countries in the framework of the initiatives promoted by the UNIDO/PTC/ECB branch.

This background paper is a working document and can contain possible errors. Moreover, authors are aware that information and data, e.g. on biofuel production capacities, can appear not complete. It is expected that improvements and other useful suggestions will be made following discussion of this background paper with UNIDO international and national experts during the abovementioned Workshop.

This document has been prepared within the ICS-UNIDO Work Programme 2007 in the Area of Pure and Applied Chemistry by experts and fellows of ICS-UNIDO in tight cooperation with a group of experts of the Institute of Energy and Environment (Leipzig, Germany). Contribution of Sergey Zinoviev, Sivasamy Arumugam, Franziska Mueller-Langer, Martin Kaltschmitt, Alexander Vogel, Daniela Thraen, and Paolo Fornasiero is appreciated.

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## **Part 1. Introduction**

### ***Biomass***

*Biomass* refers to material of biological origin excluding material embedded in geological formations and transformed to fossil. Biomass can directly or indirectly be converted to biofuels which can be of solid, liquid or gaseous forms. Major sources of biomass for energy purposes are various types of woody and herbaceous biomass, biomass from fruits and seeds (e.g. energy crops) as well as biomass mixtures like animal or horticultural by products etc. Within these products solar energy directly or indirectly (in terms of biomass of animal by-products) by the process of photosynthesis is stored which enables the plants to produce biomass. Biomass is available in abundance and is cheap and its better utilization is to convert it to energy rich products using suitable processes.

Biomass has been the most important energy source for humans since the discovery of fire, and today it is still the main source for almost half of the world's population. The need to increase the use of renewable energy is fundamental to make the world energy matrix more sustainable.

The total use of biomass energy is inherently difficult to measure, especially because much of it does not involve commercial transactions. Globally, the primary energy use of biomass in 2000 was about 52 EJ. Of this total, roughly 45 EJ was consumed as traditional household fuel in developing countries, with some of this converted to charcoal for urban and industrial uses. This is why biomass is only a small percentage of primary energy in industrialized countries but is 42 % of primary energy in India and up to 90% in the world's poorest countries in Africa and Asia. Modern uses of biomass comprise the remaining 7 EJ, mostly in the production of electricity and steam in industrialized and developing countries, such as in the pulp and paper industry, but also in some production of biofuels, as with ethanol in Brazil.

Combustion to produce thermal energy is the traditional way of using biomass, which is what humans have been doing since they discovered fire. The positive benefits of wood combustion to human well-being and longevity were undoubtedly enormous, but there were also costs. Archaeologists tell that cave walls of our ancestors were coated with residues from the thick smoke that would have filled the air and clogged the lungs of cave dwellers.

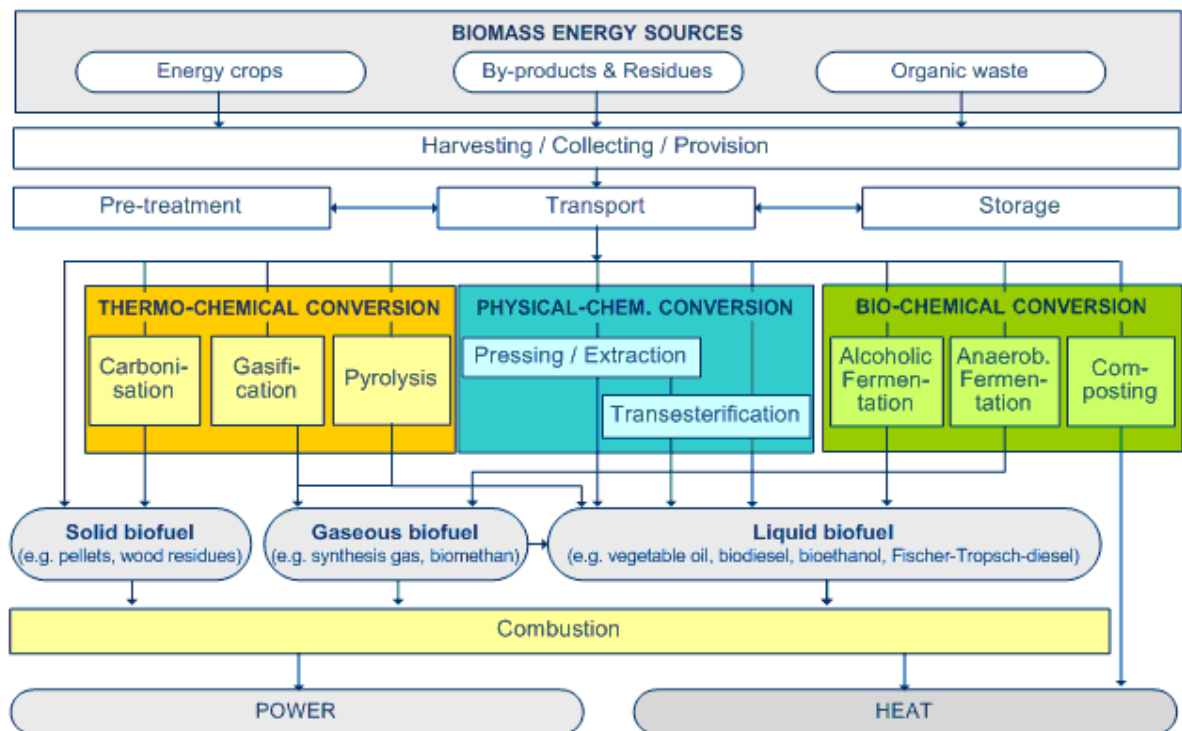
Smoke-filled interior spaces are still the norm for the one third of humanity that continues to rely on wood as its primary energy source, and the particulates and noxious fumes from cooking with open fires and inefficient and poorly ventilated stoves fuelled by wood and crop residues have substantial health impacts. The transition in developing regions of the world from traditional technologies using biomass to more efficient technologies using fossil fuels (propane, butane) results in a dramatic improvement in indoor air quality and increased life expectancy.

### ***Biomass to energy conversion technologies***

Advanced technologies are now under development to convert biomass into various forms of secondary energy including electricity, gaseous and liquid biofuels, and even hydrogen. The purpose of biomass conversion is to provide fuels with clearly defined fuel characteristics that meet given fuel quality standards. To ensure that these fuel quality standards are met and these biomass based fuels can be used with a high efficiency in conversion devices (like engines, turbines) upgrading is needed. In general, there are various options to produce alternative transportation fuels based on biomass. Biogenous energy sources can be converted by means of highly different supply chains into gaseous and liquid biofuels that can be used for transportation purposes. This treatment leads to an upgrading of energy sources in terms of one or more properties named as follows:

- \* Energy density,
- \* Handling,
- \* Storage and transport,
- \* Environmental compatibility,
- \* Utilising of by-products and residues.

Depending on the conversion of biomass in principal three main pathways come into consideration (Scheme 1.1): (i) the thermo-chemical pathway, (ii) the physical-chemical conversion pathway, (iii) the bio-chemical conversion pathway. Those processes provide biofuels in the form of solids (mainly charcoal), liquids (mainly biodiesel and alcohols), or gases (mainly mixtures with methane or carbon monoxide), which can be used for a wide range of applications, including transport and high-temperature industrial processes. These pathways are introduced as follows.



*Scheme 1.1. Basic pathways for the provision of final energy derived from biomass (IEE-Leipzig, 2007)*

### ***Biofuels types and generations***

Biofuel is any fuel that is derived from biomass, recently living organisms or their metabolic byproducts, such as manure from cows. It is a renewable energy source, unlike other natural resources such as petroleum, coal and nuclear fuels.

Biofuels can be grouped in 'generations', according to the type of technology they rely on and the biomass feedstocks they convert into fuel. The principal biofuels of the first and second generations, including respective feedstocks and production technologies are presented in Table 1.1.

Table 1.1. Overview of biofuels of the first and second generation and their related feedstock and conversion processes

	<i>Generic name</i>	<i>Chemical composition</i>	<i>Feedstocks</i>	<i>Technology</i>
<i>1<sup>st</sup> generation</i>	<b>Biodiesel</b>	Methyl or ethyl esters of fatty acids (FAME);  Hydrocarbons (products of cracking)	Oil crops (e.g. rape, palm, soya, jatropha, canola, colza etc.), waste oil (e.g. frying oil), and animal fats	Cold/hot pressing, extraction & transesterification (Homogeneous, heterogeneous, and bio-catalysis); Hydrogenation (hydro-cracking)
	<b>Bioethanol</b>	Ethanol	Sugars (glycosides) and starch from bio-waste and woody biomass (sugarcane, sugar beet, cereals)	Hydrolysis & fermentation
	<b>Vegetable oil</b>	Straight Vegetable Oil (SVO) – triglycerides of fatty acids	Oil crops (e.g. rape, palm, soya, jatropha, canola, colza etc.)	Cold/hot pressing, extraction, and purification
	<b>Biogas</b>	Methan, hydrogen and light hydrocarbons	Biomass (humid)	Anaerobic digestion
<i>2<sup>nd</sup> generation</i>	<b>Cellulosic bioethanol</b>	Ethanol	Lignin, cellulose and hemicellulose from bio-waste	Hydrolysis & fermentation
	<b>Bio-SNG</b>	Synthetic (substitute) natural gas – methane	Lignocellulosic biomass	Pyrolysis, gasification, methanation
	<b>Synthetic biofuels</b>	Hydrocarbons (BTL/FT), methanol (biomethanol), mixed heavy alcohols, dimethyl ether (bio-DME)	Lignocellulosic biomass	Pyrolysis, gasification, synthesis
	<b>Bio-hydrogen</b>	Hydrogen	Lignocellulosic biomass	Pyrolysis, gasification, water gas shift reaction (WGSR)

### *First Generation Biofuels*

First (1<sup>st</sup>)-generation biofuels are biofuels which are produced from food crops (sugar or oil crops) and other food based feedstock (e.g. food waste). These biofuels are on the market in considerable amounts today and their production technologies are well established. The most important biofuels of the 1<sup>st</sup>-generation are bioethanol, biodiesel, and biogas.

Bioethanol is produced by fermenting sugars from starch and sugar biomass (e.g. cereal crops such as corn or maize and sugarcane). It can be used in pure form in specially adapted vehicles or blended with gasoline in any proportion up to 10% (US), provided that fuel specifications are met.

Ethyl-tertiary-butyl-ether (ETBE) is synthesized from bioethanol and isobutylene. It can be blended with gasoline in any proportion up to 15%. It is currently the biggest biofuel contributor in Europe.

Biodiesel (FAME) is made from vegetable oils of rapeseed, soya, palm fruits or other oil crops via the reaction of triglycerides with methanol (transesterification process). It can be used in pure form in specially adapted vehicles or be blended with automotive diesel in any proportion up to 5% (up to 30% for captive fleets).

Biogas is obtained by anaerobic treatment of manure and other humid biomass materials (e.g. in landfills), including food waste, and then upgraded to biomethane that can be feed-in into the natural gas grid and e.g. used in natural gas vehicles. There is a discussion whether to refer to biogas as to the first or the second generation, because it can be produced from a variety of biomass and not only from food crops. However, in view of the maturity and wide use of the technology of its production, in this paper biogas is considered within the first generation, which is also an opinion shared by many experts in the field.

For these types of fuels, only easily extractible parts of plants are used, such as starch-rich corn kernels, grains or the sugar in canes or oilseeds are used. Remaining by-products, such as press cake from vegetable oil production, glycerine from biodiesel production or DDGS (Dried Distillers Grains with Solubles) from bioethanol based on starch, are typically used for fodder or chemical purposes. Integrated concepts that are in R&D stage include the energetic use of by-products (e.g. for process energy provision).

The production of 1<sup>st</sup>-generation biofuels is commercial today, with almost 50 billion litres (approx. 39.5 million t) of bioethanol and 5.4 million t of biodiesel produced worldwide in 2006. The production capacity of ETBE plants in Europe was approx. 2.3 million t in 2005.

### *Second Generation Biofuels*

Different from the 1<sup>st</sup> generation the so called second (2<sup>nd</sup>) or 'next' generation of future biofuels can be produced from wider range of feedstocks, which are represented mainly by non-food crops. For example, the whole plant biomass can be used or waste streams that are rich in lignin and cellulose, such as wheat straw, grass, or wood. In order to breakdown this biomass, two main conversion pathways come into consideration: 1) hydrolysis (can be done via bio-chemical processes using special enzymes) of ligno-cellulose into sugars, which can then be fermented into alcohol - this technology is best known as 'cellulosic bioethanol' and is still in development; 2) thermo-chemical processes (use of high temperatures to pyrolyse and gasify biomass) of lignocelluloses to a raw gas which is then treated and conditioned into synthesis gas (syngas), consisting mainly of carbon monoxide and hydrogen. This gas can further be processed into different types of liquid and gaseous fuels via different fuel syntheses. Fuels from this route are then called 'synthetic biofuels'. Most promising liquid synthetic biofuels, also called BtL: biomass-to-liquids, are biomethanol and Fischer-Tropsch fuels. Gaseous synthetic biofuels are e.g. dimethylether (DME) and Bio-SNG, which is also a form of biomethane and can be similarly used as natural gas substitute like biogas. Alternatively, the cleaned and conditioned product gas can be converted into hydrogen.

### *Third Generation Biofuels*

Third generation biofuels rely on biotechnological interventions in the feedstocks themselves. Plants are engineered in such a way that the structural building blocks of their cells (lignin, cellulose, hemicellulose), can be managed according to a specific task they are required to perform. For example, plant scientists are working on developing trees that grow normally, but that can be triggered to change the strength of the cell walls so that breaking them down to release sugars is easier. In third generation biofuels, a synergy between this kind of interventions and processing steps is then created: plants with special properties are broken down by functionally engineered enzymes. Notably, this latter generation of biofuels is only gradually being explored.

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## **Part 2. First generation of biofuels**

### ***Biodiesel production from vegetable oils***

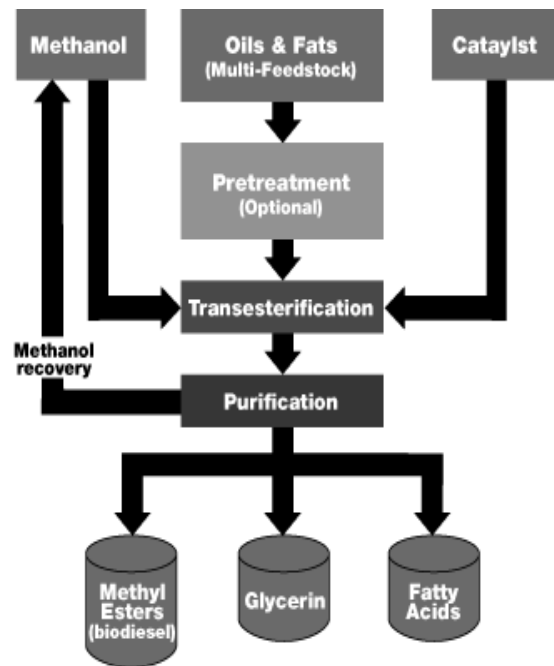
The first generation biodiesel is usually referred to as the mixture of fatty acid methyl esters (FAME) produced from vegetable oils and animal fats via their transesterification reaction. Several production methodologies are available, which employ the use of homogeneous, heterogeneous, or bio-catalysts. The mostly used commercial technology for biodiesel production is the transesterification reaction of the triglyceride of the fatty acid with methanol under the basic conditions (e.g. sodium hydroxide as the catalyst) to yield the methyl ester of the fatty acid (biodiesel).

In addition, other types of biofuels can be produced from vegetable oils and fats. Such include, for example, direct use of straight vegetable oils (SVO) as fuels. This application is less common and is not considered promising due to inferior properties of SVO with respect to the diesel fuels. In addition to the commonly used FAME diesel, a biodiesel can be obtained from vegetable oils via their hydrocracking. Such a diesel is mainly composed of alkanes and is similar to petroleum diesel or the next generation FT diesel. However, since it is obtained from the food crops (oil) it is, however, considered as the first generation of biodiesel. Its production technology is less developed but is believed by some to be in the next future a competitive option to the FAME diesel.

Feedstocks for first generation of biodiesel basically include vegetable oil obtained from oil (energy) crops, as well as recycled oil, animal fats, algae, etc. Different feedstocks may require different conditions of treatment and different pretreatment technology to be adopted, consecutively, the cost and complexity of the process and the quality of the product can vary.

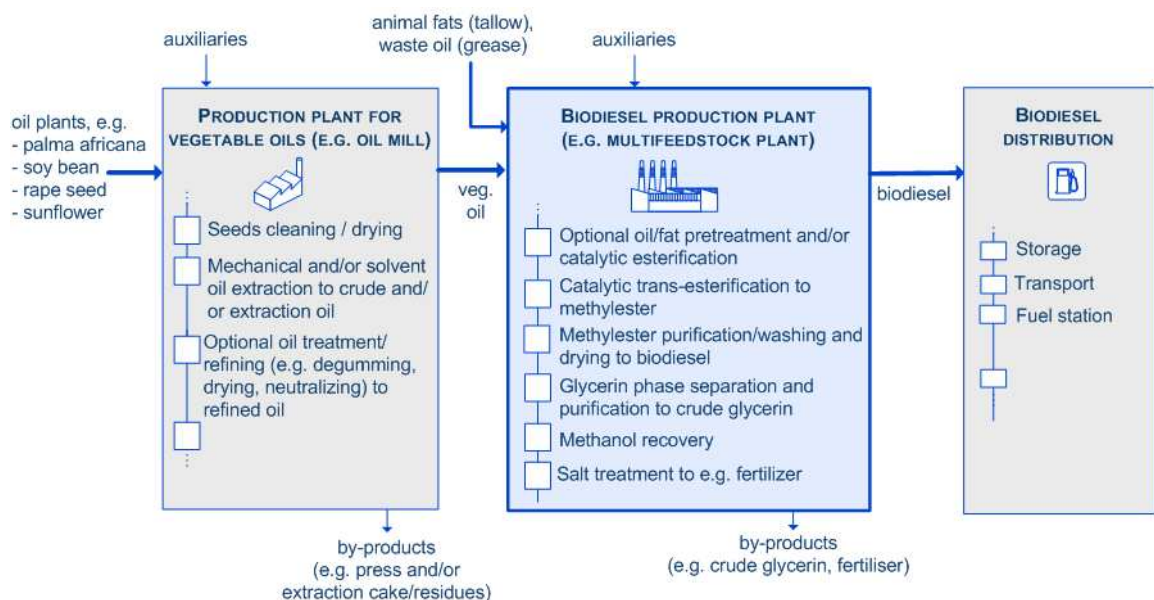
This chapter is dedicated to the issues related to the production technologies for biodiesel of the first generation, including biodiesel produced by vegetable oil hydrocracking. The use of straight vegetable oils (SVO) as fuels, directly or as blends, is also described. Production of other types of biodiesel, e.g. second generation synthetic biodiesel from bio-SNG (synthetic natural gas), will be considered in the next chapters.





*Scheme 2.2. Flowchart of the esterification process*

As illustrated in the Scheme 2.3, a typical supply chain includes the production of vegetable oils or provision of other feedstocks. The extracted and purified oils/fats then undergo the conversion to biodiesel in the production plant. The product, after purification steps is distributed to the end user.



*Scheme 2.3. Feedstock supply and biodiesel production and distribution (from IEE-Leipzig, 2007)*

Critical quality parameters in the process are:

- Complete reaction.
- Removal of glycerol.
- Removal of catalyst.
- Removal of alcohol.
- Absence of free fatty acids.
- Low sulphur content.

#### *Product properties and quality*

While the suitability of any material as fuel, including biodiesel, can be influenced by contaminants arising from production or other sources, the nature of the fuel components ultimately determines the fuel properties. Some of the properties included as specifications in standards can be traced to the structure of the fatty esters comprising biodiesel. However, as biodiesel consists of fatty acids esters, not only the structure of the fatty acids but also that of the ester moiety derived from the alcohol can influence the fuel properties of biodiesel. Since the transesterification reaction of an oil or fat leads to a biodiesel fuel corresponding in its fatty acid profiles with that of the parent oil or fat, biodiesel is a mixture of fatty esters with each ester component contributing to the properties of the fuel. The properties of a biodiesel fuel that are determined by the structure of its component fatty esters include ignition quality, heat of combustion, cold flow, oxidative stability, viscosity and lubricity.

#### *Feedstock issues*

The kind and quality of feedstock is the decisive factor according the technical design of a transesterification plant respectively on the corresponding material and energy flows, which are not only indicators of technical efficiency, but also affect the economic efficiency of biodiesel production. The most relevant feedstock parameters and their relevance for the production process and biodiesel use are, as follows:

- Free fatty acids (FFA)
- Total contamination
- Water content
- Cinematic viscosity
- Cold flow properties
- Iodine number

- Phosphorus content
- Oxidation stability

#### *By-products issues*

An important aspect is that related with glycerol, the principal by-product of this process. It occurs in vegetable oils at a level of approximately 10 % by weight. Crude glycerol possesses very low value because of the impurities. However, as the demand and production of biodiesel grows, the quantity of crude glycerol generated will be considerable, and the utilization of it will become an urgent topic. Refining of the crude glycerol will depend on the economy of production scale and/or the availability of a glycerol purification facility. It is generally treated and refined through filtration, chemical additions and fractional vacuum distillation to yield various commercial grades. Small to moderate scale producers who cannot justify the high cost of purification find crude glycerol utilization or disposal to be a problem. Larger scale biodiesel producers refine their crude glycerol and move it markets in the food, pharmaceutical and cosmetic industries. There are a plenty of added value chemicals that can be obtained from glycerol.

#### *Direct use of vegetable oils and their blends as fuels*

Although vegetable oils occupy a prominent position in the development of alternative fuels although, there are many problems associated with using them directly in diesel engine (especially in direct injection engine). These include coking and trumpet formation on the injectors, carbon deposits, oil ring sticking, thickening or gelling of the lubricating oil, and lubricating problems. Other disadvantages to the use of vegetable oils and especially animal fats are the high viscosity (about 11–17 times higher than diesel fuel) and lower volatilities. These problems can be avoided by modifying the engine less or more according to the conditions of use and the oil involved.

To solve the problem of the high viscosity of vegetable oils, microemulsions with solvents such as methanol, ethanol and 1-butanol have been studied. Methanol was often used due to its economic advantage over ethanol. A microemulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimensions generally in the 1±150 nm range formed spontaneously from two normally immiscible liquids and one or more ionic or non-ionic amphiphiles. It is possible to improve spray characteristics by explosive

vaporization of the low boiling constituents in the micelles. It has been demonstrated that short term performances of both ionic and non-ionic microemulsions of aqueous ethanol for example in soybean oil are nearly as good as that of conventional diesel, in spite of the lower cetane number and energy content. Although the process lowers the viscosity, engine performance problems (e.g. carbon deposit, lubricant oil contamination) still exist.

#### *Production of biodiesel by pyrolysis of oils and fats*

Pyrolysis, strictly defined, is the conversion of one substance into another by means of heat or by heat with the aid of a catalyst in the absence of oxygen or in the reductive environment, e.g. using molecular hydrogen. It involves cleavage of chemical bonds of organic molecules to yield low molecular weight hydrocarbons. Pyrolysis chemistry is difficult to characterize because of the variety of reaction paths and the variety of products that may be obtained. The pyrolyzed material can be any type of biomass, such as vegetable oils, animal fats, wood, bio-waste, etc.

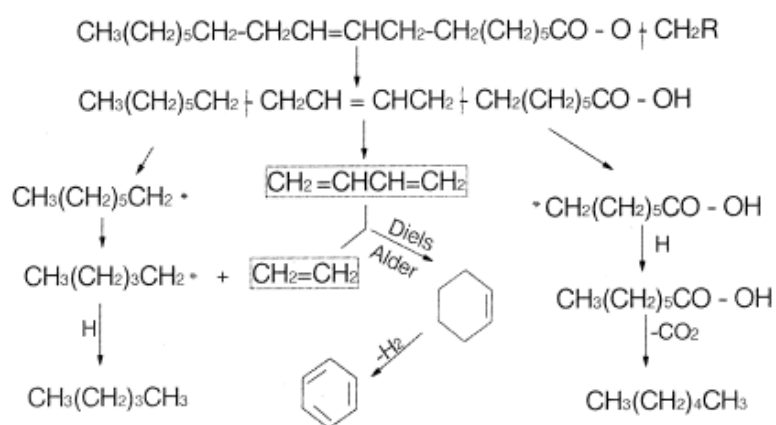
Different types of pyrolysis exist, depending on the temperature, reaction time, pressure, reagents, and catalysts involved. For example, in the case of the use of pyrolytic technologies for biomass conversion, fast or flash pyrolysis technology is utilized for conversion of solid biomass into bio-oil (pyrolysis oil) - the process also known as liquefaction. Fast pyrolysis of biomass is a developed technology widely used in US, Canada and EU countries. Other types of pyrolysis for liquefaction of biomass include direct hydrothermal liquefaction, where biomass is undergone heating and pressurizing in contact with water in the presence of alkali.

The pyrolysis of oils and fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum. Basically, pyrolysis (also called cracking) of oils can be carried out directly (direct thermal cracking) or in the presence of catalysts. Cracking of oils in the presence of hydrogen (used to remove oxygen from oil molecules) can be also called hydrocracking (terms like hydrogenation, hydrogenolysis or hydrotreatment are sometimes used). In the catalytic cracking reaction, typically, four main catalyst types are used including transition metal catalysts, molecular sieve type catalysts, activated alumina, and sodium carbonate. Basically, cracking represents the same principle of conversion as pyrolysis, where it applies for conversion of higher molecular weight oils in lower molecular weight ones. Hydrocracking involves the same reaction in the presence of

hydrogen in order to yield oxygen free fossil diesel like hydrocarbons. In this case hydrogenation and cracking reactions occur simultaneously.

While the processes of pyrolysis of solid biomass, coal, and cracking of bio-oil are well studied and implemented on the large scale, the cracking technologies applied to vegetable oils and fats are still in the research phase. No commercial technologies or scaled up productions have been introduced so far.

The general mechanism for the thermal decomposition of a triglyceride is given in scheme 2.4.



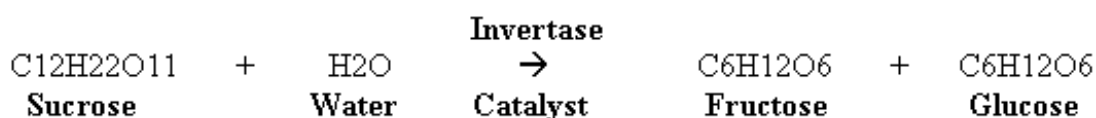
*Scheme 2.4. General representation of the mechanism of thermal decomposition of triglycerides*

There are controversial viewpoints on the future potential of development of the technology based on hydrocracking of vegetable oils for diesel fuel production. While some say that the technology, once commercialized, will represent a competitive alternative to the conventional biodiesel, the others indicate that that significant drawbacks and limitations exist. Besides higher cost of the equipment for thermal cracking and pyrolysis especially for modest throughputs, there is also concern that the removal of oxygen during the thermal processing removes any environmental benefits of using an oxygenated fuel. On the other hand, the deoxygenated diesel fuels obtained via hydrocracking process are more stable than FAME, which contain oxygen and double bonds and can be sometimes better suitable for the use at low temperatures.

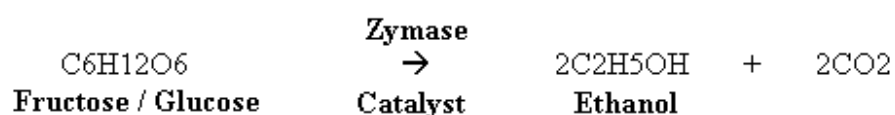
### ***Production of bio-ethanol from energy crops***

Bio-ethanol is the common name for ethanol obtained from the conversion of carbon based feedstock. In this chapter we will focus on the production of bio-ethanol of the first generation via fermentation of sugars obtained directly from sugar-rich plants, such as sugar cane, bagasse, sugar beet, etc. The first generation ethanol is also referred to as the ethanol produced from starch (e.g. grain cultures, potatoes, etc.), where the latter should undergo prior hydrolysis to sugars. Bio-ethanol, obtained via hydrolysis of lingo-cellulosic matter derived from the plants other than energy/food crops or from bio-waste, or the so-called cellulosic ethanol is considered to be the second generation biofuel and is addressed in a separate chapter.

The principal step of bioethanol production from sugars is the fermentation technology which involves biochemical conversion of sucrose into ethanol in the presence of yeast. The yeast contains an enzyme called invertase, which acts as a catalyst and helps to convert the sucrose into glucose and fructose (both  $C_6H_{12}O_6$ ). The chemical reaction is shown below:

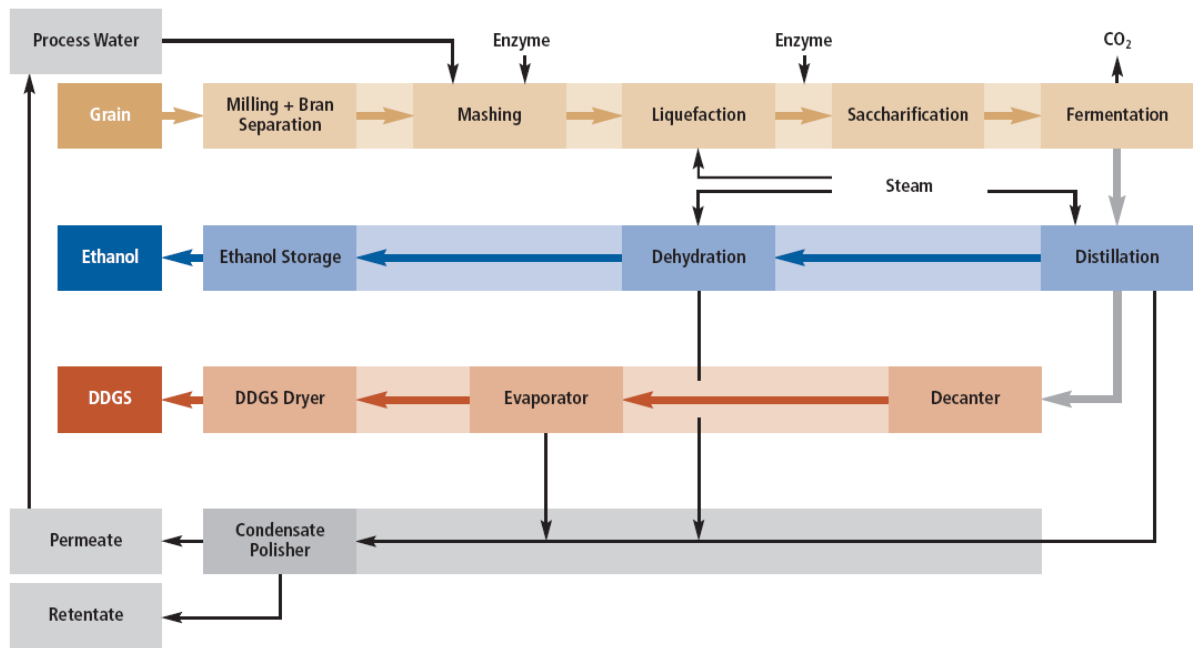


The fructose and glucose sugars then react with another enzyme called zymase, which is also contained in the yeast to produce ethanol and carbon dioxide, as follows:



The fermentation process takes around three days to complete and is carried out at a temperature of between 250 °C and 300 °C. This chemical process is well known and the technology is well established in the production of beer and alcohol.

In the case of production of ethanol from more complex carbohydrates, such as starch liquification and saccharification (hydrolysis of starch into glucose) steps would be required before the fermentation of simple sugars.



*Scheme 2.5. Bioethanol production from sugar crops (reproduced from GEA Wiegand GmbH)*

During the milling process, the kernels or other starchy grain is first ground into flour, which is referred to in the industry as “meal” and processed without separating out the various component parts of the grain. The meal is slurried with water to form a “mash”. Enzymes are added to the mash to convert the starch to dextrose, a simple sugar. Ammonia is added for pH control and as a nutrient to the yeast. The mash is then processed in a high-temperature cooker to reduce bacteria levels ahead of fermentation. The mash is cooled and transferred to fermenters where yeast is added and the conversion of sugar to ethanol and carbon dioxide (CO<sub>2</sub>) begins. The fermentation process generally takes about 40 to 50 hours. During this part of the process, the mash is agitated and kept cool to facilitate the activity of the yeast. After fermentation, the resulting “beer” is transferred to distillation columns where the ethanol is separated from the remaining “stillage”.

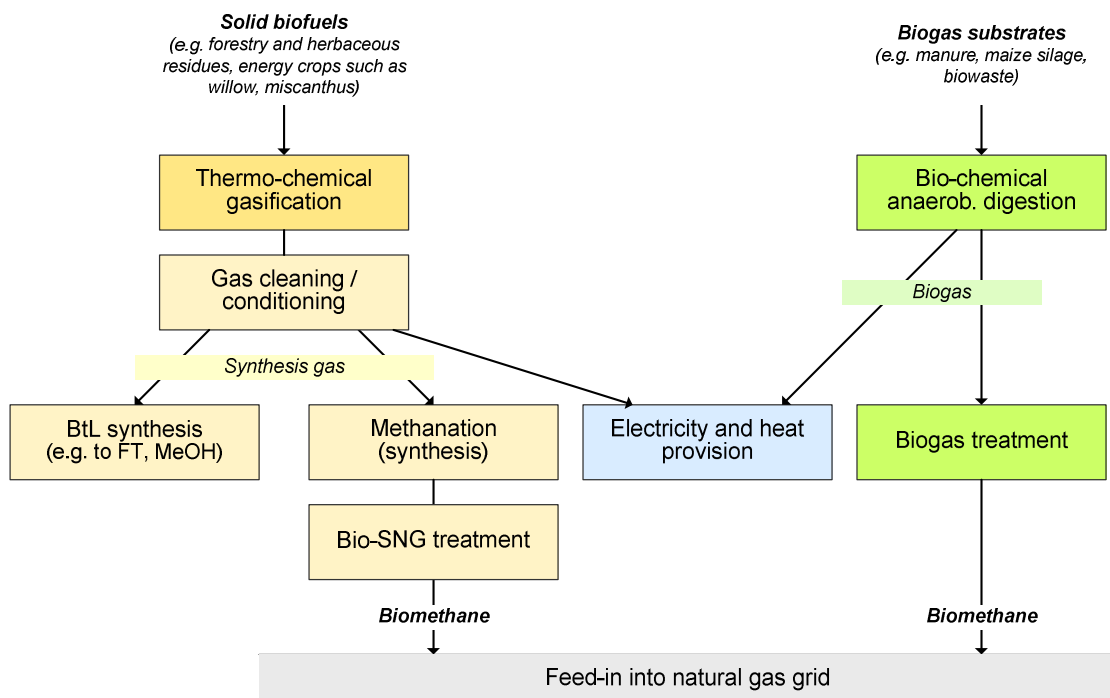
The stillage is sent through a centrifuge that separates the coarse grain from the solubles. The solubles are then concentrated to about 30% solids by evaporation, resulting in Condensed Distillers Solubles (CDS) or “syrup”. The coarse grain and the syrup are dried together to produce dried distillers grains with solubles (DDGS), a high quality, nutritious livestock feed. The CO<sub>2</sub> released during fermentation can be captured and sold for use in carbonating soft drinks and the manufacture of dry ice.

For the ethanol to be usable as a fuel, water must be removed. Most of the water is removed by distillation, but the purity is limited to 95-96% due to the formation of a low-boiling water-ethanol azeotrope. The 96% ethanol, 4% water mixture may be used as a fuel, and it is called hydrated ethyl alcohol fuel. However, for blending with gasoline, purity of 99.5 to 99.9% is required, depending on temperature, to avoid separation. Currently, the most widely used purification method is a physical absorption process using molecular sieves. Another method, azeotropic distillation, is achieved by adding benzene which also denatures the ethanol. On the other hand, benzene is a powerful carcinogen and so will probably be illegal for this purpose soon.

### ***Biogas produced by anaerobic digestion of biomass***

Biomethane is seen to play an important role when feed-in to the natural gas grid for the use as natural gas substitute or in addition to that. Methane has a high market potential as a well known energy carrier for the transport sector and stationary applications (heat and power) and for material utilisation. Within the existing and well developed natural gas grid biomethane can easily be fed in and distributed to the final consumer in industry and households. In addition to the above mentioned advantages the combustion properties of methane are already well known and characterised through comparably low emissions.

As shown in Scheme 2.6, biomethane can be provided either by the treatment of bio-chemical produced biogas or by the synthesis of treated gas coming from thermo-chemical gasification. In this chapter we will focus on the biomethane produced via the biochemical pathway.



*Scheme 2.6. Options for the provision of biomethane*

### ***Biomethane by anaerobic digestion (via biogas)***

In recent years, increasing awareness that anaerobic digesters can help control the disposal and odour of animal waste has stimulated renewed interest in the technology. New digesters now are being built because they effectively eliminate the environmental hazards of dairy

farms and other animal feedlots. Notably that it is often the environmental reasons - rather than the digester's electrical and thermal energy generation potential - that motivate farmers to use digester technology. This is especially true in areas where electric power costs are low. Developing rural areas can therefore find this technology highly attractive due to the fact that it requires low cost infrastructures.

Furthermore, anaerobic digester systems can reduce fecal coliform bacteria in manure by more than 99%, virtually eliminating a major source of water pollution. Separation of the solids during the digester process removes about 25 % of the nutrients from manure, and the solids can be sold out of the drainage basin where nutrient loading may be a problem. In addition, the digester's ability to produce and capture methane from the manure reduces the amount of methane that otherwise would enter the atmosphere. Methane is a green house gas and its release in the atmosphere contributes to global climate change.

#### *The process of anaerobic digestion*

The process of anaerobic digestion occurs in a sequence of stages involving distinct types of bacteria. Hydrolytic and fermentative bacteria first break down the carbohydrates, proteins and fats present in biomass feedstock into fatty acids, alcohol, carbon dioxide, hydrogen, ammonia and sulphides. This stage is called "hydrolysis" (or "liquefaction").

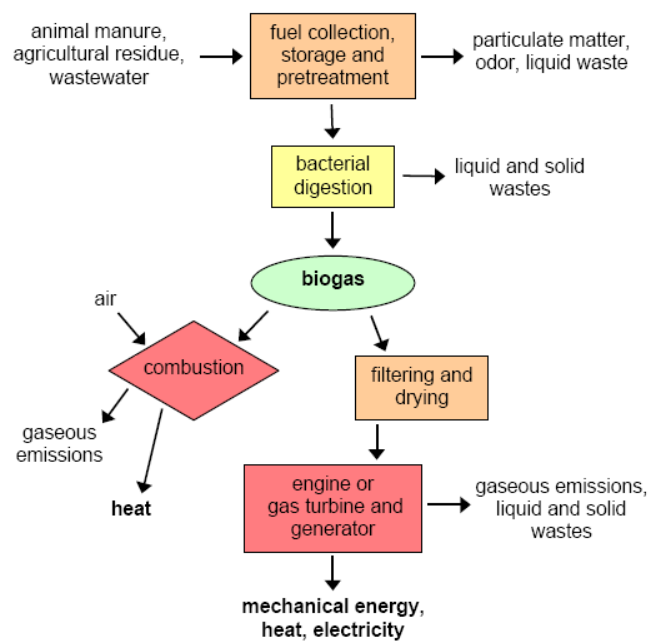
Next, acetogenic (acid-forming) bacteria further digest the products of hydrolysis into acetic acid, hydrogen and carbon dioxide. Methanogenic (methane-forming) bacteria then convert these products into biogas.

The combustion of digester gas can supply useful energy in the form of hot air, hot water or steam. After filtering and drying, digester gas is suitable as fuel for an internal combustion engine, which, combined with a generator, can produce electricity. Future applications of digester gas may include electric power production from gas turbines or fuel cells. Digester gas can substitute for natural gas or propane in space heaters, refrigeration equipment, cooking stoves or other equipment. Compressed digester gas can be used as an alternative transportation fuel.

### *Digester Technology*

Biomass that is high in moisture content, such as animal manure and food-processing wastes, is suitable for producing biogas using anaerobic digester technology.

During anaerobic digestion, bacteria digest biomass in an oxygen-free environment. Symbiotic groups of bacteria perform different functions at different stages of the digestion process.



*Scheme 2.7. Anaerobic digestion*

There are four basic types of microorganisms involved. Hydrolytic bacteria break down complex organic wastes into sugars and amino acids. Fermentative bacteria then convert those products into organic acids. Acidogenic microorganisms convert the acids into hydrogen, carbon dioxide and acetate. Finally, the methanogenic bacteria produce biogas from acetic acid, hydrogen and carbon dioxide.

Controlled anaerobic digestion requires an airtight chamber, called a digester. To promote bacterial activity, the digester must maintain a temperature of at least 18 °C. Using higher temperatures, up to 65 °C, shortens processing time and reduces the required volume of the tank by 25 to 40%. However, there are more species of anaerobic bacteria that thrive in the

temperature range of a standard design (mesophilic bacteria) than there are species that thrive at higher temperatures (thermophilic bacteria). High-temperature digesters also are more prone to upset because of temperature fluctuations and their successful operation requires close monitoring and diligent maintenance.

The biogas produced in a digester (also known as “digester gas”) is actually a mixture of gases, with methane and carbon dioxide making up more than 90 % of the total. Biogas typically contains smaller amounts of hydrogen sulphide, nitrogen, hydrogen, methylmercaptans and oxygen.

Methane is a combustible gas. The energy content of digester gas depends on the amount of methane it contains. Methane content varies from about 55 to 80 %. Typical digester gas, with a methane concentration of 65%, contains about 600 Btu of energy per cubic foot.

For individual farms, small-scale plug-flow or covered lagoon digesters of simple design can produce biogas for on-site electricity and heat generation. For example, a plug-flow digester could process 8,000 gallons of manure per day, the amount produced by a herd of 500 dairy cows. By using digester gas to fuel an engine-generator, a digester of this size would produce more electricity and hot water than the dairy consumes.

Larger scale digesters are suitable for manure volumes of 25,000 to 100,000 gallons per day. In Denmark and in several other European countries, central digester facilities use manure and other organic wastes collected from individual farms and transported to the facility.

#### *Types of Anaerobic Digesters*

There are three basic digester designs. All of them can trap methane and reduce fecal coli form bacteria, but they differ in cost, climate suitability and the concentration of manure solids they can digest.

A covered lagoon digester, as the name suggests, consists of a manure storage lagoon with a cover. The cover traps gas produced during decomposition of the manure. This type of digester is the least expensive of the three. Covering a manure storage lagoon is a simple form of digester technology suitable for liquid manure with less than 3-percent solids. For this type of digester, an impermeable floating cover of industrial fabric covers all or part of

the lagoon. A concrete footing along the edge of the lagoon holds the cover in place with an airtight seal. Methane produced in the lagoon collects under the cover. A suction pipe extracts the gas for use. Covered lagoon digesters require large lagoon volumes and a warm climate. Covered lagoons have low capital cost, but these systems are not suitable for locations in cooler climates or locations where a high water table exists.

A complete mix digester converts organic waste to biogas in a heated tank above or below ground. A mechanical or gas mixer keeps the solids in suspension. Complete mix digesters are expensive to construct and cost more than plug-flow digesters to operate and maintain.

Complete mix digesters are suitable for larger manure volumes having solids concentration of 3 percent to 10 percent. The reactor is a circular steel or poured concrete container. During the digestion process, the manure slurry is continuously mixed to keep the solids in suspension. Biogas accumulates at the top of the digester. The biogas can be used as fuel for an engine-generator to produce electricity or as boiler fuel to produce steam. Using waste heat from the engine or boiler to warm the slurry in the digester reduces retention time to less than 20 days.

Plug-flow digesters are suitable for ruminant animal manure that has a solids concentration of 11 percent to 13 percent. A typical design for a plug-flow system includes a manure collection system, a mixing pit and the digester itself. In the mixing pit, the addition of water adjusts the proportion of solids in the manure slurry to the optimal consistency. The digester is a long, rectangular container, usually built below-grade, with an airtight, expandable cover.

New material added to the tank at one end pushes older material to the opposite end. Coarse solids in ruminant manure form a viscous material as they are digested, limiting solids separation in the digester tank. As a result, the material flows through the tank in a "plug." Average retention time (the time a manure "plug" remains in the digester) is 20 to 30 days.

Anaerobic digestion of the manure slurry releases biogas as the material flows through the digester. A flexible, impermeable cover on the digester traps the gas. Pipes beneath the cover carry the biogas from the digester to an engine-generator set.

A plug-flow digester requires minimal maintenance. Waste heat from the engine-generator can be used to heat the digester. Inside the digester, suspended heating pipes allow hot water to circulate. The hot water heats the digester to keep the slurry at 25°C to 40°C, a temperature range suitable for methane-producing bacteria. The hot water can come from recovered waste heat from an engine generator fuelled with digester gas or from burning digester gas directly in a boiler.

#### *Biogas from wastes*

Municipal sewage contains organic biomass solids, and many wastewater treatment plants use anaerobic digestion to reduce the volume of these solids. Anaerobic digestion stabilizes sewage sludge and destroys pathogens. Sludge digestion produces biogas containing 60 to 70% methane, with an energy content of about 600 Btu per cubic foot.

Most wastewater treatment plants that use anaerobic digesters burn the gas for heat to maintain digester temperatures and to heat building space. Unused gas is burned off as waste but could be used for fuel in an engine-generator or fuel cell to produce electric power. Before use, the gas is cleaned to remove impurities. These are principally hydrogen sulphide, halogens (fluorine, chlorine and bromine), moisture, bacteria and solids. Biogas also contains carbon dioxide, which cannot be removed easily.

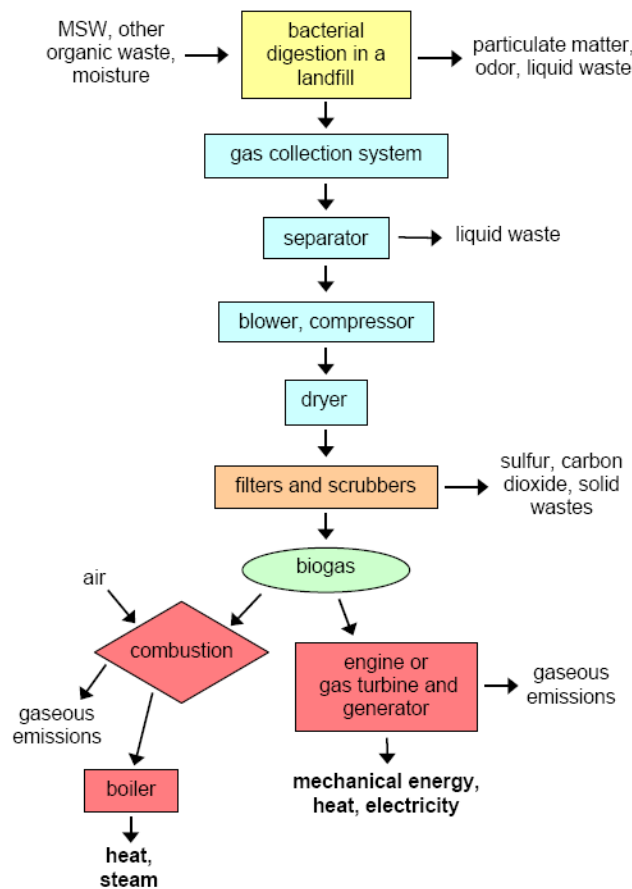
#### *Landfill Gas*

Underground decomposition of cellulose contained in municipal and industrial solid waste produces biogas. The digestion occurring in landfills is an uncontrolled process of biomass decay.

The efficiency of the process depends on the waste composition and moisture content of the landfill, cover material, temperature and other factors. The biogas released from landfills, commonly called "landfill gas," is typically 50% methane, 45% carbon dioxide and 5% other gases. The energy content of landfill gas is 400 to 550 Btu per cubic foot.

Capturing landfill gas before it escapes to the atmosphere allows for conversion to useful energy. A landfill must be at least 40 feet deep and have at least one million tons of waste in place for landfill gas collection and power production to be technically feasible. Notably that by capturing landfill gas will contribute to the reduction of green house gas emissions.

A landfill gas-to-energy system consists of a series of wells drilled into the landfill. A piping system connects the wells and collects the gas. Dryers remove moisture from the gas, and filters remove impurities. The gas typically fuels an engine-generator set or gas turbine to produce electricity. The gas also can fuel a boiler to produce heat or steam. Further gas cleanup improves biogas to pipeline quality, the equivalent of natural gas. Reforming the gas to hydrogen would make possible the production of electricity using fuel cell technology.



*Scheme 2.8. Landfill gas*

### *Biogas upgrading to biomethane*

Yet, in order to feed biogas into the gas grid, the raw biogas has to undergo two major processes to obtain natural gas quality, namely cleaning and upgrading. For the employment in a steam reformer the biogas has to be purified from trace components, primarily H<sub>2</sub>O, H<sub>2</sub>S and NH<sub>3</sub>. The heating value, Wobbe index and other parameters, which highly depend on the CH<sub>4</sub> content, are adjusted to pipeline specifications by removing the CO<sub>2</sub>. The upgrading process basically consists of the separation of CH<sub>4</sub> and CO<sub>2</sub>.

A couple of technologies enable the removal of H<sub>2</sub>S and CO<sub>2</sub> combining the two steps. However, the relevance, feasibility and sequence of the different cleaning and upgrading processes depends on the specific gas composition and pipeline specifications. Upgrading technologies for biogas result mainly from technological applications from the natural gas sector where partly comparable upgrading tasks have to be solved, but at a by far larger scale. Until today, some technologies show long time experiences but on the background of actual political discussions and decisions not only companies change the owner - also lots of research is done in this field. Thus, the main technologies will be characterized in the following.

Generally it has to be stated that all companies offering upgrading plants pledge to reach a biomethane quality of more than 96% methane content and a methane loss with less than 3%. Additionally a very high availability for all technologies is promised and confirmed in practice with at most plants about 95 %. Practical measurements in Sweden have shown different results, but more or less independent on the used technology. Especially it seems to be necessary to care about the methane losses which are reported with up to 10%, because they influence ecological and economical parameters of such plants very strongly.

One of the mainly used technologies for biogas upgrading is the water scrubbing process which is very common in Sweden and shows a very long history of experiences. The process is based on sorption of carbon dioxide in water at high pressures at about 10 bar and desorption of carbon dioxide at lower pressures in another vessel to separate carbon dioxide and methane. At the same time most trace gases as for example H<sub>2</sub>S are separated during this process. As water source circulated fresh water or cleaned waste water without circulation can be used. Advantages of waste water use are compensated by bio fouling in the scrubbers due to the relatively high organics content.

Due to the long research and development period the technology has reached a very high level of development and is proven in practice. Thus, it has to be expected, that the technology has to compete with other technologies in economical questions but is seen as technological state of the art.

A lot of upgrading plants install pressure swing absorption technologies for biomethane production. The technology is based on high pressure absorption of carbon dioxide at molecular sieves or activated charcoal in at least two steps. Other trace gases have to be separated e. g. in filter systems before carbon dioxide absorption. Absorption materials have long operation durations but have to be exchanged from time to time. This technology shows long time experiences and is well established and competes as solid and reliable technology.

Chemical absorption is possible with a number of substances (e.g. Selexol, MEA, DEA and others), which are capable to absorb carbon dioxide at ambient pressure combined with heat demand or at raised pressure. Available information about efficiencies of the processes are very different, but a lot of experiences exist and research is going on. The advantage of chemical absorption is that used substances are selective for carbon dioxide (and sometimes for H<sub>2</sub>S too, most times H<sub>2</sub>S-separation is done before upgrading) and thus no methane will be absorbed what results in high methane concentrations in the purified gas. Absorption processes under pressure seem to be of comparable behaviour as water scrubbing processes but ambient pressure systems (where only pilot plants are known) promise less electrical energy demand for the continuous process and could be of high interest for applications where only low pressure is required after upgrading and heat is available. Summarizing it can be stated that some chemical absorption technologies are reliable and well established and others are under development.

Due to the different molecule size of methane and carbon dioxide it is generally possible to separate both gases through membranes. The smaller methane molecules can pass a membrane and a gas with very high methane content and a gas with very high carbon dioxide content can be produced. Technologies were developed for dry separation (transport through the membrane is forced by very high pressure) and for wet separation (transport is forced by a very low concentration of methane in a fluid where methane is absorbed in). Both technologies are only known from pilot plants and efficiencies regarding methane losses and energy demand are not known from continuously practiced processes.

Additionally it is possible to use the differences in dew and condensation point of methane and carbon dioxide. Therefore it has been shown in small scale that both gas components can be separated by cooling down of biogas to less than -45 °C at about 80 bar pressure.

Applications of this process, called cryogenic upgrading, are under research in Sweden and Germany but not available at the market.

For safety reasons the treated biogas has to be odourised prior to being injected into public natural gas grid. Concerning the different biogas treatment options, further technical equipment is required, including an appropriate periphery to the gas grid, compressors adjusting required grid pressure specifications as well as gas counter and measurement of the injected gas composition. If biogas is injected into the nearest low-pressure gas grid (e.g. 4 to 5 bar) additional gas compression is not required. Most of the upgrading technologies (e. g. water scrubbing and PSA) are appropriate to provide biogas at this pressure level. In addition, a gas mixer might be necessary to add high-calorific gas (e.g. propane or butane). This addition is an option aimed at maximising the methane yield if biogas is upgraded to a lower gas quality as required.

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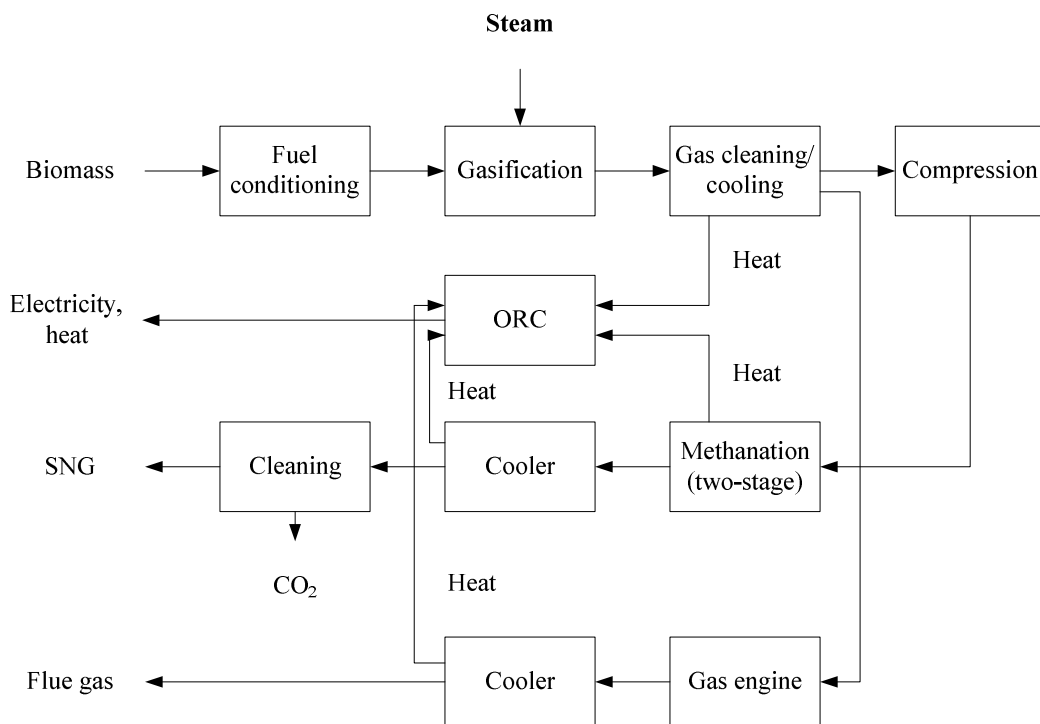
<http://www.biodiesel.org>

### Part 3. Second generation of biofuels and biorefineries

#### *Bio-SNG produced by gasification of biomass*

The bio-SNG (synthetic natural gas) production is characterised through the possibility that relatively small conversion units with capacities in a range of 10 up to 100 MW<sub>th</sub> biomass input can be used. Thus, the conversion of locally available lignocellulosic biomass is possible. The production of synthetic biofuel, electricity and heat (so called tri-generation) allows high overall efficiencies (e.g. high CO<sub>2</sub> mitigation potential) within the entire production process. In comparison to the production of BtL-fuels (like Fischer-Tropsch-fuels) is the SNG production system marked through lower technical and financial risks due to a technology that is less complex (e.g. synthesis and fuel treatment) and basically smaller units can be used. Based on these circumstances a rapid and easy market entrance seems to be possible.

The production of SNG can occur within a very promising concept via the steam gasification of woody biomass with water as gasification agent, gas cleaning, subsequent methanation and up-grading. One promising concept is shown in Scheme 3.1.



*Scheme 3.1. System concept of the Bio-SNG production*

For example, the steam gasification using a fast internal circulating fluidised bed gasifier (FICFB) and the gas cleaning have been demonstrated successfully in a full technical scale (8 MW thermal capacity) at the biomass combined heat and power (CHP) gasification plant in Güssing/Austria whereas during the last years experiences in commercial use for more than 30,000 hours have been achieved. Steam gasification leads to a producer gas with a relatively high content of hydrogen and methane as well as a low content of nitrogen. These properties are necessary for an efficient SNG production.

The gas cleaning of the producer gas from biomass gasification for application in gas engines and turbines can be considered as state of the art. Additionally for the methanation process acid components such as H<sub>2</sub>S, HCl and organic sulphur that could damage the catalyst have to be removed (e.g. a rapeseed-methyl-ester (RME) scrubber). For the conversion of the producer gas (also called bio-syngas as it is close by composition to the synthesis gas) into biomethane a fluidized bed methanation reactor will be constructed at the demonstration plant in Güssing/Austria. Therewith biomethane can be derived from woody biomass with an overall efficiency of 60 to 65 % depending on the biomass assortment.

Beside the production of SNG as a biofuel for the transport sector, additionally electricity can be generated in a gas engine as well as through the use of rejected heat in the ORC process. The arising heat can be provided for district heating purposes as well. Currently the methanation reactor is within a laboratory scale in operation (thermal capacity 10 kW), fed by a slipstream at the biomass CHP gasification plant in Güssing/Austria to find out the optimal operation conditions.

#### *R&D challenges for bio-SNG production*

The biomass gasification for example has to be further developed, upscaled to larger scales and improved to secure the production of a favourable bio-syngas (i.e. optimisation of the gasification regarding the composition of the gas (primarily regarding the H<sub>2</sub>/CO ratio). The optimisation and the extension of the gas cleaning and conditioning is a premise for the production of an appropriate bio-syngas that can fulfil the necessary requirements with regard to the gas properties. With regard to the arising problem in the field of the methanation catalyst, gas impurities like sulphur and chlorine compounds have to be removed more intensive whereas the gas cleaning has to be further developed. The already demonstrated methanation process has to be scaled up on the MW range. Concerning the

utilized catalyst further optimization has to be performed to ensure a long term performance of the catalyst.

Within the overall SNG conversion system the single interactions between the different system components (like gasification, gas cleaning, methanation and upgrading) have to be optimised. Additionally, the availability and reliability of the entire facility have to be demonstrated and improved.

### *Gaseous fuel by pyrolysis*

The main advantage that pyrolysis offers over gasification is a wide range of products that can potentially be obtained, ranging from transportation fuel to chemical feedstock. Considerable amount of research has gone into pyrolysis in the past decade in many countries. Any form of biomass can be used (over 100 different biomass types have been tested in labs around the world), but cellulose gives the highest yields at around 85-90% wt on dry feed. Liquid oils obtained from pyrolysis have been tested for short periods on gas turbines and engines with some initial success, but long-term data is still lacking.

Pyrolysis of biomass generates three main different energy products in different quantities: charcoal, oils, and gases. Fast pyrolysis gives high oil yields, but still needs to overcome some technical problems needed to obtain pyrolytic oils. However, fast pyrolysis is one of the most recently emerging biomass technologies used to convert biomass feedstock into higher value products.

The surge of interest for pyrolysis stems from the number of multi-products than can potentially be obtained from this technology e.g. liquid fuels that can easily be stored and transported, and the large number of chemicals (e.g. adhesives, organic chemicals, and flavouring) that offer a good possibilities for increasing revenues.

Low gravimetric and energetic efficiencies are observed in today's operating carbonization processes. Recovery of liquid by-products associated to the production of charcoal is not significant. The recovery efficiency for tar (Tar: term used for designating of bio-oils of slow pyrolysis) varies from 8% to 15% (based on charcoal produced), which is obtained in rectangular ovens. These figures represent about 2 to 4 tons produced in each carbonization cycle involving 60 to 70 wood tons (db).

Currently, charcoal production technologies based on pressurized systems and bio-oil by fast pyrolysis is not commercially available. The main projects, operational or under development, involve capacities between 20 kg/h and 4 ton/h. The main feedstock sources, depending of available technology, are agricultural, forest, and other industrial residues.

#### *Slow and fast pyrolysis technologies*

Pyrolysis is a process that generally occurs under temperatures that vary from 400 °C up to 650 °C in total or partial absence of oxygen. Gases, liquids and solids are generated in proportions that depend on the parameters considered, that is, the temperature and pressure of the reactor, the residence time of the solid, liquids and gaseous phases inside the reactor, the time and the rate of heating of the biomass particles, the reactor's internal environment, and initial conditions of the biomass.

The pyrolysis process most commonly utilized for charcoal production is carbonization. Among the main types of ovens commercialized in Brazil, rectangular ovens allow the higher efficiencies. They have high capacity for recovering tar (bio-oil from slow pyrolysis). Tar is recovered and stored for subsequent energy production. Tar can also be used in the production of high added value products, mostly by means of distillation.

Because of environmental and efficiency issues which need to be improved, the technology available to make bio-oil recovery systems economically feasible may not be available before 2015.

The use of biomass as liquid fuels has attracted significant interest on pyrolysis during the past two decades. The fast pyrolysis concept for organic compounds has attracted most of the attention. Some industrial sectors, chiefly concentrated in Europe and North America, are putting considerable efforts to find commercial applications for products obtained from bio-oil.

The main characteristics of the fast pyrolysis process are: short heating time for carbonaceous particles and for vapours formed within the reactor; high heating rates and mass-transfer coefficients; and moderate temperature from the heating source. In general, the residence time for vapours should be lower than 1 minute.

All fast pyrolysis technologies apply these basic principles aiming at maximizing bio-oil yield. The bio-oil formed from the fast pyrolysis of biomass is primarily tar. This product is formed from successive decomposition reactions, isomerisation, cracking (split), recombination by condensation, polymerization, depolymerisation and fragmentation, and has high water content in its composition. Over the past 20 years, many studies have been carried out on fast pyrolysis concepts and technologies. The ultimate goal is producing commercially viable large-scale bio-oil facilities for the production of heat, electric energy and chemicals.

### *Synthetic biofuels from bio-syngas*

In comparison with conventional fossil fuels based on crude oil, synthetic biofuels can be produced with clearly defined properties contributing to meet the current and future vehicle exhaust emission standards. Their production is characterised by four main steps:

- gasification of lignocellulosic biomass to a raw gas,
- cleaning and conditioning of raw gas to bio-syngas,
- catalytic synthesis of this gas to synthetic liquid biofuels (i.e. FT, MeOH),
- final conditioning of fuels.

Regardless a long history of the development of a broad variety of system elements as well as system layouts for the provision of liquid and/or gaseous fuels via biomass gasification, no market break through has been realised so far. One reason for it is difficulties in combining system elements. Additionally, some system elements are still under development. But there are also opposite frame conditions: on the one hand fuel synthesis plants (based on fossil fuels) are only in use in large-scale (because of economic issues) and on the other hand biomass for gasification is available decentralised and gasification plants are installed only in small scale so far. Therefore, the combination of these system elements in an appropriate scale is one of the future key challenges.

### *Aspects of bio-syngas production*

For an efficient production of synthetic biofuels with regard to “economy of scale” and biomass transportation costs conversion concepts that are in a medium to large-scale are required for the production of liquid biofuels. This scale is necessary to provide sufficient amount of raw gas for gas cleaning/conditioning and fuel synthesis as well as to produce this gas via gasification at economically justifiable costs.

Despite the scale of a gasifier, no gasification system is a priori appropriate for biomass. Among other criteria, chemical characteristics, physical and mechanical properties of the utilised biomass are of importance. But, all reactors for biomass gasification are still in an R&D stage up to now. Furthermore, previous developments on gasification were mostly not focused on syngas production but rather on the use of product gas for heat and power generation.

Depending on fuel synthesis – where reactors are available – specific qualities of bio-syngas at constant compositions and large amounts have to be achieved (e.g. for the production of 100 to 1,000 m<sup>3</sup><sub>STP</sub>/h of FT); primarily with regard to the gas purity and the H<sub>2</sub>-to-CO-ratio. Because so far no gasification system meets these requirements, appropriate gas cleaning and conditioning system have to be applied.

During gasification, besides the main components (CH<sub>4</sub>, H<sub>2</sub>, CO and CO<sub>2</sub>) also impurities are generated such as tars, coarse and fine particles, sulphur compounds, alkalis, halogen and nitrogen compounds as well as heavy metals. Their quantities vary depending on the gasification process.

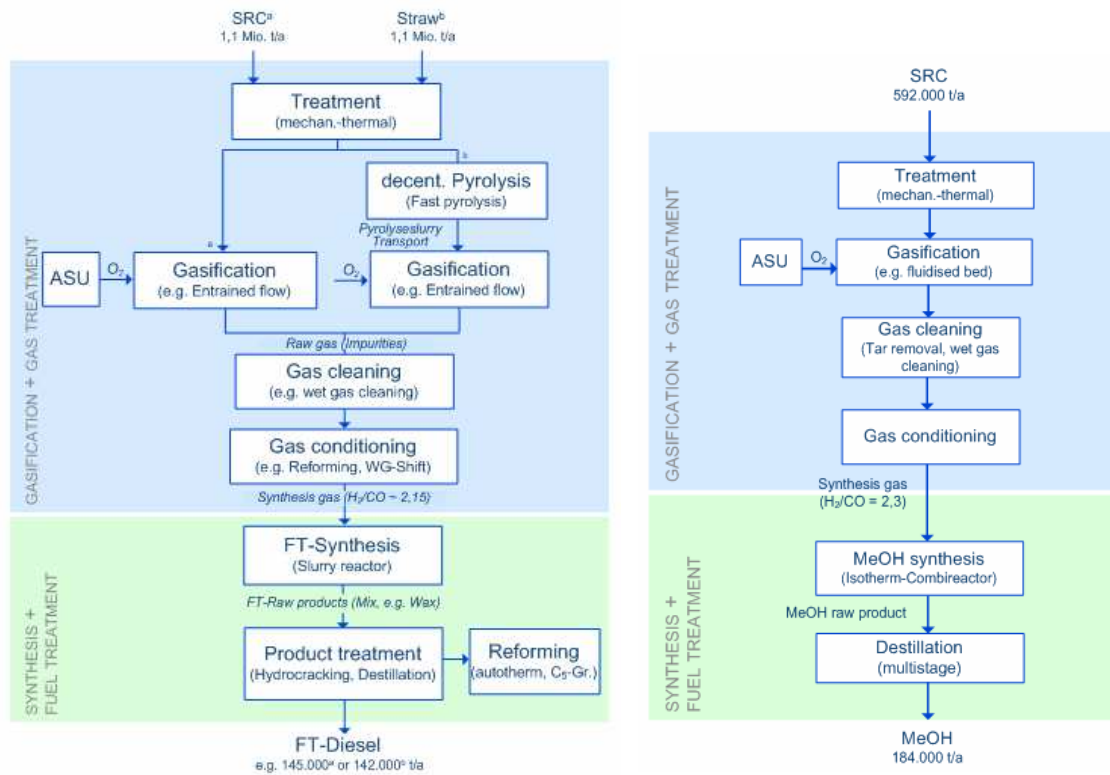
For raw gas cleaning either low temperature wet gas cleaning or, alternatively, hot gas cleaning can be applied. The effectiveness of wet gas cleaning (e.g. cyclone and filter, scrubbing based on chemical or physical absorption and ZnO-bed) has been well proven for large-scale coal gasification systems. Different to that, not all elements of hot gas cleaning (e.g. tar cracking, granular beds and filters, physical adsorption or chemical absorption, ZnO-bed, physical absorption) are of mature technology yet. Nevertheless, hot gas cleaning offers benefits for the overall energy balance and with regard to the avoidance of contaminated sewage.

For gas conditioning available system components can be applied: hydrocarbons in the product gas can be converted by means of an additional steam reforming step resulting in a higher H<sub>2</sub>/CO ratio. To achieve the required quality for fuel synthesis the water-gas CO conversion is conducted as final step of bio-syngas production.

### *Overall concepts*

Based on these and further aspects the following overall concepts for liquid biofuel production seem to be promising (Scheme 3.2). Thereby the technological performance of FT synthesis can be carried out in low temperature solid bed reactors or slurry reactors followed by fractioning and hydrocracking of FT products to diesel. For the production of MeOH synthesis low pressure synthesis is used in commercial practise by means of solid bed reactors. MeOH is also applied as feedstock for indirect DME synthesis that is matured. In general, the complexity of an overall system for production of synthetic biofuels strongly

depends on the necessary gas cleaning and gas conditioning. For a high efficient production the efficiency of bio-syngas production is crucial.



Scheme 3.2. Concepts for liquid synthetic biofuels

With regard to that overall concept, the technologies for liquid synthetic biofuels (BtL) can be briefly characterised as follows:

### Fischer-Tropsch fuels

In addition to the presented concept, there are many other different concepts to produce FT-fuels that are characterised by the typical by-products waxes, naphtha and electricity. Basically the technology is more complex (e.g. when compared to Bio-SNG), whereby mechanical-thermal biomass treatment (e.g. chipping and drying of solid biofuels) is matured. The pyrolysis and transport of pyrolysis products (e.g. slurry) is in an R&D stage. Biomass gasification is demonstrated in small-scale. Basically, the synthesis and fuel treatment of the FT raw products (refinery technology required) are commercial available for fossil material. The expected overall efficiency is between 40 to 45%. Particularly in Europe, the FT-technology is in view of many technology developers and mineral oil industries. The first commercial demonstration plant with a capacity of approx. 15 kt/a FT-diesel (45 MW<sub>th</sub>

biomass input) is currently built by Choren Industries in Freiberg/Germany and will start its operation end of 2007. However, for a broad market implementation existing techno-economic barriers have to be overcome in the years to come. This is expected to after 2010. Until then, several R&D demand is required, e.g. with regard to (i) further development of pyrolysis and gasification (e.g. upscale, operation under pressure), (ii) efficient and economic gas treatment technologies, (iii) treatment of FT-raw products (e.g. downsizing hydrocracking, use in refineries) as well as the successful demonstration of plants availability and reliability for the use of approved system components.

### *Biomethanol*

Methanol synthesis and fuel treatment are not that complex as FT-fuel production. Thus, higher overall efficiencies of up to 55% can be expected. Currently, the R&D activities are with regard to produce an intermediate product for further fuel production (e.g. gasoline). The required R&D demand is quite similar to FT-fuels for gasification and gas treatment. Moreover, the adaptation of methanol synthesis units has to be carried out. This is also true for the demonstration of biomethanol plants in pilot scale.

### *Dimethylether (DME)*

The synthetic biofuel DME can be applied similar to LPG (liquefied petroleum gas) in adapted diesel engines. However, DME might potentially be used for non-transport energy purposes. While the processes of gasification of solid biofuels and the gas cleaning and conditioning to bio-syngas are similar, significant differences exist with regard to the catalytic synthesis.

For DME production synthesis can either be realised via the previous step of methanol synthesis (so called indirect synthesis) or directly. The most common types for methanol synthesis and catalytic dehydration of methanol (DME synthesis) are presented in the following.

A typical reactor type for methanol production is the so called adiabatic quench reactor. The cooling is done by an internal quench (fast cooling by injection of condensate) with fresh syngas. The reaction heat is withdrawn at the exit of the reactor, which is at the bottom. The conversion of methanol to DME where water is chemically separated is done in a DME reactor. Usually, fixed bed reactors are used for this purpose. First, methanol is heated to a

temperature of about 250 °C (e.g. by a heat exchanger) before entering the reactor, where an exothermic reaction takes place at temperatures of 250 to 300 °C and DME is formed. Afterwards, the reactor effluents are cooled down and DME is separated from unconverted methanol and water. The conversion rate of raw methanol to DME ranges from 86 to 88 %. Raw DME contains some water, dissolved gases and little amounts of higher ethers, which have to be withdrawn by distillation.

### *Hydrogen from biomass*

It is widely acknowledged that hydrogen is an attractive energy source to replace conventional fossil fuels, both from the environmental and economic standpoint. It is often cited as a potential source of unlimited clean power.

When hydrogen is used as a fuel it generates no pollutants, but produces water which can be recycled to make more hydrogen. Apart from its use as a clean energy resource, hydrogen can be used for various other purposes in chemical process industries. It is used as a reactant in hydrogenation process to produce lower molecular weight compounds. It can also be used to saturate compounds, crack hydrocarbons or remove sulphur and nitrogen compounds. It is a good oxygen scavenger and can therefore be used to remove traces of oxygen to prevent oxidative corrosion. In the manufacturing of ammonia, methanol and syngas, the use of hydrogen is well known. The future widespread use of hydrogen is likely to be in the transportation sector, where it will help reduce pollution. Vehicles can be powered with hydrogen fuel cells, which are three times more efficient than a gasoline-powered engine. As of today, all these areas of hydrogen utilization are equivalent to 3% of the energy consumption, but it is expected to grow significantly in the years to come.

The commercially usable hydrogen currently being produced is extracted mostly from natural gas. Nearly 90% of hydrogen is obtained by steam reformation of naphtha or natural gas. Gasification of coal and electrolysis of water are the other industrial methods for hydrogen production.

However, these processes are highly energy intensive and not always environment-friendly. Moreover, the fossil-fuel (mainly petroleum) reserves of the world are depleting at an alarming rate. So, production of hydrogen by exploiting alternative sources seems imperative in this perspective.

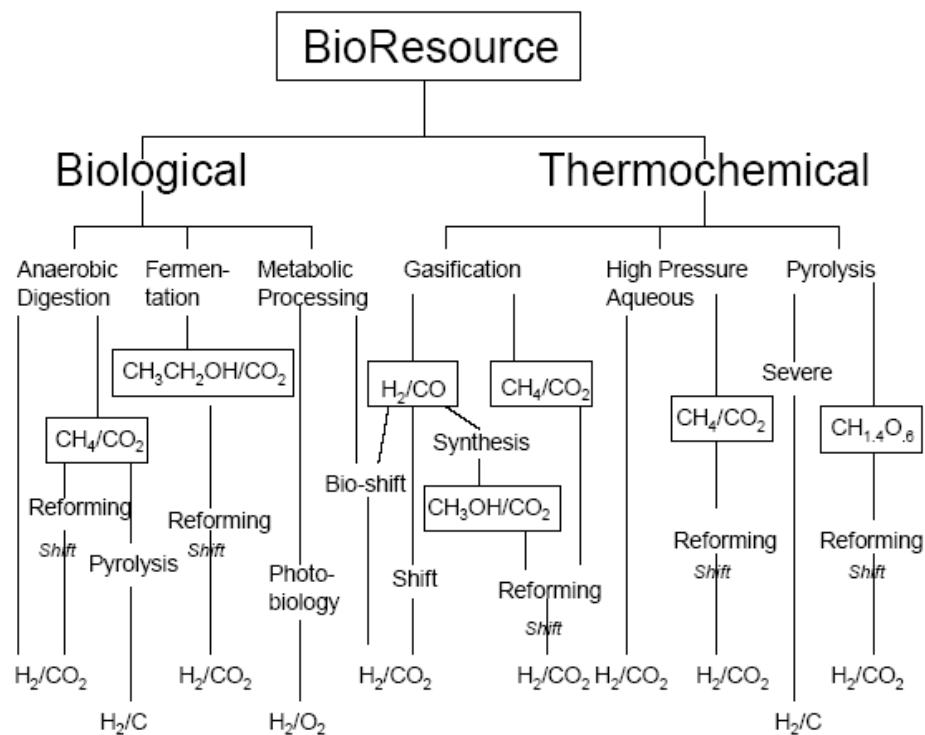
### *Production technologies*

There are different process routes of hydrogen-production from biomass:

- 1) thermochemical gasification coupled with water gas shift;
- 2) fast pyrolysis followed by reforming of carbohydrate fractions of bio-oil;
- 3) direct solar gasification;
- 4) miscellaneous novel gasification process;

- 5) biomass-derived syngas conversion;
- 6) supercritical conversion of biomass;
- 7) microbial conversion of biomass.

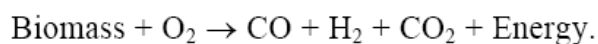
Among the mentioned technologies, the processes based on thermal gasification and pyrolysis of biomass are the most developed and can be envisaged to operate on commercial basis in the near future.



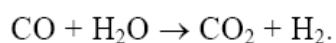
Scheme 3.3. Pathways from biomass to hydrogen

#### *Thermo-chemical gasification coupled with water gas shift*

Gasification coupled with water gas shift is the most widely practised process route for biomass to hydrogen. Thermal, steam and partial oxidation gasification technologies are under development around the world. Feedstock include agricultural and forest product residues of hard wood, soft wood and herbaceous species. Thermal gasification is essentially high-rate pyrolysis carried out in the temperature range of 600–1000 °C in fluidized bed gasifiers. The reaction is as follows:

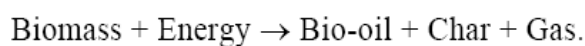


Other relevant gasifier types are bubbling fluid beds and the high-pressure high-temperature slurry-fed entrained flow gasifier. However, all these gasifiers need to include significant gas conditioning along with the removal of tars and inorganic impurities and the subsequent conversion of CO to H<sub>2</sub> by water gas shift reaction.

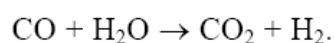
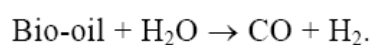


*Fast pyrolysis followed by reforming of carbohydrate fraction of bio-oil*

Pyrolysis produces a liquid product called bio-oil, which is the basis of several processes for the development of fuel chemicals and materials. The reaction is endothermic:



Catalytic steam reforming of bio-oil at 750–850 °C over a nickel-based catalyst is a two-step process that includes the shift reaction:



## ***Biorefineries***

### *Definition for Biorefinery*

Biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry.

By producing multiple products, a biorefinery can take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock. A biorefinery might, for example, produce one or several low-volume, but high-value, chemical products and a low-value, but high-volume liquid transportation fuel, while generating electricity and process heat for its own use and perhaps enough for sale of electricity. The high-value products enhance profitability, the high-volume fuel helps meet national energy needs, and the power production reduces costs and avoids greenhouse-gas emissions.

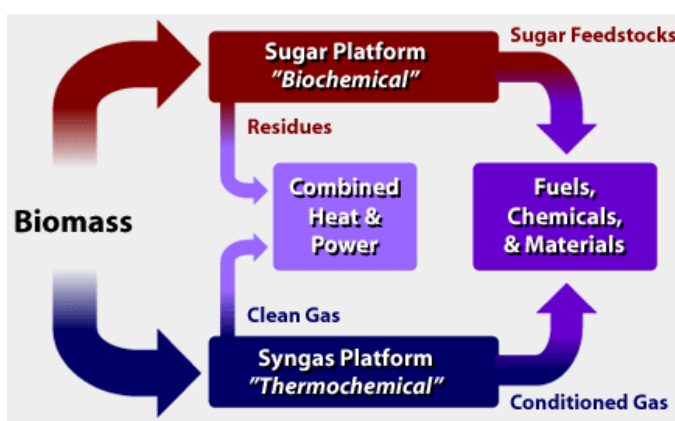
### *Biorefinery Concept*

Although a number of new bioprocesses have been commercialized it is clear that economic and technical barriers still exist before the full potential of this area can be realized. One concept gaining considerable momentum is the biorefinery. The biorefinery concept could significantly reduce production costs of plant-based chemicals and facilitate their substitution into existing markets. This concept is analogous to that of a modern oil refinery in that the biorefinery is a highly integrated complex that will efficiently separate biomass raw materials into individual components and convert these into marketable products such as energy, fuels and chemicals. By analogy with crude oil; every element of the plant feedstock will be utilized including the low value lignin components. However, the different compositional nature of the biomass feedstock, compared to crude oil, will require the application of a wider variety of processing tools in the biorefinery. Processing of the individual components will utilize conventional thermochemical operations and state-of-the-art bioprocessing techniques. The production of biofuels in the biorefinery complex will service existing high volume markets, providing economy-of-scale benefits and large volumes of by-product streams at minimal cost for upgrading to valuable chemicals. A pertinent example of this is

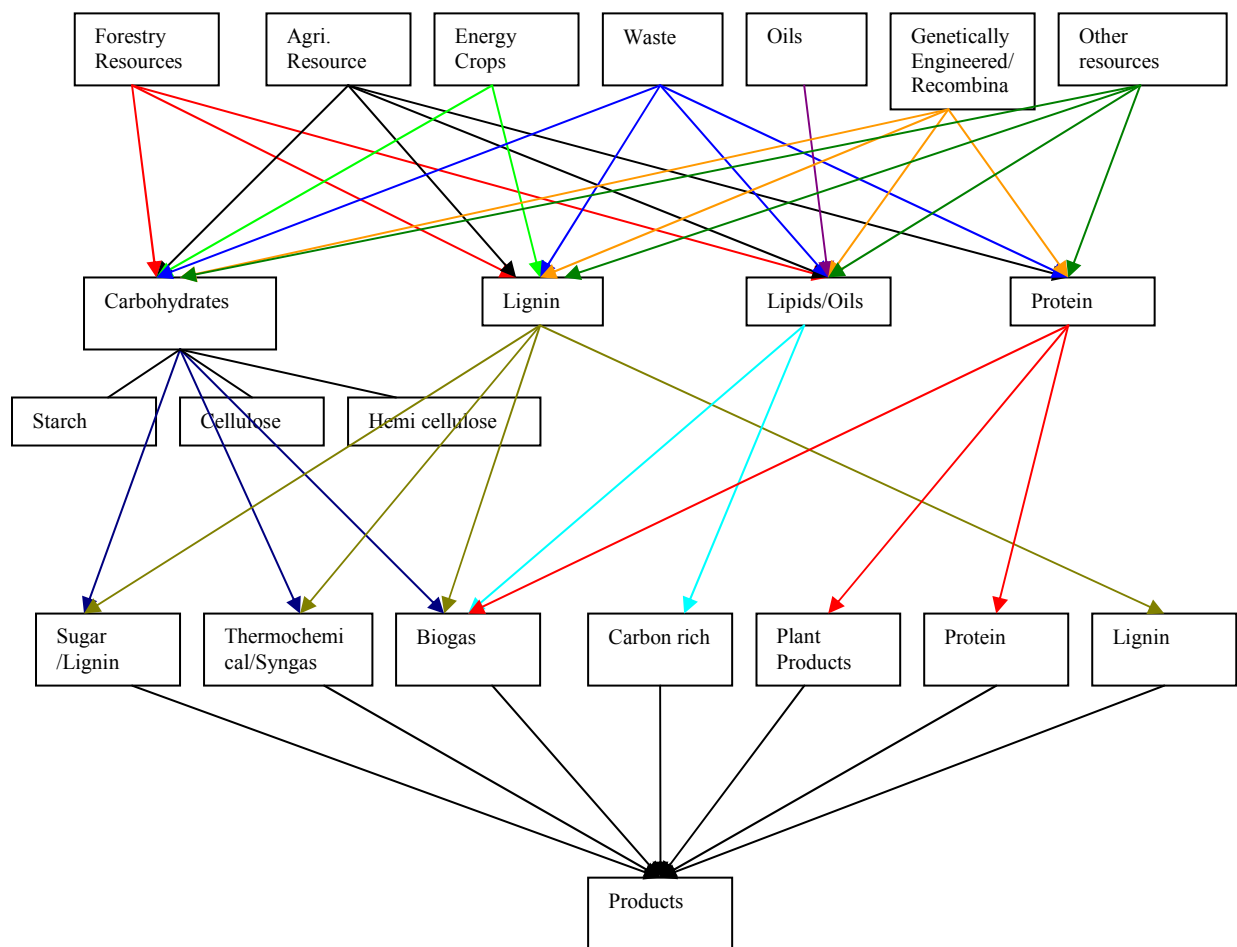
the glycerol by-product produced in biodiesel plants. Glycerol has high functionality and is a potential platform chemical for conversion into a range of higher value chemicals. The high volume product streams in a biorefinery need not necessarily be a fuel but could also be a large volume chemical intermediate such as ethylene or lactic acid. A key requirement for delivery of the Biorefinery concept is the ability to develop process technology that can economically access and convert the five and six membered ring sugars present in the cellulose and hemicellulose fractions of the lignocellulosic feedstock. Although engineering technology exists to effectively separate the sugar containing fractions from the lignocellulose, the enzyme technology to economically convert the five ring sugars to useful products requires further development.

As a result when the biorefinery concept realized the production of platform chemicals using bio or catalytic processes would drastically reduce the over all production cost. It has been speculated that to be viable, a biorefinery complex would need to process some 5 to 10 thousand tones of biomass per day to achieve the appropriate economies of scale and could cost somewhere in the region of \$200-250 million.

Biorefinery concept is built on two different "platforms" to promote different product slates. The "sugar platform" is based on biochemical conversion processes and focuses on the fermentation of sugars extracted from biomass feedstocks. The "syngas platform" is based on thermochemical conversion processes and focuses on the gasification of biomass feedstocks and by-products from conversion processes. Schemes 3.4 explains the basic concept of biorefinery and Scheme 3.5 shows connections between different types feedstocks and different approaches if product utilization.



*Scheme 3.4. Biorefinery concept (NREL, [www.nrel.gov/biomass/biorefinery.html](http://www.nrel.gov/biomass/biorefinery.html))*



*Scheme 3.5 Concept of biorefinery: inter-correlation of crops, energy and product valorizations*

*Advanced Biorefineries: Chemicals from Biomass feedstock*

Although transportation fuels will be the single largest biobased product from a biorefinery, commodity chemicals, natural fibres, and electricity are also products with significant economic potential. Already commercially available biobased products include adhesives, cleaning compounds, detergents, dielectric fluids, dyes, hydraulic fluids, inks, lubricants, packaging materials, paints and coatings, paper and box board, plastic fillers, polymers, solvents, and sorbents. Of course, the products from an advanced biorefinery will be strongly influenced by the feedstock processed by the facility. Much attention has been paid to the corn-based biorefinery, which produces predominately starch and carbohydrate derivatives from it, but also smaller amounts of oil, protein, and fibre. Commercially significant carbohydrate derivatives from starch are currently limited to ethanol, nutritive sweetener, and lactic acid (used in the production of polylactate). A number of carbohydrate derivatives are

possible, list of “top twelve” building block molecules from sugars, these include three diacids (succinic, fumaric, and malic acids), seven carboxylic acids with additional functionality (2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, and levulinic acid), one ketone (3-hydroxybutyrolactone), and three polyols (glycerol, sorbitol, and xylitol/arabinitol). Other groups have suggested 1,3-propanediol as an attractive building block molecule from carbohydrate. Biorefineries using fibrous (lignocellulosic) biomass as feedstock will produce C6 sugar (glucose), C5 sugars (predominately xylose and arabinose), and lignin. These sugars can be fermented to produce so-called “cellulosic” ethanol although the same carbohydrate derivatives contemplated for corn-based biorefineries are also appropriate secondary products for a fiberbased biorefinery. Lignin, a phenylpropane-based polymer, is not fermentable but has potential as a urea-formaldehyde substitute or even the starting point for the production of hydrocarbon fuels. First generation biorefineries, however, are expected to simply use lignin as boiler fuel.

A fundamentally different approach to lignocellulosic biorefineries thermochemically breaks down plant material into a mixture of carbon monoxide (CO) and hydrogen (H<sub>2</sub>) known as syngas. This simple gas mixture can be catalytically upgraded to a wide variety of compounds, including alcohols, carboxylic acids, and hydrocarbons. It is the process proposed for the production of “green” diesel in Europe. Another kind of biorefinery is based on plant oils or animal fats and is commonly known as an oleochemical plant. For such a plant based on oilseed crops such as soybeans the primary products are oil (triglyceride) and meal, the later of which contains significant quantities of protein and fibre and some residual oil. The oil can be either hydrolyzed to fatty acids and glycerol or converted into methyl (or ethyl) esters and glycerol by the process of transesterification the fatty acids and esters are potential platform chemicals for the production of a vast array of derivative chemicals used in high value products. Much of the focus on methyl esters today has been on their use as biodiesel but there has also been limited diversification into ester-based solvents and lubricants. The industry has shown only limited interest in upgrading the glycerol byproduct although technologies are rapidly emerging for its conversion to 1,3-propanediol, a precursor in the production of plastics. Similarly, although the protein in the meal as potential to replace urea-formaldehyde in adhesives, commercialization has been slow to emerge. Biobased transportation fuels, also known as biofuels, are currently dominated by ethanol and biodiesel. However, there are other candidate liquid biofuels including methanol, mixed

alcohols, and Fisher-Tropsch liquids, as well as gaseous biofuels including hydrogen ( $H_2$ ), methane ( $CH_4$ ), ammonia ( $NH_3$ ), and dimethyl ether ( $CH_3OCH_3$ ).

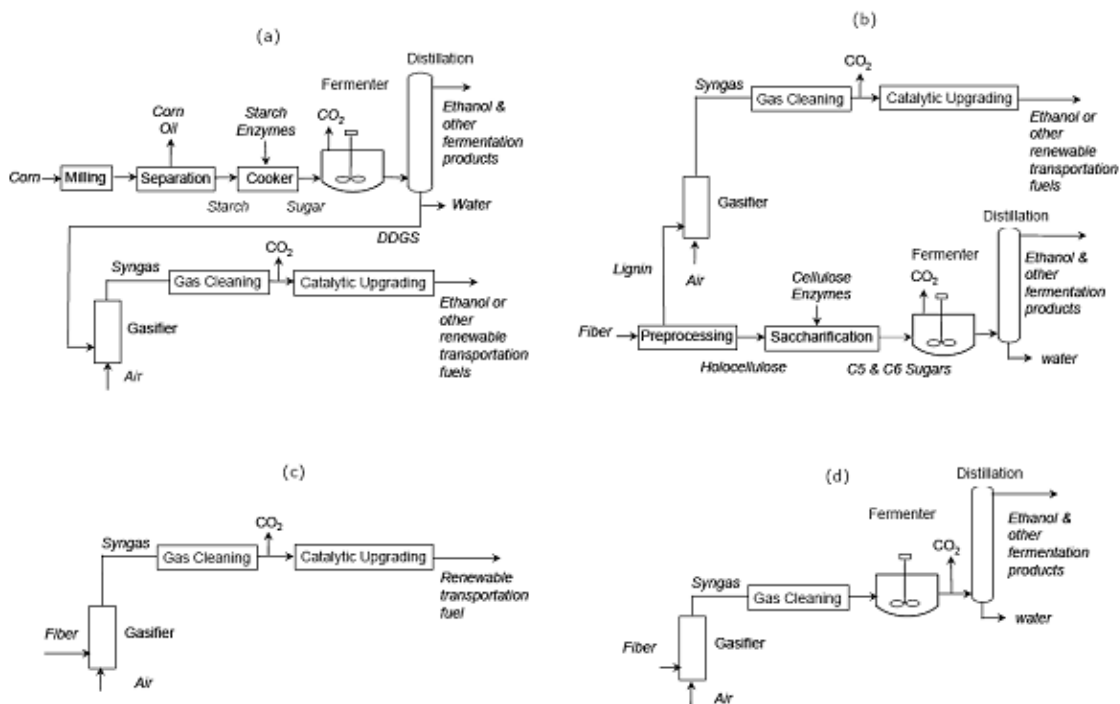
### *Types of advanced biorefineries*

Modern wet corn milling plants and pulp and paper mills can rightly claim to be biorefineries. Advanced biorefineries, however, should be able to process all components of the biomass feedstock into high-value biobased products. Corn fibre as cattle feed additive and lignin as boiler fuel from corn milling plants and pulp and paper mills, respectively, would be of relatively low economic value in a greatly expanded biofuels market. Kamm and Kamm have defined three kinds of biorefineries that would meet this requirement: whole grain biorefineries that make better use of such byproducts as distillers dried grains and solubles (DDGS) and protein meal during the processing of conventional starch and oil crops; lignocellulosic biorefineries that efficiently convert cellulose, hemicellulose, and lignin to products; and so-called “green” biorefineries that convert high moisture biomass, such as silage corn or kelp, into products via ensiling or anaerobic digestion. The whole grain biorefinery, which is an outgrowth of existing grain ethanol manufacturing, is illustrated in Scheme 3.6 (a). The grain, assumed in the scheme to be corn grain for illustrative purposes, is brought from the field and milled (or pressed, in the case of oil seeds) to separate economically recoverable plant components, which might include sugar, starch, oil, protein, and fibre. In Scheme 3.6 (a) an advanced dry grind operation is assumed, which recovers oil from the germ while fibre and protein remain mixed with the starch (in a wet milling operation, the oil, protein, and fibre are separately recovered, leaving nearly pure starch for further processing). One or more of these components is subjected to fermentation. In the case of corn grain, this component is either starch-rich mash from a dry grind operation or pure starch from a wet milling operation, after it has been treated with enzymes and the starch hydrolyzed to glucose. Since the fermentation products, such as ethanol and lactic acid, are usually produced in the fermentation broth at concentrations typically less than 150 g/L, distillation is required to recover these products. At this point the unfermented constituents of the mash from the dry grind operation known as distillers dried grains and solubles (DDGS) is also separated and dewatered.

Although some of the DDGS from a whole grain biorefinery may be sold as animal feed, the large quantities that will be generated in a greatly expanded grain ethanol industry suggest its use in higher value applications. In Scheme 3.6 (a) it is assumed that the DDGS is gasified to

CO and H<sub>2</sub> (syngas), which is cleaned and catalytically converted to alcohols or hydrocarbon-based fuels (Fischer Tropsch liquids).

The lignocellulosic biorefinery is illustrated in Scheme 3.6 (b). The feedstock for such a facility is fibrous biomass such as switchgrass, hybrid poplar, or cornstover. The plant material is first pre-treated to increase the surface area of lignocellulose, making the polysaccharides more susceptible to hydrolysis. A number of pre-treatments have been developed, including dilute acid, hot water, steam explosion, and ammonia explosion. The product streams usually include cellulose, hexose and pentose from hydrolyzed hemicellulose, and lignin. The cellulose is treated with enzymes to hydrolyze it to glucose in a process known as saccharification after which the C<sub>5</sub> and C<sub>6</sub> sugars are separately or together fermented to ethanol or other fermentation products. Lignin, the non-carbohydrate constituent of fibre, cannot be fermented and is instead thermochemically converted to syngas followed by catalytic conversion to alcohols or other renewable transportation fuels. Clearly, the technology to convert lignocellulose into monosaccharides could also be employed in the previously described whole *grain* biorefinery to make a whole *crop* biorefinery. For example, a whole crop biorefinery for corn would bring both corn grain and corn stover (stalks, leaves, husks, and cobs) to the facility. The starch recovered from the grain would be subjected to hydrolysis with starch enzymes as illustrated in Scheme 3.6 (a) while the cornstover and the DDGS (or corn fibre) from fractionating the grain would be subjected to pretreatment and enzymatic hydrolysis illustrated in Scheme 3.6 (b). The resulting sugar streams would be fermented into ethanol or other products while the lignin would be gasified as shown in Scheme 3.6 (b). The lignocellulosic biorefinery illustrated in Scheme 3.6 (b) is based on hybrid biological-thermochemical processing of biomass.



*Scheme 3.6. Classification of Biorefineries based on feedstock:*

- a) Whole grain biorefinery; b) Lignocellulosic biorefinery with thermochemical processing of lignin; c) lignocellulosic biorefinery with pure thermochemical processing;*
- d) lignocellulosic biorefinery with syngas fermentation*

Production of transportation fuels from lignocellulosic biomass since it builds upon the fermentation technology used in the present fuel ethanol industry. In Europe, on the other hand, the idea of a lignocellulosic biorefinery based on pure thermochemical processing is gaining favour. This biorefinery, illustrated in Scheme 3.6 (c), is really nothing more than the lignocellulosic biorefinery illustrated in Scheme 3.6 (b) with the pretreatment, hydrolysis, and fermentation operations stripped out. Fibrous biomass is taken directly from the fields to the gasifier where it is converted to syngas and then catalytically converted into a wide selection of fuel products and commodity chemicals. This flexibility in product mix as well as the tolerance of the gasification process to a wide variation in biomass composition is among the chief attractions of the thermochemical biorefinery.

Gasification and syngas technologies were extensively developed and commercialized in Germany during World War II to convert coal into motor fuels. Likewise South Africa, faced

with an oil embargo during their era of apartheid, produced Fischer-Tropsch liquids from coal to sustain its national economy.

Any solid carbonaceous fuel can be employed for the production of syngas as long as sulphur and chloride contaminants are removed ahead of the catalytic reactors where they can poison the metal catalysts used in the synthesis reactions. In this respect, biomass is a very suitable fuel for a refinery based on thermochemical processing although cost has historically favoured coal over biomass. The apparent simplicity of the flow chart in Scheme 3.6 (c) is somewhat deceptive because economical operation of such a facility is thought to be strongly dependent upon integrating the many energy flows in the plant and building extremely large facilities to capture economies of scale, as subsequently described. Thus, it is uncertain whether future biorefineries will be based on biological/thermochemical processing or pure thermochemical processing. Interestingly, a third kind of lignocellulosic biorefinery, shown in Scheme 3.6 (d), has been proposed. Like the biorefinery illustrated in Scheme 3.6 (b), this lignocellulosic biorefinery is based on hybrid biological/thermochemical conversion. Instead of partitioning the plant components between biological and thermochemical processes, all of the biomass is thermochemically processed followed by biological conversion. Like the lignocellulosic biorefinery based on pure thermochemical processing, all of the biomass is gasified to syngas. However, instead of using inorganic (metallic) catalysts for the synthesis reactions, biocatalysts are employed in a process known as syngas fermentation. Whereas traditional fermentations rely on carbohydrates as the source of carbon and energy in the growth of microbial biomass and the production of commercially valuable metabolites, syngas fermentation employs microorganisms able to utilize less expensive substrates for growth and production. These include autotrophs, which use C1 compounds as their sole source of carbon and hydrogen as their energy source, and unicarbonotrophs, which use C1 compounds as their sole source of both carbon and energy. Among suitable C1 compounds are CO, CO<sub>2</sub>, and methanol (CH<sub>3</sub>OH), all of which can be produced from thermochemical processing of biomass. Products include carboxylic acids, alcohols, and polyesters. One example is the anaerobic bacterium *Clostridium ljungdahli*, which co-metabolizes syngas to form acetic acid (CH<sub>3</sub>COOH) and ethanol (C<sub>2</sub>H<sub>5</sub>OH).

Above all for the realization of biorefinery, it needs intensive research in different areas such as agronomy, catalytic greener process, genetically modified crops and encouraging government policies on promotion of biofuels and co-product valorisation.

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#### **Part 4. Technology evaluation aspects**

Biomass is of particular interest within the ongoing discussion on sustainable mobility due to its advantages concerning e.g. climate relevance and security of supply. Within the framework of sustainability main superior targets relating biofuels are e.g. (i) efficiency regarding system technology and economics, (ii) environmental and climate protection regarding ecology (e.g. greenhouse gas emissions) and (iii) energy supply security regarding biofuel potentials and available resources. Further energy policy targets for biofuels are committed within the European biofuels directive (2003/03/EG) up to the year 2010 and the roadmap for renewable energies (COM (2006) 848) up to 2020. Accordingly, the share of biofuels within the transport sector has to be increased to 5.75% (energy related) in 2010 and 10% in 2020. Besides, there is e.g. a commitment of German gas suppliers to reach a share of biomethane as natural gas substitute for transportation purposes of 10% in 2010 and 20% in 2020.

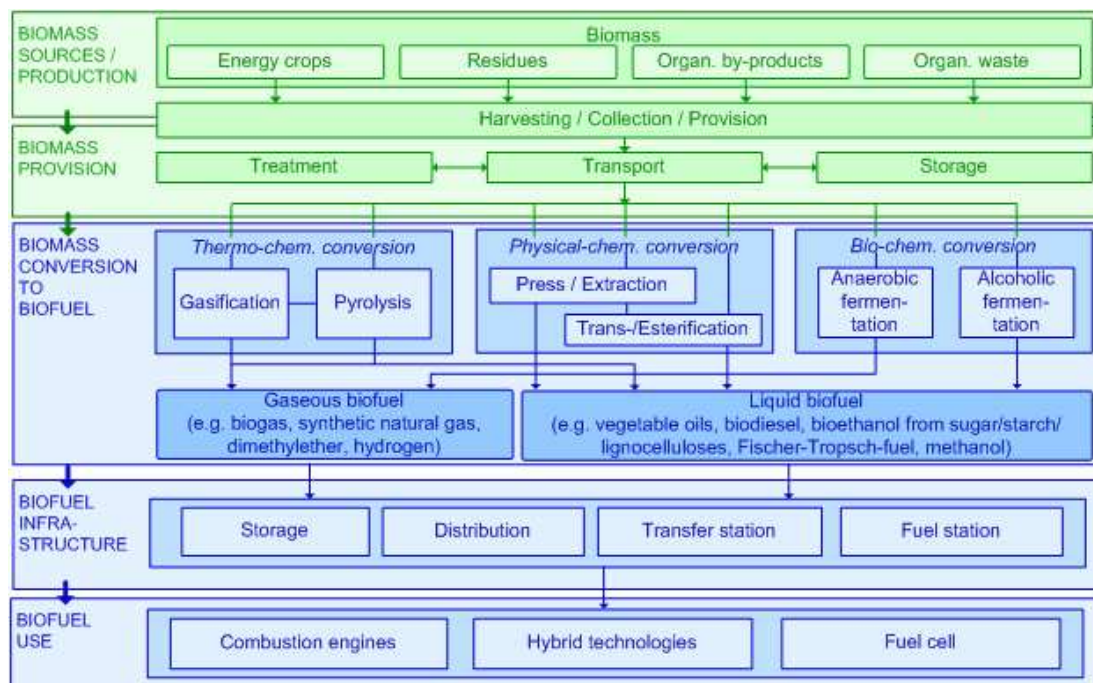
Moreover, technical targets on biofuels have to be achieved. Therefore, future biofuel production systems should be integrated into existing technical biomass potentials. Only a reasonable mix of promising biofuels should be implemented into the energy system under consideration of the existing infrastructure of fuel distribution and use. These biofuels have to achieve current and future exhaust emission standards (e.g. EURO 5/6) as well as have to be produced technical and economic efficient (i.e. high conversion rates and competitive costs).

To meet these future targets, there are many several promising biofuel options of the so called 2nd generation under discussion (i.e. bioethanol based on lignocelluloses, synthetic liquid and gaseous biofuels, biogas and biohydrogen). These options will be evaluated in the following. The different technologies for future biofuels options have been assessed in terms of (i) technology aspects, (ii) economic, and (iii) environmental aspects. For that not only the production of biofuels is considered but also their distribution and use.

##### ***General aspects of future biofuel production options***

Biofuels of the future generation are currently at R&D stage, but – different to the commercial available 1<sup>st</sup> generation (i.e. vegetable oils, biodiesel as well as bioethanol based on sugar and starch) – whole crops can be used for their production. Thus, they offer benefits regarding use of area land for crop production and GHG mitigation. A simplified scheme of

the whole fuel supply chain from well to wheel (i.e. biomass production and provision, their conversion into biofuels and the distribution and use) is shown in Scheme 4.1.



*Scheme 4.1. Overview on production pathways*

The characteristic conversion paths of the future biofuel generation are (i) the bio-chemical conversion (i.e. using micro organism) for the production of biogas and bioethanol (EtOH) and (ii) the thermo-chemical conversion for the production of synthetic biofuels such as Fischer-Tropsch fuels (FT), methanol (MeOH), dimethylether (DME) and synthetic natural gas (SNG) as well as gaseous and liquid biohydrogen (CG/LHyd). Their status of technology as well as the R&D demand is characterised in the next sections.

### *Lignocellulosic bioethanol*

While the production of bioethanol via fermentation of sugar and starch plant fruits (e.g. melasse, maize, cereals) is a matured and established technology all over the world, the use of lignocellulosic biomass is more complex. This is due to the higher treatment expenditure for the hydrolysis (e.g. via acids and enzymes) and saccharification of e.g. wood or straw for the alcoholic fermentation. The thereby extracted lignin can be used e.g. for captive process energy provision. The ethanol treating (i.e. distillation, rectification and absolution) is similar to the conventional ethanol plants. Currently, there are some pilot plants e.g. in Canada

(Iogen), Sweden (ETEK/SEKAB) and Spain (Abengoa). The expected plant capacity in future is in the range of 5 to 110 MW<sub>fuel</sub> at a concept specific overall efficiency of approx. 45 to 50 %.

The R&D demand primarily includes the development of pulping technologies for lignocelluloses (e.g. efficient and rentable enzymes) as well as further optimisation of process integration with ethanol plants (e.g. regarding lignin and mash residues use for energy purposes).

### *Synthetic biofuels*

The production of synthetic fuels (i.e. “design fuels” with clearly defined properties) is characterised by three main steps: (i) gasification of lignocellulosic biomass to a raw gas, (ii) cleaning and conditioning of raw gas to bio-syngas, (iii) catalytic synthesis of this gas to synthetic biofuels (i.e. FT, MeOH, DME and SNG) and (iv) final product treatment.

Regardless a long history of the development of a broad variety of system elements as well as system layouts for the provision of liquid and/or gaseous fuels via biomass gasification, no market break through has been realised so far. One reason is e.g. difficulties in combining system elements. Additionally, some system elements are still under development. With regard to “economy of scale” concepts in medium- to large-scale are required for an efficient production of synthetic biofuels. Thus, the expected plant capacity will be in the range of 30 to 340 MW<sub>fuel</sub>.

Despite the scale, for gasification system particularly chemical characteristics, physical and mechanical properties of the utilised biomass are of importance. But, all reactors for biomass gasification are still in an R&D stage up to now and only available in small-scale. Depending on fuel synthesis – where reactors are available – specific qualities of bio-syngas at constant compositions have to be achieved (gas purity and the H<sub>2</sub>-to-CO-ratio). Because so far no gasification system meets these requirements, appropriate gas cleaning and conditioning system have to be applied.

For raw gas cleaning either low temperature wet gas cleaning or, alternatively, hot gas cleaning can be applied. The effectiveness of wet gas cleaning (e.g. cyclone and filter, scrubbing based on chemical or physical absorption) has been proven for large-scale coal

gasification systems. Different to that, not all elements of hot gas cleaning (e.g. tar cracking, granular beds and filters, physical adsorption or chemical absorption) are of mature technology yet. For gas conditioning basically available and matured technologies (e.g. steam reforming, water gas shift) for achieving bio-syngas requirements can be used; so far only limited experiences exist for the required scale.

Based on CtL- and GtL-production fuel synthesis and conditioning are technical and commercial feasible. However, there are only limited experiences regarding “green” syngas and the expected plant scale. Comparing the different synthetic biofuel options, the FT raw product treatment after synthesis is more extensive since refinery-similar technologies (e.g. hydrocracker) are required.

In terms of overall efficiency, for biofuels such as SNG high thermal efficiencies up to 65% can be expected. Different to that overall thermal efficiencies are lower (approx. 40 to 52%) for FT, MeOH and DME based on MeOH.

Further R&D for synthetic fuel options is primarily required with regard to the development of pyrolysis and gasification (e.g. upscale, operation under pressure) and the efficient and economic gas treatment technologies. Moreover, the demonstration and commercial operation of the whole chain (i.e. use of approved system components and their efficient interaction, plants availability and reliability) is still needed. In terms of that, first results are expected from the operation of the first demonstration plants for FT in Germany (Choren Industries), SNG in Austria and DME in Sweden (Chemrec).

### *Biohydrogen*

Even though biohydrogen is not a synthetic fuel, similar system components as for the production of synthetic biofuels (i.e. gasification, gas cleaning and conditioning) can be applied. After raw gas treatment the hydrogen rich gas is finally purified via pressure swing adsorption. For distribution and use hydrogen need to be either compressed or liquefied. The expected plant capacity will be in a similar range to synthetic fuels at an expected overall efficiency of about 50 to 55%. The further R&D demand is quite similar to that of synthetic biofuels.

### *Biogas*

Biogas plants using wet and dry fermentation are a matured technology when the produced biogas (methane-rich gas) is applied in power generation engines for CHP. To achieve natural gas quality (e.g. for feed-in into the natural gas grid) system components for biogas treatment (e.g. water or pressure swing adsorption) are basically available and successfully demonstrated (e.g. in Sweden and Switzerland). A first demonstration plant in Germany is located in Jameln/Wendland. Plant capacities, that can be expected, are in the range of up to 8 MW<sub>fuel</sub> at concept and feedstock specific overall efficiencies of 43 to 86%.

Objectives of further R&D are the optimisation of process automation to increase the methane yield in the biogas during fermentation and the upscaling of typically small-scale biogas plants. Furthermore, biogas cleaning technologies need to be optimised and the feed-in of upgraded biogas into the natural gas grid has to be demonstrated under long-run conditions.

### *Technology aspects*

Based on the technology characteristics, the biofuel options have been compared by means of biofuel production (i.e. stage of development, technical effort in terms of system complexity, expected plant capacity and overall efficiency) and the biofuels suitability concerning current fuel distribution systems as well as current use in vehicle fleets. A summary is shown in Table 4.1.

Therefore, it can be revealed that the different concepts for biofuel options of the future generation are associated with appropriate benefits and bottlenecks along the pathway. While e.g. FT fuels are less promising concerning the technical effort, the range of capacities (with regard to suitable plant locations) and the overall efficiency, it seems to be very promising regarding the implementation into the current distribution and use infrastructure.

Table 4.1. Comparison of technology aspects

	Current stage of development		Techn. Effort <sup>a</sup>	Expected plant capacity <sup>b</sup> [MW <sub>bf</sub> ]	Overall efficiency <sup>c</sup> [%]	Distri-bution <sup>d</sup>	Use <sup>d</sup>
	Concept / Lab	Pilot/ Demo					
Biofuel option 2 <sup>nd</sup> generation				10.....1,000	0.....80		
<b>Liquid</b>							
Bioethanol	→→→→→		++	■	■	+++	+++
FT-Fuels	→→→→→		+	■	■	++++	++++
Methanol	→→→→→		++	■	■	++	++
<b>Gaseous</b>							
Biogas	→→→→→		++++	■	■	+++	+++
Bio-SNG	→→→→→		+++	■	■	+++	+++
Dimethylether	→→→→→		++	■	■	++	++
Hydrogen	→→→→→		++(+)	■	■	+	+

<sup>a</sup> regarding system complexity (+ less promising....++++ very promising)  
<sup>b</sup> related to biomass feedstock  
<sup>c</sup> according state of development (many different concepts) only theoretical values  
<sup>d</sup> suitability for current distribution and use (+ less promising....++++ very promising)

**Economic aspects**

In addition to technical aspects, the decision on a preferable fuel is mainly driven by economic reasons. Thus, the production costs of future generation biofuels have been analysed and compared for exemplary overall concepts (Fig. 4.1).

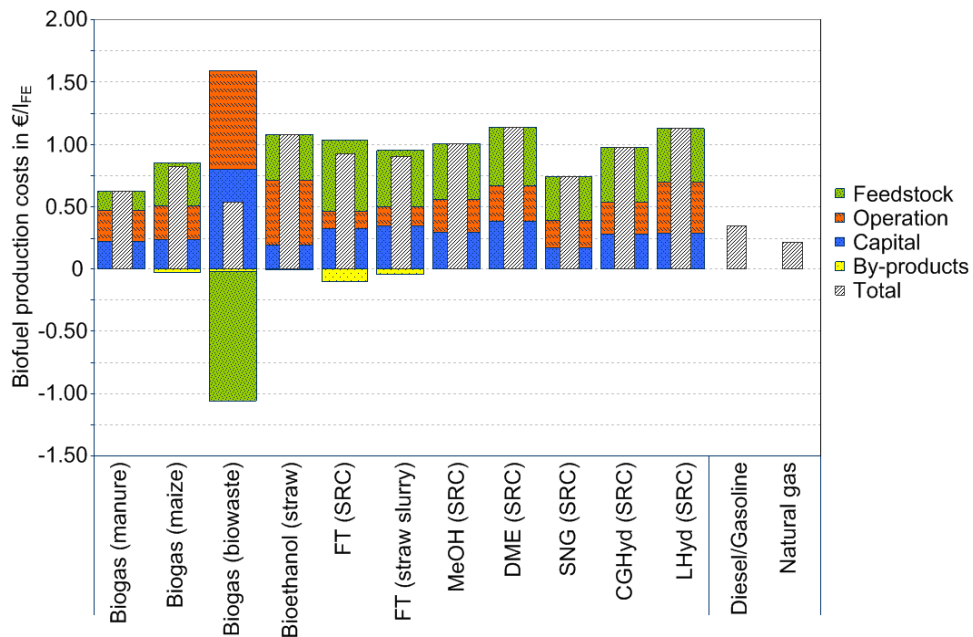


Figure 4.1. Biofuel production costs

As the results of the economic analysis reveal, biofuel production costs show significant differences. Based on litre fuel equivalent (FE) biomethane options (SNG and biogas) are the most favourable. However, no cost reduction can be expected compared to biofuels of the 1<sup>st</sup> generation that are at a medium level of 62 €/l<sub>FE</sub>.

The sensitivity analyses – carried out for the determination and optimisation of influencing cost components to the total biofuels production costs – show that besides the annual full load hours of the plant, feedstock costs and capital requirements are strongly important. It is expected that biofuel production costs will moderately increase in future due to increasing energy prices with expected price effects for feedstocks during broad implementation of biofuel strategies.

However, for a market implementation not only biofuel production costs but also total driving costs relating to the well to wheel chain (WTW) are of importance for end users. Therefore, with regard to the WTW biofuel costs involving costs of fuel distribution (i.e. via pipeline or tank) and vehicles costs of private cars (i.e. in combustion and hybrid engines, fuel cells) the following results (Fig. 4.2) can be indicated per vehicle km. The differences in biofuel production costs will be lowered in terms of total driving costs as – except for fuel cell application – there is a similar cost range for all biofuels, primarily dominated by vehicle use costs. The costs for biofuel distribution play only a minor role. For a number of reasons (e.g. immature large-scale production) the biofuels of the future generation are significantly more expensive when compared to conventional oil-derived fuels such as diesel at total driving costs of approx. 0.33 €/km.

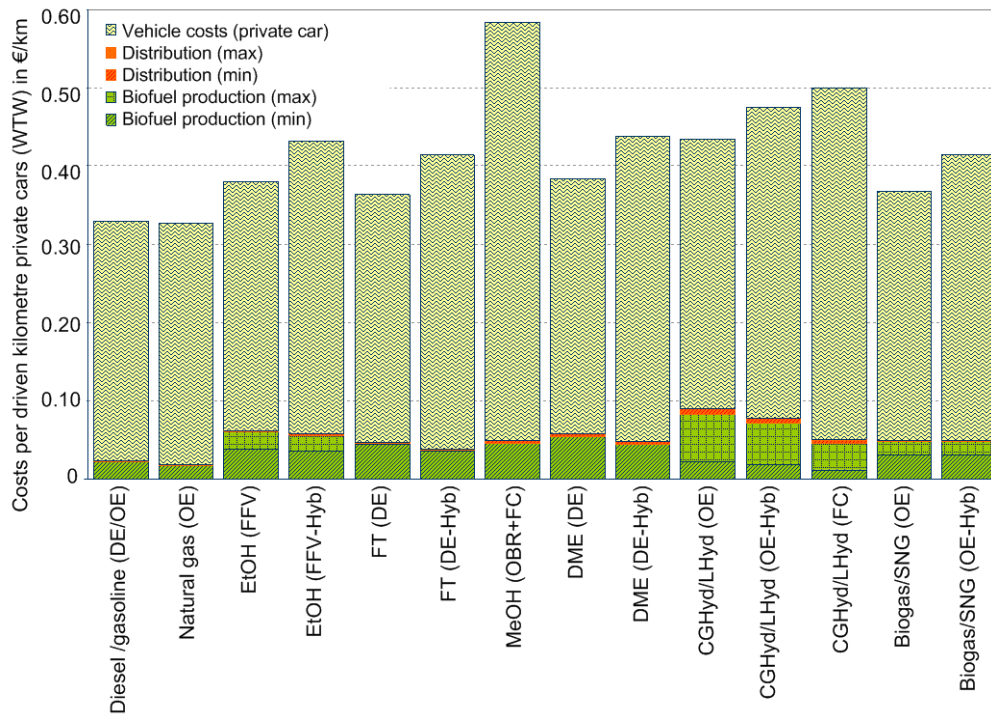


Figure 4.2. Total driving costs – private cars (WTW)

To identify very promising biofuel options, a relative comparison of technology and economic aspects are shown in Fig. 4.3. Therefore, the technical feasibility has been determined including flexibility and process requirements of the used feedstock, the technical effort, availability and the input/output ratio biofuel production as well as the biofuel quality and the environmental quality biofuel production (cf. Table 4.1). Based on that, very promising technologies are options of a high technical feasibility and low biofuel production costs. This is true for bio-SNG as well as partly for FT and biogas based on bio-waste and manure.

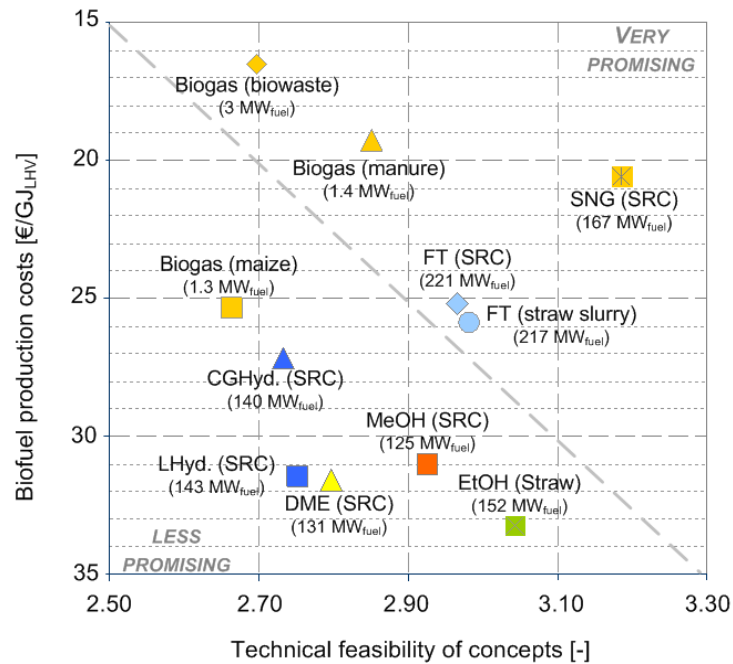


Figure 4.3. Technology versus economic aspects

### Environmental aspects

The environmental effects of a product are not limited to their use or the production process. Substantial environmental effects may also occur within the pre-chains. The most important method to assess selected environmental effects throughout the life cycle assessment (LCA), which can be applied to consider environmental impact categories such as the “anthropogenic green house effect” indicated by the greenhouse gas emissions in form of CO<sub>2</sub> equivalents.

Biofuels options of the current and future generation have been compared related to vehicle kilometres according to this impact. The results (given compared to the WTW costs) show significant differences between the biofuel options (Fig. 4.4). Biofuels of the future generation such as EtOH, SNG, FT and biogas promise better effects regarding GHG mitigation. However, WTW costs are slightly higher for most of future biofuels generation compared to 1<sup>st</sup> generation.

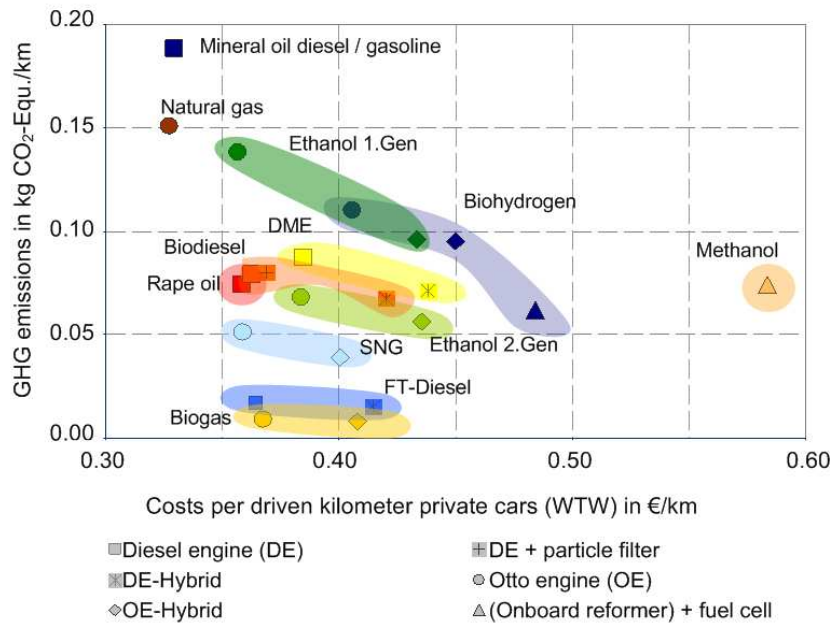


Figure 4.4. Economic versus environmental aspects

### Conclusions

To meet the future energy policy and technical targets for the implementation of biofuels into the energy system basically many different biofuel options as well as several alternative concepts of the future generation with different benefits and bottlenecks are under discussion. However, so far no silver bullet could be identified.

Production concepts for biofuel option of the future generation are currently in laboratory (e.g. biohydrogen) to pilot and demonstration stage (e.g. bioethanol, Fischer-Tropsch fuel, dimethylether and Bio-SNG). Thus, further R&D is required with regard to (i) further development and use of promising biofuel concepts in practice, (ii) upscaling to medium- and large-scale plants, (iii) use of approved system components and demonstration of efficient interaction, (iv) plant availability and reliability. For a successful market implementation existing techno-economic barriers have to be overcome and capital risks need to be minimised.

From economic viewpoint no cost reduction can be expected from the 1<sup>st</sup> to the future biofuel generation. The costs for biofuel production are dominated by feedstock costs as well as capital related costs. Thus, concepts efficiency and plants availability are of high importance. Except for fuel cells, costs per driven kilometre of private cars (WTW) are at a comparable level. They are dominated by vehicle costs, while distribution costs are only less relevant.

Comparing technology and economic aspects relatively, biofuel options such SNG as well as partly FT and biogas based on bio-waste and manure are the most promising. Despite of this, in context of the entire supply chain of transportation fuels synthetic biofuels can be seen as a bridge into the future hydrogen including economy in the long term.

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## **Part 5. Biofuels production in Europe with the focus on Central & Eastern Europe**

In this chapter we present a preliminary overview of the industrial biofuel production in selected European countries. It is expected that this chapter will be extended and completed on the basis of the most recent reports of the countries represented at the *Regional Workshop on Promoting Sustainable Biofuels Production and Use in Central and Eastern Europe* organized by UNIDO in cooperation with the Energy Institute Hrovoje Pozar in Cavtat-Dubrovnik, Croatia on 12-13 November 2007. Further elaboration of this document will also take into consideration other reports/publications to be made available.

### ***Biofuels in Europe: A general overview***

The continuing increase in the price of petrol has favoured the rise in importance of green oil all over the world. Production and usage of biofuels in transport, heating, and industrial establishments is an increasing phenomenon in all EU member states and sustain the industrial growth the EU biofuel industry has been developing very fast. In January 2007 EU commission proposed to introduce a 10% binding target for biofuel by year 2020. Biodiesel production EU in the year 2005 it was estimated 2,879,700 MT, and is expected to 8,100,000 MT by end of 2007. The production of bioethanol has also been increasing, from 830,976 MT in 2005 to reach an expected level of 3,690,150 MT in 2008.

### ***Biodiesel***

In 2005, biodiesel remained the leading biofuel in the EU, representing 81.5% of production. 3184000 tons of biodiesel were produced in the EU, i.e. 1,250,600 tons more than in 2004 (+64.7%).

Among all EU member states, Germany alone represents 52.4% of this production, with 1,669,000 tons produced in 2005, i.e. 61.3% growth with respect to 2004. This spectacular growth in the German market is the result of a very favourable legislation granting a total tax exemption for biofuels, and this whether it's in pure or mixed form. However, this legislation was modified on 1st August 2006. Emphasising the strong rise in the price of petrol, the German government introduced a 0.10 € tax for biodiesel used in pure form, and a 0.15 € tax for biodiesel when mixed in refineries.

In France the production of biofuels, which has continued to decrease since 2001 (date on which it was the leading European producer country), finally recovered in 2005 with a 41.4% production increase (a total of 492,000 tons). In 2006, the excise tax on petroleum products, from which biofuels benefit, was reduced and re-established at 25 €/hl (33 €/hl in 2005) for biodiesel, and 33 €/hl (38 €/hl in 2005) for bioethanol intended to be transformed into ETBE.

Two new member States, Poland (100,000 tons) and the Czech Republic (133,000 tons), have emerged among the big European Union producer countries.

The biodiesel production capacity of selected EU member states is shown in Table 5.1. For more information see Annex 1.

*Table 5.1. Biodiesel production and capacity estimates in the EU (tons)*

COUNTRY	2004 Production	2005 Production	COUNTRY	2005 Capacity	2006 Capacity
Germany	1.035	1.669	Germany	1.903	2.681
France	348	492	Italy	827	857
Italy	320	396	France	532	775
Czech Rep.	60**	133	UK	129	445
Poland	0	100	Spain	100	224
Austria	57	85	Czech Republic	188	203
Slovakia	15	78	Poland	100	150
Spain	13	73	Portugal	6	146
Denmark	70**	71	Austria	125	134
UK	9	51	Slovakia	89	89
Slovenia	0	8	Belgium	55	85
Estonia	0	7	Denmark	81	81
Lithuania	5	7	Greece	35	75
Latvia	0	5	Sweden	12	52
Greece	0	3	Estonia	10	20
Malta	0	2	Slovenia	17	17
Belgium	0	1	Hungary	0	12
Cyprus	0	1	Lithuania	10	10
Portugal	0	1	Latvia	5	8
Sweden	1.4	1	Malta	2	3
TOTAL EU	1.933 Kt	3.184 Kt	Cyprus	2	2
			TOTAL	4.228 Kt	6.069 Kt

Source: EBB, April 06  
 Subject to a +/- 5% margin of error  
 \*\* Subject to a +/- 10% margin of error

Source: EBB, April 06  
 Calculation based on 330 working days per year, per plant (situation on 01/07/2005 and 01/07/2006).

### Bioethanol

Bioethanol is the second biofuel in the European Union (18.5% of biofuel production). It is

estimated that in 2005 production level at 720,927 tons, i.e. an increase of 70.5% with respect to 2004. While Spain continues to be the biggest producer country in the EU (240,000 tons in 2005), it's Germany that's had the most significant growth (+500%, i.e. a total of 120,000 tons). Sweden's growth (+130%, i.e. 130160 tons) can be explained by the transformation of wine alcohol purchased by the European Union. The overall increase in bioethanol production is explained by the arrival of new producer countries like Hungary (11,840 tons), Lithuania (6,296 tons) and the Czech Republic (1,120 tons). No growth in this sector is expected for 2006 in France. In 2005, the national agricultural alcohol producers union (SNPAA) established bioethanol production at 99,780 tons vs. 102,000 tons in 2004.

Bioethanol production in EU is illustrated in Table 5.2. For more information see Annex 2.

*Table 5.2. Bioethanol production in selected EU countries \* (tons)*

	<b>2004</b>	<b>2005</b>
Spain	202 354	240 000
Sweden	56 529	130 160
Germany	20 000	120 000
France	80 887	99 780
Poland	38 270	68 000
Finland	3 768	36 800
Hungary		11 840
Lithuania		6 296
Netherlands	11 146	5 971
Czech Republic		1 120
Latvia	9 800	960
<b>Total EU</b>	<b>422 754</b>	<b>720 927</b>

\* included ethanol production from wine alcohol sells by EC.

Source: *EurObserv'ER 2006, EBIO, UEPA*

### *Biogas*

Ever increasing petrol prices and of increasing natural gas prices, more and more countries are setting up incentive legislations to valorise this energy that resembles natural gas (biogas contains between 55% and 65% methane).

In this way 4.7 million toe were produced in the countries of the European Union in 2005, out of an estimated deposit of more than 20 Mtoe. The main exploited deposit is that of rubbish dumps (2,961.4 ktoe in 2005), coming ahead of sewage purification plants (898 ktoe)

and other types of deposits (855.6 ktoe) like agricultural biogas, methanisation units of solid municipal waste or centralised co-digestion units.

These co-digestion units are capable of treating different types of waste at the same time, principally liquid and solid manures mixed with diverse organic waste. European primary energy production grew by 11.1% between 2004 and 2005 and principally benefited the production of methanisation biogas other than sewage purification plants (+57.9%, constituted in particular by agricultural biogas). 14.6 TWh of electricity was produced in 2005, an increase of 1.8 TWh with respect to 2004 notably due to the development of electricity coming from rubbish dump biogas and from CHP (combined heat and power) production from small agricultural units (principally in Germany). The United Kingdom remains the leading European country in terms of production with, according to the British Ministry of Industry and Trade, 1,600 ktoe in primary energy production (+6.4% with respect to 2004). The largest part of this biogas is valorised in the form of electricity (4.7 TWh produced in 2005). This production benefits, in particular, from the Renewable Obligation Certificate System that has been in place in the United Kingdom since 2002. This system imposes that electricity suppliers annually increase the renewable electricity share of their electricity production. This obligation was of 3% in 2002- 2003; 4.3% in 2003-2004 ; 4.9% in 2004-2005 ; 5.5% in 2005-2006, and should reach 15.4% in 2026-2027.

*Table 5.3. Electricity production from biogas in selected EU countries in 2004 and 2005 (in GWh)*

	<b>2004</b>	<b>2005</b>
Germany	4 414,0	5 564,0
United Kingdom	4 383,0	4 690,0
Italy	1 170,3	1 313,1
Spain	824,7	879,4
France	444,0	460,0
Netherlands	282,0	286,0
Denmark	265,0	274,0
Belgium	231,9	236,9
Greece	179,0	179,0
Poland	155,0	175,1
Czech Republic	138,8	160,9
Ireland	101,0	122,0
Austria	57,7	57,7
Portugal	14,6	34,4
Slovenia	30,3	32,2
Sweden	61,6	53,4
Luxembourg	20,3	27,1
Hungary	23,0	25,0
Finland	21,7	21,7
Slovakia	2,0	2,0
<b>Total EU</b>	<b>12 819,9</b>	<b>14 593,8</b>

Source: EurObserv'ER 2006

Table 5.4. Primary production of biogas in selected EU countries in 2004 and 2005 (in ktoe)

	2004				2005			
	Décharges	Station	Autres	Total	Décharges	Station	Autres	Total
	Landfill Gas	d'épuration Sewage sludge gas	biogaz Other biogas		Landfill gas	d'épuration Sewage sludge gas	biogaz Other biogas	
United Kingdom	1 327,0	177,0		1 504,0	1 421,0	179,0		1 600,0
Germany	573,2	369,8	351,7	1 294,7	573,2	369,8	651,4	1 594,4
Italy	297,7	0,3	37,5	335,5	334,1	0,4	42,0	376,5
Spain	219,1	52,4	23,6	295,1	236,5	56,8	23,6	316,9
France	127,0	77,0	3,0	207,0	129,0	77,0	3,0	209,0
Netherlands	67,1	53,8	28,9	149,8	59,8	50,7	29,6	140,1
Denmark	13,8	19,8	55,6	89,3	14,3	20,5	57,5	92,3
Belgium	56,3	9,7	7,8	73,8	56,3	9,7	7,8	73,8
Czech Republic	18,6	28,7	2,9	50,2	21,5	31,4	2,8	55,8
Poland	21,5	23,9		45,4	25,1	25,3	0,3	50,7
Austria	11,8	19,1	14,5	45,4	11,8	19,1	14,5	45,4
Greece	20,5	15,5		36,0	20,5	15,5		36,0
Ireland	19,9	4,8	5,1	29,9	24,9	4,8	5,1	34,8
Sweden	12,0	22,1	1,2	35,3	10,1	18,7	0,9	29,8
Finland	16,6	9,9		26,5	16,6	9,9		26,5
Portugal			4,5	4,5			10,0	10,0
Slovenia	5,8	0,9		6,6	6,0	0,7		6,8
Luxembourg			5,00	5,0			6,7	6,7
Slovakia		5,7	0,2	5,9		5,7	0,2	5,9
Hungary	0,7	2,6	0,2	3,5	0,8	2,9	0,2	3,8
<b>Total EU</b>	<b>2 808,6</b>	<b>893,1</b>	<b>541,7</b>	<b>4 243,3</b>	<b>2 961,4</b>	<b>898,0</b>	<b>855,6</b>	<b>4 715,0</b>

Source: EurObserv'ER 2006

### Forecast of Biofuel status in Europe

The rise in importance of biofuels in the European Union has been more than confirmed. Tax exemption policies have been set up, in particular in Germany, Spain, the United Kingdom, Italy and France. France has also established an ambitious biofuel plan running until the year 2015, since it is question of reaching European directive objectives as early as 2008 (5.75% biofuels in the transport sector) with a 7% incorporation rate in 2010 and 10% in 2015. It's probable, however, that many countries will not succeed in reaching the European directive objectives. In effect, taxes on fuels constitute a very sizeable portion of the budgets of the different member States, which can lead certain countries to delay necessary investments.

Taking current development of the two sectors into consideration, we estimate biofuel production at 9.9 Mtoe in 2010, while, according to the Joint Research Centre of the European Commission, it should have to reach 18.2 Mtoe at this date to meet the european directive's objectives, which are very near to those of the White Paper (18 Mtoe). And yet

this figure could even be revised upward if all of the EU member states set up more aggressive tax exemption and production approval policies. Decisions shall have to be made very quickly, keeping in mind that it takes at least a year and a half to build a brand new production unit.

Regarding second gen. plants, currently one BtL plant is built up in Freiberg/Germany (planned capacity 15 kt/a BtL). A bioethanol plant using wheat residues will be built in Sas van Gent/Netherlands (planned capacity 158 kt/a).

References to the existing plants in Europe can be found at the websites of some biodiesel plant manufacturers, e.g.

AT Agrartechnik (<http://www.biodieselanlagenbau.de/en/references.html>) and

BDI Biodiesel International (<http://www.biodiesel-intl.com/>).

including some plants in CEE, e.g. in Agropodnik Jihlava/Czech Republic (1994/2001, capacity biodiesel 35 kt/a), in RT Trzebinia (ORLEN Biodiesel)/Poland 2004 (capacity biodiesel 100 kt/a); project SKOTAN in Torun and SKOTAN in Krakow / Poland, each with a capacity biodiesel 100 kt/a; in Olomouc/Czech Republic (1994, capacity 30 kt/a) in Ventspils/Latvia (2007, see [biodiesel.lv](http://biodiesel.lv)); in Klaipeda/Lithuania (2007, see [www.mestilla.com/en/](http://www.mestilla.com/en/)).

### ***Biofuels production in CEE Countries***

Major European countries like Germany, France, Italy, Netherland, Austria, Spain and United Kingdom have formulated clear policies in promoting all forms of biofuels and achieved success in technologies, production, distributing facilities and using them in transportation etc. But recently joined EU member states and candidate states, which are represented mainly by Central and Eastern European countries, are just focusing on developing their national strategies for feedstock, production, use, etc.

*Table 5.5. CEE countries (according to OECD)*

	<b>Country</b>	<b>EU membership</b>
1	Albania	Potential candidate country
2	Bosnia and Herzegovina	Potential candidate country
3	Bulgaria	EU since 2007
4	Croatia	In accession negotiation
5	Czech Republic	EU
6	Estonia	EU
7	Hungary	EU
8	Latvia	EU
9	Lithuania	EU
10	Macedonia	Candidate country
11	Montenegro	Potential candidate country
12	Poland	EU
13	Romania	EU since 2007
14	Slovakia	EU
15	Slovenia	EU
16	Serbia	Potential candidate country

*Table 5.6. Other European countries and NIS (non-EU, non-CEE)*

	<b>Country</b>	<b>EU membership</b>
1	Armenia	-
2	Azerbaijan	-
3	Belarus	-
4	Georgia	-

5	Moldova	-
6	Russia	-
7	Turkey	In accession negotiation
8	Ukraine	-

In this chapter an attempt is made to overview the existing data on the production of biofuels in Europe, and in particular in less developed CEE countries and Eastern European NIS (New Independent States). Some total figures of the existing total capacities of biodiesel/bioethanol production (2006) in CEE states are given below:

*CEE countries with existing biodiesel capacities are:*

Poland: approx. 116 kt/a

Czech Republic: approx. 107 kt/a

Slovakia: approx. 82 kt/a

Slovenia: approx. 11 kt/a

Romania / Lithuania: each approx. 10 kt/a

Latvia: approx. 7 kt/a

Bulgaria: approx. 4 kt/a

*CEE countries with existing bioethanol capacities are:*

Poland: approx. 127 kt/a

Hungary: approx. 27 kt/a

Lithuania: approx. 14 kt/a

Czech Republic: approx. 12 kt/a

Latvia: approx. 9 kt/a

See below more particular overview of the situation on biofuel production in selected CEE countries and European NIS.

### **Bulgaria**

The biofuels market in Bulgaria is just getting off the ground. Biodiesel and bioethanol are currently produced in small quantities although a number of facilities are being constructed. It is estimated that the local biofuel production should reach 350,000 MT in the next two

years. The Government of Bulgaria is in the process of drafting the necessary EU-harmonized legislation with the goal of establishing a regulatory framework by end-2006. The biofuel industry, however, faces challenges related to Government concerns over reduced budget revenue, and a still significant gray market in oil and distilled spirits.

The biofuels industry in Bulgaria is an emerging sector. Biodiesel and bioethanol are currently produced only in small quantities in Bulgaria, although an increasing number of investors are constructing facilities for production of biofuels, mainly biodiesel. Constraints to production and trade include a lack of access to capital; lack of clear and regulated Government support; a limited local market; and lack of appropriate fixed investment to facilitate trade by other market players (refineries, storage houses and retail distributors).

The major current constraint for biodiesel investors is the lack of raw material (sunflower seeds, rapeseed, and soybeans). Investors are looking at sunflower as a possible source of biomass for biodiesel production. Sunflower seeds are traditionally exported in big volumes to the regional market (Turkey). MY2006/2007 sunflower production is likely to reach over 950,000 MT. However, according to industry sources, sunflower biodiesel is not in high demand due to its lower quality compared to rapeseed biodiesel, and since it does not meet the EU biodiesel standards. In addition, the industry indicates that sunflower diesel can be used only during the summer; therefore, commercial use in bigger volume is not likely. Bulgaria is not a traditional producer of rapeseed. The rapeseed crop in 2006 is likely to be 33,000 MT, a 51% increase over 2005 but still significantly below the capacity of facilities which are being constructed. Larger farmers are willing to increase the rapeseed area in the near future; however, the crop is vulnerable to frequent winter cold spells and summer dryness, and is less well-suited than sunflower to production in Bulgaria.

Bulgarian wheat and corn production has traditionally exceeded domestic consumption. On average, Bulgaria exports about 1.0 MMT of wheat and 100,000 MT to 400,000 MT of corn annually. Due to considerable production of wheat and corn in Bulgaria and bioethanol is produced using the same.

As with biodiesel production, however, it is still unclear if locally-produced ethanol will be more competitive than imports. Some of the significant disadvantages of current biofuel operations or investment projects are their relative inefficiency and small size. For example,

local industry estimates show corn and wheat conversion rates for grains into ethanol close to 3.4-3.8 compared to around 2.0 for most U.S. bioethanol plants.

Total petroleum diesel consumption in Bulgaria currently is estimated at 1.0 million MT. This implies about 50,000 MT in Bulgaria biodiesel consumption by 2007. Estimates for local consumption of bioethanol are for 100,000 MT annually; or total potential consumption of biofuels (biodiesel and bioethanol) in Bulgaria by 2007 is estimated at 150,000 MT. Taken together, production from all current and short-term investment capacity (in the next 2-3 years) should amount to 350,000 MT of biofuels, substantially exceeding local market demand. All managers in the biofuel industry are expecting to export at least 80% of the final product to the EU.

The local market is currently limited to one major buyer, the Russian company LukOil on the Black Sea port of Bourgas. The LukOil refinery in Bourgas is the only refinery in Bulgaria and has good technology for mixing petroleum products with biodiesel and/or bioethanol.

The other major player, which is the country's largest oil distributor, Petrol, imports oil/diesel/propane and distributes these via its own distribution and retail network. These two companies together have 539 retail gas stations in Bulgaria. There are at least 20 other companies which independently import and trade smaller volumes of oil and diesel. Some of them have their own distribution networks, and some sell to other distributors. Aside from LukOil and Petrol, other major distributors are OMV, Shell, Opet etc. These companies buy regular petroleum-based fuels from LukOil or Petrol or import on their own.

According to industry sources, oil importers have the technical ability to mix biofuels with petroleum-based fuels at their storage warehouses. Currently, however, there are only a few gas stations in Bulgaria equipped and ready to offer retail sales of biodiesel/bioethanol or mixed fuels. Government sources indicate that the oil industry will welcome increased use of biofuels on the market if clear and transparent regulations are written and enforced. Reportedly, the oil industry prefers to see government regulations which give preferences for mixtures of up to 5% biofuels, rather than sales of pure biofuels, mainly due to the fact that there are no flex engine vehicles in the country now. Currently, local biofuel prices are lower than EU prices due to different excise duties and other oil market regulations. The average price of biodiesel in the EU is about 1.07 Euro/liter, about 10% less than the price of

petroleum-based diesel at 1.18 Euro/liter. In Bulgaria, the few stations selling biodiesel are charging a price of 0.75-0.86 Euro/liter, which is about 7% lower than the price of petroleum diesel 0.91 Euro/liter. Bulgarian retail biodiesel prices are therefore about 20% below EU retail prices. The lower Bulgarian prices appear to reflect production costs fairly accurately since the subsidies and other preferences provided to EU farmers and refiners are largely unavailable to Bulgarian producers.

Table 5.6. Biofuel companies and investment projects in Bulgaria as of September 2006

<b>Biofuel companies and investment projects in Bulgaria as of September, 2006</b>			
<b>Company</b>	<b>Location</b>	<b>Annual capacity</b>	<b>Raw material</b>
<b>Biodiesel</b>			
BioDreems	Lovetch	20,000 MT in operation	sunflower, soybeans and rapeseed
Galaksi Oil	Silistra	15,000 MT in operation	sunflower, soybeans and rapeseed
Galaksi Oil	Pleven	30,000 MT expected launch by September 2007	sunflower, soybeans and rapeseed
Slantchevi luchi/TIM	Provadia	100,000 MT expected launch by 2007	sunflower, soybeans and rapeseed
Klas Olio	Karapelit/Dobrich	30,000 MT in operation	sunflower, soybeans and rapeseed
EkoPetroleum	Vidin	175,000 MT with plans to expand to 300,000 MT estimated needs in oilseeds ay 400,000 MT; ready for operation by 2008;	Sunflower (50% or 200,000 MT) and rapeseed (50% or 200,000 MT)
BulMarket	Rousse	60,000 MT ready to start operations by February, 2007; estimated needs in oilseeds at 150,000 MT	Rapeseed (40% or 60,000 MT) and sunflower (60% or 90,000 MT)
<b>Bioethanol</b>			
Slantchevi luchi/TIM	Rousse/Silistra area	100,000 MT expected launch by 2008	Wheat and corn
EvroEtil	Alfatar/Silistra	18,000 MT in operation; new project for 36,000 MT to be built in 2007; estimated current consumption of grain 60,000 MT;	Wheat and corn
Alcol Group	Gorna Malina/Sofia	10,000 MT, estimated grain consumption 30,00 MT,	Wheat and corn

		expected launch of the facility in 2007	
BioGroup (German investment fund ICS International Consulting SP)	Silistra, Shoumen, Yambol, Chirpan, Mezdra and Pernik	Total 600,000-700,000 MT/year 2 facilities for bioethanol and 4 facilities for diesel;; Expected launch of the facilities by 2008	Biomass (urban garbage) and used vegetable/animal oils/fats
Farin	Varna	20,000 MT-30,000 MT, expected launch of the facilities by 2008	Wheat and corn
Note: Information in this table is based on trade interviews, industry sources estimates and media publications. The FAS office Sofia can not officially confirm the truthfulness and completeness of the above information due to lack of any Government of other official public registers or sources.			

## Romania

The legislation in force and the incentives currently considered for promoting bio fuels in transport system in of Romania

Concerning biodiesel use, there are some small private producers of biodiesel on the internal market (using rapeseed, sunflower and less soybean or corn as raw material), in different areas of the country where they are testing bio diesel on agricultural vehicles and cars (taxi), using until 80% blending (B80).

The producer of Baia Mare city, SC AUTOELITE SRL, is declaring that with the price of 2.7ron/l (about 0.82euro/l) for B70, comparing with the price of 3.1ron/l (0.94euro/l) and a consumption of 7l/100kms, the 20 taxi of their own fleet are annually saving about 10,000 euro.

The first important biodiesel plant in Romania is becoming operational to the end of 2007, having an installed capacity of about 50,000 tonnes/year. Estimations are showing that the internal production of biodiesel would be of about 400,000 tonnes annually, starting with 2009, which should cover the task of 10% biodiesel of the diesel consumption, estimated for

that year, according to the Romanian resort ministry commitment by law for 2010.

Public Transport operators are showing interest to use biodiesel in their current bus fleet, going even beyond B30 or B40, however not before knowing the terms (mainly technical) of the vehicles providers in order to keep valid their contractual guarantee offered when purchasing these buses.

### **Serbia**

Recently, the first €20 million bio-diesel plant in Serbia from Victoria Oil was opened. Production of bio-diesel is expected to reduce Serbia's foreign trade deficit which is mainly due to large import of energy sources. Victoria Group invested €20 million in this plant and employed 200 workers. The price of bio-diesel per litre is going to be RSD 63.8 whereas the plant's annual capacity is 100,000 tons.

### **Poland**

There is no clear situation for biofuels production in Poland. Polish experts in the field have different views on the status of biofuels, their cost-effectiveness and even its effect to the environment protection. One of the suggested solutions is a subsidy of 350 PLN (45 euro)/1ha for crops harvested for biofuel production. It may concern potatoes harvest for bioethanol production or rape crops harvest aimed at production of esters for biodiesel. Another proposal aims at tax preferences for public transport fleets and taxi vehicles using alternative fuels. Free parking areas in city centres might also be one of the new support programmes for using biofuels.

Demand for methyl-esters production could significantly increase demand for local rapeseed and increase rapeseed crushing. Methyl-ester production has just started in Poland and almost 64,000 MT of methyl-esters were produced in 2005. Majority of these esters were exported to Germany, where legislation allows for benefits from such use. Under an EU directive from 2003, the Commission recommends that bio-fuel use reach 5.75% by 2010 in each member state. To reach this level, Poland will need to expand its rapeseed production to nearly 2.5 MMT, to be able to crush about 1.4 MMT rapeseed in order to produce 570,000 MT of methyl-esters. This would require almost double the current rapeseed acreage. It is likely that within the next 3 years, rapeseed planting will increase by 300,000 hectares to 800,000 hectares.

## **Hungary**

There is a significant production potential of biofuels in Hungary, mainly from rapeseed and sunflower, but other possibilities are also considered. According to the Ministry of Agriculture and Rural Development, 23 000-77 000 tons of biodízel could be produced from sunflower, and 90 000-160 000 from rapeseed. Even if you only consider the lower limit, that amounts to 125 million liters.

These factories are only capable to produce vegetable oil, but not transesterificated biodiesel (Rapeseed Methyl Ester, RME). Cereol, the major oilseed crushing company produces some rapeseed oil, but its 50,000-120,000 MT rapeseed crush is minor compared to the 650,000 MT sunflower seed processed. More than half of the rapeseed crop is regularly exported.

The Hungarian legislation kept the pure (100%) use of biodiesel and the blended use of bioethanol (in Ethyl-Tertiary-Butyl-Ester [ETBE]) tax free from 2003 to the end of 2004. (There was no commercial production and utilization in this period of time). The November 2004 amendments of the Act on Excise Tax (CXXVII/2003) recognized only the blending use of biofuels (vs. pure use) and terminated the tax-free status of pure use of biodiesel. The amended Act set excise tax preferences for biofuels for the 2004-2007 period.

In the field of biofuels, the 2005 utilization of 4,000 MT bioethanol is still far under the 0.4 percent target, but both the national gasoline company (MOL Rt.) and the GOH have made steps to increase utilization.

## **Slovenia**

Even though biodiesel is the most common and well known alternative fuels in Slovenia its use is still very poor. Some progress was made in the production of this fuel, but mostly the product is exported to Austria and Germany. In 2005 just 6000 tons of biodiesel was produced, in 2006 the production increased to 15.000 tons, all the main producers are planning to expand the capacities so that in 2008 the production could reach 155.000 tons per year.

Beside the biofuel regulation demanding the share of biofuels in transport fuels from the distributors and exempting biofuels from excise duties, there are no other regulations valid in

Slovenia that would encourage the use of biodiesel. For instance if a company decides to convert its fleets to biodiesel, they face many problems:

- higher costs of vehicle purchase, there are no exemptions from duties for purchasing these vehicles;
- if they decide to convert their existing vehicles to biodiesel they risk losing the warranty for the vehicles;
- they would have to organise a refuelling point for their fleet themselves;
- if they would use B25 or even a higher share of biodiesel in their fleets biodiesel would be more expensive, since the cost of the fuel would not be reduced by the excise duty exemption;
- they would face higher costs of vehicle service. Beside good image of the company economically for managers and fleet owners there are no advantages in using biodiesel in their fleets.

There is only one publicly accessible refuelling point for B100 and even this is not an ordinary filling station, it is a small private biodiesel production plant in a rather remote part of Slovenia. The owner of this plant persuaded a few nearby farmers to switch to using biodiesel in their agricultural machinery.

B100 is used in 20 buses of Ljubljana public city bus operator as a part of CIVITAS II MOBILIS project. Ljubljana city bus operator has its own refuelling point for B100 at their bus parking garage.

The biggest transport fuel provider in Slovenia started mixing biodiesel in its diesel fuel in 2004. Because of the micro-organisms in the fuel a series of lawsuits followed and biodiesel was pulled out of the market. They continued with mixing in 2005 with more attention to the storage of the fuel and now they are distributing the mixture randomly to different filling stations in Slovenia. If a customer asks the people working at a counter desk at any filling station of this provider whether their diesel is mixed with biodiesel, they would start assuring you that their diesel is absolutely biodiesel free, as if it was something to be avoided if possible.

Only one official research on the use of biodiesel in vehicles was done in Slovenia so far and it has not ended yet. It is a part of the already mentioned CIVITAS II MOBILIS project.

Ljubljana public city bus operator used 2 buses first running on B20, afterwards they switched to 20 buses running on B100. These are old buses, their motors fall in the category of Euro 0 standard. Some alterations were made on the buses: cleaning of the fuel storage and supply system, exchange of oil filter, exchange of rubber parts in the fuel supply system and adaptation of the fuel injection angle according to the calculations made by the Faculty for Mechanical Engineering from Maribor. The engine power of the buses running on B100 decreased for 6%, the engine lever for about 4%, the average fuel consumption increased for 10%.

Again we can only mention the data gathered in the CIVITAS project. The greatest advantage of B100 buses is in 50% reduction of PM emissions.

Yearly costs (2006) of one bus running on diesel in Ljubljana (60.000 km covered) are around 26.000 €, yearly costs of one bus running on B100 are according to the CIVITAS study about 3.000 € higher due to higher costs of the fuel and of the halved interval of regular mechanical service of such a bus.

The price of biodiesel in Slovenia varies from 0,79 € to 0,92 € per litre. Last year the price of fossil diesel increased from 0,92 €/l in January to 1 € in August, then they fell again to 0,89 € in February 2007, in the beginning of May 2007 the price is 0,96 €/l.

If a distributor is mixing less than 5% of biodiesel in the motor fuel no special declaration is needed for the informing of the customer. The price of the fuel is the same at any filling station of this provider, that means the 33,7 % excise duty on diesel fuel is charged to the customer, but in the case of mixing of biodiesel into the diesel up to 5 % of this excise duty falls into the pocket of the distributor and not the state budget.

### **Slovakia**

A new member to the EU, Slovakia has encouraged the expansion of renewable energy projects by offering tax based incentives. This suggests that the Slovakian government is in a position to support renewable energy projects, and may lead to more significant incentives in the near future. Current feed-in tariffs are relatively low, at 3 Eurocents/kWh.

Slovakia aims to boost the amount of energy produced from renewable sources to around 12.0 percent in 2020, well below the EU-wide target figure of 20.0 percent.

Slovakia's renewable efforts could exceed those targets if it found "more effective means" of producing such energy, he said, adding that hydro, biomass and geothermal energy offered the best prospects.

EU heads of state agreed at their spring summit for renewables to account for 20.0 percent of energy consumption across the 27-country bloc by 2020. Individual targets for countries allowing the EU to achieve that overall goal were not set at the summit.

Biomass, geothermal, and hydro appear to be the most promising renewable energy resources for project development. Despite the extensive use of forestry wastes for energy production, it is estimated that only 10 percent of this resource is currently being utilized. The significant amount of forestry byproducts could potentially be used to generate electricity on a large scale, or more completely utilized to supply heat for residential and industrial needs. Although Slovakia's geothermal reserves are primarily low to medium enthalpy, there are some high enthalpy areas in the Kosice basin suitable for electric geothermal development. Slovakia also has over 180 small hydropower plants currently in operation. In addition, there are over 250 locations on the rivers of Danube, Váh, Hron, Bodrog and Hornád with nearly 100 MW of generation potential. Slovakia has poor technical potential for solar and wind project development.

## **Ukraine**

Ukraine has a program of state support for the development of non traditional and renewable energy sources and small hydro power plants. The target set for renewables is 10 percent of generation by 2010.

In 1996 the President of the Ukraine declared wind generation a national priority and established a target of 200 MW by 2010. This has resulted in 40 MW of installed wind capacity in the Ukraine. It is estimated that the Ukraine has 5,000 MW of mid term potential for wind generation in over 40 percent of its territory.

Ukraine has a moderate technical potential for solar energy. The incidence of solar radiation increases from northwest to southeast with the highest potential on the Crimean peninsula.

An emphasis has been put on the development of solar hot water heating. Hydro power currently meets 7 percent of the Ukrainian demand for electricity. Some 327 MW of potential new hydro projects exist, with 220 MW of that on the Tisa River alone.

Ukraine has considerable geothermal resources that are used primarily for heat supply. Total installed capacity of thermal systems is 13 MWth. Plans are in place to increase the thermal water utilization up to 250 MWth by 2010. There are prospects for binary geothermal plants using existing wells at abandoned oil and gas fields, and a 1.5 MWe pilot binary geothermal is scheduled for Poltova in 2005.

The biomass potential is 4.0 million toe, which includes livestock manure, straw, and lumber mill waste. There is strong interest in the use of livestock manure for biogas power generation as well as straw and wood combustion for district heating plants and combined heat and power facilities.

The major impediments to the growth of renewables are the uncertain economy, lack of financing and extreme bureaucracy. However, given the good technical potential and experience with existing capacity, renewable energy prospects are reasonably good.

Ministry of transport and communication of Ukraine considers the general scheme of development of Kherson trading seaport by 2015 that foresees building of the first in Ukraine terminal for accumulation, storage and shipments of bioethanol (biodiesel) in ports with capacity of 15.000 tons of simultaneous storage. This project is possible if based on investment contract.

According to Yegorov, investors of the project would be Ukrainian company producing bioethanol. The approximate price of the project is \$5 mln.

Let us remind that total capacity of bioethanol producing companies in Kherson region is 14.200 tons per year. "Liber", the main producer of biofuel in the region, produces 10.000 tons of biodiesel per year. Besides there are many companies in Kherson region that produce biodiesel for their own needs. Their producing capacities are a bit lower as compared to "Liber".

In order to provide the raw material for biodiesel production, the enterprises of the region sowed 59.300 ha of rapeseeds to harvest 72.100 tons of rapeseeds.

### **Czech Republic**

Aside from strong political support for renewable energy development, the Czech Republic has the highest renewable energy feed-in tariffs identified in this study. These high tariffs demonstrate the importance of renewable energy development to the government and greatly enhance the economics of renewable energy projects. A new law was enacted in August 2005 will even further enhance the support for renewable development. In general, Czech Republic has established excellent institutional support mechanisms for the promotion of renewable energy.

Wind, biomass, and solar appear to be the most promising renewable resources for energy development in the Czech Republic. The Czech Republic has a long tradition of wind energy utilization. With an attractive 9.5 US cents/kWh feed-in tariff, wind energy development may be highly economical. The original study identified a near-term technical potential of 2,220 MWe. With only 30 percent of biomass resources currently being used and a feed-in tariff of over 8 US cents/kWh there is also an excellent opportunity for the development of biomass projects. Although the Czech Republic only has mediocre solar insolation levels, it is a very promising country for solar project development, with a feed-in tariff of over 19 US cents/kWh. Despite the high feed-in tariff for solar projects, the high costs of photovoltaics may still hinder project development.

The new trend of using biofuels in transport is setting up a niche for biofuel producing companies. One of the first local companies to recognize the business opportunity was largest Czech sugar producer Cukrovary TTD. The company invested Kč 1.3 billion (€ 46.9 million) into the construction of a new bioethanol distillery in Dobrovice, Central Bohemia, that produced some 200,000 hectoliters of bioethanol last year. As there was not a sufficient market for biethanol here, Cukrovary TTD sold it to Germany.

Cukrovary TTD is planning to increase its production of ethanol and bioethanol. Last year the firm bought 1.5 million tons of sugar beet, out of which 1.3 million tons was used for sugar production and the rest for ethanol, and in two to three years it would like to buy over 2 million tons of sugar beet and use approximately 750,000 tons for production of ethanol and

bioethanol, said Reinbergr, who doubles as a chairman of the Association of Distilleries of the Czech Republic (SLČR), a nonprofit group that was created this year to promote bioethanol producers. This year, Cukrovary TTD plans to produce 800,000 hectoliters of bioethanol and sell it here as well as in neighboring countries including Germany.

The company that has so far secured most of the local biofuel market is food and chemical producer Setuza. It launched operation of a new facility Aug. 2007 at its headquarters in Ústí nad Labem, North Bohemia, with an annual capacity for the production of 100,000 tons of RME. The Kč 750 million production plant makes the firm the biggest RME producer in the Czech Republic. The company will now fully cover RME consumption in the Czech Republic. Setuza, which also produces 50,000 tons of RME at two other plants in the country, processes some 600,000 tons of rapeseed annually, which is about 60 percent of the total Czech rapeseed production.

Another company hoping to cash in on the emerging trend is biofuel producer PLP, which is finishing its new plant in Trmice, North Bohemia. The Kč 1.26 billion facility, which will use up to 280,000 tons of corn for producing bioethanol annually, is scheduled to start production in November, 2007.

Czech farmers have been waiting years for bioethanol producers to start buying their surplus grain, corn and sugar beet. Last year the seed crop surplus reached some 600,000 tons, said Jan Veleba, president of the Czech Agrarian Chamber (AK ČR), a nonprofit lobby organization for farmers. Czech farmers and food producers estimate that the introduction of biofuels will raise their product prices by 5 to 10 percent this year, with even a bigger price growth to come in the following years. Seed crop prices are already growing. While last year farmers sold a ton of seed crop for Kč 2,700, this is year it sells for Kč 4,000.

The prices of not only food but also fuel are expected to rise due to the obligatory addition of RME to fuel. While some analysts anticipate that the prices of diesel oil and later gasoline could rise by up to Kč 0.40 per liter, the Ministry of Agriculture said the price would grow by a maximum of Kč 0.20 per liter. But the final price growth depends on the continually changing prices of oil and biofuels.

Consumption of RME as an additive to diesel oil is estimated at 307,000 hectoliters this year in the Czech Republic, for which 76,000 tons of rapeseed would be needed, or 7 percent of this year's harvest. The country has an annual capacity for producing 3.4 million hectoliters of RME and a part of this output will continue to be exported, according to the Association for the Production of Biofuels.

### **Estonia**

Estonia's entry into the European Union is influencing its emphasis on renewable energy. The investment climate for renewables appears favorable in Estonia with high public awareness, and a positive legal and regulatory framework. There is now a goal to increase the use of renewable energy by 67 percent by the year 2010. Tax reliefs are offered to many renewable sources, and generation from biomass and waste fuels avoid the imposed CO2 charges. The most promising renewable energy resources in Estonia are wind and biomass.

According to local information agency, two large plants on biodiesel production should be built in Estonia in the nearest time. In fact, in 2008 the plant on biodiesel production with annual capacity of 100.000 tonnes of fuel should be built in Paldiski town. The production of this plant would be based on rape oil.

In 2009, they expect for the finishing of building of another large plant on biodiesel production with annual capacity of 100.000 tonnes in Kunda town. The main raw material here would be grain crops. The annual needs of grain for this plant are estimated at 350.000 tonnes. They should buy the whole volume of grain in Estonia, but also concluded contracts for grain delivery from Ukraine and Kazakhstan. The sales markets for both plants would be Scandinavian countries as they face lack of biofuel.

*Source: 2001-2003 APK-Inform Information Agency.*

### **Croatia**

Croatian Government's Decree on quality of bio-fuels introduces liability for Croatia to introduce 5.75% of bio-fuel in overall consumption of fuel in Croatia by the end of 2010. At this time, there is only one facility for production of bio-diesel in Croatia, located in Ozalj, with a capacity of 30.000 tonnes.

Feasibility study will be completed at the end of this month, when it would be revised by experts from Austria. Researches have shown that the city of Zagreb annually "produces" more than 1,400.000 litres of scrap edible oil in the city's hotels, restaurants and other facilities, along with 1,600.000 litres from households.

The quantity of bio-diesel manufactured from such scrap edible oil is sufficient for 80 city buses per year. Remaining necessary quantity of scrap edible oil for production of bio-diesel would be extracted from oil seed rape. At this time, edible oil producer IPK Cepin and INA expressed interest in production of bio-diesel.

### **Lithuania**

Lithuania is a major producer and user of biomass for thermal and electricity production. It currently has moderate production of biodiesel (methyl-ester) and ethanol but has ambitious plans to increase production of biofuels to 380,000 tons by 2010.

Currently Lithuania produces 33 percent of its energy from nuclear power, 33 percent from oil and about 24 percent from natural gas. Renewable resources such as biomass, biofuel, geothermal and hydropower generate the majority of the remaining 10 percent. On January 2007, Lithuania published an Updated National Energy Plan which emphasizes its commitment to renewable energy, both biomass and biofuel. Lithuania wants to become less dependent on the world market for its energy needs.

Lithuania began producing biofuel in 2004 in two plants, Rapsoila located near Mazeikiai and Biofuture in Silute (see <http://www.biofuture.lt/en/>). In 2006 Lithuania produced 25,000 MT of biofuel, 10,000 of biodiesel and 15,000 of ethanol. (In contrast, 1.2 million MT of conventional fuel was consumed in Lithuania in 2006.) Domestic agricultural production supplies all the raw material for the two biofuel production plants. Rapeseed is used for biodiesel production and wheat, rye and a wheat/rye blend is used for ethanol production. Lithuania permits 5 percent biodiesel and 7 percent ethanol components in fuels. The government believes they will surpass the EU target of 5.75 percent biofuel components in fuel used for transportation by 2010 and it supports making these EU goals mandatory.

In 2007 Lithuanian biofuel production should reach 60,000 MT. Ethanol production will increase to 20,000 MT with increased production in the Biofuture plant. Mestila, a new biodiesel production plant that was completed near Klaipeda in an economic free zone, is due to begin production this spring and will increase national production of biodiesel to 40,000 MT.

Biofuel production is subsidized in Lithuania. The producers of grain ethanol receive 114 Lithuanian Litas (about \$38 USD) per MT and biodiesel receive 160 Litas (about \$53 USD) based on raw input. Even with these subsidies these companies are not making a profit. (Government sources speculate that biofuel production is only profitable when oil prices rise above \$70.00 USD/barrel.)

The Lithuanian Ministry of Agriculture has set production targets of 190 thousand tons of biodiesel and 190 thousand tons of ethanol for 2010. Even at those levels, Lithuania believes it can produce enough raw materials domestically for biofuel production, but above 380 thousand MT, it would need to import grain.

Lithuania is 33 percent forested, compared to Latvia and Estonia each with 50 percent forested area, but it is the largest producer and consumer of biomass among the three Baltic counties. Inputs for biomass in Lithuania are domestic and include wood, straw, grasses, municipal waste, and fast growing trees.

By far the largest producer of biomass in Lithuania is operated by Vilnius energija, a district heating company that operates a plant in Vilnius producing 60 mega watts of energy, 12 in electricity and 48 in thermal heat. It supplies 10 percent of all heat for Vilnius and its surrounding district. Lithuania has introduced new biomass technology in seven regional heating plants throughout the country that supply 14 percent of the country's heat.

Lithuania currently produces 500 megawatts of biomass thermal power annually. One of the largest Lithuanian companies producing biomass incineration equipment is Axis Industries that has built more than 100 biomass wood-input boiler houses. An important producer of straw-based biomass boiler houses in Lithuania is Umega.

In the Updated National Energy Plan the plans are for 50 percent of Lithuania's central heating to be provided by biomass thermal production by 2025. In addition, Lithuania plans to double its use of biomass renewables for heat and electricity production using wood, straw, municipal waste, as well as fast growing trees and crops. Lithuania is also looking to 1 this level of subsidy is currently limited to a total of 2 million hectares EU-wide in order to guarantee an expenditure ceiling for the program. The regional plants are located in: Telsiai, Kelme, Kazlu Ruda, Marijampole, Kybartai, Vilkaviskis, and Palanga.

## ***Biofuels production in Western Europe***

In analogy with the previous chapter and for comparison reason below there is an overview of the situations on biofuel production in selected Western European countries.

### **Germany**

Germany is the leading biodiesel producer and this can be explained by favourable legislation, the absence of quotas and a low price for vegetable oil associated with a high price for biodiesel fuel. The German biodiesel industry has worked closely with the automotive industry from the beginning. This was essential for persuading the auto industry to issue the same warranties for biodiesel use. Making DIN 51606 for plant-oil methyl ester mandatory in 1994 was an important step. As of June 2002, biodiesel was available at 1,500 filling stations in Germany. The average distance between the filling stations selling biodiesel was about 30 km, although with substantial regional variation. About 40 percent of biodiesel is sold through filling stations and 60 percent to fleet operators.

In Germany the cost of biodiesel production from rapeseed is about €0.50 - 0.64 per liter. In the other EU countries, the cost of biodiesel production is about €0.41-0.42 per liter in the Baltics, €0.65 in Hungary, €0.75 in Poland, and €0.70 in the Slovak Republic.

In 2004 biodiesel once again achieved by far the largest market share among biofuels in Germany. In 2005 car manufacturers withdrew permission for new diesel cars to use biodiesel. The reasons are technical problems with new exhaust after treatment systems.

In addition to biodiesel which has been used as pure fuel since 1993, more rape methyl ester (RME/biodiesel) has also been added to fossil diesel fuel since the beginning of 2004. In 2005 some 600 000 t of biodiesel was used for adding to fossil diesel. Commercial vehicles refueled with about 680 000 t at companies' private filling stations and about 276 000 t at public pumps. Another 244 000 t in 2005 went into private cars from public filling stations. Sales of pure fuel, at 1 200 000 t, thus make up the largest market share at about 66%. The addition of biodiesel to fossil diesel fuel up to the 5% limit by volume which standards allow is expected to continue increasing significantly.

## **Austria**

According to the Association of Biodiesel Manufacturers, there were eight biodiesel plants in Austria in 2005. The total capacity is approximately 92,000 tonnes a year. In 2004, approximately 55,000 tonnes of biodiesel were produced in Austria, according to information from the producers. From this quantity, however, roughly 90% was sold abroad. In 2005, some 70,000 tonnes of biodiesel were produced in Austria according to information from the producers/estimates. From this quantity, however, approximately 50% was sold abroad. It is forecast to increase to some 200,000 tonnes in 2006.

Of the quantities sold in the domestic market, roughly half went to blending by those subject to the substitution requirement. Some 17,000 tonnes were used as pure biofuel in the Austrian transport sector.

## **The United Kingdom**

Biodiesel is currently available at over 100 filling stations in the UK; the majority is at or below 5% level blend in diesel. Fuel duty differentials are currently the UK's primary means of support for biofuels. The duty incentive on biodiesel (20 pence per litre), has been in place since July 2002.

## **Italy**

In Italy, the Directive 2003/30/EC was implemented by the Decree 30/05/2005 n. 128, followed by the Law 11/03/2006 n. 81. The Decree 128 lays down targets on biofuels and renewable fuels consumption, expressed in percentage as to the overall diesel oil and petrol present on the national market: 1% by 31/12/2005; 2,5% by 31/12/2010. According to Confagricoltura (the farming companies trade association), 200,000 tons of biodiesel were produced in Italy in 2005, of which 13,000 by national raw materials and the rest imported from foreign countries. There is one biodiesel refuelling station in operation in Tortona (Piedmont Region).

## **Spain**

The present productive capacity installed in Spain in biodiesel plants was 322,000 t/year in 2005. However, total production during this year was about 150,000 t/year equivalent to 135,000 tep, because some of the production plants started to operate at the end of that year. Specifically, there exist 10 biodiesel plants in Spain, 8 of them were running during 2005,

and 2 started to run at the end of that year. The main feedstocks for producing biodiesel in Spain are used oils, rape and sunflower. Nowadays, there are 128 refuelling stations in Spain which offer biodiesel. In the Municipal Transport Company of Madrid there are 209 biodiesel run vehicles.

### **Portugal**

GALP-Energia is the main fuel supplier in Portugal (95% of total) and is currently distributing diesel with up to 5% of biodiesel mixed in (in 2006, something like 3% were accomplished). Thus, there are some small-scale private companies producing biodiesel and supplying it among captive fleet and/or private users. The production of biodiesel from used cooking oils is becoming popular in Portugal (OEIRAS and SINTRA are the best experiences so far) - many interesting citizens and companies have emerged in the last year. Biodiesel is also a subject worked in some primary and high-schools in the country. The Governement also announced a goal of 10% Biofuels in the total selling for 2010.

### **Greece**

During the first stage of biodiesel implementation in Greece, which started at the end of December 2005, biodiesel is blended with automotive diesel at refineries or petroleum product marketing companies in a proportion which currently fluctuates around 2% by volume, but which can rise to 5% by volume (as specified in the EN 590:2004 standard) – this is expected to happen towards the end of 2006 – and is marketed via the existing automotive diesel distribution network throughout the market. At a later stage once any technical and institutional issues have been resolved it is planned to distribute blends of biodiesel and automotive diesel exceeding 5% by volume, and also pure biodiesel. The first domestic biodiesel production plant, operated by Hellenic Biopetroleum Industrial and Commercial S.A. at Kilkis, with an annual production capacity of 40,000 tonnes, started operating in December 2005. A second biodiesel production plant, operated by VERT OIL S.A. in Thessaloniki, with an annual production capacity of 25,000 tonnes, is expected to start production by July 2006; a third plant, operated by Pavlos N. Pettas Industrial and Commercial S.A., with an annual production capacity of 50,000 tonnes, is expected to start production at about the same time. The construction of a fourth plant, with an annual production capacity of 40,000 tonnes, has been started by Elinoil S.A. at Volos and of a fifth, with an annual production capacity of 250,000 tonnes, by Agroinvest S.A. at Fthiotida: both are expected to start production in the second half of 2006. Construction of the first plant was

financed by the “Competitiveness” Operational Programme, which draws funds from the Third Community Support Framework, and construction of the third plant was financed via Development Act 3299/2004.

According to currently available data, a further eight biodiesel production units are at the initial stages of design and construction: four with a capacity of 5,000 tonnes, two with a capacity of 11,000 tonnes, one with a capacity of 22,000 tonnes and one with a capacity of 120,000 tonnes, with estimated production start dates ranging from end 2006 to the first half of 2007. Many other companies have expressed serious interest in the construction of further biodiesel production units with a small, medium or large annual production capacity, at various locations, with estimated production start dates not before the second half of 2007. The raw materials used by the above biodiesel production units comprise about 70% imported oils (rapeseed, soya-bean, etc.) and about 30% domestically produced oils (cottonseed, sunflower, used cooking oil, etc.). Attempts to intensify domestic sunflower and oilseed rape crops are on the increase, with a view to domestically produced raw materials exceeding imports.

Biodiesel may also be imported, both from other EU Member States or accession countries (Bulgaria, Romania, Turkey) and from non-member States, provided the price of the biodiesel is not increased excessively by the transport costs. Automotive biodiesel distributed in Greece has to comply with the specifications of the ELOT EN 14214 standard.

Initially, biodiesel is intended only for blending with automotive diesel in a proportion not exceeding 5% by volume. Distribution of pure biodiesel on the retail market will follow, as will the blending of a higher proportion of biodiesel in automotive diesel intended for vehicle fleets (e.g. public transport vehicles). The distribution of biodiesel in Greece started in December 2005 when the first batches were distributed to refineries by Hellenic Biopetroleum S.A. The blend of 2% biodiesel by volume in automotive diesel has been distributed to all final consumers since February 2006 and continues to be distributed smoothly. This percentage is expected to be increased to 4% by volume by about the end of 2006, when the biodiesel production units currently under construction, start operating.

In Greece, four oleiferous crops (groundnut, sesame, soybean and sunflower) are currently cultivated for their seeds. Among them, groundnut, sesame and soybean are cultivated in a

relatively small area, while sunflower is cultivated in relatively larger area in the northern part of the country. These crops are traditionally used mainly for oil extraction and edible seed. In the last few decades, the area cultivated with groundnut, sesame and soybean has significantly declined, while sunflower presented an upward trend since 1993. Meanwhile, rapeseed cultivation is still at demonstration scale.

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## Annex 1. Some examples of large scale biodiesel production facilities in Europe

Source: BiofuelsMarketplace.com

*Company* *Location* *Capacity* *Feedstock*

### Austria

Energea		40.000 t	Recycled oil
Biodiesel Karnten GmbH	Arnoldstein	25.000 t	Multi
PPM Energie aus nach-wachsenden Rohstoffen	Asperhofen	1.500 t	
NOVAOL Österreich	Bruck	25.000 t	
BAG Gössing	Gössing	2.000 t	
SEEG Mureck	Mureck	9.000 t	Multi
Zuckermantelhof	Schönkirchen		
RME-Alternativtreibstoff Starrein	Starrein	3.000 t	
Bioenergy - Biodiesel-Erzeugung	Wöllersdorf	20.000 t	
Biodiesel Raffinerie GmbH	Zistersdorf	40.000 t	Multi

### Bulgaria

Slunchevi Luchi			Multi
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### Czech Republic

Agropodnik	Polna	25.000 t	Rapeseed oil
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### France

Diester Industrie	Grand-Couronne	250.000 t	Multi
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### Germany

3B-Diesel GmbH		1.000 t	
BKK Biodiesel GmbH		4.000 t	
Biodiesel Bokel GmbH		10.000 t	
Biodiesel Holding GmbH		150.000 t	
Biodiesel Kyritz GmbH		30.000 t	
Biodiesel Wittenberge GmbH		60.000 t	
BioWerk Kleisthöhe GmbH		5.000 t	
BioWerk Sohland GmbH		5.000 t	
Campa Biodiesel GmbH		75.000 t	
Delitzscher Raps GmbH & Co. KG		5.000 t	
GREENPOWER Umwelttechnik Oranienburg		10.000 t	
Hallertauer Hopfen-Verwertungsgesellschaft		8.000 t	
Kartoffelverwertungsges. Cordes & Stoltenburg GmbH & Co.		15.000 t	
Landwirtschaftliche Produkt- Verarbeitungs GmbH		5.000 t	

Oelmühle Hamburg AG		120.000 t	
Natural Energie West		120.000 t	
Petrotec GmbH		35.000 t	
Rapsveredelung Vorpommern GmbH & Co. KG		37.000 t	
Rheinische Bio-Ester GmbH		100.000 t	Rapeseed oil
Verwertungsgenossenschaft Biokraftstoffe		2.000 t	
EOP ElbeOel Prignitz Ag	Falkenhagen	30.000 t	Rapeseed oil
Mitteldeutsche Umesterungswerke GmbH & Co.KG	Greppin	150.000 t	Rapeseed oil
Oelmühle Leer Connemann GmbH & Co. KG	Leer	110.000 t	Rapeseed oil
Bio-Ölwerk Magdeburg GmbH	Magdeburg	50.000 t	Rapeseed oil
SARIA Bio-Industries GmbH & Co. Verw. KG	Malchin	12.000 t	Multi
Thüringer Methylesterwerke GmbH & Co. KG	NiederpÄlnitz	45.000 t	Multi

### Greece

Elvi	Thessaloniki	50.000 t	Multi
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### Italy

Novaol SRL	Livorno	100.000 t	Multi
Estereco	Umbertide	30.000 t	Multi
Fox-Petroli	Vasto	120.000 t	Rapeseed, soy

### Poland

Biopaliwa			Rapeseed
KS Wroclawia	Wroclaw		Multi

### Portugal

Fabrica Torrejana de Combustiveis S.A.	Lisboa	50.000 t	Multi
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### Romania

Rompetrol		60.000 t	Multi
Martifer			Multi

### Slovakia

Ekoil Biodiesel, s.r.o.	Zohor	40.000 t	Vegetable/ recycled oils
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### Spain

Linares Biodiesel Technology, S.L.		100.000 t	Multi
Stocks del Valles S.A.	Montmelo	31.000 t	Recycled oils/ recycled fats

### United Kingdom

Greenergy	Immigham		Multi
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## Annex 2. Some examples of large scale bioethanol production facilities in Europe

Source: BiofuelsMarketplace.com

Company	Location	Capacity	Feedstock
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### Austria

Agrana	Pischelsdorf	600000 lpd	Wheat
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### Belgium

Alcogroup/Aveve	Gent	100 mio l	Grain
Tirlemontoise (Südzucker)	Wanze	300 mio l	Grain

### Bulgaria

Vivaagrotex	Alfatar		
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### Czech Republic

Chebio			
Citronelle			
SWP Trading			
Jihocesky zemedelsky			
Korfil			
Cukrovary TTD/Tereos	Dobrovice		
Moravsky Lihovar	Kojetin		
Biopal	Kolin		Wheat
Aliachem	Napajedla		
ADW Bio	Okříšky		
Dehtochema, Bitumat	Vrdy, Kutna Hora		Grain

### Denmark

Elsam/Fynsvaerket	Odense		Straw
Elsam	Studstrup		Wheat

### France

SDHF (now Tereos)		450 mio l	
Cristal Union	Areis sur Aube	120000 t	Beet
Tereos	Artenay		Wheat/ sugar beet
Cristanol (Cristal Union)	Bazancourt	238000 t	Beet
Cristanol (Cristal Union)	Bazancourt II	280000 t	Beet
Roquette	Beinheim		Wheat
SLS (Südzucker)	Epeville		
AB Bioenergy	Lacq		

Tereos/Sodes	Lillebonne		Wheat
Soufflet (Familie)	Meriot, Aube		Wheat
Tereos	Morains		Wheat/ sugar beet
SODES SA	Normandy		
Ethanord	Noyelle- Godault		Beet
Ethanord	Noyelle- Godault		Wheat
Tereos - Bio-Ethanol Nord Picardie	Origny	200 mio l	Wheat/ sugar beet
AB Bioenergy(Abengoa)/APGM/etc	Pardies		Corn
Tereos - BCE	Provins		Wheat/ sugar beet

### Germany

Sasol	Herne	60000 t	
	Hünxe		
BEP Biokraft Emsland	Papenburg		Wheat, rye
NAWARO	Rostock		Rye
NBE/Sauter	Schwedt	180000 t	Rye
Südzucker	Zeitz	800000 lpd	Wheat
MBE/Sauter	Zörbig	80000 t	Rye

### Greece

Hellenic Sugar			
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### Hungary

Hungrana		63 mio l	
Magosz	Hajdúsámson		
MOL	Tiszaujvaros		

### Italy

Assodistil ENI			
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### Latvia

Stumbras		13 mio l	
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### Lithuania

Lako			
Jaunpagasts			Wheat

### Netherlands

Nedalco		90 mio l	Beet
Harvest Energy	Amsterdam		Wheat

Nedalco	Sas van Gent		
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### Poland

Akwawit	Leszno	80,000 t	
Biopaliwa	Nysa		Wheat

### Portugal

Copar			corn
Copar			corn

### Russia

VipOil	Volgograd		Grain
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### Slovakia

Enviral	Leopoldov		
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### Spain

EVE/Abengoa	Bilbao, Punta Sollana		
Ecocarburantes Españoles	Cartagena	100 million liters	
Biocarburantes Castilla y León	Salamanca		Barley/ wine
Bioetanol Galicia	Teixeiro-Curtis	126 million liters	
Sniace/Elecnor	Torrelavega		Grain

### Sweden

Sekab	Domsjö		
Agroetanol	Norrköping		Wheat
Etek	Örnsköldsvik		Cellulose

### United Kingdom

Wessex Grain/Green Spirit Fuels	Henstridge		Wheat
Vireol	Teesside		Wheat
British Sugar	Wissington		Beet