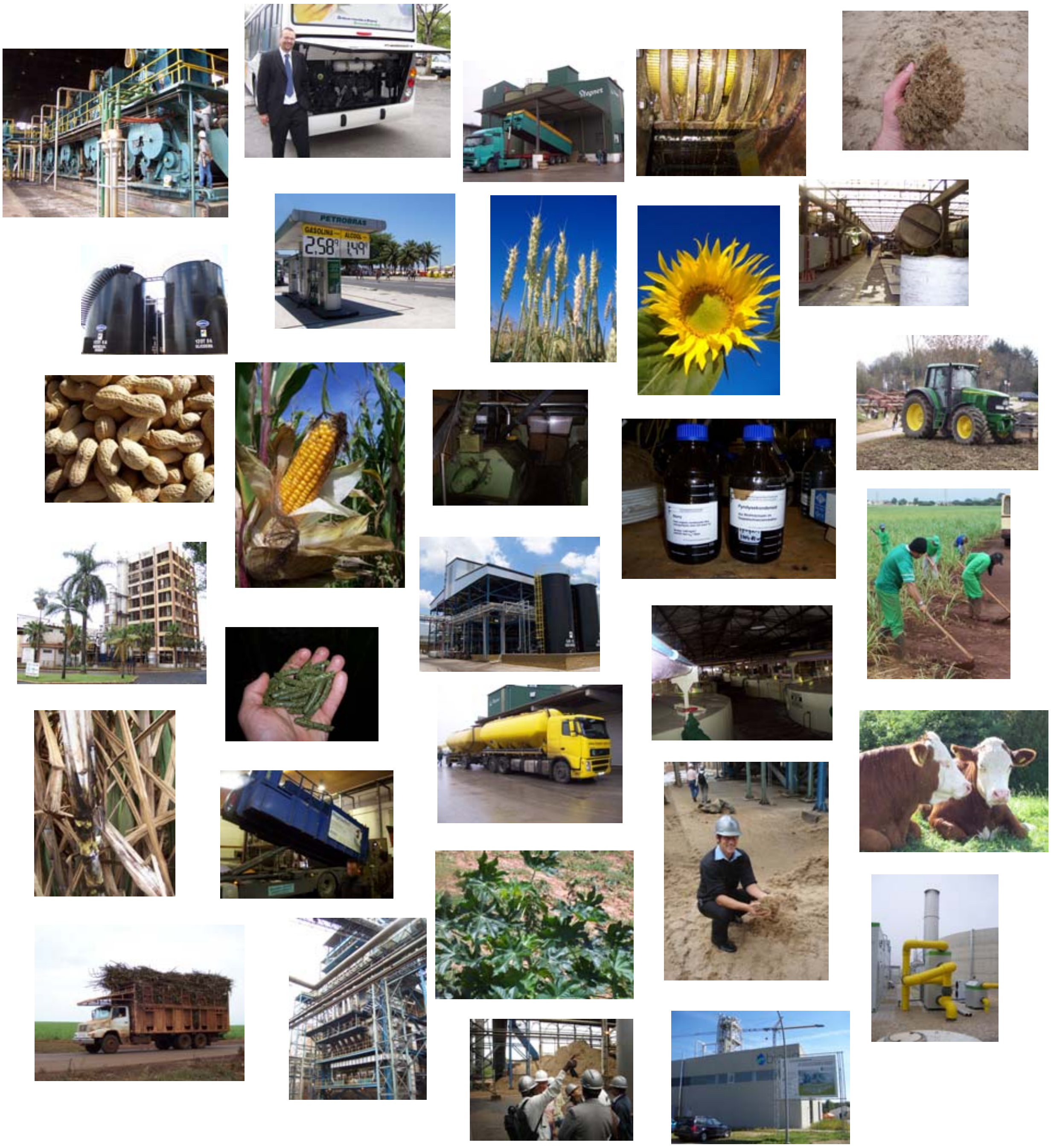
Biofuel Technology Handbook



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Dominik Rutz & Rainer Janssen 2008

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Sylvensteinstr. 2
81369 München
Germany
www.wip-munich.de
Dominik.Rutz@wip-munich.de

***Autors*:**
Dipl.-Ing. Dominik Rutz M.Sc.
Dr. Rainer Janssen

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Content

1. Introduction

This comprehensive handbook is the revised version of the “BioFuel Technology Handbook” developed under the Biofuel Marketplace project, supported by the Intelligent Energy Europe Program of the European Commission.

It was created in order to promote the production and use of biofuels and to inform politicians, decision makers, biofuel traders and all other relevant stakeholders about the state-of-the-art of biofuels and related technologies. Thereby, the large variety of feedstock types and different conversion technologies are described. Explanations about the most promising biofuels provide a basis to discuss about the manifold issues of biofuels. The impartial information given in this handbook further contributes to diminish existing barriers for the broad use of biofuels.

Emphasis of this handbook is on first generation biofuels: bioethanol, biodiesel, pure plant oil[1], and biomethane. However, it includes also second generation biofuels such as BtL-fuels and bioethanol from lingo-cellulose as well as biohydrogen.

The whole life cycle of biofuels is assessed under technical, economical, ecological, and social aspects. Characteristics and applications of biofuels for transport purposes are demonstrated and evaluated. This is completed by an assessment about the most recent studies on biofuel energy balances.

GHG balances and sustainability aspects are important issues in the current discussion about biofuels. This handbook describes the current discussion about these issues and summarizes results of several studies. GHG calculation methods are presented and potential impacts of biofuel production characterized: deforestation of rainforests and wetlands, loss of biodiversity, water pollution, human health, child labor, and labor conditions.

Finally, future developments in the biofuel sector are outlined. This includes discussions on 1st versus 2nd generation biofuels, integrated refining concepts and strategies for new vehicle technologies.

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[1] Although the name „pure plant oil“ (PPO) refers to a vegetable origin, also oils from other resources, e.g. waste oil and animal fat, are defined by this term. Nevertheless, it is evident to keep in mind that all types of oil have to fulfil certain requirements to be used in transport engines. In other publications PPO is also defined as „straight vegetable oil“ (SVO).

PART A: COMMON ASPECTS OF BIOFUELS

Today, applications in the transport sector are based on **liquid fuels**. The advantage of liquid fuels is that they are easy to store. Furthermore, today's infrastructure for transport is mainly based on liquid fuels. **Gaseous fuels** are less utilized in the transport sector. Even less applications exist for **solid fuels**. They were only used in the past e.g. for trains.

However, today transport fuels are classified into two basically different categories: **fossil fuels** which are mainly based on crude oil and natural gas, and **biofuels** made from renewable resources.

Biofuels have some common characteristics although processes for biofuels can be very different. These common aspects are jointly described in three chapters of Part A of this handbook: potential of biomass, biofuel policies and biofuel life cycles.

The use of biofuels largely depends on the **potential** of available feedstock sources. The overall biofuel potential which largely depends on climate, land availability and the productivity of dedicated energy crops is discussed in chapter 2.

Biofuel policies on regional, national, European and global level largely influence the success of biofuel market penetration. In the EU several targets have been introduced to promote biofuels. A summary of these policies is given in chapter 3.

Finally, the basic **life cycle** of biofuels is described in chapter 4: feedstock production, biofuel production, biofuel transport and biofuel use. This includes general discussions about energy balances, emissions, sustainability, economy and the use of co-products.

2. Biomass Potential

The continuous growth of plants on our planet exceeds men's primary energy requirements many times. Of course, only a part of the overall growing biomass can actually be used for energy. However, there remains a large amount of biomass that is very suitable for exploitation. Biomass resources include feedstock from agriculture and forestry and their related industries as well as waste material from other industries and households.

According to the European Environment Agency (EEA), the use of biomass for clean energy generation in the European Union could be significantly increased in the next decades without harming biodiversity, soil and water resources. The potential biomass available in Europe seems to be sufficient to support the ambitious renewable energy targets in an environmentally responsible way. Extracted from agriculture, forestry and organic waste, biomass can provide heat, power and transport fuels in an environmentally friendly way. Consequently, its use can both help reduce greenhouse emissions and achieve the European renewable energy targets (EC DG ENV 2006).

Obviously, the production of biofuels from biomass competes with other applications and utilizations which are not part of the energy sector. Recent concerns arise that biofuel production **competes with food production**. However, in Europe the production of many agricultural products is more than saturated. In order to guarantee profitable market prices, production limits were introduced and high premiums are paid for agricultural products and set-aside land. Therefore the production of biofuels does not compete with food production at the moment. But once the demand for biomass increases, the production of biofuels will not only compete with the food sector, but also with **chemical industries** and **regenerative raw materials**. Nevertheless, profitable synergies between the utilization of different intermediate products and co-products are detected and first applications of so-called integrated refining concepts are already implemented (chapter 11).

In order to increase the biomass supply, the European Commission (EC 2006, p. 16) highlights three main challenges concerning biomass resources in its Vision Report:

- **Supply the industry with secure raw material**. Efficient land use by the use of whole-crop solutions and by exploiting both fertile and marginal land. Ensure that both primary production and residues are evaluated for their energy potential. Sustainability in biomass production- handling techniques.
- **Improve the acceptability of the biomass sector** by strengthening the communication channels among the relevant stakeholders, especially the farming and forestry sectors with the respective fuel and energy sectors.
- **Balance domestic biomass production** against international biomass trade.

The productivity of agriculture in Europe has risen constantly for decades, a trend which will continue in the future. But, in order to further extend the production of biofuels, much larger areas must be cultivated with energy crops in future. On the other hand, more biomass will be available through **increased agricultural productivity** and **progress in plant breeding**. New agricultural methods of cultivation and harvesting such as mixed crop cultivation and double crops promise an increasing productivity. These methods are also contributing to aspects of nature and environmental conservation. In addition, new energy crops which are not yet cultivated will be developed. Varieties of trees and bushes, which have been adapted to local surroundings, could be planted on waste land (e.g. Jatropha in India and Africa) and grazing land that makes up approximately one quarter of the earth's total land surface. A high potential can also be expected from plant residues. This includes waste wood from forestry and landscape conservation, straw and also biological wastes.

However, extended biomass production may create **adverse environmental pressures**, mainly on biodiversity, soil and water resources. It is therefore of major importance to guarantee sustainable production of biomass. The quantity of biomass that can be used without creating such additional pressures has to be carefully assessed (EC DG ENV 2006).

The European Environment Agency has recently assessed the **quantity of the potential European "environmentally-compatible biomass"** and shows that the potential of environmentally compatible biomass for producing energy could increase from the predicted 190 Mtoe in 2010 to about 295 Mtoe in 2030 (EEA 2006, p. 52). This means that there is sufficient biomass in the EU to support the European renewable energy target of 2010 without harming the environment. According to the Biomass Action Plan of the EC (EC 2005) an estimated 150 Mtoe of biomass use is required, which can avoid some 210 Mt CO_2eq. The potential also allows ambitious future renewable energy targets beyond 2010 that may require around 230–250 Mtoe of primary biomass (EEA 2006, p. 52).

The EEA study takes into account the key drivers of bioenergy production (agriculture, forestry, waste, greenhouse emissions reductions) and a number of environmental constraints. The latter include:

- Maintenance of extensively cultivated agricultural areas
- Dedication of at least 30% of the agricultural land to environmentally-oriented farming
- Establishment of ecological areas in intensively cultivated agricultural lands
- Use of bioenergy crops that reduce soil erosion, nutrients input, pesticide pollution and water abstraction
- Maintenance of current protected forest areas
- Adaptation of the forest residue removal rate to local site
- Increased share of protected forest areas
- Waste minimization strategies

Considering only the potential of environmentally-compatible agricultural bioenergy and excluding the bioenergy potential from forestry and from wastes, the EEA assessed that around 47 Mtoe of bioenergy can be derived from the released agricultural land area in 2010 without creating additional environmental pressures. As shown in Figure 1 this production could increase to around 95 Mtoe in 2020 and 144 Mtoe in 2030 (EEA 2006 p. 26). The tripling of the potential is due to:

- a combination of a steep increase in the available land potential - triggered by the liberalization of the agricultural markets and productivity increases,
- rising energy and CO_2 permit prices and
- a general energy yield increase per hectare, especially for innovative bioenergy crops.

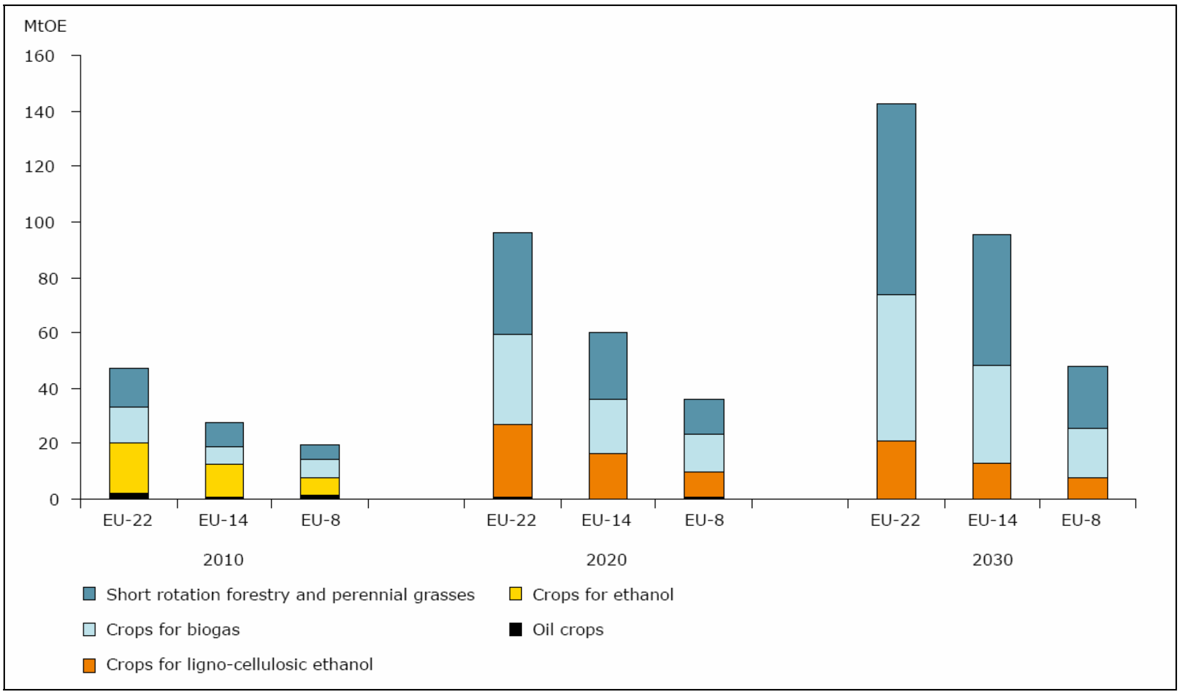

Figure 1: Environmentally-compatible agricultural bioenergy potential (Source: EEA 2006)[2]

Whereas the EEA study considers the biomass potential for solid, gaseous and liquid biofuels at the same time, the Vision Report (EC 2006a) only shows the needed biomass

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[2] No data available for Cyprus, Luxembourg and Malta. 'Oil crops' comprise rapeseed and sunflower. 'Crops for ethanol' include the potential of grains from maize, wheat, barley/triticale. 'Crops for lignocellulosic ethanol' cover the energy value of the whole plant (corn and straw) for wheat and barley/triticale. 'Crops for biogas' are maize (whole plant), double cropping systems, switch grass and the grass cuttings from permanent grassland. 'Short rotation forest and perennial grasses' include poplar, willow, miscanthus, reed canary grass, giant reed and sweet sorghum, which may often be used in whole-plant conversion systems like gasification, or biomass-to-liquid processes.

for fuel production. Thus, in order to achieve the 2010 RES 12% target, 18 Mtoe biomass will be needed in 2010 for biofuel production.

Apart from the EEA study and the Vision Report, many other studies exist on the potential of biofuel production in several countries and regions of Europe. For instance, KAVALOV (2004, p. 22) assessed the "Biofuels Potentials in the EU" by using different scenarios. He concluded that meeting the 5.75% transport biofuel target in 2010 will require significant changes in the agricultural production patterns in the EU. He also mentioned that implementing such changes might be quite challenging in practice if techno-economic concerns and agriculture policy objectives are considered.

However, since the European biofuel potential depends on many factors, such as for instance biofuel policies, crude oil prices, food supply, technical improvements, democracy, consumer behavior and trade issues, it is difficult to predict the real biofuel potential for the future.

3. Biofuel Policies

3.1. Biofuel Policy in the EU

In the European Union (EU) several targets have been defined in order to promote biofuels. These policies are formulated in official papers of the European Commission and will be subsequently shortly summarized.

In the "**Biomass Action Plan**" (EC 2005) of the European Commission various actions are described which will encourage the use of biomass for renewable energy production. Regarding biofuels, the EC has formulated three aims in the paper "**An EU Strategy for Biofuels**" (EC 2006b, p.4):

- to further **promote biofuels** in the EU and developing countries, ensure that their production and use is globally positive for the environment and that they contribute to the objectives of the Lisbon Strategy taking into account competitiveness considerations,
- to **prepare for the large-scale use of biofuels** by improving their cost-competitiveness through the optimized cultivation of dedicated feedstocks, research into "second generation" biofuels, and support for market penetration by scaling up demonstration projects and removing non-technical barriers and
- to **explore the opportunities for developing countries** – including those affected by the reform of the EU sugar regime – for the production of biofuel feedstocks and biofuels, and to set out the role the EU could play in supporting the development of sustainable biofuel production.

In this paper seven policy axes are described. They include measures, which the Commission will use in order to promote the production and utilization of biofuels. These policy axes are:

- Stimulating demand for biofuels
- Capturing environmental benefits
- Developing the production and distribution of biofuels
- Expanding feedstock supplies
- Enhancing trade opportunities
- Supporting developing countries
- Supporting research and development

The so-called Vision Report "**Biofuels in the European Union - A Vision for 2030 and beyond**"[3] (EC 2006a) describes a vision for biofuels in Europe:

> *By 2030, the European Union covers as much as one quarter of its road transport fuel needs by clean and CO_2-efficient biofuels. A substantial part is provided by a competitive European industry. This significantly decreases the EU fossil fuel import dependence. Biofuels are produced using sustainable and innovative technologies; these create opportunities for biomass providers, biofuel producers and the automotive industry.*

The Vision Report was drafted by the Biofuels Research Advisory Council (BIOFRAC), an expert group of high level experts set up by the EC DG Research. The report is „is based on the members' past experience, current practice and future expectations. This vision paper did not mean to carve in stone a roadmap, or to elicit the setting of a target. Rather, it lays out the challenges ahead and suggests what it would take to meet them. Within this ambit, the vision report lays the foundations for a Strategic Research Agenda. It also recommends the creation of a European Technology Platform for Biofuels that will elaborate and implement this research agenda." (EC 2006a p.1)

Two of the main energy policy targets of the EU are to increase – by 2010 – the share of Renewable Energy Sources (RES) in gross inland consumption to 12% and the share of biofuels in the market to 5.75% by energy content. For the transport sector in particular, the EU is supporting biofuels with the objectives of reducing greenhouse gas emissions, sustaining European competitiveness and diversifying fuel supply sources by developing long-term replacements for fossil fuels.

Recent assessments have concluded that the 2010 targets are unlikely to be achieved, and further efforts are needed. In 2003, total biomass use for energy purposes was 69 Mtoe. For the biomass sector in particular, to achieve the 2010 RES 12% target, 74 Mtoe more are needed by 2010, with the split between sectors as follows: electricity 32 Mtoe, heat 24 Mtoe, and biofuels 18 Mtoe (see chapter 2). Total biomass use for energy would therefore be 130 Mtoe in 2010. This additional biomass production can only be achieved in the short term with targeted measures and actions, and a better co-ordination of EU policies.

The Commission has therefore taken an ambitious and coordinated approach to promote the use of biomass and biofuels. The approach includes the above mentioned Biomass Action Plan and an EU Strategy for Biofuels. In the Commission's judgment, the measures in the action plan could lead to an increase in biomass use to about 150 Mtoe in 2010 or soon after.

In order to support achieving these targets, the EC has passed various legislative actions. The EU's Biofuel Directive **2003/30/EC** "**Promotion of the use of biofuels or other renewable fuels for transport**" was agreed and adopted in 2003. The Directive promotes the use of biofuels and (1) introduced a voluntary biofuel target of 2% by 2005 and 5.75%

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[3] Which is subsequently called "**Vision Report**"

by 2010, (2) obliged member states to issue annual reports, and (3) called on the Commission to conduct a review in 2006 which included a public consultation.

On 10 January 2007 the European Commission made proposals for a new Energy Policy for Europe. These included a renewable energy roadmap proposing a binding 10% target for the share of biofuels in petrol and diesel in each Member State in 2020, to be accompanied by the introduction of a sustainability scheme for biofuels.

The European Parliament is now scrutinising the whole energy package and is about to vote on proposed amendments. Once done, the European Commission will draft legislation for the new Biofuels Directive, which will be published in January 2008. This will then need to be agreed between the Parliament, national Ministers and the Commission.

Further, the promotion of biofuels is largely associated with the taxation of biofuels. Issues about taxation of biofuels are included in directive **2003/96/EC** "**Restructing the framework for the taxation of energy products and electricity**". This directive permits the EU member states to exempt all biofuels from mineral oil duties. This ruling applies both to pure fuels and pro rata to the mixing of biogenic components with fossil fuels.

Since only high quality biofuels are desirable, biofuels are crucially linked with directive 98/70/EC, which is updated by directive **2003/17/EC** "**Quality of petrol and diesel fuels**". Currently, this directive allows fuel distributers to blend petrol and diesel with 5% bioethanol and biodiesel respectively. These blending possibilities are discussed in more detail in chapter 3.3 on standardization and accordingly in the sections about standardization of each biofuels in Part B of the handbook.

3.2. Market Barriers of Biofuels

The promotion of renewable energies is faced by various market barriers. These barriers limit the development of renewables unless special policy measures are enacted, unless no other fossil resources are available or unless the price advantage of renewables highly exceeds that of fossil fuels. In order to promote a fast introduction of biofuels, barriers have to be detected and solutions have to be found.

The Union of Concerned Scientists has formulated four main categories of barriers to the use of renewable energy technologies (RET) in general (UCS 1999):

- **Commercialization barriers** faced by new technologies competing with mature technologies
- **Price distortions** from existing subsidies and unequal tax burdens between renewables and other energy sources
- **Failure of the market to value the public benefits of renewables**
- **Other market barriers** such as inadequate information, lack of access to capital, high transaction costs

These barriers to RETs also apply to biofuels. In order to find solutions for overcoming these barriers, they have to be described in more detail. The main market constraints specific to biofuels can be summarized by nine main market barriers:

1. **Economical barriers**: The production of biofuels is still expensive, markets are immature and beneficial externalities are not accounted.
2. **Technical barriers**: The fuel quality is not yet constant and conversion technologies for certain biofuels are still immature (e.g. for synthetic biofuels).
3. **Trade barriers**: For some biofuels still no quality standards exist. Also no common European sustainability standard exists. Barriers exist for international trade of bioethanol due to denaturation obligations.
4. **Infrastructural barriers**: Depending on the type of biofuel, new or modified infrastructures are needed. Especially the use of biohydrogen and biomethane need profound infrastructural changes.
5. **Causality dilemma**: Before owners of filling stations sell biofuels, they claim that car manufacturers have to sell refitted cars first. The automotive industry claims that the infrastructure has to be developed first. This dilemma is a visible barrier for the introduction of FFV and the promotion of E85 in some European countries (Dilemma of the chicken and the egg: which came first, the chicken or the egg?).
6. **Ethical barriers**: Biomass feedstock sources may compete with food supply.
7. **Knowledge barriers**: The general public, but also decision makers and politicians are lacking knowledge on biofuels.
8. **Political barriers**: Lobbying groups influence politicians to create or conserve an unfavorable political framework for biofuels.
9. **Conflict of interest**: Conflict between ‘promoters’ of first and second generation biofuels may weaken the overall development of biofuels.

Above mentioned barriers will also largely depend on the type of biofuel and the specific framework conditions. In the following years significant technological promotional and political challenges are thus to be faced in order to establish biofuel as a main pillar of a sustainable worldwide transportation system.

3.3. Biofuel Standardization

With the advancement and expansion of the European Union, generally the role of national standards has been increasingly taken over by international standards, primarily European standards. These European standards are developed by the European Committee for Standardization (CEN).

As the market share of biofuels increased considerably in the last few years, the need for specifications and standards of these biofuels has been highlighted by stakeholders and authorities. Consequently large efforts have been made on biofuel standardization in the European Union: since 2003 a common European standard for biodiesel exists. Also the standardization for bioethanol proceeded. The Technical Committee number 19 of CEN is working very hard to issue the common European standard for bioethanol. A first draft is already publicly available.

The development and implementation of standardizations diminishes trade barriers, promotes safety, increases compatibility of products, systems and services, and promotes common technical understanding. All standards help build the 'soft infrastructure' of modern, innovative economies. They provide certainty, references, and benchmarks for designers, engineers and service providers. They give 'an optimum degree of order' (CEN 2006). Thus standards are of vital importance for producers, suppliers and users of biofuels. A standard is a prerequisite for the market introduction and commercialization of new fuels.

European standards for automotive fuels and a fuel quality monitoring system are linked with Directive **98/70/EC**, which is updated by Directive **2003/17/EC** “Quality of petrol and diesel fuels”. Standards for biofuels depend on the European directive **2003/30/EC** “Promotion of the use of biofuels or other renewable fuels for transport”. The promotion of biofuels is largely associated with the taxation of biofuels. Issues about taxation of biofuels are included in directive **2003/66/EC** “Restructing the framework for the taxation of energy products and electricity”.

Detailed descriptions about standards of each biofuel are given in chapter 5.5 for bioethanol, in chapter 6.5.1 for PPO, in chapter 6.5.2 for biodiesel and in chapter 8.5 for biomethane. A short overview and recommendations about biofuel standardization in the European Union is also given by RUTZ & JANSSEN (2006).

3.4. International Trade of Biofuels

International trade of biofuels is small compared to international trade of fossil fuels. Biofuels are traded mainly between neighboring regions and countries. But since biofuel production is growing continuously, new trading relationships will be established in future. Thus, also trade over long distances will increase.

The trade of any good beyond the national boarders is affected by several national, EU wide and international policies. Also the international trade of biofuels has its own policies and regulations. In order to better understand these policies some explanations and definitions are given.

The origin of a good is its “economic” nationality in international trade. There are two kinds of origin, non-preferential and preferential. **Non-preferential origin** confers an “economic” nationality on goods. It is used for determining the origin of products subject to all kinds of commercial policy measures (such as anti-dumping measures, quantitative restrictions) or tariff quotas. It is also used for statistical purposes. Other provisions, such as those related to public tenders or origin marking, are also linked with the non-preferential origin of the products. In addition, the EU’s export refunds in the framework of the Common Agricultural Policy (CAP) are often based on non-preferential origin.

Preferential origin confers certain benefits on goods traded between particular countries, namely entry at a reduced or zero rate of duty.[4]

In either case, an important element in determining the origin of goods is their tariff classification. Goods in trade are identified in the Community by a code number in the **Combined Nomenclature** (CN) and before trying to determine their origin it is essential that their CN code has been identified.[5]

The CN determines which rate of customs duty applies and how the goods are treated for statistical purposes. The CN is a method for designating goods and merchandise which was established to meet, at one and the same time, the requirements both of the Common Customs Tariff and of the external trade statistics of the Community. The CN is also used in intra-Community trade statistics.[6]

For biofuels there is no specific customs classification at the moment. Thus the exact amount of imported ethanol, oilseeds and vegetable oil ultimately used in the transport sector cannot be quantified exactly. The European Commission will assess the advantages and disadvantages as well as the legal implications, of putting forward a proposal for separate nomenclature codes for biofuels (EC 2006b, p. 14).

Given the rising demand for biofuels, the Commission is seeking the appropriate development of both EU domestic production and enhanced import opportunities for biofuels and their feedstocks and to develop their economic viability (EC 2006b, p. 14).

One of the main international institutions involved in policies on trade of biofuels is **Task 40**, a task under the **IEA Bio-energy Agreement**[7]. Its aim is to contribute to the development of sustainable biomass markets on short and on long term and on different scale levels (from regional to global). The future vision of this task on global biomass trade is that it develops to a real “commodity market” which will secure supply and demand in a sustainable way. Sustainability is a key factor for long-term security.

Another important stakeholder in the international trade of biofuels is the **World Trade Organization** (**WTO**) which deals with the rules of trade between nations at a global or near-global level. The WTO is an international body whose purpose is to promote free trade by persuading countries to abolish import tariffs and other barriers. It is the only international agency overseeing the rules of international trade. It polices free trade agreements, settles trade disputes between governments and organises trade negotiations. WTO decisions are absolute and every member must abide by its rulings. When the US and the European Union are in dispute over biofuel trade, it is the WTO which acts as judge and jury. WTO members are empowered by the organisation to enforce its decisions by imposing trade sanctions against countries that have breached the rules.

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[4] Source: http://ec.europa.eu/taxation_customs/customs/customs_duties/rules_origin/index_en.htm [26.06.06]

[5] Source: http://ec.europa.eu/taxation_customs/customs/customs_duties/rules_origin/index_en.htm [26.06.06]

[6] Source: http://ec.europa.eu/taxation_customs/customs/customs_duties/tariff_aspects/combined_nomenclature/index_en.htm [26.06.06]

[7] www.bioenergytrade.org

3.4.1 Trade of Biodiesel and Related Products

At present there is no significant international trade in biodiesel, its feedstock and related products. International trade between EU member states and other countries in biodiesel itself is small due to the fact that the EU is by far the world's largest producer (EC 2006b, p. 25). Thereby, Germany is the world's largest producer of biodiesel made from rapeseed. This is consumed mainly domestically and within the EU (WWI 2006, p. 120).

Currently, trade in palm oil increases. For example Malaysia and Indonesia plan to export the fuel to the EU, and Malaysia is also planning exports to Colombia, India, South Korea, and Turkey. However, this fact has also raised substantial concerns about forest loss and environmental degradation in producer countries.

Besides the trade with biofuels, also trade with feedstock exists. Nevertheless, it has to be carefully assessed if long-distance trade is reasonable due to low energy contents of feedstock materials. Global trade in whole oilseeds, particularly soybeans, is relatively unrestricted by tariffs and other border measures.

Higher import tariffs are put on processed products like oilseed meals and particularly vegetable oils (WWI 2006, p. 123). In contrast, plant oils for biodiesel face low or no tariffs in the European Union. Imports of biodiesel into the EU are subject to an ad valorem duty of 6.5% (EC 2006b, p. 25).

These conditions apply only to the import of biodiesel (FAME) itself, but not to the import of source products like tallow or used cooking oil. Rules and tariffs governing pure plant oil (PPO) are separate and specific because of the potential for these oils to enter into food production (WWI 2006, p. 123).

3.4.2 Trade of Bioethanol

Today, a much larger portion of bioethanol is traded for purposes other than transport applications. Most ethanol is traded for alcoholic beverages, for solvent purposes, and for other industrial applications. Nevertheless, fuel ethanol will be traded increasingly as crude oil prices rise and as governments adopt new policies promoting biofuels (WWI 2006, p. 118).

Currently, Brazil is the main exporter for ethanol. The export of Brazilian sugar cane ethanol for all uses accounts approximately half of total global trade of liquid renewable biofuels. Several other producer countries, including Pakistan, the United States, South Africa, Ukraine, and countries in Central America and the Caribbean, also contribute to ethanol trade, though their relative exports compared to Brazil are quite small. Also small amounts of ethanol are shipped from Africa and Asia to Europe. This is mainly due to preferential access to the European market. Pakistan has historically been the largest exporter of ethanol to the European Union. Most of the ethanol traded today is pre-processed ethanol, manufactured in the country where the feedstock is grown, as it has generally not been economical to transport feedstock long distances for ethanol production. As sugar is currently the cheapest feedstock, many low-cost producers of sugar cane in

Africa, Latin America, and Asia plan to increase their share in global ethanol trade (WWI 2006, p.119).

International trade depends on policies, import restrictions and import duties[8]. In order to facilitate trade between the EU and other countries, the EU exempted certain countries from import duty fees for ethanol. The EU's preferential trade basically comes under two regimes: the Generalized System of Preferences (GSP) (including, among others, the Everything But Arms (EBA) initiative) and the Cotonou Agreement.

Within the Generalized System of Preferences, the former Council Regulation (Regulation (EC) No 2501/2001) classified denatured and undenatured alcohol under code 2207 as a sensitive product. This regulation was in force until 31 December 2005. According to article 7(4) of the regulation, imports of this alcohol from all GSP beneficiary countries qualified for a 15% reduction on the MFN (Most Favored Nation) duty.

The new GSP Regulation (Council Regulation (EC) No 980/2005 of 27 July 2005), which applies from 1 January 2006 to 31 December 2008, no longer provides for any tariff reduction for either denatured or undenatured alcohol under code 2207 (still classified as a sensitive product). This regulation puts in place a special incentive arrangement for sustainable development and good governance (the new GSP+ incentive scheme), which applies on a permanent basis from 1 January 2006 to 31 December 2008. This new incentive arrangement grants unlimited and duty-free access (suspension of Common Customs Tariff duties) to denatured or undenatured alcohol under code 2207. It includes all the countries that already benefited from the previous drugs scheme, with the exception of Pakistan, which is subject to the full MFN duty. The new incentive arrangement now also includes Georgia, Sri Lanka, Mongolia and Moldova, which have not so far exported bioethanol to the EU. Moreover, a special arrangement for least developed countries (the EBA initiative) under the new GSP Regulation offers unlimited duty-free access to denatured or undenatured alcohol under code 2207.

Under the Cotonou Agreement, ACP countries qualify for duty-free access for denatured and undenatured alcohol under code 2207 with the sole exception of South Africa. Under Regulation (EC) 2501/2001, South Africa enjoyed a 15% reduction in customs duties. From 1 January 2006 it has to pay full MFN duty.

To a large extend, future ethanol trade may be driven by countries that are not necessarily interested in developing domestic biofuel production, but in reducing oil dependency and in meeting carbon emissions targets of the Kyoto Protocol by substituting crude oil with biofuels (e.g. Sweden).

Determining imported ethanol for transport purposes is difficult as currently no specific CN for transport ethanol exists. However, ethanol is traded under the common code 2207, which covers both denatured (CN 2207 20) and undenatured alcohol (CN 2207 10), but which is not specific to transport purposes (EC 2006b, p.25). Both denatured and undenatured alcohol can be used for biofuel production. Due to the lack of a specific CN, it is not possible to determine how much ethanol imported is used as fuel. Only fuel ethanol that is pre-blended with gasoline is classified separately under heading 3824.

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[8] A detailed description on trade in biofuels can be found in Annex 5 of „An EU Strategy for Biofuels" (EC 2006b).

Ethanol is taxed at varying rates depending on its intended use and depending if it is denatured or not. An import duty of €19.2/hl is levied on undenatured alcohol, while an import duty of €10.2/hl applies to denatured alcohol. For pre-blended ethanol under CN 3824 a normal customs duty of around 6 percent is charged.

As the un-denaturated ethanol is heavily taxed, denaturation may be an option to reduce costs for producers and traders. Denaturation of ethanol is made by blending it with additives to render it unfit for human consumption. These additives, called denaturants, are generally either toxic (such as methanol) or have unpleasant tastes or odors (such as benzoate). Typical additives are methanol, isopropanol, methyl ethyl ketone, methyl isobutyl ketone, denatonium, and even aviation gasoline. With respect to international bioethanol trade, EU import regulations for denatured alcohol today often constitute a trade barrier to imports of fuel ethanol.

In order to stimulate international trade, IEA Bioenergy Task 40 gives recommendations about long-term and short-term developments of trade with biofuels. Thereby, on longer-term import barriers for biomass and biofuels should be lowered or abolished, but in short-term, local industries should also have the chance to develop innovative and improved processes for biomass and biofuels production. There arises also the need for sustainability criteria for biomass in order to prevent unsustainable production of biomass. Both, importing and exporting countries should develop a minimum set of sustainability criteria on the short-term and should thrive for the development of an international sustainability framework for biomass on the longer term.

4. Biofuel Life Cycle

Biofuels can have positive or negative impacts on various issues. In order to assess benefits from the utilization of biofuels compared to fossil fuels, life cycles have to be determined. Life cycles largely depend on type of feedstock, choice of location, production of by-products, process technology and on how the fuel is used. Within this variety, the basic components of life cycles in biofuel processing are always the same. Therefore some aspects of the general life cycle of biofuels are presented, whereas results of in-depth life cycle analyses (LCA) are discussed in the biofuel chapters (Part B).

As it is shown in Figure 2 the life cycle of biofuels has several **vertical process steps**: biomass production and transport, biofuel processing, biofuel distribution and biofuel consumption. In addition, the industrial process steps of creating fertilizers, seeds and pesticides for the production of biomass must be included.

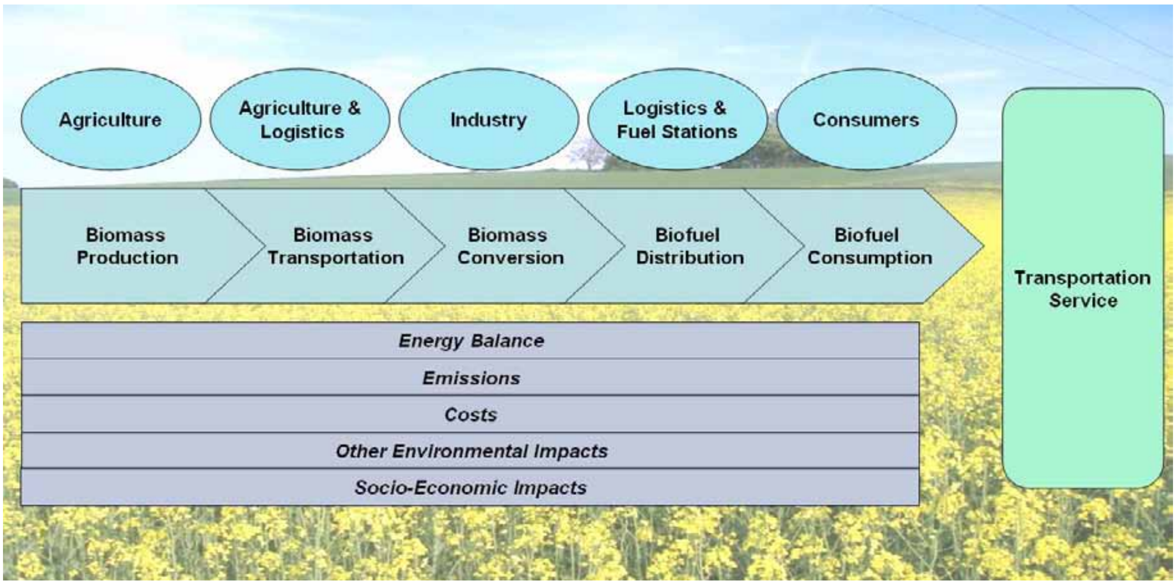

Figure 2: Actors, life cycle and horizontal attributes of biofuel production

In each process step of biofuel production **different actors** are involved. Biomass is produced and transported by farmers. It is sometimes also transported by logistic services or by the biomass conversion industry itself. The conversion of biomass to biofuels can be either made by farmers or by industry, which is more common. Finally, biofuels are distributed by logistic services or fuel stations and consumed by private or industrial consumers.

The life cycle is also influenced by **horizontal attributes** which have to be carefully assessed in order to allow comparisons among different biofuels: energy balance, emissions, greenhouse gas emissions, other environmental impacts, biofuel costs, and socio-economic impacts.

For example, total **costs of biofuels** at the filling station include costs for biomass production, biomass transportation, biomass conversion and distribution. Also taxes and profit margins of distributors have to be considered. External costs, like costs for environmental damages, are also important, but they are often neglected.

Environmental criteria for the evaluation of biofuels are mainly energy and greenhouse gas balances. They have to be carefully assessed over the whole life cycle to receive credible results. A general overview of the energy flow and the emissions are shown for all process steps in Figure 3.

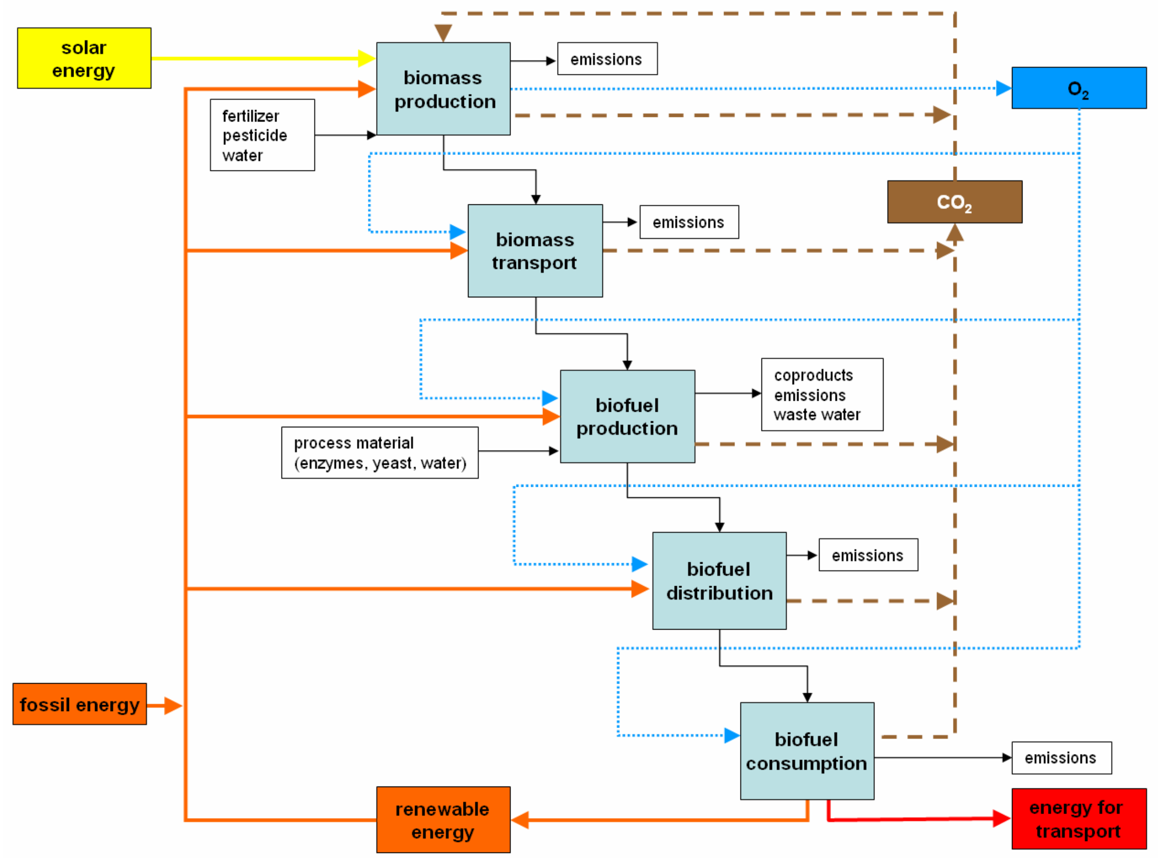

Figure 3: Overview of energy flow and emissions for all process steps in the life cycle of biofuels.

Finally, biofuels have the potential to create **socio-economic benefits**. During the life cycle of biofuels, new jobs can be created and agricultural income can be increased. On the other side, labor standards have to be respected and e.g. child labor and slavery has to be avoided.

4.1. Energy Balance Methodologies

The energy ratios of biofuels depend on the **energy input** of the whole life cycle and the **energy output** for the final fuel. Typically for all biofuels, different steps of the life cycle are characterized by a huge variety which depends on feedstock, agricultural practices, regional feedstock productivity, and process technology. Therefore, the validity of data about biofuel energy balances has to be carefully checked. For example, biofuels from tropical plants have more-favorable energy ratios than biofuels from temperate regions, as tropical crops grow under more favorable climatic conditions. Furthermore, they are often cultivated manually with fewer fossil energy requirements and fewer inputs of fertilizer and pesticides. In contrast, biofuels from temperate regions usually require more energy input. Nevertheless, in recent decades their energy balances have become significantly more efficient.

There are two primary measures for evaluating the energy performance of biofuel production pathways, the energy balance and the energy efficiency (WWI 2006, p. 134).

- The **energy balance** is the ratio of energy contained in the final biofuel to the energy used by human efforts to produce it. Typically, only fossil fuel inputs are counted in this equation, while biomass inputs, including the biomass feedstock itself, are not counted. A more accurate term for this concept is fossil energy balance, and it is one measure of a biofuel's ability to slow the pace of climate change. The ratio number of the energy balance can exceed one.
- The **energy efficiency** is the ratio of energy in the biofuel to the amount of energy input, counting all fossil and biomass inputs as well as other renewable energy inputs. This ratio adds an indication of how much biomass energy is lost in the process of converting it to a liquid fuel, and helps to measure more- and less-efficient conversions of biomass to biofuel. The ratio number of the energy efficiency can never exceed one, because some of the energy contained in the feedstock is lost during processing.

The energy balance is a useful metric for biofuel promotion efforts which aim to reduce the use of fossil fuels. For social and ecological reasons it is desirable to reduce fossil energy input in biofuel production. Therefore subsequently mainly the energy balance is quoted.

Fossil transport fuels have energy balances between 0.8 and 0.9 (WWI 2006, p. 137). Biofuels significantly contribute to the transportation fuel needs only when these numbers are exceeded. The energy balances of ethanol from wheat, sugar beets and corn are between 1 and 2.5. Ethanol from sugar cane is reported to have an energy balance of approximately 8. The energy balances of lipid derived fuels are between 2.5 and 9. These numbers show that the energy balance of all biofuels is better than that of fossil fuels.

A current problem of evaluating energy balances is the definition of system boundaries. There are debates on whether to include items like the energy required to feed the people processing the feedstock and even the amount of energy a tractor represents. In addition, there is no consensus on what sort of value to give the co-products. In some studies co-products are left on the field to protect the soil from erosion and to add organic matter, while in other studies co-products are used to power the ethanol plant. They do not address the resulting soil erosion which would require energy in the form of fertilizer to replace. In order to get a complete picture about the energy balance of biofuels, at least following variables have to be considered:

- Type of feedstock and agricultural production process
- Geographical and climate conditions of the producing region
- Utilized technology for fuel processing
- Production capacity and scale
- Sources of process energy
- Utilization and evaluation of co-products

Examples for energy balances and energy numbers of different biofuels are demonstrated in chapter 5.6 for bioethanol and in chapter 6.6 for lipid biofuels.

4.2. Biofuel Emissions

4.2.1 Greenhouse Gas Emissions

One of the major drivers for biofuel developments worldwide is the concern about **global climate change** which is primarily caused by burning fossil fuels. There is substantial scientific evidence that accelerating global warming is a cause of greenhouse gas (GHG) emissions. One of the main greenhouse gases is carbon dioxide (CO_2). But also nitrous oxide (N_2O), methane (CH_4) and several other compounds are greenhouse gases which are even more severe to global warming than CO_2. As their relative potentials for causing global warming differ so much, it has become practice to weight their emissions according to their **global warming potentials** (GWP) over 100 years (Table 1) and then aggregate them to CO_2 equivalents. GWP is an index for estimating relative global warming contribution due to atmospheric emission of one kg of a particular greenhouse gas compared to emission of one kg of carbon dioxide. GWPs calculated for different time horizons show the effects of atmospheric lifetimes of the different gases. For the assessment of GHG impacts of biofuels mainly CO_2, N_2O and CH_4 are relevant.

Table 1: Global warming potentials (GWP) of 100 years for several greenhouse gases, relative to carbon dioxide (IPCC 2001)

Carbon Dioxide (CO_2)	1
Methane (CH_4)	23
Nitrous Oxide (N_2O)	296
HFC-23	12 000
HFC-125	3 400
HFC-134a	1 300
HFC-143a	4 300
HFC-152a	120
HFC-227ea	3 500
HFC-236fa	9 400
Perfluoromethane (CF_4)	5 700
Perfluoroethane (C_2F_6)	11 900
Sulfur Hexafluoride (SF_6)	22 200

As biofuels are produced from biomass, the combustion of these biofuels principally is considered to be CO_2 neutral (this applies only for **direct emissions** from biofuel combustion). During the combustion process about the same amount of CO_2 is being set free, that has been bound from the atmosphere during photosynthesis and growth of the plants. Therefore the carbon cycle is closed. The major part of combustion engine exhaust streams consists of the components nitrogen, carbon dioxide and water which are non-toxic. However, also greenhouse gases that are directly toxic to human health are emitted. For example the principal transport emissions from the combustion of both fossil and renewable fuels are particulate matter (PM), volatile organic compounds (VOCs) (including hydrocarbons HC), nitrogen oxides (NO_x), carbon monoxide (CO) and a variety of unregulated toxic air pollutants. Currently, these emissions (NO_x, HC, CO, PM) are regulated for most vehicle types by European emission standards, which are sets of requirements defining the acceptable limits for exhaust emissions of new vehicles sold in EU member states. The stages of these European emission standards are typically referred to as EURO norms as described in the next chapter. They apply for all types of fuels including biofuels.

Apart from direct GHG emissions from burning fuels (which are not accounted in the GHG balance of biofuels as they are renewable), there are significant **indirect emissions** which are associated with all stages of the biofuel life cycle. For biofuels these emissions are created during cultivation, transport, conversion process and distribution. Thereby emissions from feedstock production are largest in the biofuel life cycle (ARNOLD et al. 2005, p. 28). Nevertheless, it has to be considered, that the life cycle of fossil fuel production produces considerable amounts of emissions, too.

As inputs for the production of biofuels are usually still of fossil origin, the impact on climate of biofuels greatly depends on the fossil energy balance of biofuel production. The combustion and use of fossil sources emit CO_2 which was bound for thousands of years in the earth.

Nevertheless, for the whole assessment of how the production of biofuels influences global warming, not only the fossil energy balance is important, but also other factors have to be included. For example, fertilizing, pesticide use, means of irrigation, and treatment of the soil also play an important role in determining the climate impact of biofuels. One of the most significant factors in terms of climate impact is the use of chemical fertilizers. For their production large inputs of fossil sources usually needed. Fertilizers and in particular nitrogen (N) fertilizers, but also pesticides are manufactured using large input of natural gas. Furthermore, direct emissions from fertilizing may occur. Therefore, biofuels are stated by CRUTZEN et al. (2007) even to be more harmful to climate than beneficial, due to the N_2O emissions associated with N-fertilization. The report of CRUTZEN et al. (2007) was subject of criticism and discussions and the issue of N_2O emissions associated with N-fertilization has to be investigated in further research.

The overall critical point of how biomass production influences climate is the **type of feedstock**. It determines the energy yield per unit of land, the use of fertilizer, as well as the amount of carbon that can be sequestered in the soil. It also has to be considered what these crops are replacing. If they replace natural grasslands or forests, GHG emissions will likely increase. But if energy crops are planted on unproductive or arid land where conventional crops cannot grow, they have the potential to significantly reduce associated emissions. For example jatropha can thrive on unproductive or arid lands where conventional crops cannot grow. GHG emissions might also be reduced if fuel feedstock replaces annual crops. In this aspect, perennial energy crops are advantageous compared to annual energy crops such as corn or rapeseed. Finally the GHG balance for biofuels could be even more favorable if waste streams, like agricultural and forestry residues, are used as feedstock. Therefore, advanced technologies are necessary, which are not available on a commercial scale today. Finally, the feedstock source also determines the utilization of co-products which has substantial influence on greenhouse gas emissions. Co-products can be used for generating additional renewable energy, for example in combined heat and power plants (CHP).

In conclusion, the emissions during the full life cycle of biofuels, from changes in land use to combustion of fuels, determine their impact on the climate. In modeling this complex calculation, estimates vary widely. Methodologies and calculations of net GHG emissions are highly sensitive to assumptions about system boundaries, key parameter values and how various factors are weighted. Nevertheless, today it is found in nearly all studies that GHG emissions from first generation ethanol and biodiesel are significantly reduced, relative to fossil fuels. There exists broad agreement that the use of biofuels, made with today's technologies, can result in significant net reductions in carbon emissions (WWI 2006).

An appropriate method in determining the environmental impacts of GHG emissions is the so called Well-to-Wheel analysis (WTW). This approach can be divided into a Well-to-Tank analysis (WTT) which includes cultivation and conversion process and Tank-to-Wheel analysis (TTW) which analyses the use of biofuels itself and includes vehicle and engine performance. Currently GHG calculation tools for biofuels from different feedstocks are being developed by the institutes Imperial College London, UK, Senter Noven, The Netherlands, and ifeu Institute, Germany.

Since the GHG emissions for different biofuels largely vary, GHG emission numbers are shown in chapter 5.7.1 for bioethanol, in chapter 6.7.1 for lipid biofuels and in chapter 8.6.2 for biomethane.

4.2.2 Vehicle Emission Standards

Emissions from the combustion of biofuels and fossil fuels in vehicles are regulated by common European emission standards. These standards are sets of limits for exhaust emissions of new vehicles which are sold in EU member states, but new standards do not apply to vehicles already on the roads. The standards are defined in a series of European Union directives that envisage the reduction of exhaust emissions by the progressive introduction of increasingly stringent standards. Currently, emissions of nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), and particulate matter (PM) are regulated for most vehicle types, including cars, lorries, trains, tractors and similar machinery and barges. Seagoing ships and airplanes are excluded by these standards at the moment. The classifications for vehicle types are defined by directive 2001/116/EC[9] (amending Directive 70/156/EEC) (EC 2001).

For each vehicle type, different standards apply. The compliance is determined by running the engine at standardized test cycles. However, in order to receive real emission reductions it is crucial that the test cycles under which the emissions have to comply reflect normal driving situations. Vehicles that do not fulfill the regulations of the standardized test cycles cannot be sold in the EU. No use of specific technologies is mandated to meet the standards, though available technology is considered when setting the standards.

The standards are typically referred to as EURO I, EURO II, EURO III, EURO IV and EURO V. Sometimes these standards are characterized by numbers instead of using

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[9] http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/l_018/l_01820020121en00010115.pdf

Roman numerals. Nevertheless, the directives in which the standards are defined do not refer to them in either way.

The legal framework is defined in a series of amendments to the 1970 directive 70/220/EEC[10]. Limits of the original directive 70/220/EEC are superseded by the EURO emission limits. Subsequently, all EURO standards are briefly presented.

- **EURO I**, also referred to as Euro 1, was the emission standard for cars introduced in the EU in 1992. EURO I was replaced by Euro II in 1995. (91/441/EEC & 93/59/EEC)
- **EURO II**, also referred to as Euro 2 (or as "EC 96"), was the emission standard for cars introduced in the EU in 1995. EURO II was replaced by Euro III in 1999. (94/12/EC & 96/69/EC)
- **Euro III**, also referred to as Euro 3, is the emission standard for vehicles introduced in the EU in 1999. EURO III was replaced by Euro IV in 2005. (98/69/EC)
- **EURO IV**, also referred to as Euro 4, is applied to new road vehicles sold in the EU from 2005 or later. Though no specific technology is mandated to meet the requirements, the reductions in emissions are typically achieved through the use of either Selective Catalytic Reduction (SCR) or Exhaust Gas Recirculation (EGR) technologies. For heavy duty diesel trucks Euro IV will be succeeded by Euro V, to be introduced in 2008 and coming into force in 2009. For passenger cars, a Euro V standard is not set yet but is currently considered by the European Commission in the proposed regulation COM(2005) 683 final. (98/69/EC & 2002/80/EC)
- **EURO V**, also referred to as Euro 5, is the most recent set in the series of mandatory European emission standards. For heavy duty vehicles (lorries) the standards apply to vehicles brought on the market from October 2008. Until now, there is no Euro V standard applying for passenger cars, but a proposal is in preparation.

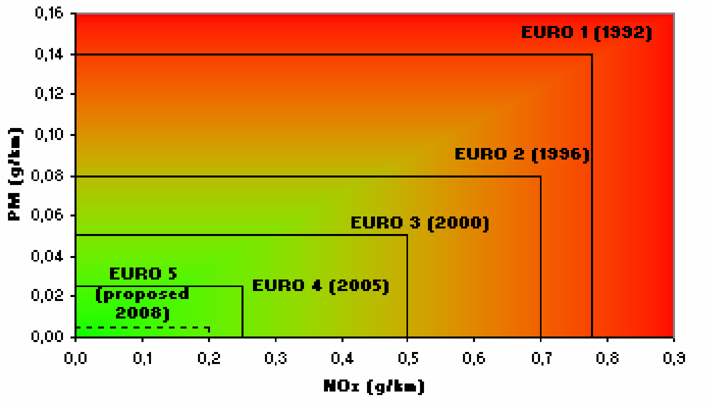

Figure 4: Simplified chart showing the progression of European emission standards (NO$_x$ and PM) for *Diesel* cars (Source: WIKIPEDIA 2006)

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[10] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31970L0220:EN:NOT

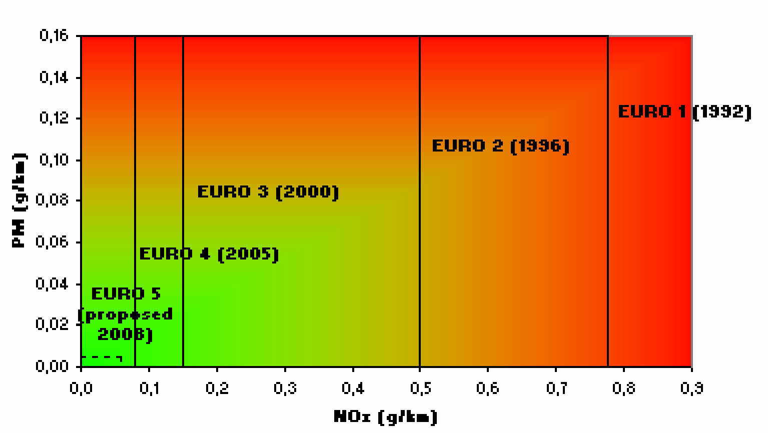

Figure 5: Simplified chart showing the progression of European emission standards for *Petrol* cars (NO_x and PM). Note that until Euro 5, there were no PM limits (Source: WIKIPEDIA 2006)

Emission standards for passenger cars (category M1)[11] are summarized in Table 3. In the EURO I stage, all emissions for petrol and diesel were the same, except for PM which was only applied to diesel. From the EURO II stage on, different emission limits for diesel and gasoline vehicles were introduced. Diesel vehicles have more stringent CO standards but are allowed higher NO_X. Generally gasoline vehicles are exempted from PM standards but in the proposal of EURO 5 limits for PM are supposed for lean-burning gasoline cars.

Table 2 shows the Emission Standards for Light Commercial Vehicles (category N1) [12].

Also for heavy trucks, lorries and busses (category N2[13] and N3[14]) emission standards exist. Whereas for passenger cars, the standards are defined in g/km, for lorries (trucks) they are defined by engine power, g/kWh. An explicit table for these vehicles is beyond the scope of this handbook.

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[11] Category M1: Vehicles designed and constructed for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.

[12] Vehicles of category N1 are designed and constructed for the carriage of goods and having a maximum mass not exceeding 3,5 tonnes.

[13] Category N2: Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes.

[14] Category N3: Vehicles designed and constructed for the carriage of goods and having a maximum mass exceeding 12 tonnes.

Table 2: EU emission standards for light commercial vehicles (category N1), g/km[15]

Class†	Tier	Date	CO	HC	HC+NOx	NOx	PM
Diesel							
N1, Class I <1305 kg	Euro 1	1994.10	2.72	-	0.97	-	0.14
	Euro 2, IDI	1998.01	1.0	-	0.70	-	0.08
	Euro 2, DI	1998.01[a]	1.0	-	0.90	-	0.10
	Euro 3	2000.01	0.64	-	0.56	0.50	0.05
	Euro 4	2005.01	0.50	-	0.30	0.25	0.025
	Euro 5‡	mid-2008	0.50	-	0.25	0.20	0.005
N1, Class II 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	0.19
	Euro 2, IDI	1998.01	1.25	-	1.0	-	0.12
	Euro 2, DI	1998.01[a]	1.25	-	1.30	-	0.14
	Euro 3	2001.01	0.80	-	0.72	0.65	0.07
	Euro 4	2006.01	0.63	-	0.39	0.33	0.04
	Euro 5‡	mid-2008	0.63	-	0.32	0.26	0.005
N1, Class III >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	0.25
	Euro 2, IDI	1998.01	1.5	-	1.20	-	0.17
	Euro 2, DI	1998.01[a]	1.5	-	1.60	-	0.20
	Euro 3	2001.01	0.95	-	0.86	0.78	0.10
	Euro 4	2006.01	0.74	-	0.46	0.39	0.06
	Euro 5‡	mid-2008	0.74	-	0.38	0.31	0.005
Petrol (Gasoline)							
N1, Class I <1305 kg	Euro 1	1994.10	2.72	-	0.97	-	-
	Euro 2	1998.01	2.2	-	0.50	-	-
	Euro 3	2000.01	2.3	0.20	-	0.15	-
	Euro 4	2005.01	1.0	0.1	-	0.08	-
	Euro 5‡	mid-2008	1.0	0.075	-	0.060	0.005[b]
N1, Class II 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	-
	Euro 2	1998.01	4.0	-	0.65	-	-
	Euro 3	2001.01	4.17	0.25	-	0.18	-
	Euro 4	2006.01	1.81	0.13	-	0.10	-
	Euro 5‡	mid-2008	1.81	0.10	-	0.075	0.005[b]
N1, Class III >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	-
	Euro 2	1998.01	5.0	-	0.80	-	-
	Euro 3	2001.01	5.22	0.29	-	0.21	-
	Euro 4	2006.01	2.27	0.16	-	0.11	-
	Euro 5‡	mid-2008	2.27	0.12	-	0.082	0.005[b]

† For Euro 1/2 the reference mass classes were Class I < 1250 kg, Class II 1250-1700 kg, Class III > 1700 kg.
‡ Proposed
a - until 1999.09.30 (after that date DI engines must meet the IDI limits); b - applicable only to vehicles using lean burn DI engines

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[15] Source: http://www.dieselnet.com/standards/eu/ld.html [15.01.2007]

Table 3: EU emission standards for passenger cars (category M1*), g/km[16]

Tier	Date	CO	HC	HC+NOx	NOx	PM
Diesel						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
Euro 5‡	mid-2008	0.50	-	0.25	0.20	0.005
Petrol (Gasoline)						
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.2	-	0.5	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-
Euro 5‡	mid-2008	1.0	0.075	-	0.06	0.005[b]

* Before Euro 5, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
‡ Proposed
a - until 1999.09.30 (after that date DI engines must meet the IDI limits)
b - applicable only to vehicles using lean burn DI engines

Recently doubts are voiced whether the European emission standardization is an efficient tool to ensure real emission reductions of the proposed EURO 5 standards. The EU emission limits are considered too generous, especially with respect to NO_x limits which have not seen a significant reduction in the last 13 years. This is due to the fact that the test cycle relates to a much smaller area of the engine than true road driving conditions. This has allowed manufacturers to tune engines to reduce NO_x on the test cycle only, a practice known as “cycle beating” (T&E 2006).

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[16] Source: http://www.dieselnet.com/standards/eu/ld.html [15.01.2007]

4.3. Sustainability of Biofuels

The growing market for biofuels stimulated discussion about sustainability of biofuels and pushed the call for sustainability standards. This includes environmental and social aspects.

Within the discussion about negative **social impacts**, compliance with laborers rights, prevention of child labor, and implementation of minimum working conditions are among the most important issues. This includes also gender issues, land use rights, food versus fuels, health and safety, quality of life, and education.

The most important issues in the discussion about negative **environmental impacts** are, apart from GHG savings, destruction of rain forests and wetlands, loss of biodiversity, water pollution, acidification, eutrophication, and impact on ground source water. These environmental impacts are mainly associated with agricultural practices and feedstock production. But also impacts of biomass transport, biofuel production, distribution, and consumption have to be considered in the life cycle analysis.

The size of negative impacts depends on different parameters, and especially on the practices of feedstock producers. But if feedstock production is done in a sustainable manner, environmental impacts can also be positive. For example dedicated perennial energy crops can prevent soil erosion and the practices of double cropping, crop mixing and the plantation of second generation feedstock can even enhance biodiversity.

Because of the large variety of feedstock types and its production processes, social and environmental impacts of biofuel production can not be evaluated in general. They depend on local conditions and on the amount of land necessary to cultivate biofuel feedstock. Thus, for each case social and environmental impacts have to be evaluated separately. Therefore environmental impacts will be discussed in the specific chapters of the biofuel types (Part B).

4.4. Economy of Biofuels

In the whole life cycle of biofuels, the relatively high production costs still remain a critical barrier to commercial development, although continuing improvements are achieved. Nevertheless, technologies for pure plant oil and biodiesel production from oilseed crops are already fairly mature (OECD/IEA 2004, p. 67).

The **competitiveness** of biofuels will increase as prices for crude oil and other fossil sources increase and overstep a critical threshold. Today biofuel competitiveness still largely depends on the national legislative frameworks and subsidies in EU member states. Subsidies can be both agricultural aids and market incentives for the biofuel itself. Also tax exemptions have considerable impacts on end-user costs for biofuels.

For **first generation biofuels**, the **feedstock** is a major component of overall costs. As crop prices are highly volatile, the overall **production costs** of biofuels vary. The production scale of biofuels has significant impact on cost. It is more important for ethanol processing than for production of pure plant oil and biodiesel. This advantage for lipid derived fuels is especially important for small scale agricultural producers and SME’s.

Thus, for example in Germany, biodiesel is currently mainly produced by small scale producers at relatively low process costs.

Generally biofuels are expected to have large **socio-economic impacts**, especially for local actors. Biofuel production opens new market opportunities for agricultural products and thus new income options for farmers. In the future agriculture will not only play a role in food production, but also in energy provision. The increased feedstock production is expected to strongly contribute to the multi-functionality of the agricultural sector. Nevertheless it is difficult to assess the real dimension of additional employment and impact on local economy in the biomass sector. On EU level no detailed study has been conducted on this topic.

Second generation fuels are not yet produced on commercial scale. Due to high production costs, they are not competitive at the moment, but as technology improves, they may become an important role in biofuel provision. The great advantage of these fuels is the vast range of feedstock that can be used for biofuel production, as well as the reduced feedstock (e.g cellulose crops) costs.

By using a holistic approach, biofuels offer large economic advantages over fossil fuels, but direct cost comparisons are difficult. Negative **externalities** associated with fossil fuels tend to be poorly quantified, such as military expenditures and costs for health and environment. However, biofuels have the potential to generate many positive externalities, such as reduced greenhouse gas emissions, decreased air pollution, and job creation. Additionally biofuels decrease dependency from crude oil imports. Consequently biofuels are a more socially and environmentally desirable liquid fuel, a fact that is often neglected in direct-cost calculations. Therefore biofuels often seem uncompetitive although a biofuel market may actually provide long-term economic benefits when comparing environmental and social costs (WWI 2006, p. 91f).

4.5. Consideration of Co-Products

During biofuel production large quantities of co-products are received. The utilization of these co-products contributes to an increase of energy efficiency of the whole process by subsidizing other products like mineral fertilizer made from fossil fuel. Co-products also reduce GHG emissions and constitute an additional economical value. But it is difficult to value and predict the benefits of co-products. Especially when an increase of ethanol production enhances the supply of co-products, reactions of the market can hardly be foreseen.

KALTSCHMITT & RHEINHARDT (1997) and SCHMITZ et al. (2005 p. 32) mention four different methods how co-products can be considered in the process of ethanol biofuel production:

- **Target product orientated method**: This very simple method is used in many old studies. Thereby the whole energy input is charged to the target product (e.g. ethanol), co-products are not considered. The energetic and economic use of co-products is neglected and no holistic approach is implemented. This conservative method represents the worst-case scenario, but uncertainties and vagueness are eliminated.

- **Allocation method**: Environmental effects are determined and allocated separately to the co-product and to the target product.
- **Credit method**: The energy content of co-products is credited to the target product. Precondition is the real use of the co-product. Additional energy inputs for the preparation of the co-products have to be considered.
- **Substitution method**: As co-products substitute similar products, environmental effects can be avoided. These effects are credited to the target product.

In the fermentation of sugar and starch-bearing plants, co-products are produced in large quantities. They can be used as fodder, fertilizer, heat fuel, industrial raw material or as substrate for biogas plants (PAUL & KEMNITZ 2006). An excellent example how co-products from ethanol production can be used is the bagasse, the fibrous residuals of sugar cane after pressing. In Brazil, bagasse is burned and the heat is used for the distillation process and for electricity generation.

Similar, large quantities of co-products are received from the production of lipid derived fuels, such as biodiesel and PPO. For instance, press cake from rapeseed oil extraction is a high value and protein rich fodder. In biodiesel production glycerin is a valuable co-product for industrial purposes.

Figure 6: Co-products: bagasse from sugarcane (left) and rape seed cake (right)

PART B: TYPES OF BIOFUELS

Part B of this handbook describes different biofuels in detail. All transport fuels can be **classified** in fossil fuels and renewable fuels. The process chains for all transport fuels are shown in Figure 7. For the production of fossil and renewable transport fuels different primary energy sources are needed. Although mainly crude oil is used for the production of transport fuels today, the figure shows various opportunities for the production of biofuels. Thereby the utilization of biomass as feedstock source does not necessarily create a different fuel type than today. For instance, biodiesel is similar to fossil diesel and bioethanol has similar properties as petrol. This is a great advantage, since existing infrastructure does not have to be intensively modified.

However, there exists a large variety of different feedstock sources, biofuels, process technologies and utilizations of biofuels. Thus, PPO and biodiesel (FAME, FAEE) can be produced directly from oil containing plants. Ethanol can be processed from sugar, starch and cellulose. In addition, biomass can be liquefied to yield “bio crude” or gasified. A promising application for the future is the utilization of biomethane for transport.

In contrast, the use of other renewable energies, like electricity from wind or photovoltaic, is more complicated to use with today’s infrastructure. Hydrogen can be used in very different ways, directly for vehicle propulsion in a combustion engine or preferably in a fuel cell or indirectly as a component for the production of other fuels. However, hydrogen requires far-reaching changes in technology and infrastructure. In particular, energy effective use of hydrogen requires the introduction of fuel cells instead of internal combustion engines. This presents another technology and cost challenge. According to the vision report of the EC, hydrogen from renewables for fuel cell driven vehicles might be a long term option (EC 2006a p. 20).

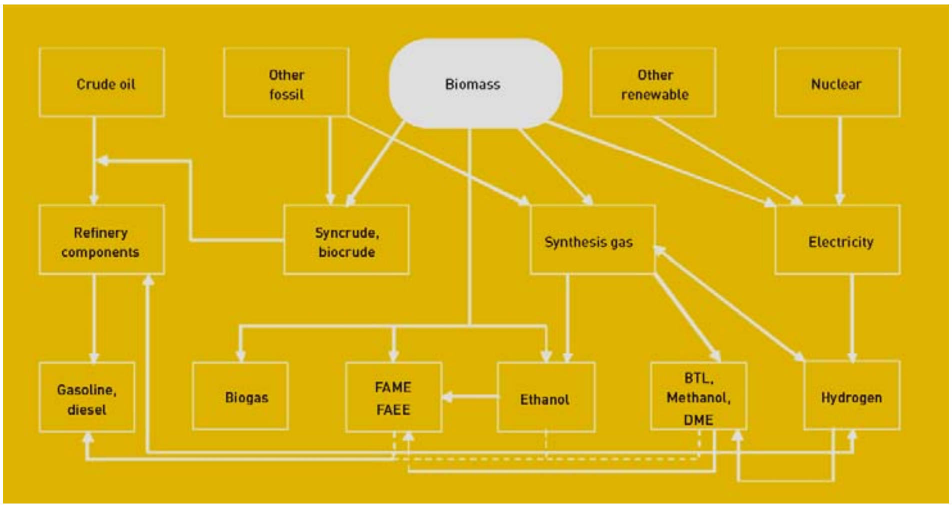

Figure 7: Process chains for fuel production (Source: EC 2006a p. 20)

Whereas Figure 7 also includes the utilization of fossil energy for transport fuel production, Figure 8 concentrates exclusively on the pathways of biofuel production. Feedstock sources can be divided into animal fats, oil crops, sugar plants, starchy plants, cellulosic biomass and wet biomass. During processing theses feedstocks, they can be transformed into liquid and gaseous biofuels.

Another classification of biofuels can be applied to first generation and second generation biofuels. PPO, biodiesel, ETBE and bioethanol are **first generation biofuels** since the conversion and engine technologies are widely developed and approved in practice. They offer the greatest short-term potentials of biofuels today. Although they differ in properties, technical requirements, economical aspects and potential, they can contribute to guarantee long-term mobility.

Second generation biofuels are not yet commercial available since their conversion technologies have to be improved. They include e.g. BTL fuels and ethanol from lingo-cellulose. BtL fuels are a promising option for the future, but will not achieve relevance to the market before 2015. However, the boundaries first and second generation fuels are fluently and not exactly defined. Currently, the use of biomethane in the transport sector shifts from 2nd to 1st generation biofuel. First biomethane stations are built at the moment. Biomethane from biogas can be used in natural gas vehicles without any adjustments.

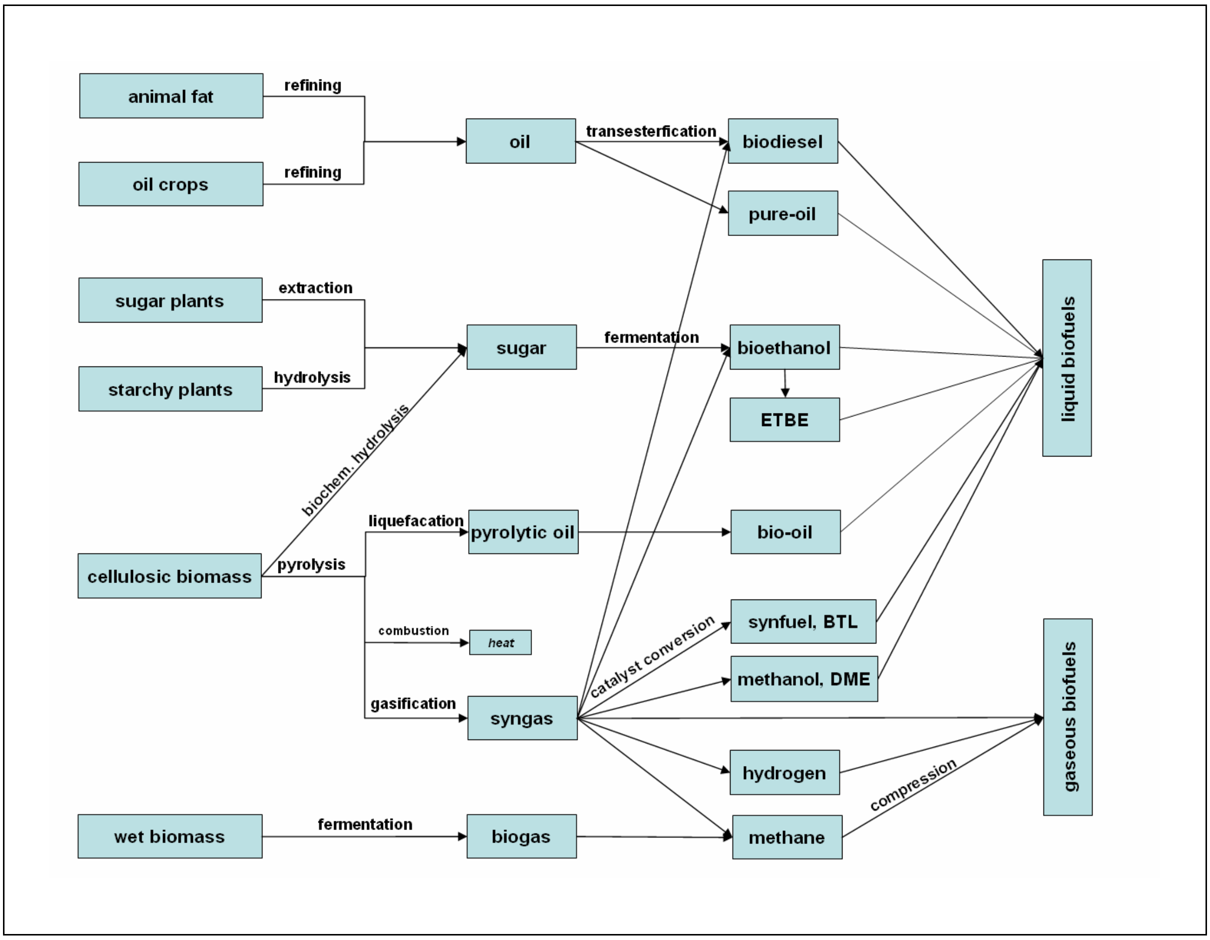

Figure 8: Pathways of different biofuels

5. Bioethanol

Whereas PPO and biodiesel are suitable for diesel engines, bioethanol can substitute petrol such as premium, super and lead replaced petrol (LRP).

5.1. Feedstock Production

Ethanol can be produced from any biological feedstock that contains appreciable amounts of sugar or materials that can be converted into sugar such as starch or cellulose. As shown in Figure 9, many different feedstock sources can be used for ethanol production. They can be divided into sugary, starchy and cellulosic feedstock. After a general introduction of feedstock production, a brief description of the most relevant feedstock types for ethanol production will be given in the following sub-chapters.

Two examples of feedstock for ethanol production are sugar beets and sugar cane which contain high percentages of **sugar**. Sugars can be easily fermented. For example, Brazil developed a successful fuel ethanol program from sugarcane. In Europe, sugar beets are used for ethanol production. Currently, ethanol imports from Brazil are entering the European fuel market.

Corn, wheat, barley, rye and other cereals are typical feedstocks containing **starch** in their kernels. Starch can relatively easily be converted into sugar and then into ethanol. In the USA and Europe, ethanol is manufactured mainly from maize and grain. At the moment substantial capacities for the manufacture of ethanol are being created in Germany. Other starchy crops that can also be used for bioethanol production are sorghum grains, cassava and potatoes. Recent research includes bioethanol production from potatoes and waste potatoes from food industry (LIIMATAINEN 2004).

Since ethanol from sugar and starch bearing plants is readily available today, these feedstock types are also called first-generation feedstocks. First generation feedstocks are characterized by the fact that only parts of the plants (starch, sugar, oil) are used for biofuel production (WWI 2006 p. 20).

Contrary to this, next-generation feedstock types provide the opportunity to use nearly the whole plant for biofuel production and not only parts of the plants (grains, tubes, stalks). In order to use second generation biofuels for ethanol production, advanced technologies are necessary (WWI 2006 p. 20). A large variety of feedstock is available for producing ethanol from biomass that contains large amounts of **cellulose** and hemicellulose. Cellulose and hemicellulose can be converted to sugar, though with more difficulty than conversion of starch.

Considered cellulosic biomass are agricultural wastes (including those resulting from conventional ethanol production), forest residues, municipal solid wastes (MSW), wastes from pulp/paper processes and energy crops. Cellulosic agricultural wastes for ethanol production include crop residues such as wheat straw, corn stover (leaves, stalks and cobs), rice straw and bagasse (sugar cane waste). Forestry wastes include logging residues as well as wood which is not used and thus left in the forest. MSW contains high percentages of cellulosic materials, such as paper and cardboard.

In contrast to cellulosic waste materials, dedicated energy crops, which are grown specifically for ethanol production, include fast-growing trees (poplars), shrubs (willows), and grasses (switchgrass). The cellulosic components of these materials range between 30% and 70%.

This new concept of utilizing cellulosic feedstock for bioethanol production is not yet applicable on the large scale, but is currently subject to intensive research.

However, independent from the feedstock type, the large-scale production of agricultural ethanol requires substantial amounts of cultivable land with fertile soils and water (except for wastes). Therefore ethanol production is less attractive for densely occupied and industrialized regions like Western Europe, or for regions where desire for increased farmland puts pressure on important natural resources like rainforests.

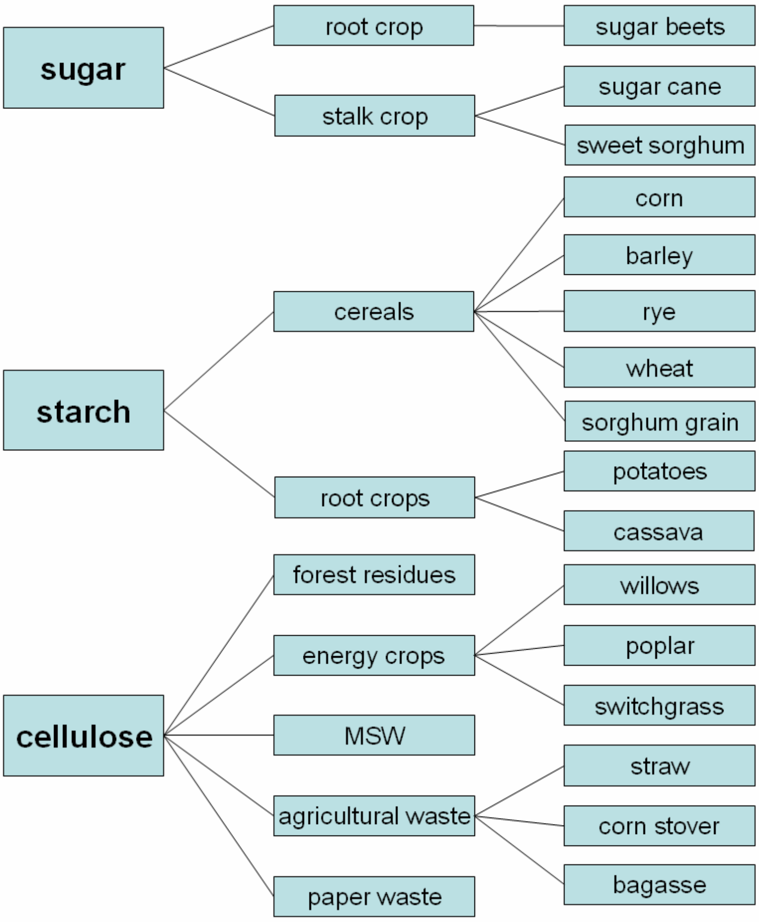

Figure 9: **Types of feedstock for ethanol production (examples)**

5.1.1 Sugar Crops

Sugar beets

Sugar beet (*Beta vulgaris* L.) belongs to the subfamily of the *Chenopodiaceae* and to the Family of the *Amaranthaceae*. Its roots contain a high concentration of sucrose and therefore it is grown commercially for sugar production. The three largest sugar beet producers worldwide are the European Union, the United States, and Russia. Only Europe and Ukraine are significant exporters of sugar from beet. Ukraine and Russia have the largest cultivated area, but the largest producers by volume are France and Germany (WWI 2006 p. 23). Apart from the food industry, sugar beets are a valuable feedstock for bioethanol especially in France.

Figure 10: Harvested sugar beets (Germany)

Sugar beet is a hardy biennial plant that can be grown commercially in a wide variety of temperate climates. During growth it produces a large (1–2 kg) storage root whose dry mass is 15–20% sucrose by weight. This sucrose and the other nutrients in the root are consumed to produce the plant's flowers and seeds if it is not harvested in the first year. In commercial beet production, the root is harvested in the first growing season, when the root is at its maximum size. Beets are planted from small seeds. In most temperate climates, beets are planted in spring and harvested in autumn. A minimum growing season of 100 days can produce commercially viable sugar beet crops. In warmer climates, sugar beets can be cultivated as winter crop, being planted in the autumn and harvested in the spring.

Harvesting of sugar beets is entirely mechanical. The sugar beet harvester chops the leaf and crown which is high in non-sugar impurities from the root. It further lifts the root, and removes excess soil from the root in a single pass over the field. A modern harvester is typically able to cover 6 rows at the same time. The beet is usually left in piles on the field and then delivered to the factory. Thereby sugar beets do not have to be stored too long as it quickly deteriorates and modifies the sugar molecules.

Due to concerns about the potential survival of pests in the soil, the beets can be cultivated only every three years on the same field. The yields strongly depend on climatic conditions. Sugar beets generate good yields in many temperate settings, but compared to sugar cane, they are a more chemical- and energy-intensive crop. Since sugar beets are a more expensive feedstock for fuel production than sugar cane, the economic competitiveness often depends on governmental protection through subsidies and import duties especially for cane sugar (WWI 2006 p. 23f).

Sugar cane

Sugar cane (*Saccharum* sp.) is a genus of 37 species of tall grasses and belongs to the family of the *Poaceae* and is native to warm temperate to tropical regions. All the species interbreed, and the major commercial cultivars are complex hybrids. Sugarcane is a grass originally from tropical Southeast Asia. The plants have stout, jointed fibrous stalks which are 2 to 6 meters tall and rich in a sugar bearing sap. Today about 107 countries grow sugar cane whereas Brazil is the world leading producer. Sugar cane is the most significant crop for biofuel production today, supplying more than 40 % of all fuel ethanol (WWI 2006 p. 22). Besides the production of bioethanol, sugar cane is also used for the production of alimentary sugar, molasses, and rum.

Figure 11: Sugar cane plantation (India)

Sugarcane cultivation requires a tropical or subtropical climate, with a minimum of 600-850 mm of annual moisture. It is one of the most efficient plants in photosynthesis which is able to convert up to 2 % of incident solar energy into biomass. In prime growing regions, sugarcane can produce up to 20 kg for each square meter exposed to the sun.

Sugarcane is propagated from cuttings, rather than from seeds. Modern methods of stem cuttings have become the most common method of reproduction. Once planted, a stand of cane can be harvested several times as the cane continuously sends up new stalks. Usually, each successive harvest gives a smaller yield, and eventually the declining yields justify replanting. Depending on agricultural practice, two to ten harvests may be possible between plantings.

Sugar cane is harvested by using a sugarcane combine or a chopper harvester. Nevertheless more than half of the world's production is still harvested manually, especially in the developing world. When harvested by hand, the field is first set on fire, burning away dry and dead leaves, and killing venomous snakes, but leaving the water-rich stalks and roots unharmed. Once the cane is cut, it rapidly begins to modify its sugar molecules. Damage on the cane caused during harvesting accelerates this decay.

In a sugar mill the harvested sugarcane is washed, chopped, and shredded by revolving knives. The shredded cane is repeatedly mixed with water and crushed between rollers. The collected juice contains 10–15 % sucrose. The remaining fibrous solids, also called bagasse, can be used as co-product to generate process heat. It makes a sugar mill more than self-sufficient in energy. The surplus bagasse can be used for animal feed, in paper manufacture, or burned to generate electricity for the local power grid.

The juice from sugar cane is further processed, refined, fermented and distilled for bioethanol production.

Sweet sorghum

Sweet sorghum (*Sorghum bicolor*) belongs to the Family of the *Poaceae*. The genus of Sorghum has many species of which sweet sorghum is one of the most grown plants. Similar to sugarcane it is cane-like plant with a high sugar content of the stalk. Besides the stalk, also its seeds can be used for several purposes. Farmers can harvest sweet sorghum as a multi-used crop in separating the seeds at the top of the plant for food and the sugars in the stalk for fuels. In settings where land is particularly scarce, this co-harvesting of sorghum may be particularly efficient.

Figure 12: Plants, seeds and stalks of sweet sorghum

Although currently not a significant ethanol feedstock, sweet sorghum has many promising advantages. For instance it grows under drier and warmer conditions than many other crops. It only needs 1/3 water of sugarcane and is tolerant to drought, heat, water logging and salt-alkali. But sweet sorghum can be grown in temperate areas as well. Additionally, sweet sorghum has a relatively short growing season and can be harvests 1-3 times per year. In contrast to sugarcane, sweet sorghum can be also sown very well and has not to be propagated by stalk clippings.

With its drought tolerance and ability to produce sugar, sweet sorghum could receive increasing attention as a feedstock for ethanol production (WWI 2006 p. 24).

5.1.2 Starch Crops

Cereals

Cereal crops are grasses which are cultivated originally for their edible grains or seeds (actually a fruit called a caryopsis). Worldwide cereal grains are grown in greater quantities and provide more food energy to the human race than any other type of crop. The most planted cereal crops are corn (maize)http://en.wikipedia.org/wiki/Maize, wheat and rice, which account for more than 80 % of all grain production worldwide.

Although each species has its specific characteristics, the cultivation of cereal crops is similar. In general, they are annual plants and consequently one planting yields one harvest. Nevertheless, in Europe, all cereals can be divided into cool-season and warm-season types.

wheat ***barley*** ***oat*** ***corn***

Figure 13: Different types of starchy crops for ethanol production

Wheat, rye, triticale, oats, barley, and spelt are the **cool-season cereals**. These are hardy plants that grow well in moderate weather and cease to grow in hot weather (approximately 30 °C but this varies by species and variety). Barley and rye are the hardiest cereals, able to overwinter in subarctic regions like Siberia. Wheat is the most popular cereal crop. All cool-season cereals are grown in the tropics as well, but only in the cool highlands, where it may be possible to grow multiple crops in a year. Cool-season cereals can be sub-divided into either winter or spring types. Winter varieties are sown in the autumn, germinate and grow vegetatively, then become dormant during winter. They resume growing in the springtime and mature in late spring or early summer. This cultivation system makes optimal use of water and frees the land for another crop early in the growing season.

Winter varieties do not flower until springtime because they require exposure to low temperature for a genetically determined length of time. Spring cereals are planted in early springtime and mature later that same summer. Spring cereals typically require more irrigation and yield less than winter cereals.

Warm-season cereals are tender and prefer hot weather. They are grown in tropical lowlands for the whole year and in temperate climates during the frost-free season.

However, once the cereal plants have grown their seeds, they have completed their life cycle. The plants die and become brown and dry. As soon as the parent plants and their seed kernels are reasonably dry, harvest can begin. In Europe, cereal crops are usually machine-harvested, typically using a combine harvester. It cuts, threshes, and winnows the grain during a single pass across the field.

Potatoes

The potato plant (*Solanum tuberosum*) is a perennial plant of the *Solanaceae* or nightshade family. It is commonly grown for its starchy tuber and is therefore the world's most widely grown tuber crop and the fourth largest crop after rice, wheat, and maize. The origin of the potato plant is in South-America mainly in the Andes. Potatoes spread to the rest of the world after European contact with the Americas in the late 1400s and early 1500s.

Figure 14: Blooming potato plants (left) and their starchy tubes

Potatoes are generally grown from the eyes of another potato and not from seed. They are planted as a row crop using seed tubers, young plants or microtubers. In most cases three steps of plowings including harrowing and rolling are necessary before the land is in suitable condition for planting potatoes.

Commercial harvesting is typically done with large potato harvesters which also pre-clean the tubes. Further inspection and separation occurs when the potatoes are unloaded from the field vehicles and put into storage.

Recently bio-ethanol is produced by using waste potatoes which are a co-product of the food industry. For instance waste potatoes are used as feedstock in Finland where oy Shaman Spirits Ltd in Tyrnävä (near Oulu) uses 1.5 million kilograms of waste potatoes per year for ethanol production (LIIMATAINEN et al. 2004).

5.1.3 Cellulosic Feedstock

Besides the so called first generation feedstock which is received from sugar and starch crops, cellulosic feedstock is a promising source for bioethanol production in the future. Since the technology for converting cellulosic feedstock into ethanol is not yet competitive, this feedstock is a second generation feedstock. Bioethanol production from cellulose is expected to significantly expand in the future, when technologies will improve. Subsequently, cellulosic wastes and biomass that is specifically cultivated for energy purposes will be discussed in detail.

Cellulosic wastes

Depending on their origin, cellulosic wasted can be divided into primary, secondary and tertiary wastes (WWI 2006 p. 39f).

Primary cellulosic wastes are produced during production and harvesting of food crops such as e.g., straw, corn stalks and leaves. Also residues from forestry such as e.g. wood thinning from commercial forestry belong to primary cellulosic wastes. These types of biomass are typically available in the field or forest and must be collected to be available for further use. Thereby attention has to be paid as there are long-term economic and environmental concerns associated with the removal of large quantities of residues from cropland. Removing residues can reduce soil quality, promote erosion, and reduce soil carbon, which in turn lowers crop productivity and profitability. But, depending on the soil type, some level of removal can be also beneficial. Establishment and communication of research-based guidelines is necessary to ensure that removal of residue biomass is done in a sustainable manner (WWI 2006 p. 42).

Figure 15: Primary cellulosic wastes, such as forest waste (left) and agricultural residues (right)

Secondary cellulosic wastes are generated during the production of food products and biomass materials. This biomass include nut shells, sugar cane bagasse, and saw dust, and are typically available at e.g. industries for food and beverage production as well as at saw and paper mills.

Tertiary cellulosic wastes become available after a biomass-derived commodity has been used. A large variety of different waste fractions is part of this category: organic part of municipal solid waste (MSW), waste and demolition wood, sludge, paper, etc.

Cellulosic energy crops

Feedstock from dedicated cellulosic energy corps is a promising source for ethanol production in the future. There are several advantages for the cultivation of cellulosic energy crops, such as perennial herbaceous plant species and short-rotation woody crops (SRWC) (WWI 2006 p. 46f). Firstly, the change of land from intensive annual crop production to perennial herbaceous species or to SRWC progressively increases the content of soil organic matter. In contrast, shifting land from natural cover to intensive annual crop production typically decreases soil organic matter steadily. Secondly, the roots of perennial crops protect soil from erosion. Thirdly, these crops generally require less fertilizer, pesticide and less energy input for crop management, especially since it is not necessary to plow the field each year.

Today, there is already some use of **short-rotation woody crops** for industrial purposes. For example, eucalyptus trees are grown for pulp markets and to supply charcoal for the steel industry in Brazil. In Europe and the United States, poplar trees are cultivated to provide fiber for the pulp and paper industry. Nevertheless, efforts to evaluate and develop energy crops are still in a relatively early stage of development when compared to conventional crops where cultivation and plant breeding has been under way for many years. The relatively early phase of energy crop development reflects a situation where tremendous opportunities exist to use advanced plant science and agronomy to dramatically increase biomass yields (WWI 2006 p. 46f).

In temperate climates the cultivation of **willow** (*Salix* sp.) is suitable as SRWC. Willow trees and shrubs are very productive. In short-rotation coppice (SRC) plantations they can achieve high biomass yields by harvesting the young sprouts. The plant quickly regenerates with vigorous growth of new shoots and branches from the remaining tree trunks. SRWC can be harvested every few years. For instance, willows in SRC plantations can typically be harvested every 2–5 years over a period of some 20–25 years. Research on genetics and breeding has drastically increased the yields. In Europe most experience with willow plantations has been made in Sweden, where this crop is produced on approximately 14,000 hectares.

Besides willow, also **hybrid poplar trees** (*Populus* sp.) are cultivated in SRC plantations as they have similar fast-growing and high productive properties.

Parallel to willow and poplar trees in Europe, **eucalyptus** (*Eucalyptus* sp.) plantations are grown in tropical regions.

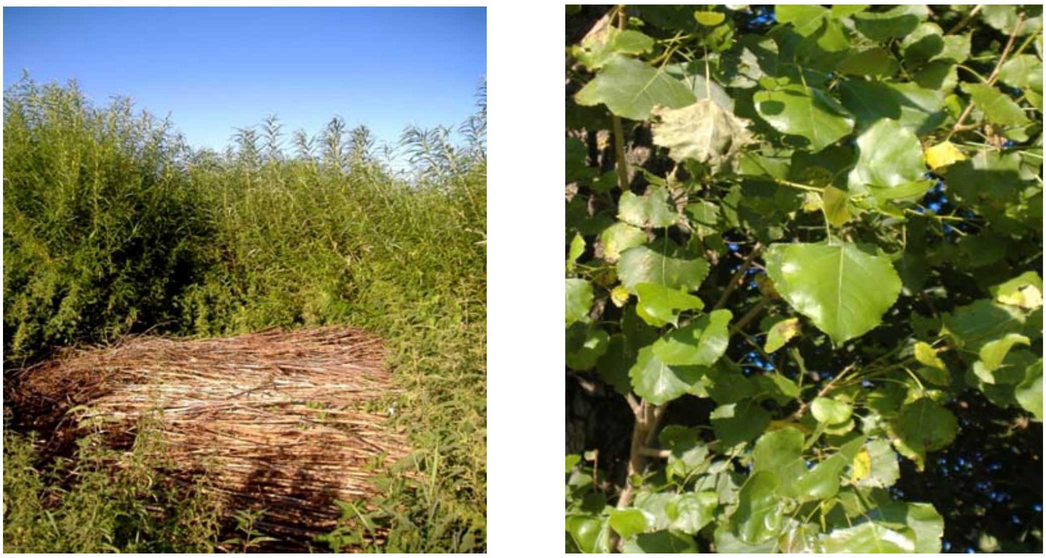

Figure 16: Willow plantation (left) and poplar leaves (right)

Along with woody cellulosic energy crops also **perennial grass species** are a promising opportunity for future feedstock production. Miscanthus (*Miscanthus sinensis, M. sacchariflorus, Miscanthus x giganteus*), switchgrass (*Panicum virgatum)*, and reed canary grass (*Phalaris arundinacea)* are examples of perennial crops that can be harvested every year. They have been the focus of considerable interest in Europe and North America where sugar bearing grasses such as sugar cane and sweet sorghum can not be cultivated due to too cold climates. It is expected that breeding could highly increase productivity and at least double energy grasses productivity. Such advances in breeding will be realizable much easier than breeding food crops since it is easier to breed for size rather than for a particular quality, such as taste in fruits or vegetables.

5.2. Bioethanol Production

Ethanol, also known as “ethyl alcohol” or “grade alcohol”, is a flammable, colorless chemical compound, one of the alcohols that is most often found in alcoholic beverages. In common parlance, it is often referred to simply as alcohol. Its molecular formula is C_2H_6O, variously represented as EtOH, C_2H_5OH or as its empirical formula C_2H_6O. The most important properties of ethanol are shown in Table 4.

Table 4: Properties of ethanol

Density and phase	0.789 g/cm^3, liquid
Solubility in water	Fully miscible
Melting point	−114.3 °C (158.8 K)
Boiling point	78.4 °C (351.6 K)
Acidity (pKa)	15.9 (H+ from OH group)
Viscosity	1.200 cP at 20 °C
Dipole moment	1.69 D (gas)

Generally, ethanol can be produced either synthetically from petrochemical feedstock (petroleum) or by microbial fermentation which is applicable to bioethanol production. The process for production of fuel bioethanol from biomass can be broken down as follows:

- **Feedstock production**: harvesting , reception, storage
- **Physical pretreatment**: milling
- **Saccarification**: conversion of starch and cellulose into sugar
- **Chemical treatment**: dilution of the sugars with water and addition of yeast or other organisms
- **Fermentation**: production of ethanol in solution with water along with waste and by-products
- **Distillation**: separation of ethanol
- **Dehydration**: Removal of the remaining water by molecular sieves (anhrour ethanol)
- **Co-product preparation**: Drying of the alcohol free stillage (mash) for high-value animal feed

These steps in the feedstock-to-ethanol conversion process largely depend on the type of feedstock. They are shown for different feedstock sources in Table 5.

Table 5: Ethanol production steps by feedstock and conversion technique

Feedstock type	Feedstock	Harvest technique	Feedstock conversion to sugar	Process heat	Sugar conversion to Alcohol	Co-products
Sugar crops	cane	Cane stalk cut, mostly taken from field	Sugars extracted through bagasse crushing, soaking, chemical treatment	Primarily from crushed cane (bagasse)	Fermentation and distillation of alcohol	Heat, electricity, molasses
	sugar beet	Beets harvested, foliage left on the field	Sugar extraction	Typically from fossil fuel	Fermentation and distillation of alcohol	Animal feed, fertilizer
Starch crops	wheat	Starchy parts of plants harvested; stalks mostly left in the field	Starch separation, milling, conversion to sugars via enzyme application	Typically from fossil fuel	Fermentation and distillation of alcohol	Animal feed (e.g. distillers dried grains)
	corn	Starchy parts of plants harvested; stalks mostly left in the field	Starch separation, milling, conversion to sugars via enzyme application	Typically from fossil fuel	Fermentation and distillation of alcohol	Animal feed (e.g. distillers dried grains), sweetener
	potatoes	Potatoes harvested, foliage left on the field	Washing, mashing, cooking, starch separation, conversion to sugars via enzyme application	Typically from fossil fuel	Fermentation and distillation of alcohol	Animal feed, industrial use
Cellulosic crops	trees	Full plant harvested (above ground)	Cellulose conversion to sugar via saccarification (enzymatic hydrolysis)	Lignin and excess cellulose	Fermentation and distillation of alcohol	Heat, electricity, animal feed, bioplastics, etc.
	grasses	Grasses cut with regrowth	Cellulose conversion to sugar via saccarification (enzymatic hydrolysis)	Lignin and excess cellulose	Fermentation and distillation of alcohol	Heat, electricity, animal feed, bioplastics, etc.
Waste biomass	Crop residues, forestry waste, municipal waste, mill waste	Collected, separated, cleaned to extract material high in cellulose	Cellulose conversion to sugar via saccarification (enzymatic hydrolysis)	Lignin and excess cellulose	Fermentation and distillation of alcohol	Heat, electricity, animal feed, bioplastics, etc.

5.2.1 Sugar-to-Ethanol Process

The simplest way to produce ethanol is the sugar-to-ethanol production. Thereby biomass is used that contains six-carbon sugars which can be fermented directly to ethanol. Examples for typical sugary feedstock types are sugar cane and sugar beets which contain substantial amounts of sugar.

Although fungi, bacteria, and yeast microorganisms can be used for fermentation, the specific yeast *Saccharomyces cerevisiae* (Bakers' yeast) is frequently used to ferment glucose to ethanol. Traditional fermentation processes rely on yeasts that convert six-carbon sugars (mainly glucose) to ethanol. Theoretically, 100 grams of glucose will produce 51.4 g of ethanol and 48.8 g of carbon dioxide (BADGER 2002).

In Brazil and in most tropical countries which produce ethanol, sugar cane is the most common feedstock for ethanol production. In these warm countries costs of ethanol production from sugar cane are among the lowest for any biofuels. Since the climate for sugar cane is too cold in most parts of the European Union, sugar beets are used to produce ethanol.

Figure 17: Sugar mill for bioethanol production from sugar cane in Brazil

5.2.2 Starch-to-Ethanol Process

Another potential ethanol feedstock is starch. In Europe and in the United states a large portion of bioethanol is produced from the starch component of grain crops, primarily corn and wheat in the US and wheat and barley in Europe.

Starch molecules are made up of long chains of glucose molecules which have to be broken into simple glucose molecules (saccharification). Therefore starchy materials require a reaction of starch with water (hydrolysis). Typically hydrolysis is performed by mixing the starch with water to form slurry which is then stirred and heated to rupture the cell walls. During the heating cycle, specific enzymes are added, which break the chemical bonds (BADGER 2002). Organisms and enzymes for starch conversion and glucose fermentation on a commercial scale are readily available. The whole starch-to-ethanol process is shown in Figure 18.

In conventional starch-to-ethanol processes, only the starchy part of the crop plant is used. The kernels of corn, barley or wheat represent a fairly small percentage of the total plant mass. The fibrous portion of these plants like seed husks and stalks remain. Current research on cellulosic ethanol production is focused on utilizing these waste cellulosic materials to create fermentable sugars. This leads to more efficient production of ethanol than from using just the sugars and starches directly available (OECD/IEA 2004).

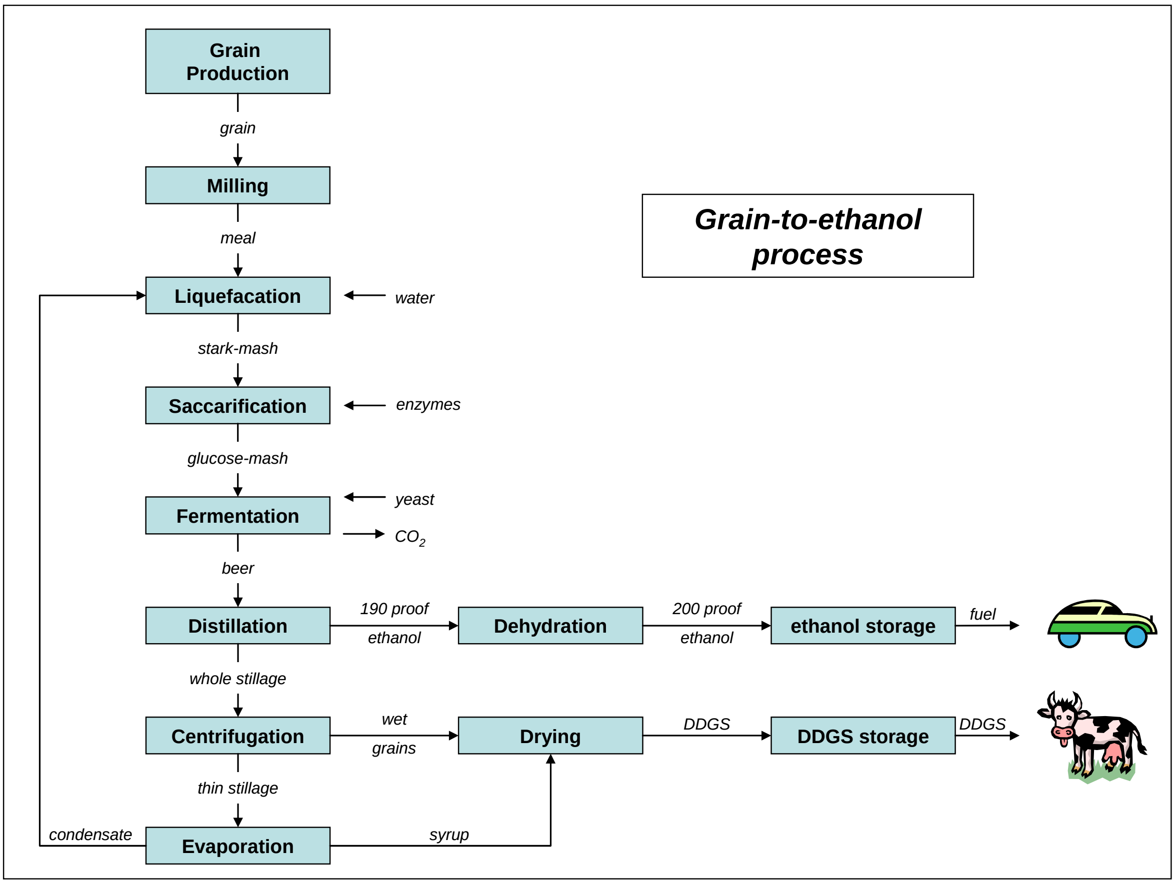

Figure 18: Grain-to-ethanol-process

5.2.3 Cellulose-to-Ethanol Process

Besides sugar and starch, also cellulose can be converted into ethanol, but the cellulosic biomass-to-ethanol production process is more complicated than the sugar- or starch-to-ethanol process.

Cellulosic materials are comprised of lignin, hemicellulose, and cellulose and thus are sometimes called lignocellulosic materials. They have to be converted to five- and six-carbon sugars, before they can be fermented and converted into ethanol. One of the primary functions of lignin is to provide structural support for the plant. Thus, in general, trees have higher lignin contents then grasses. Unfortunately, lignin which contains no sugars encloses the cellulose and hemicellulose molecules, making them difficult to reach. Cellulose molecules consist of long chains of glucose molecules as do starch molecules, but have a different structural configuration. These structural characteristics plus the encapsulation by lignin makes cellulosic materials more difficult to hydrolyze than starchy materials. Also hemicellulose is comprised of long chains of sugar molecules. The exact sugar composition of hemicellulose can vary depending on the type of plant (BADGER 2002).

For complete fermentation of cellulosic materials special organisms are required (OECD/IEA 2004). Bacteria have drawn special attention from researchers because of their speed of fermentation. In general, bacteria can ferment in minutes as compared to hours for yeasts (BADGER 2000).

There are three basic process types for conversion of cellulose to ethanol: acid hydrolysis, enzymatic hydrolysis, and thermochemical process. The most common type is acid hydrolysis. Virtually any acid can be used. However, sulfuric acid is most commonly used since it is usually the least expensive (BADGER 2000).

Today, there is virtually no commercial production of ethanol from cellulosic biomass, but there is substantial research going on (OECD/IEA 2004). There are several potentially important benefits from developing a viable and commercial cellulosic ethanol process:

- Access to a much wider array of potential feedstock types (including waste cellulosic materials and dedicated cellulosic crops such as grasses and trees), opening the door to much greater ethanol production levels.
- Greater avoidance of conflicts with land use for food and feed production.
- A much greater displacement of fossil energy per liter of fuel, due to nearly completely biomass-powered systems.
- Much lower net well-to-wheels greenhouse gas emissions than with grain-to-ethanol processes powered primarily by fossil energy (OECD/IEA 2004).

5.2.4 Distillation and Dehydration Process

Ethanol produced by fermentation results in a solution of ethanol in water. For ethanol to be used as fuel, water must be removed. The oldest method therefore is distillation, but the purity is limited to 95-96 % due to the formation of a low-boiling water-ethanol azeotrope. An azeotrope is a liquid mixture of two or more substances that retains the same composition in the vapor state as in the liquid state when distilled or partially evaporated under a certain pressure. It means that the composition of this liquid at its azeotropic composition can not be changed by simple boiling.

Figure 19: Distillery for bioethanol production from sugarcane in Brazil.

Thus it is not possible to obtain ethanol of higher purity of 96 % by distilling any more dilute solution. But for blending with gasoline, ethanol purities of 99.5 to 99.9% are required, depending on temperature, to avoid separation. Currently, the most widely used purification method is a physical absorption process using molecular sieves.

5.3. Properties of Bioethanol

The properties bioethanol is shown in Table 6 and compared to the properties of fossil petrol.

Table 6: Parameters of bioethanol in comparison with petrol (PAUL & KEMNITZ 2006)

	Density [kg/l]	Viscosity [mm²/s]	Flashpoint [°C]	Caloric value [at 20°C MJ/kg]	Caloric value [MJ/l]	Octane-number [RON]	Fuel-equivalence [l]
Petrol	0.76	0.6	< 21	42.7	32.45	92	1
Bioethanol	0.79	1.5	< 21	26.8	21.17	> 100	0.65

Ethanol has many favorable properties. For example the **octane number** of ethanol is higher than the octane number of conventional petrol. The octane number influences the antiknocking property of the fuel. The anti knocking number (AKI) and the research octane number (RON) of pure ethanol is 116 and 129 compared to ordinary petrol with 86/87 AKI and 91/92 RON. A high octane number stands for an antiknocking fuel. Knocking describes uncontrolled combustion which puts heavy mechanical and thermal loads on the engine.

On the other hand, the **energy yield** of ethanol is about one third lower than petrol. One liter of ethanol substitutes only about 0.65 liters of petrol. This is due to the different caloric values of petrol and ethanol. The energy content of petrol is 32.5 MJ/l and 21.2 MJ/l of ethanol.

Another property of ethanol is its low **vapor pressure**. When stored as a pure fuel (or even as an E-85 blend), it has a lower vapor pressure than gasoline, and thus will have fewer evaporative emissions. In colder climates, the low vapor pressure of pure ethanol can cause cold start problems. Therefore in cold climates ethanol is blended with gasoline (E85). In contrast, lower-level blends of ethanol in gasoline, tend to raise the vapor pressure of the base gasoline to which ethanol is added. When ethanol is blended up to about 40 percent with gasoline, the two fuels combined have higher evaporative emissions than either does on its own (WWI 2006 p. 192).

This example shows that different blends of ethanol and petrol have different properties. Depending on the situation and the desired fuel, ethanol is therefore blended with gasoline at any ratio. Common **ethanol blends** are E5, E10, E20, E25, E70, E85, E95, and E100, which contain 5%, 10%, 20%, 25%, 70%, 85%, 95%, and 100% ethanol, respectively. Also other varying quantities are possible. In the European Union, so-called flexible-fuel vehicles (FFV) are currently entering the market. They can run with an ethanol proportion of any mixture up to 85 %.

Ethanol is also increasingly used as an **oxygenate additive for standard petrol**, as a replacement for methyl tertiary butyl ether (MTBE). MTBE is usually mixed with petrol as an additive to improve the octane number. Because MTBE has toxic properties and is responsible for considerable groundwater and soil contamination, MTBE is more and more frequently replaced by ETBE (ethyl tertiary butyl ether). ETBE is produced from bioethanol and may be mixed in maximum quantities of 15 percent with petrol.

5.4. Technology Applications for Bioethanol

5.4.1 Spark Ignition Engines

For the combustion of petrol, usually spark ignition engines are used. These are internal combustion engines where the fuel-air mixture is ignited with a spark. These engines differ to compression-ignition engines, where the heat and pressure from compression alone ignites the mixture. Spark-ignition engines can be either two-stroke or four-stroke. A four-stroke spark-ignition engine is an Otto cycle engine. Originally the fuel of spark-ignition engines is mixed outside the cylinders, as opposed to compression-ignition engines where the fuel is mixed inside the cylinders. However spark-ignition engines are increasingly being designed with direct injection, eliminating this distinction.

Generally all spark ignition engines can run with bioethanol as well. If 10 to 25% ethanol is mixed with gasoline, typically no engine modifications are needed. Many modern cars can run on these mixtures very reliably. But, the higher the ethanol component of blended petrol becomes, the lower is its suitability for standard car engines. This is due to certain characteristics of bioethanol.

Extensive international experience demonstrates that, in general, **E10** blends do not require engine tuning or vehicle modifications. And since most of the materials that have been used by the motor industry over the last two decades are E10 compatible, substitution of parts is not usually required. However, because European Union fuel quality regulations have limited the ethanol content to 5 % (E5) or less, automakers have typically restricted the warranty coverage of vehicles sold in the EU to this level. This limit is currently discussed to be increased up to a 10 % limit (WWI 2006).

In Brazil, all brands of automotive gasoline contain anhydrous ethanol in the range of 20−25 % (**E20−E25**). Foreign vehicles have been adapted by using ethanol-compatible materials in the fuel system and by tuning the engines for a mid-range point, usually at the 22 % ethanol level (E22). This customization has resulted in good drivability and performance, with fuel consumption comparable to gasoline operation.

For using fuels that are higher blended with ethanol (**E20-E100**) conventional engines have to be refitted with more efforts. This is due to the characteristics of ethanol to dissolve certain rubber and plastic materials. Further, engines running with high blends of ethanol have to be refitted as pure ethanol has a much higher octane rating (116 AKI, 129 RON) than ordinary petrol. Therefore changes to the compression ratio and spark timing are needed to obtain maximum benefits. To refit an engine which will be fueled with pure ethanol, larger carburetor jets, which are about 30-40% larger by area, have to be installed. Additionally, below temperatures of 13 °C, ethanol engines also need a cold-starting system to maximize combustion and minimize uncombusted non-vaporized ethanol. Depending on the particular customization requirements, refitting costs may run from a few euros for substitution of fuel lines to more than €500 if the fuel-supply system is fully upgraded (fuel lines, tank, pump, filter, etc).

As an example, in Brazil some vehicles are exclusively running with pure ethanol. They are equipped with ethanol compatible materials and with on-board electronic engine management systems, which can adjust engine operation to ethanol fuelled conditions.

Recently an increasing number of vehicles are manufactured with engines which can run on any petrol/bioethanol ratio from 0% ethanol up to 85% ethanol. Sensors of these **flexible fuel vehicles (E85 FFV)** can automatically detect the type of the fuel and adapt engine running. They adjust the air/fuel ratio and the ignition timing to compensate the different octane levels of the fuel in the engine cylinders. The main reason to limit ethanol content to 85 % is to enhance volatility conditions for cold start, particularly in cold climates. Therefore the technology does not need any cold start ancillary system.

Worldwide, in February 2006, there were an estimated six million E85 FFVs on the road (WWI 2006). In Europe FFVs are used especially in Sweden, but also in other countries, e.g. in Germany or the United Kingdom, these vehicles are introduced. Pioneers in the European market are the manufacturers Ford and Saab.

As opposed to Europe, in Brazil so called **E100 FFV**s were introduced in 2003. This variant of the E85 FFV technology is capable to operate either within the E20/E25 range, exclusively with hydrous ethanol (E100), or with any blend between E20/E25 and E100. The ethanol sensors used in the E85 versions are replaced in this technology by an advanced software component in the engine's electronic control unit. This uses inputs from conventional oxygen sensors in the exhaust system (lambda sensors) and self-calibrates the engine to fuel requirements. This technology has proved feasible in Brazil in large part because the warm climate allows blending of hydrous ethanol to E20/E25 without the risk of phase separation. E100 FFVs have become a sales phenomenon since their introduction in the Brazilian marketplace, in part because E100 is significantly less expensive than E20/E25 in much of the country (WWI 2006).

Dedicated ethanol vehicles are even more efficient in using pure ethanol due to better combustion characteristics than FFVs which must retain dual-fuel capability. In these engines the compression ratio is increased. According to WWI (2006), the average fuel consumption has been 25 % lower than for equivalent E20/E25 fueled versions. Most experience with this technology is made in Brazil, again. Volkswagen, Fiat, General Motors, and Ford have all produced dedicated ethanol versions for more than 25 years, with full warranty coverage.

5.4.2 Compression Ignition Engines

Compression ignition engines, also called diesel engines, are internal combustion engines in which the fuel is ignited by high pressure and temperature, rather than by a separate source of ignition, such as a spark plug, as is the case in the spark ignition engine. The German pioneer Rudolf Diesel invented this type of engine in 1892. He also demonstrated that this engine is running with peanut oil, too. Originally, compression ignition engines are designed for being fuelled with diesel. Nevertheless also ethanol can be combusted in these engines, but this application is limited.

For example, since ethanol is difficult to ignite in a compression ignition engine, one option is to blend it with an additive to enhance fuel ignition. Therefore, 5 % of the additive “Beraid” is mixed with 95 % hydrous ethanol. Experiences with approximately 500 urban buses using this fuel mixture for compression ignition engines have been made in Sweden. In October 2007, the first E95 bioethanol bus has been introduced in Brazil (JANSSEN et al. 2007). Also the engine has to be refitted e.g. in that the compression ratio and the volumetric capacity of the fuel pump are increased. The use of material that is compatible to ethanol is a precondition for using ethanol in engines as well.

Another option for using ethanol in standard compression ignition engines is to blend ethanol with diesel. It has been shown that a good compromise in terms of fuel economy, performance, drivability and emissions can be achieved when diesel is blended with about 7 % ethanol (WWI 2006). Other approaches of using ethanol in diesel engines are either to use diesel and ethanol simultaneously by “fumigation” or to convert the diesel engine into a spark ignition engine.

5.4.3 Fuel Cells

Although the use of bioethanol in fuel cells is not yet commercially viable, technical applications of ethanol in so called direct-ethanol fuel cells (DEFC) is possible. DEFC systems are a subcategory of proton-exchange fuel cells, also known as polymer electrolyte membrane fuel cells (PEMFC). Their distinguishing features to other fuel cells include lower temperature/pressure ranges and a special polymer electrolyte membrane. When bioethanol is applied to these fuel cells, ethanol is not reformed, but fed directly to the fuel cell.

Using bioethanol in DECF applications has several advantages. As it is fed directly into the DEFC, complicated catalytic reforming is not needed. Further, storage of ethanol is much easier than that of hydrogen which is usually used for fuel cells. Storage of liquid ethanol does not need to be done at high pressures, as it is needed for hydrogen, which is a gaseous fuel under normal conditions. Thus, the use of ethanol would overcome both the storage and infrastructure challenge of hydrogen for fuel cell applications. Additionally, the energy density of ethanol far greater than even highly compressed hydrogen.

Besides the use of ethanol in DEFC technologies, vehicles could also be equipped with multi-fuel on-board reformers. These devices could continuously generate hydrogen out of ethanol and would enable vehicles to use a combination of conventional and lower-cost fueling systems. Alternatively, commercial-size multi-fuel reformers could generate hydrogen from biofuels on-site at retail stations, avoiding costly hydrogen distribution infrastructure (WWI 2006 p. 223).

5.5. Standardization of Bioethanol

European Union

The use of ethanol as transport fuel is growing in Europe during the last few years. Parallel to this development the need for specifications and standards raised on European level.

Since recent times there was no European standard, neither on the utilization of additives in ethanol, nor on ethanol as fuel itself. Consequently the European Commission has inter alia mandated CEN/TC 19 (Comité Européen de Normalisation - Technical Committee 19) to produce a standard on ethanol for blending with petrol. This standard **prEN 15376** "Automotive fuels - Ethanol as a blending component for petrol - Requirements and test methods" is currently under approval and will be issued most probably in October 2007. A first draft is already publicly available. Since the Swedish market is the most established ethanol market in the EU, Swedish stakeholders actively participate in the creation of this standard (ATRAX ENERGI 2005). In parallel the European standard for gasoline, **EN 228**, has been adapted to allow a maximum content of 5 % ethanol.

As mentioned before CEN/TC/19 has set up a "New Fuels Coordination Group", which has the task to advise CEN/TC 19 on "feasibility and time frames of promising alternative liquid and gaseous fuels for transport and stationary applications". The first report of the New Fuels Coordination Group was issued in January 2006 (CEN/TC 19 N1252). In this report standardization work on 10 % ethanol in EN 228 gasoline was given high priority, but only if the Fuels Directive will allow this (WOLDENDORP 2006).

Under the auspice of CEN, a Workshop Agreement on ethanol for use in Flexible Fuel Vehicles (E85, 85 % ethanol and 15 % gasoline) has been developed (Workshop No 14 on 12.06.2003). Swedish stakeholders actively participate in this work. Furthermore the Swedish standard Institute (SIS) has started working, on initiative from the Swedish stakeholders, to produce a Swedish standard for E85 based on the Workshop Agreement (ATRAX ENERGI 2005).

On a national level Sweden does not have a national standard for fuel ethanol. But the Swedish Standardization Group (STG) decided in 1997 a Swedish standard (SS) on Alcohols for diesel engines, "Motor fuels – Fuel alcohol for high-speed diesel engines", **SS 155437** in response to a growing demand for a standard on the use of neat ethanol in diesel engines. This standard includes not only ethanol, but also methanol, under the common name "Alcohols". A high-speed engine is defined in the standard as an engine with at least 16 revolutions per minute, at maximum performance (ATRAX ENERGI 2005). The standard furthermore specifies limits, regulations and guidelines for alcohols (ethanol and methanol) to be used as vehicle fuel in high-speed diesel engines. Following properties are addressed by this standard:

- Sampling
- Test methods
- Minimum content of alcohol (ethanol or methanol) (%)
- Maximum content of other alcohols (%).
- Density (kg/m³).
- Ash content (%)
- Acidity
- Water content (%)
- Flammability (C)
- Content of aldehydes (%)
- Content of esters (%)
- Content of lead (mg/l)
- Content of phosphor (mg/l)

As there is no official Swedish standard on ethanol for petrol engines, some Swedish manufacturers guarantee product norms for ethanol. Agroetanol AB and Sekab Svensk Etanolkemi AB are the two main providers of fuel ethanol in Sweden. Sekab Svensk Etanolkemi AB markets two different kinds of fuels:

- **ETAMAX D** is a neat bioethanol fuel for use in diesel engines, mainly busses. It consists of ethanol (92.2 mass%), ignition improver (5 mass%), MTBE (2.3 mass%), iobutanol (0.5 mass%), and corrosive inhibitor (90 ppm).
- **ETAMAX B** is a mix of gasoline and bioethanol for Flexible Fuel Vehicles. It consists of ethanol (86 mass%), gasoline (11.6 mass%), MTBE (2 mass%), and isobutanol (0.4 mass%).

In addition to these two product norms Sekab Svensk Etanolkemi AB also specifies the ethanol which is used in these two fuel norms. Two "**Sekab Sales Specifications for Technical Ethanol**", 95 % and 99.5 % are offered and currently serve as industry standard (Table 7) (VONA et al. 2004). Sekab Svensk Etanolkemi AB also guarantees the properties shown in Table 8 although they are not tested on each delivery.

The guaranteed but not regularly tested specifications are selected by the supplier and not discussed by the industry, but some such as methanol and fusel oil may be included in the future EU standard.

Table 7: Sekab 99.5% Ethanol specification (www.sekab.se)

Property	Specification	Test method
Ethanol content, %vol (min)	99.8	AMSE 1112
Density, g/ml (max)	0.790	SS-ISO 758
Appearance	Clear, without particles	ASTM D 2090
Color, Hazen (max)	5	AMSE 1102
Water, %mass (max)	0,3	SS-ISO 760
Aldehydes (as acetaldehyde), %mass (max)	0.0025	AMSE 1118
Acidity (as acetic acid), %mass (max)	0.0025	AMSE 1114

Table 8: Additional specification for Sekab 99.5% Ethanol (www.sekab.se)

Property	Specification	Test method
Distillation Interval: - Starting point °C (min) - Drypoint °C (max)	77 81	ASTM D 1078
Flashpoint °C	+12	SS-EN 22719
Fusel Oil, mg/l (max)	50	AMSE 1136, GC-method
Methanol, mg/l (max)	20	AMSE 1135, GC-method
Explosion limits, %vol air	3,5 - 15	Accepted from literature
Refractive Index, n_D20	1,3618	Accepted from literature
Evaporation residue, mg/l (max)	10	AMSE 1124

Besides the large efforts on standardization of bioethanol in Sweden, also Poland has introduced a national standard for anhydrous ethanol as fuel: **PN A 79521**. It is based on the US ASTM D 4806 standard. The Polish standard will be replaced, once the European standard has been finalized.

Regarding the standardization of bioethanol, it is worth looking beyond the European Union to other countries like Brazil and USA.

USA

The US industry standard for ethanol is **ASTM D 4806** "Standard Specification for Denatured Fuel Ethanol for Blending with Petrol for Use as Automotive Spark Ignition Engine Fuel" by the American Society for Testing and Materials (ASTM). The purpose of this ASTM specification is to provide parameters so that petrol and petrol oxygenate blends will perform satisfactorily in as wide a range of consumer vehicles as possible. The ASTM has followed the premise that the only ethanol to be used in the marketplace as a gasoline extender will be denatured, and hence the specification D 4806 is for denatured fuel ethanol only (VONA et al. 2004).

A separate ASTM specification **ASTM D 5798** “Specification for Fuel Ethanol (Ed75-Ed85) for Automotive Spark-Ignition Engine Fuel” applies for fuel ethanol to be used in specially designated vehicles as a petrol substitute. This Ed75-Ed85 fuel ethanol is produced from ethanol complying with the ASTM D 4806 standard, and contains additional specifications for parameters applicable to vehicles designed to operate with high percentages of ethanol in their fuel. Additional parameters specified include hydrocarbon volume (as opposed to small amounts of hydrocarbon denaturant in the ethanol standard), vapor pressure, lead, phosphorus, sulfur, and total and inorganic chloride. The limits of several parameters are also different than the ethanol standard, which is understandable since the fuel is comprised of up to 30 vol% of hydrocarbons. (VONA et al. 2004)

The 15 % petrol (and 25 % petrol during winter) in the ASTM D 5798 standard specification for fuel ethanol are required to increase the fuel volatility and prevent engine cold-start difficulties. An additional benefit is one of safety, since ethanol burns with a colorless blue flame making it more difficult to detect a fire in the engine system, whereas the presence of hydrocarbons would result in a clearly visible flame. (VONA et al. 2004)

Brazil

Brazil is the world leader in the production and utilization of bioethanol. Ethanol production capacity in Brazil is of the order of 16 billion liters per year. The primary feedstock is sugar from sugarcane.

The National Petroleum Agency (ANP) set specifications for both hydrous and anhydrous fuel ethanol. The test methods specified are from the Brazilian Association of Technical Standards (NBR) and American Society for Testing and Materials (ASTM).

Australia

Besides these fuel quality standards in the US and in Brazil, also in Australia a quality standard for bioethanol is planned. In July 2005, the Department of Environment and Heritage of the Australian Government released a Government position paper for a quality standard for fuel grade ethanol (AUSTRALIAN GOVERNMENT 2005). The objective of this position paper was to inform stakeholders and generate a stakeholder discussion on a suitable quality standard. The call for comments on this paper closed on 17 August 2005.

5.6. Energy Balance of Bioethanol

The energy balance of bioethanol depends on the energy input for processing bioethanol during the life cycle in comparison to the energy content of the final fuel. Typically, life cycles of different biofuels can be very different and depend on feedstock type, agricultural practices, regional feedstock productivity, process technology, and final driving efficiency. Therefore attention has to be paid when using data about energy balances of ethanol. Generally they are valid only for dedicated cases which can vary considerably. Although there exist studies in which the energy balance of different methods of bioethanol production are analyzed and evaluated, in many of these studies assumptions and data on agricultural and industrial conversion technologies are not updated (SCHMITZ et al. 2005). More recent studies are based on new technologies. An extensive overview about these studies are given and compared by SCHMITZ et al. (2005).

However, examples of current energy balances of bioethanol from different feedstock sources are shown in Table 9 and compared to the energy balance of fossil petrol. As described in chapter 4.1, energy balances are drawn up to illustrate the relationship between the input of fossil energy necessary for the production of the energy carrier and the usable energy contained. The energy balance is better, the higher the value.

Table 9: Estimated fossil energy balances of selected fuel types from several studies (summarized by WWI 2006 p. 136)

Fuel type (feedstock)	Estimates of Fossil Energy Balance
Ethanol (cellulose)	2 - 36
Ethanol (sugar cane)	~ 8
Ethanol (wheat)	~ 2
Ethanol (sugar beets)	~ 2
Ethanol (corn)	~ 1.5
Ethanol (sweet sorghum)	~ 1
Petrol (crude oil)	~ 0.8

The best energy balances are received for bioethanol from sugar cane. It is only exceeded by ethanol made from cellulosic feedstock, but the technology is not yet in commercial operation. Significantly, all types of bioethanol not only have better energy balances than fossil petrol, but even have energy balances larger than one.

SCHMITZ et al. (2005) investigated and analyzed several studies for energy balances of ethanol by using absolute values in MJ/l instead of output/input ratios. They found that in older studies the energy input for producing one liter ethanol is between 21 and 36 MJ/l. Since the energy content of one liter ethanol is 21.2 MJ/l, the result of most of these studies showed a negative net energy balance (based on absolute values). The fault of these studies was that co-products were not considered. In contrast to these older studies, SCHMITZ et al. (2005) show that more recent studies are based on actual technical developments and assume lower energy inputs between 18 and 29 MJ/l. The IEA even predicts energy inputs of 13 MJ/l for future technologies.

In comparison to ethanol, the energy input of producing petrol is 26.1 MJ when referred to the energy content of one liter ethanol (21.2 MJ is equivalent to 0.647 l petrol) (SCHMITZ et al. 2005 p. 118). This means that, depending on the different production paths of ethanol, up to 23 MJ could be saved per liter ethanol when substituting petrol with ethanol. Regarding the energy balance, in future bioethanol is becoming even more advantageous to fossil fuel mainly due to improvements of feedstock production and conversion processes. On the other hand, energy balance of crude oil is getting worse as oil production is becoming more difficult due to shrinking crude oil fields.

5.7. Bioethanol Emissions

5.7.1 Greenhouse Gas Emissions

As it was described in chapter 4.2.1, one of the major drivers of biofuel promotion worldwide is the concern about climate change and the potential of biofuels to reduce GHG emissions. Although it is incontestable that the use of bioethanol is able to reduce GHG emissions significantly when compared to fossil fuels, assessments of quantified GHG reductions are useful and necessary. However, the GHG balance for bioethanol is highly variable and includes emissions of cultivation, transport, conversion process and distribution. Further, the GHG reduction potential depends on type of feedstock, agricultural practices, site productivity, conversion technology, and finally on the whole design of the study.

Detailed summaries of studies, indicating GHG reductions by using neat or blended bioethanol, are given by WWI (2006 p.152) and OECD/IEA (2004 p. 53ff). They show reductions of up to 96 % for anhydrous bioethanol in Brazil (MACEDO et al. 2003). Generally, ethanol produced from **sugar cane** grown in Brazil shows one of the greatest benefits. This is confirmed by several studies which all have found that emission reductions of sugar cane ethanol in Brazil far exceed those from grain-based ethanol produced in Europe and the United States. KALTNER et al. (2005) estimate that the total life-cycle GHG emissions reductions associated with the ethanol industry in Brazil are equivalent to 46.6 million tons annually. These are approximately 20 % of Brazil's annual fossil fuel emissions. This is due to high site productivity in Brazil and its favorable climate for sugar cane, which is highly productive and only needs low inputs of fertilizer. Additionally almost all conversion plants use bagasse for process energy which also reduces GHG emissions. Many plants also co-generate heat and electricity. Well-to-wheel CO_2 emissions of sugar cane-ethanol are estimated to be, on average 0.20 kg per liter of fuel used, versus 2.82 kg for gasoline. These figures based on CO_2 also take methane and N_2O emissions into account (both mainly released from farming, from the use of fertilizers and from N_2 fixed in the soil by sugar cane then released to the atmosphere) (OECD/IEA 2004 p. 61).

Apart from sugarcane, other combinations of biofuel feedstock and conversion processes can reduce well-to-wheels CO_2-equivalent GHG emissions to near zero, too. An example therefore is enzymatic hydrolysis of **cellulose** where ethanol is produced and biomass is used as process fuel (OECD/IEA 2004 p. 51).

In contrast, ethanol from **corn** shows very small GHG reductions within all potential feedstock options (WWI 2006 p. 153). Using commercial processes, the use of ethanol derived from grains, brings a 20% to 40% reduction in well-to-wheels CO_2-equivalent GHG emissions, compared to gasoline (OECD/IEA 2004 p. 52).

For Europe, ethanol production from **sugar beets** is important, due to its high dominance in several European countries. Some European studies, which are summarized by OECD/IEA (2004 p. 58f), show that this feedstock and conversion process can provide up to a 56% reduction in well-to-wheels GHG emissions, when compared to gasoline.

Nevertheless, some results (WWI 2006 p. 153) point out that using ethanol to make ETBE results in even greater GHG savings than blending ethanol directly with gasoline. This is because ETBE replaces MTBE, which has relatively high energy demand, whereas ethanol replaces gasoline, which requires less energy for production than does MTBE.

5.7.2 Toxic Exhaust Emissions

The major part of engine exhaust streams during ethanol combustion consists of the components nitrogen, carbon dioxide and water. All three components are non-toxic to human health. However, about 1.4% of petrol engine exhaust emissions are composed of more or less harmful substances to human health (MITTELBACH & REMSCHMIDT 2004 p. 185).

Apart from the above mentioned emissions, fuel combustion emits particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NO_x), carbon monoxide (CO) and a variety of other toxic air pollutants. VOCs and NO_x are precursors for tropospheric ozone. Momentary weather conditions and local geographic characteristics influence the impact of these air pollutants. Ozone formation e.g. occurs more easily during hot weather. Also toxic air pollutants are more evident under hot weather conditions. They can be emitted either by the engine exhausts or by evaporation from fuel storage and fuel handling since ethanol has high volatility and generally increases evaporative emissions of gaseous hydrocarbons. As opposed to this, carbon monoxide is a larger problem in cold weather and at high altitudes.

To asses the environmental impact of substituting petrol with ethanol, both fuels have to be compared regarding their emissions. Therefore a detailed comparison between emissions of ethanol and petrol combustion will be done.

Harmful engine exhaust emissions from combustion of ethanol are generally lower when compared to the tailpipe emissions of fossil petrol. Thus ethanol can reduce certain vehicle pollutant emissions which exacerbate air quality problems, particularly in urban areas.

Among the biggest benefits from using ethanol is the high reduction potential of **carbon monoxide** (CO) emissions. The use of E10 is reported to achieve a 25% or greater reduction in carbon monoxide emissions due to the increased oxygen content of ethanol (OECD/IEA 2004 p. 112). Ethanol contains approximately 35 % oxygen which promotes a more complete combustion of the fuel. Thus, in some countries, ethanol is used as oxygenate for fossil petrol and is increasingly replacing the oxygenate MTBE due to the high ground water contamination potential of MTBE.

On the other hand ethanol-blended petrol emits higher evaporative hydrocarbons (HC) and other **volatile organic compounds** (VOCs) than petrol. When ethanol is added to gasoline, evaporative VOCs can increase due to the higher vapor pressure, measured as Reid Vapor Pressure (RVP) of the ethanol mixture. Generally, adding the first few per cent of ethanol triggers the biggest increase in volatility. Raising the ethanol concentration further does not lead to significant further increases (and in fact leads to slight decreases), so that blends of 2%, 5%, 10% and more have a similar impact (OECD/IEA 2004 p. 113).

Impacts of ethanol on **nitrogen oxides** (NO_x) are generally minor, and can either be increased or decreased, depending on conditions. NO_x emission from combustion of ethanol blends range from a 10% decrease to a 5% increase over emissions from gasoline (OECD/IEA 2004 p. 114). However, if the full life cycle of ethanol is considered, NO_x emissions can be significantly higher mainly due to emissions from feedstock production. NO_x is released from fertilizers used to grow bioenergy crops, and is emitted mostly outside urban areas.

When gasoline is blended with ethanol, emissions of most toxic air pollutants decrease. This is primarily due to the dilution effect of ethanol which substitutes some part of gasoline, which emits toxic air pollutants. For instance, toxic emissions of **benzene**, **1,3-butadiene**, **toluene** and **xylene** decrease when ethanol is added. Benzene is a carcinogen, while olefins and some aromatics which are emitted by the combustion of fossil fuels as well, are precursors to ground-level ozone. While few studies have looked at the impacts on pollution levels from high blends, it appears that impacts are similar to those from low blends (WWI 2006 p. 193).

The above mentioned toxics benzene, 1.3-butadiene, toluene and xylene, which are emitted by the combustion of fossil fuels, are considered to be more dangerous than emissions of ethanol combustion. During ethanol fuel combustion, emissions of the toxic air pollutants **acetaldehyde**, **formaldehyde**, and **peroxyacetyl nitrate** (PAN) increase relative to straight gasoline. Acetaldehyde is emitted most, but it is a less-reactive and less-toxic pollutant than formaldehyde. PAN is an eye irritant and is harmful to plants. No one of these pollutants is present in the unburned fuel, as they are only created as byproducts of incomplete combustion (WWI 2006 p. 193; OECD/IEA 2004 p. 114). Nevertheless, impacts of acetaldehyde and PAN seem to be minor as emissions are relatively low compared to other sources and as they can be efficiently removed by a vehicle's catalytic converter (ARNOLD et al. 2005 p. 32).

Strict emissions control standards for cars and trucks will tend to mute the air quality impacts of bioethanol, since manufacturers are required to build vehicles that meet these standards under a range of conditions.

5.8. Sustainability of Bioethanol

Determining the direct environmental effects of ethanol production is complex. Environmental effects of using bioethanol vary, depending on the fuel itself, vehicle technology, vehicle tuning and driving procedure. Also agricultural production practices and the design of ethanol production plants differ largely. In this chapter the main environmental problems of ethanol production and use are demonstrated.

5.8.1 Water Issues

Water issues are an important concern of both, ethanol processing and use of ethanol. In a first step, the water consumption of ethanol processing will be discussed. This will be followed by a discussion about water contaminating impacts of ethanol which is spilled and leaked unburned.

The **water consumption** for the production of bioethanol is considerably high. Thereby, much water is used for feedstock production. The amount of water used for agriculture depends on the humidity / aridity of the cultivated region and on the water demand of the feedstock type. But also for the conversion process much water is needed. The quantity of water needed for the ethanol production process depends on the design of the production plant. Modern technology and design can substantially reduce the amount of fresh water needed by a stand-alone ethanol plant. There is “zero discharge” plants in operation that recycle virtually all of the water used in production, limiting the need for large supplies. Most plants are designed with “in-house” water treatment systems for supply and discharge. However, there are always three water uses in a typical ethanol plant. The first water use in a typical ethanol plant is non contact water, primarily used for cooling. The second use is for liquefaction of the feedstock. Water must be clean and treated so that there is no microbiological contamination in the fermentation process. Thirdly, ethanol processing also results in large volumes of nutrient-rich waste water that, if not cleaned and recycled, can speed eutrophication of local rivers and streams by affecting the water’s dissolved oxygen content. In addition, sugar mills must be flushed every year, putting huge amounts of organic matter into local waterways (WWI 2006 p. 189).

Apart from the water consumption during the ethanol production process, **water contamination** impacts of released ethanol are an important environmental issue as well. Since ethanol is a naturally occurring substance produced during the fermentation of organic matter it is expected to rapidly biodegrade in essentially all environments (ULRICH 1999). Thus pure ethanol poses no threat to surface water and ground water and is much less harmful in case of spilling and leakage compared to fossil fuel which is highly toxic. When gasoline, which is blended with ethanol, contaminates soil or water, ethanol is the first component to quickly, safely, and naturally biodegrade. At the same time, studies have shown that the rapid breakdown of ethanol depletes the oxygen available in water and soil, actually slowing the breakdown of gasoline. This may increase the impact of petrol spillage on the environment in two ways. First, the harmful chemicals in gasoline persist longer in the environment than without ethanol. Second, as gasoline breaks down more slowly, it can travel farther (up to 2.5 times) in the marine environment, affecting a greater area (WWI 2006 p. 192). Although these effects of ethanol-gasoline mixtures are negative to the environment, it also has to be considered that the total percentage of petrol released to the environment is reduced by the percentage of harmless ethanol. Depending on the blended percentage, this is a great advantage of gasoline which is highly blended with bioethanol.

Attention has to be paid, if ethanol is spilled to previously contaminated soils as it can remobilize the gasoline. Since this problem is most likely to happen concentrated at gasoline terminals, it can easily avoided with precautionary measures. Therefore regulations for the handling with both fuels have to be applied.

5.8.2 Land Use and Biodiversity

Bioethanol production can have positive and negative impacts on current land use and biodiversity. Thereby feedstock production has to be discussed in more detail, including both, quality and quantity of land use.

The **quality of land use** practices strongly influences habitat and biodiversity aspects, as well as soil, water and air quality. The impacts depend on a variety of factors such as the choice of feedstock, what the feedstock replaces and how it is managed (WWI 2006 p. 168).On the one hand, land use for ethanol production offers the potential to reduce the environmental load relative to conventional agriculture. Farming practices can be adjusted to maximize total energy yield rather than the oil, starch or sugar contents of crops. This can diversify plant varieties and reduce chemical inputs. For example, corn grown for fuel would not need the same pesticide usage as for food, since consumer reaction to corn as a food (not crop productivity) is the main reason for prolific pesticide applications. Especially second generation feedstock, such as cellulose for ethanol production, can contribute to diversify current agriculture. On the other hand, feedstock production can cause severe environmental problems which can be the most environmentally disruptive stage of total ethanol production. For instance improper and massive use of pesticides and fertilizers could negatively affect ethanol production. This might be a problem especially in countries with low sustainability standards.

Regarding the **quantity of land use**, considerable amounts of agricultural land have to be cultivated for feedstock production. The key factors in determining how much land is needed to produce bioethanol are crop yields and the resulting ethanol yields. Crop yields are usually measured in kilogram or tons per hectare and ethanol yields are measured per ton of crop input and consequently in liter per hectare.

Average **crop yields** vary considerably due to the cultivated region, climate, weather condition and time. Nevertheless, both agricultural yields and conversion yields have been slowly but steadily improved in the most regions. It appears likely that yields in most regions will continue to improve in the future, at an overall rate of some 1% to 2% per year in terms of liters of biofuels per hectare of land (OECD/IEA 2004 p.126). **Ethanol yields** per hectare are generally far greater than of biodiesel. Typical average yields of ethanol are 5 500 liters per hectare for sugar beets in the EU and even up to 6 500 liters per hectare for sugar cane in Brazil (OECD/IEA 2004 p.127).

If ethanol production is dramatically expanded in the future, the cropland requirements could become quiet significant and puts limits on biofuel production potential. Therefore degraded lands, wastelands and set-aside lands can be further used for feedstock production. This would also support agriculture by using the distribution channel of feedstock for ethanol production. On the other hand some set-aside lands are very useful habitats for several plant and animal species and therefore the biodiversity would be reduced if all set-aside land would be used for ethanol production.

Another solution of enhancing the limited availability of feedstock for ethanol in the European Union would be to make imports from other countries. But there is some concern that through irresponsible farming methods some rainforest areas and other ecosystems could be cleared to make land available for growing crops for commercial commodities such as sugar cane. For example during European colonization of tropical regions such as the Caribbean, diverse ecosystems were already destroyed by early sugar plantations. Even today the danger of destroying natural ecosystems is still present.

In Brazil, the expansion of sugar cane production via large monocultures has replaced pasturelands and small farms of varied crops. In the future, the Cerrado, a largely wild central savanna that covers more than one-quarter of Brazil's land area, is prone to the expansion of sugar cane production. The Cerrado is home to half of Brazil's endemic species and a quarter of its threatened species. This expansion could irreversibly destroy the unique complex ecosystem.

5.8.3 Human Health

Ethanol is an important component of alcoholic beverages. It has been part of the human diet and the human environment for thousands of years. In low quantities and concentrations it is not harmful to human health, but pure or highly concentrated ethanol can permanently damage living tissue. Pure ethanol is a tasteless liquid with a strong and distinctive odor. It produces a characteristic heat-like sensation when brought into contact with the tongue or mucous membranes.

Although low quantities of ethanol are not toxic to human health, concerns about the possible health consequences of using ethanol as transport fuel have been raised. These concerns mainly include the inhalation of ethanol vapors by using ethanol pure or blended in transport applications. Prediction of blood ethanol concentrations (BEC) following exposure to ethanol vapors must consider several factors: (a) the concentration of ethanol in air, (b) the duration of exposure, (c) breathing rate, (d) absorption of ethanol across the lungs, and (e) the body's elimination rate of ethanol. Nevertheless, it is highly unlikely that exposure to airborne ethanol associated with gasoline use could produce toxic effects. The reasons for this are the tiny doses that might be received and the body's rapid elimination of ethanol (ARMSTRONG 1999). For instance, ethanol vapors might be inhaled at gasoline stations while fueling vehicles, but this exposure would be relatively brief, no more than five minutes. However, workmen of petrol stations can be exposed to vapors for many hours, since these vapors are released to the ambient air of the fuel station.

Another concern for human health of using ethanol as fuel could be toxic emissions by the combustion process. But as it was already shown in chapter 5.7.2, the fuel is low in sulfur and aromatic compounds, and thereby it considerably reduces the emissions of the gases that are harmful to the climate and human health. Harmful engine exhaust emissions from combustion of ethanol and ethanol blends are generally lower when compared to the tailpipe emissions of fossil petrol.

5.9. Economy of Bioethanol

The economy of bioethanol mainly depends on its production costs and on policy frameworks, but it is also influenced by positive and negative external effects. These cost-related issues will be discussed first and then followed by a market overview of bioethanol.

The **ethanol costs** for the production of bioethanol from starch and sugar crops vary considerably with the wide range of crop types, agricultural practices, land and labor costs, conversion plant sizes, processing technologies and policies in different regions and countries. Therefore Brazil is the lowest-cost producer of ethanol. This is a result of lower input costs, relatively large and efficient plants and the inherent advantages of using sugar cane as feedstock (OECD/IEA 2004 p.68).

Figure 20: Price difference (October 2007) of more than one Real between petrol (gasolina) and bioethanol (alcool) in Rio de Janeiro, Brazil

However, the major cost component for the production of bioethanol from starch and sugar crops is the feedstock costs. Also costs for processing are high. They represent about one-third of total cost per liter, of which the energy needed to run the conversion facility is an important and in some cases quite variable component. This can be reduced by using co-products for process-heat as it is broadly done with bagasse in Brazil. In addition a visible amount of co-products can be sold for several purposes, but mainly as an animal feed. For example the co-product distillers dried grains soluble (DDGS) represents a high value and protein rich feed consisting of wheat mash. Another cost factor is the costs for capital cost recovery which represents about one-sixth of total cost per liter (OECD/IEA 2004 p.68f). When bioethanol production is compared to biodiesel production, the production scale of ethanol has a significant higher impact on overall costs. Large plant sizes may reduce fuel costs up to 25 % over a small plant.

An example for a detailed cost calculation over the whole life cycle of bioethanol production is given by IGELSPACHER (2003) for Germany. Thereby especially tax incentives and the agricultural subsidies for set-aside land largely contribute to the competitiveness of bioethanol in Germany. Today the competitiveness of bioethanol still largely depends on the national **policy frameworks** such as legislation and subsidies in EU member states. Subsidies can be both agricultural aids and market incentives for the biofuel itself. Tax exemptions also have considerable impacts on end-user costs for bioethanol.

Generally biofuels offer large economic advantages over fossil fuels, but direct cost comparisons are difficult since **external effects** are often neglected and underestimated. Negative externalities associated with fossil fuels tend to be poorly quantified. The most important negative externalities among others are military expenditures and costs for health and environment. However, biofuels have the potential to generate many positive externalities, such as reduced greenhouse gas emissions, decreased air pollution, and job creation. Additionally biofuels decrease dependency from crude oil imports. Consequently biofuels are a more socially and environmentally desirable liquid fuel, a fact that is often neglected in direct-cost calculations. Therefore biofuels often look uncompetitive although a biofuel market may actually provide long-term economic benefits when comparing environmental and social costs (WWI 2006 p. 91f).

A short **market overview** of bioethanol production in the European Union is given by the EUROBSERV'ER (2006) which will be shortly summarized in this section. With 18.5% of biofuel production bioethanol is the number two biofuel in the European Union. When compared to the biodiesel sector, the accounting of bioethanol is less precise for several reasons. Differences can be noted between figures announced by the two producer unions of ethanol, UEPA (European Union of Ethanol Producers) and EBIO (European Bioethanol Fuel Association) and those figures announced by certain governments. A second difficulty consists in determining the share of bioethanol produced from wine alcohol at the different national levels. In the framework of Community wine management, the European Commission buys and sells wine alcohol on the European market to be transformed into bioethanol. The alcohol can thus be produced in one country, transformed into bioethanol in another country and then sold again on the market in a third country. Figure 21 shows the state of bioethanol production including wine alcohol in EU countries. The total bioethanol production can be estimated 2006 in the European Union at 720 927 tons, i.e. an increase of 70.5 % over 2004. This growth is due in part to doubling of bioethanol production from Community wine alcohol and due to high production increases on country level. For instance it has been multiplied by six in Germany up to a total of 120 000 tons. Growth has also been significant in Spain, with production estimated at 240 000 tons. The increase in bioethanol production can also be explained by the appearance of new producer countries like Hungary (11 840 tons), Lithuania (6 296 tons) and the Czech Republic (1 120 tons) (EUROBSERV'ER 2006).

Worldwide bioethanol plays the most important role as an alternative fuel which is mainly produced in Brazil (59 %) and the USA (36 %) (ARNOLD et al. 2005 p. 13).

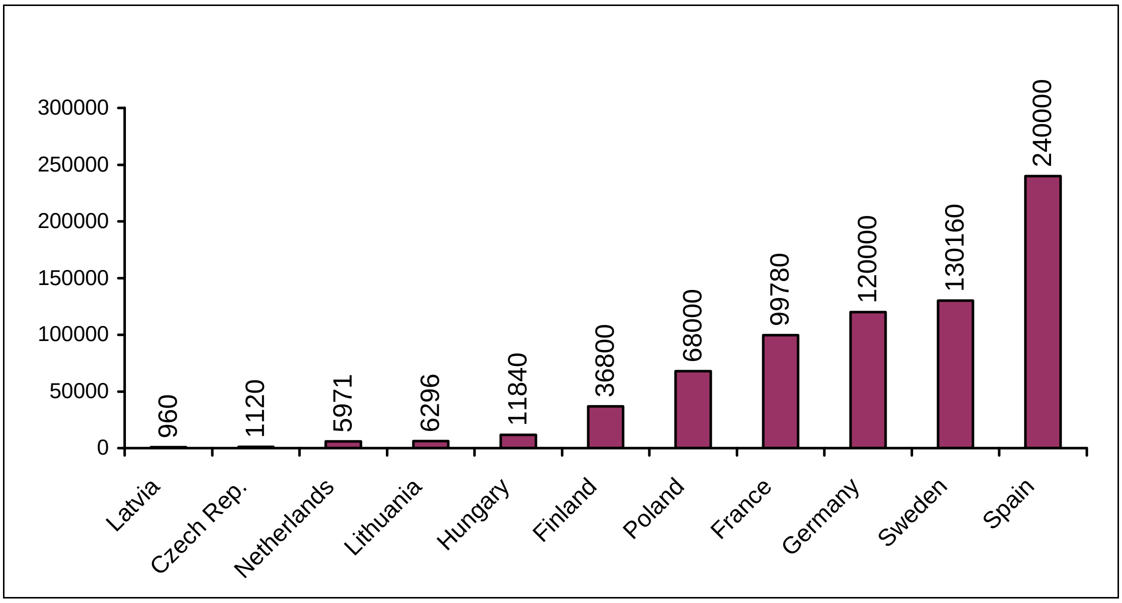

Figure 21: Ethanol production in the European Union in 2005 (estimates in tons) (EUROBSERV'ER 2006)

6. Lipid Derived Biofuels

A large portion of biofuels can be received from lipid sources. There exist mainly two types of fuels that are based on lipids: pure plant oil[17] (PPO) and biodiesel. Due to similar primary process steps of PPO and biodiesel, they are discussed in chapter 6 together under the title "lipid derived fuels". For example, feedstock production and oil extraction are the same process steps for both fuels. But, for the final production of PPO some additional purification steps are necessary, whereas for biodiesel the transesterification step has to be applied. Nevertheless, both end products (PPO and biodiesel) are completely different in properties. Therefore, properties, technology applications and standardization issues of PPO and biodiesel will be discussed in dedicated chapters. Horizontal aspects, such as energy balance emissions, environmental impacts end economics will be discussed in common chapters again.

6.1. Feedstock Production

There are many options for utilizing different feedstock types for PPO and biodiesel production. Besides dedicated oilseed crops such as e.g. rapeseed and soybean, also microalgae, animal fats and waste oil provide viable feedstock opportunities for fuel production. However, these last mentioned feedstock types are not yet used on a large scale today.

Figure 22 shows some examples for lipid feedstock sources. They can be sub-divided into palm fruits, algae, seeds and waste oil. Although the productivity of palm fruits is on of the highest, the most common feedstock sources for PPO and biodiesel production are seeds from various plants. These include seeds from ricinus, sunflower, peanut, sorghum, rapeseed, sorghum and jatropha. Detailed characteristics of these feedstock plants will be described in sub-chapters.

The choice for a dedicated feedstock is pre-determined by agricultural, geographical and climatic conditions. But it also has to be considered, that different feedstock types are characterized by different properties. For instance, the oil saturation and the fatty acid content of different oilseed species vary considerably. Biodiesel from highly saturated oils is characterized by superior oxidative stability and high cetane number, but performs poorly at low temperatures. Therefore, pure plant oil (PPO) with a high degree of saturation is more suitable as feedstock in warmer climates (WWI 2006 p. 26).

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[17] Although the name „pure plant oil" (PPO) refers to a vegetable origin, also oils from other resources, e.g. waste oil and animal fat, are defined by this term as it facilitates the further discussion. Nevertheless, it is evident to keep in mind that all types of oil have to fulfil certain requirements to be used in transport engines. In other publications PPO is also defined as „straight vegetable oil" (SVO).

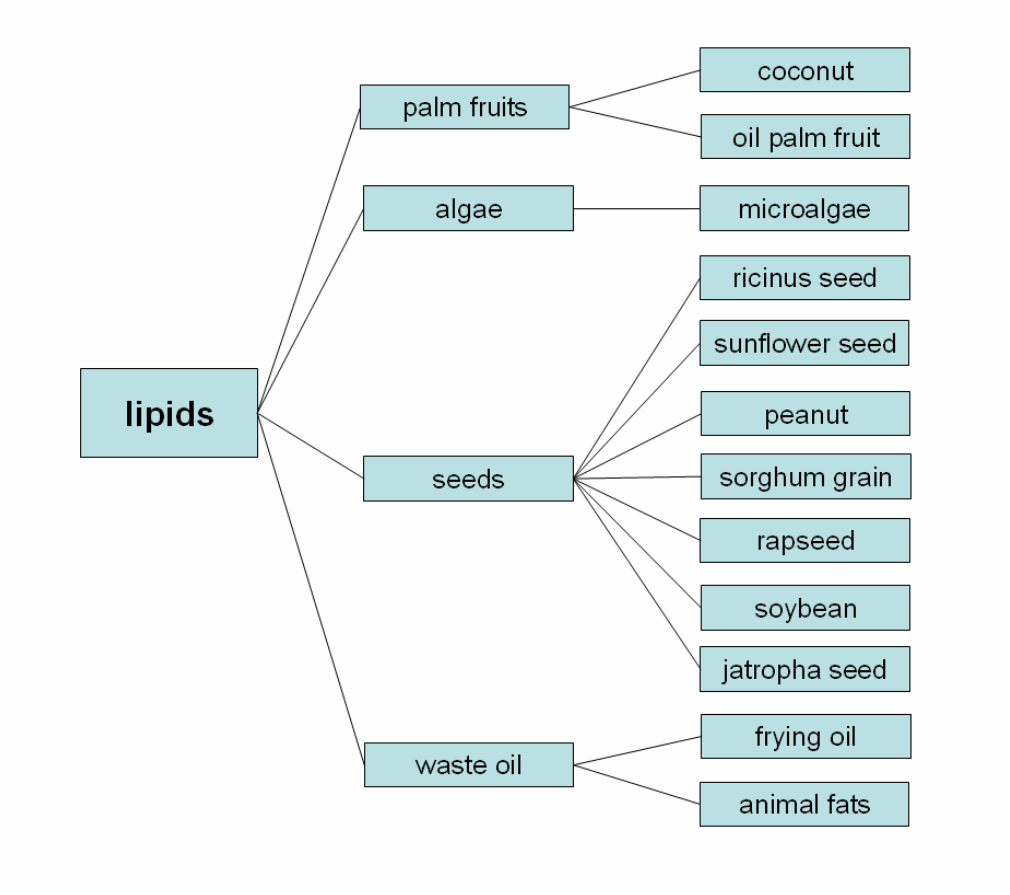

Figure 22: Types and classification of lipid feedstock sources (examples)

6.1.1 Oilseed Crops

For PPO and biodiesel production oilseed crops provide the primary feedstock. Of the major oilseeds cultivated today, soybean production is by far the world's largest, followed by rapeseed and cottonseed (WWI 2006 p. 26). The dominant feedstock used in PPO and biodiesel, however is rapeseed which is cultivated mainly in Europe. Nearly 85 % of biodiesel production is made from rapeseed, followed by sunflower seed oil, soybean oil and palm oil (MITTELBACH & REMSCHMIDT 2004 p. 9).

In temperate regions, oilseed crops typically generate lower yields per hectare than starchy cereal feedstock such as corn and wheat. But, since oil seeds require less processing, they generally have more favorable total energy balances. Thereby, particularly oilseed crops which are grown in tropical areas can be very productive (WWI 2004 p 26).

Rapeseed

Rape (*Brassica napus* L. ssp. *oleifera*), also known as canola or colza, belongs to the family of the *Brassicacea* and is closely related to other oil seed crops such as mustard species (*Brassica nigra*, *Sinapis alba*) and Gold-of-pleasure (*Camelia sativa*).

Rape is cultivated and sowed either in autumn (biennial) or in spring (annual). The plant has a long taproot and the stem can grow up to 1.5 m. The seeds are enclosed in pointed pots. Winter rape in Europe is harvested at the end of July with yields of 3 t/ha. Summer rape ripens in September and yields 2.1 t/ha.

To avoid the spread of plant disease, at least two years should be left between the cultivation of rapeseed and other cruciferous crops, such as broccoli, cauliflower, cabbage, and brussel sprouts. This restriction, along with soil quality considerations, tends to limit the expansion opportunities for rapeseed cultivation.

Figure 23: Rape seeds and rape in flower

Rapeseed oil is characterized by high levels of erucic acid (50 %), which may cause serious damage to heart and liver. Within the success of breeding, rape plants with reduced levels of these substances were created. Today most plants belong to “double zero” (00) varieties containing only low percentages of erucic acid.

Rapeseeds are characterized by high contents of monounsaturated oleic acid and low levels of both saturated and polyunsaturated acids. Therefore rapeseed oil is an ideal raw material regarding combustion characteristics, oxidative stability and cold temperature behavior (MITTELBACH & REMSCHMIDT 2004 p. 12).

Globally the cultivated area of rape is growing by 2 % annually. In China, the world’s largest rapeseed producer, the area planted is expanding rapidly. In India, the third largest producer, growth is minimal (WWI 2004 p 27).

In Europe, 1.4 million hectares of rapeseed were planted specifically for biodiesel use in 2005. About half of Europe’s biodiesel production was in Germany, but production in France, the Czech Republic, and Poland were also significant (WWI 2004 p 27).

Soybeans

Soy (*Glycine max*) is the dominant oilseed crop cultivated worldwide. Soybean oil is the most popular biodiesel feedstock in the USA. It is also the most frequently produced vegetable oil worldwide (MITTELBACH & REMSCHMIDT 2004 p. 14).

The main producing countries of soybean oil are the United States, Brazil, and Argentina, where this oil is increasingly being used for biodiesel production. This is primarily due to its prevalence, rather than its specific desirability as a biofuel feedstock. Soybean oil is characterized by iodine values of 121-143 $gI_2/100g$, which is similar to sunflower oil (MITTELBACH & REMSCHMIDT 2004 p. 14). Therefore it is discussed by experts if soybean oil can meet biodiesel standards.

Figure 24: Soy plant and beans (USDA 2006)

When compared to other oilseed crops, soy generates a relatively low yield of biodiesel per hectare. But soy can grow in both temperate and tropical conditions. Due to its ability of nitrogen-fixing, it also replenishes soil nitrogen. Relatively less fertilizer input is needed which favors a positive fossil energy balance. Soybeans are grown in rotation with corn in the United States and with sugar cane in Brazil. Only a small fraction of the soybean supply is currently transformed into fuels (WWI 2006 p. 28).

Palm oil

The oil palm (*Elaeis guineensis*) is one of the two palm trees (besides coconut palm) that are used for oil production, mainly in South Asian countries. The two largest producers are Malaysia and Indonesia, where palm oil production has grown rapidly over the last decade. Nigeria has the second largest planted area and high potentials are expected in Brazil.

While most palm oil is used for food purposes, the demand for palm biodiesel is expected to increase rapidly, particularly in Europe.

Figure 25: Fruit of palm oil tree (WIKIPEDIA 2006)

The Netherlands is the EU's largest importer of palm oil, followed by the United Kingdom. UK imports alone doubled between 1995 and 2004, to 914,000 tons, which represented 23 % of the EU total (WWI 2006).

The increasing imports of palm oil into the EU evoke the need of sustainability standards for the cultivation of this feedstock to avoid hazardous impacts in the producing countries. Nevertheless, the main advantages of palm oil are very high hectare yields and moderate world market prices today, compared to other edible vegetable oils.

Palm oil is characterized by high amounts of medium-chain saturated and monounsaturated fatty acids. High contents of saturated fatty acids are leading to unacceptable high values for cold filter plugging point (+11°C) and cloud point (+13°C) which prevents winter operation on neat palm oil methyl esters in temperate climates. Additionally, high contents of fatty acids in the feedstock cause problems in traditional alkali-catalyzed biodiesel production and thus necessitate deacidification or acid-catalyzed pre-esterification steps (MITTELBACH & REMSCHMIDT 2004 p. 15).

Coconut

The coconut palm (*Cocos nucifera*) is another feedstock source for oil production. Thereby the so-called copra is used. Copra is the dried meat, or kernel, of the coconut.

Coconut oil is a triglyceride containing high percentages of saturated fatty acids (86 %), and small amounts of monounsaturated fatty acids (6 %) and polyunsaturated fatty acids (2 %). Of its saturated fatty acids, coconut oil contains primarily lauric acid (45 %), myristic acid (17 %) and palmitic acid (8. %), though it contains seven different saturated fatty acids in total. Its only monounsaturated fatty acid is oleic acid while its only polyunsaturated fatty acid is linoleic acid.

Figure 26: Copra drying in the sun (WIKIPEDIA 2006)

Among the most stable of all vegetable oils, coconut oil is slow to oxidize and thus resistant to rancidity. Unrefined coconut oil melts at 20-25°C and smokes at 170°C (350°F), while refined coconut oil has a higher smoke point of 232°C (450°F).

This feedstock is favored in the biodiesel industry in the Philippines. It is another high yielding feedstock that produces highly saturated oil. Vehicles running on coco-biodiesel can reduce emission levels by as much as 60 % and increase mileage by 1–2 kilometers due to increase oxygenation, even with 1 % minimum blend (WWI 2006).

Sunflower

The oil of sunflower seeds (*Helianthus annuus*) is the world's fifth largest oilseed crop. After rapeseed it accounts for most of the remaining biodiesel feedstock in Europe. The yield of sunflower seeds per hectare is higher when compared to soybeans and similar when compared to rapeseed. Though slightly less productive than rapeseed, it is more accepted by the public due to its habit and it requires less water and fertilizer.

The high contents of linoleic acid limit the use of sunflower seed oil for fuel production. Additionally pure sunflower oil methyl esters have high iodine values not suitable as fuel. Pure sunflower oil fuels will also give poor ratings for oxidative stability. To solve the problems, cultivars enriched in oleic acid have been bred (MITTELBACH & REMSCHMIDT 2004 p. 13f).

Figure 27: Sunflower

Jatropha

Jatropha or physic nut (*Jatropha curcas*) is one of 150 *Jatropha* species in the family of the *Euphorbiaceae*. It is an oilseed crop that grows well on marginal and semi-arid lands. The bushes can be harvested twice annually, are rarely browsed by livestock, and remain productive for decades. Jatropha has been identified as one of the most promising feedstock for large-scale biodiesel production in India, where nearly 64 million hectares of land is classified as wasteland or uncultivated land. It is also particularly well suited for fuel use at the small-scale or village level (WWI 2006).

Figure 28: Jatropha curcas fruits (TROPILAB 2006)

The economic viability of biodiesel from jatropha depends largely on the seed yields. To date, there has been a substantial amount of variability in yield data for the plant, which can be attributed to differences in germplasm quality, plantation practices, and climatic conditions. In addition, due to absence of data from block plantations, several yield estimates are based on extrapolation of yields obtained from individual plants or small demonstration plots. (WWI 2006)

Several agencies promoting jatropha are projecting significantly improved yields as the crop is developed. In India, researchers estimate that by 2012, as much as 15 billion liters of biodiesel could be produced by cultivating the crop on 11 million hectares of wastelands. Further development and demonstration work is needed, however, to determine whether these levels of productivity are feasible. (WWI 2006)

Other oil crops

There exist many other potential oil crops that can be used for biooil and biodiesel production. Some of them are briefly describes in Table 10.

Table 10: Examples for potential oil crops for biofuel production

Cotton (*Gossypium hirsutum*)

Cottonseeds are the world's third largest oilseed crop. It is produced predominantly in India, the United States, and Pakistan, which are together responsible for 45 % of world production and 50 % of the total cultivated area.

Peanut (*Arachis hypogaea*)

Peanuts are the world's fourth largest oilseed crop. It accounts for 8.7 % of major oilseed production. The major producers are China, India, and the United States, which together account for 70 % of world production. China and India represent 56 % of the world's cultivated area.

Mustard (*Brassica nigra, Sinapis alba, Brassica carinata*)

Mustard is a relative of rapeseed and canola. It provides a potentially valuable nonfood feedstock. The plant's roots, stems, and leaves contain glucosinolates that break down in the soil into a variety of active but biodegradable chemicals, which provide a pesticide effect. Removal of the plant oil leaves a co-product (press cake) with a strong potential market and environmental value as an organic pesticide. Genetic engineering would rise the oil content of the seeds and increase the effectiveness of the residue for pesticide use.

Castor (*Ricinus communis*)

Identified as the second most-promising species for Brazil after palm oil, the castor oil, or momona, plant is a particularly labor-intensive crop that could provide jobs in the poorer northeastern regions of the country. India is the largest producer and exporter of castor oil worldwide, followed by China and Brazil. World demand for castor oil is projected to continue growing by 3–5 percent per year in the near term.

Gold-of-pleasure (*Camelina sativa*)[18]

Gold of pleasure is a flowering plant in the family Brassicaceae. It is cultivated as an oilseed crop to produce vegetable oil and animal feed. Historically, it has been grown in Europe for centuries. Gold of pleasure is also being researched due to its potential for very low requirements for tillage and weed control. This could potentially allow vegetable oil to be produced cheaper than traditional oil crops, which is particularly attractive to biodiesel producers looking for a feedstock cheap enough to allow them to compete with petroleum diesel and gasoline.

Linseed (*Linum usitatissimum*)[19]

Linseed is grown both for seed and for fiber. The seeds produce a vegetable oil known as linseed oil or flaxseed oil which can be used for biodiesel production. It is one of the oldest commercial oils. The most suitable soils for growing linseed, besides the alluvial kind, are deep friable loams, and containing a large proportion of organic matter. Heavy clays are unsuitable, as are soils of a gravelly or dry sandy nature.

Tigernut (*Cyperus esculentus*)

The Tigernut plant is a species of sedge. It is native to warm temperate to subtropical regions of the Northern Hemisphere. It is a perennial plant, growing up to 90 cm tall, with solitary stems growing from a tuber. The Tigernut tubes have excellent nutritional qualities with a fat composition similar to olives. Once planted, it is extremely difficult to remove the plant.

Cardoon (*Cynara cardunculus*)[20]

Common cardoon is a close relative of the globe artichoke (*C. scopulus*). It is highly invasive, and has become an important weed in Argentina, California and in Australia. Cardoon is a drought tolerant perennial plant that requires relatively small amounts of water. Its high biomass productivity is at around 20 to 30 tons of dry matter per hectare. Several programs aim to double this yield. The plant contains oil bearing seeds that can be directly cold-pressed to obtain oil suitable for biodiesel, whereas the bulk of the biomass can either be used as a solid biofuel for the production of electricity and heat through direct combustion, or as a feedstock for thermochemical conversion into liquid biofuels.

Beyond these common plant oils, more than 100 native Brazilian species have been identified as having potential for biodiesel production. Most of them are palm tree species (WWI 2006 p. 30).

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[18] Source of picture: http://www.inaro.de/Deutsch/d_index.htm [07.08.2006]

[19] Source of picture: http://farmstats.defra.gov.uk/cs/farmstats_data/schools/1_crops.asp [07.08.2006]

[20] Source of picture: http://www1.lf1.cuni.cz/~kocna/flowr_my/flow_my2.htm [07.08.2006]

Also in India, the potential of many plants for oil production is high. India is home to more than 300 different tree species that produce oil-bearing seeds. There, it is estimated that the potential availability of non-edible oils amounts to about one million tons per year including sal oil (180 000 t), mahua oil (180 000 t), neem oil (100 000 t) and karanja oil (55 000 t) as the most abundant oil sources (KUMAR et al. 2003 in MITTELBACH & REMSCHMIDT 2004 p. 24). These oil sources from non-edible plants are of special interest due to not directly concurring with vegetable oil for human food use and due to the fact that many plants can be grown in arid to semi-arid regions poorly suited for food crops. Non-edible oilseeds are not currently utilized on a large scale, but such oils can be an important component of local economies (WWI 2006 p. 30).

6.1.2 Microalgae

Microalgae are cultivated in so called algaecultures. They are a form of aquaculture involving farming of algae species in order to produce food or other products that can be extracted from algae. Microalgae are microscopic single-cell aquatic plants with the potential to produce large quantities of lipids (plant oils) that are well suited for use in biodiesel production.

There are two main systems of cultivating algae: Algae can be cultured in "open-pond" systems and in closed systems. In **open-pond systems** algae are vulnerable of being invaded by other algal species and bacteria. The number of species that have been successfully cultivated for oil production in an outdoor system is relatively small. In open systems there is no control about water temperature and lighting conditions. The growing season is largely dependent on the climatic location and is limited to the warmer months. The advantages of these systems are the low costs and the high production capacity.

The second possibility of cultivating algae is in a **closed system**, a pond system which is covered by a greenhouse. Mainly for economic reasons these systems usually are smaller system, but they have many advantages. These systems allow the cultivation of more species which are protected from other species from outside. It also extends the growing season. Algae can be also grown in a photobioreactor which incorporates some type of light source. It is a closed system in which everything that the algae needs to grow (CO_2, nutrients, water, light) must be introduced into the system. Also a covered pond can be considered a photobioreactor. Different types of photobioreactors include:

- Tanks provided with a light source
- Polyethylene sleeves or bags
- Glass or plastic tubes

Due to the dense growth of the algae, the mix of water and algae has to be stirred to allow that light reaches all algae, as light only penetrates the top 7-11 cm in most cultures.

In some applications also glow plates are inserted into the pond. These are sheets of plastic or glass that can be submerged into the water of a tank, providing light directly to the algae at the right concentration. Once cultivated, algae can be harvested using microscreens, by centrifugation, or by flocculation.

Using these systems microalgae can be grown in arid and semi-arid regions that have poor conditions for cultivation of common plants. This solution does not compete with agriculture for food, requiring neither farmland nor fresh water. Furthermore the per-hectare yield is estimated to be many times greater than that of even tropical oil plants. Algae can also grow in saline water, such as water from polluted aquifers or the ocean, which has few competing uses in agriculture, forestry, industry, or municipalities (WWI 2006).

Recently the potential of cultivating algae near power plants has been recognized as the algae can be feed by CO_2 emissions. This is possible because carbon dioxide and nitrogen oxides are the primary nutrients for the growth of microalgae. Thus oil-rich microalgae, that feed on the emissions of coal, petroleum, and natural gas power plants, could be produced by integrated systems. Today, the private start-up company, GreenFuel, is working to commercialize this technology.

6.1.3 Animal Fats

Animal fats are co-products of meat and fishery industries. It can be received from cattle, hog, chicken and fish. Due to the low retail prices of these co-products they may be an increasing source for biodiesel production, especially in order to replace fuel for vehicle fleets of companies producing these raw materials.

Due to several **animal diseases** and scandals ("Creutzfeldt-Jakob Disease – CJD", "Bovine Spongiform Encephalopathy – BSE"), MITTELBACH & REMSCHMIDT (2004 p. 27) also mention the potential of using two further sources of animal fats: on the one hand, animal meat and bone meal, which is not allowed to be used as fodder anymore, is tested for its applicability to biofuel production, making use of the 10-15 % of fat contained. On the other hand, tallow derived from infected cattle is also considered as an interesting feedstock.

The problem with all these sources is the **discontinuity of supply**. It is possible that suddenly a high bulk of material is available followed by a period with no supply. Naturally, all animal fat is only a co-product and therefore is often restricted as it has not been produced primarily for a biodiesel program.

Nevertheless all these animal fats are characterized by high amounts of saturated fatty acids resulting in methyl esters with poor cold temperature properties. This poses problems in winter. But the high degree of saturation makes animal fat methyl esters excellent fuels regarding heating value and cetane number (MITTELBACH & REMSCHMIDT 2004 p. 27).

Not to be neglected is the **ethical aspect** of using animal parts for transport fuel. When commercialized biofuels based on animals, public indignation could arise.

Because of these problems, the use of animal fats is not expected to contribute largely to oil and biodiesel production in the future. It will be a niche application only for certain cases.

6.1.4 Waste Oils

There is a large variety of waste oils available for biofuel production. In general these waste oils are inexpensive and offer an additional environmental impact by using substances which would otherwise have to be disposed. The origin of the oil can be characterized by three types:

- Waste oil from **households** and **restaurants**
- Waste oil from **food industry**
- Waste oil from **non-food industry**

Rape, soybean, palm and coconut oils are the waste oils most frequently used in biodiesel production. The use of these waste vegetable oils (WVO) requires additional processing to filter out residues and to handle the acids produced by high temperatures. A brief description of the use of **waste oil from households and restaurants** is given by MITTELBACH & REMSCHMIDT (2004 p. 30). They describe the success of recycled-frying oil for the use in bus fleets in Austria. There, recycled-frying oil methyl esters (RFO-ME) have been commercially produced since 1992. In the City of Graz about fifty buses are running without any problems on RFO-ME as this fuel only slightly differs from those of RME. The values of viscosity and carbon residue of RFO-ME tend to be slightly higher and cold temperature properties are poorer compared to RME.

There are many **co-products in the food industry**, which can be used for biodiesel production as well. MITTELBACH & REMSCHMIDT (2004 p. 31) mention rice-bran oil, a highly acidic oil recovered from the waste material produced during rice dehulling. Also oil from palm fruit pulp is mentioned. Palm fruit pulp is the waste material left over after the removal of the palm seeds, which normally are dumped without further treatment. During refinement steps of edible soybean oil production, soybean soapstock is produced. This co-product may be used for biodiesel production, too. Additionally highly acidic sulfur olive oil, a co-product of olive oil refining and whey, a waste product of the diary industry can serve for biodiesel production.

Besides the above mentioned sources of waste-oil, sometimes **industrial waste oils** can be used for biofuel production. An example therefore is tall oil, a co-product of the manufacture of sulfate pulp from resinous woods, such as pine and spruce (MITTELBACH & REMSCHMIDT 2004 p. 33).

6.2. Fuel production

Today, mainly oil from plant sources which are exclusively harvested for biofuel production (oil crops) is used for PPO and biodiesel processing. Therefore, in this chapter, the focus is primarily on fuel production from dedicated oil crops. The amount of fuel production from microalgae, animal fats and waste oils is only small, although the potential is expected to be very high.

The harvest of oil crops depends on the plant species and the technique available. Taking rape as an example, the harvest is conducted by using a combine harvester. The seeds are either transported directly to the oil mill or stored first. The first process step of biofuel production then is the oil extraction which can be done by several means.

6.2.1 Oil Extraction

The oil extraction of the feedstock is the first process step of both PPO and biodiesel processing. Regarding the scale of production and the infrastructure, there are two fundamental production process types for vegetable oils:

- **Industrial**: centralized production by refining in large industrial plants
- **Small scale pressing**: decentralized cold pressing directly on farms or in co-operatives

In **small scale cold pressing** facilities (Figure 29), the cleaned oil seeds are exclusively mechanically pressed at maximum temperatures of 40 ºC. Suspended solids are removed by filtration or sedimentation. As a co-product, the press cake is left with a remaining oil content of usually over 10 %, which is used as a protein-rich fodder (PAUL & KEMNITZ 2006 p. 15). Due to higher production costs, the decentralized oil production by farmers is not widely applied today, although the chance of additional income for farmers is given. Furthermore, the co-product could be directly used for feeding the animals (DREIER & TZSCHEUTSCHLER P. 2001 p. 20).

Figure 29: Small scale press for cold pressing of rape seed, Germany

The common way in oil extraction is the treatment of feedstock in centralized **industrial large scale plants**. First, the feedstock has to be pre-treated. For better illustration purposes, the processing of rape oil is used here as an example for oil extraction. The process-chart is shown in Figure 30.

Within the pre-treatment the rape seeds have to be dried first, but only if it will be stored more for than ten days. In this case, the typical water content of rape seeds, which is about 15 %, has to be reduced to 9 % (DREIER & TZSCHEUTSCHLER P. 2001 p. 20). Subsequently, the rape seeds are cleaned. Additionally, other seeds that are larger in size, such as sunflower seeds, have to be peeled.

After this treatment seeds are crushed, and temperature and moisture content are conditioned. The adjustment of a specific moisture content is important as too high contents make penetration of the solvent difficult, whereas too low contents enhances compactness and consequently also make solvent penetration difficult. The conditioning of temperature above 80 °C is necessary to deactivate microorganisms and to avoid smearing of the press through coagulated proteins. Additionally the crushed seeds can be better penetrated by the solvent and the oil flew is better as it is more liquid.

After conditioning, the oil seeds are pressed at these higher temperatures (80 °C) than with small-scale cold pressing. Thereby approximately 75 % of the total rape oil content can be extracted (DREIER & TZSCHEUTSCHLER P. 2001 p. 22). This pressed raw oil then is filtered and dehydrated and the final pure oil can be used for further refining into PPO or for biodiesel production.

When pressing rape seeds, the press cake is left as co-product. It still contains the remaining 25 % of the total rape seed oil content and therefore is further treated. First, the press cake has to be crushed so that the added solvent, which is usually hexane, can extract the oil at temperatures of up to 80 ºC (PAUL & KEMNITZ 2006 p. 15). The results of this process step are a mixture of oil with hexane, also called miscella, and the so called extraction grist. The solvent is separated from both compounds and recycled to the process.

After these process steps, the oil has more undesired components as in cold pressing. They are removed by refining. The end product is an oil designated as fully refined in edible oil quality (PAUL & KEMNITZ 2006 p. 15).

The process of oil extraction for other oilseed crops is similar to that of rape seed. Some process steps might be added or modified. For example some seeds have to be peeled, others not. Nevertheless the final end product is always unrefined oil. After refining, which is described subsequently, the plant oil can be directly used as PPO. For the use as biodiesel it has to be transesterificated.

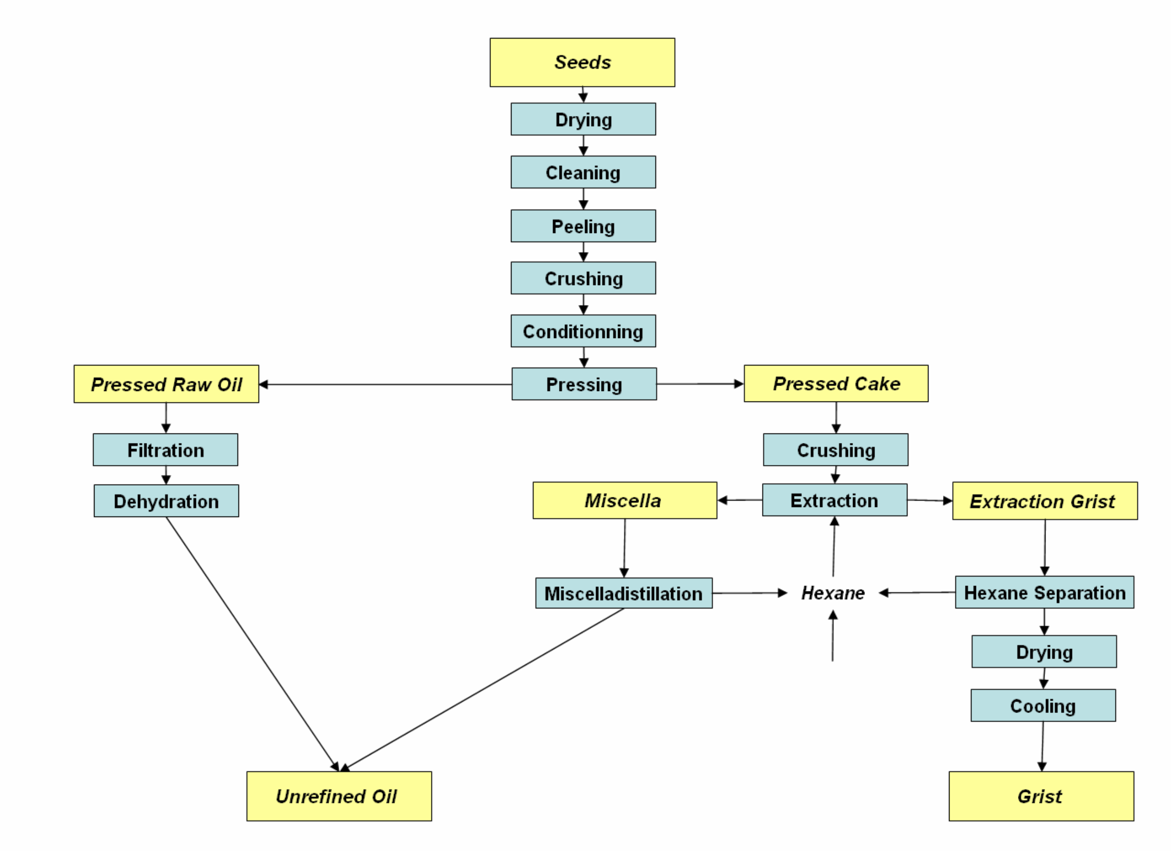

Figure 30: Example for an oil extraction process of rape seeds

6.2.2 Oil Refining

The refining process is an important treatment of creating PPO and of preparing vegetable oil for the transesterification process of biodiesel. It is important in order to remove undesirable substances, such as phosphatides, free fatty acids, waxes, tocopherols and colorants. These substances can alter oil storage life and hamper further processing. During this first refining step the oil mass (4 to 8 %) and the solvent contents are reduced.

Since the refining process depends on the vegetable oil quality, the refining steps depend on the feedstock source. There also exist alternatives of refining and some refining steps are merging. Nevertheless a simplified process chart is shown in Figure 31.

The first purification step of oil refining is the removal of phosphatides, also known as **degumming**. This is necessary as phosphatides make the oil become turbid during storage and as they promote the accumulation of water (MITTELBACH & REMSCHMIDT 2004 p. 44). Phosphatides can be removed by two different ways: water degumming and acid degumming. Soluble phosphatides can be removed by water degumming. Thereby water is added to the oil at 60-90°C and the mixture is separated by centrifugal separation of the water phase and the oil phase. Acid degumming is applied to phosphatides which cannot be hydrated. Acid substances like citric or phosphoric acid are added. MITTELBACH & REMSCHMIDT (2004 p. 44) also summarize benefits from using small amounts of methanol in this process step or the application of enzymatic hydrolysis to effectively remove both soluble and insoluble phosphatides.

The second refining step is the **deacidification**. It is an important step for edible oils as the development of rancid flavors of free fatty acids (FFA) are prevented. The content of these FFA's in unrefined pure oil is between 0.3 and 6 %. In this step also phenol, oxidized fatty compounds, heavy metals and phosphatides are removed. The purification of all these substances is not only important to edible oils, but also to fuel production as these compounds alter storage life and influence transesterification in the biodiesel process. Several methods of deacidification are in operation:

- Neutralization with alkali: This is the most applied method. FFA's are saponified with alkaline solutions and the resulting soap is separated.
- Distillation: For this alternative more energy is needed.
- Deacidification by esterification: This is done by esterification of FFA's with glycerin
- Deacidification and extraction of colorants and odors with various solvents: (z. B. ethanol, furfural, propane)

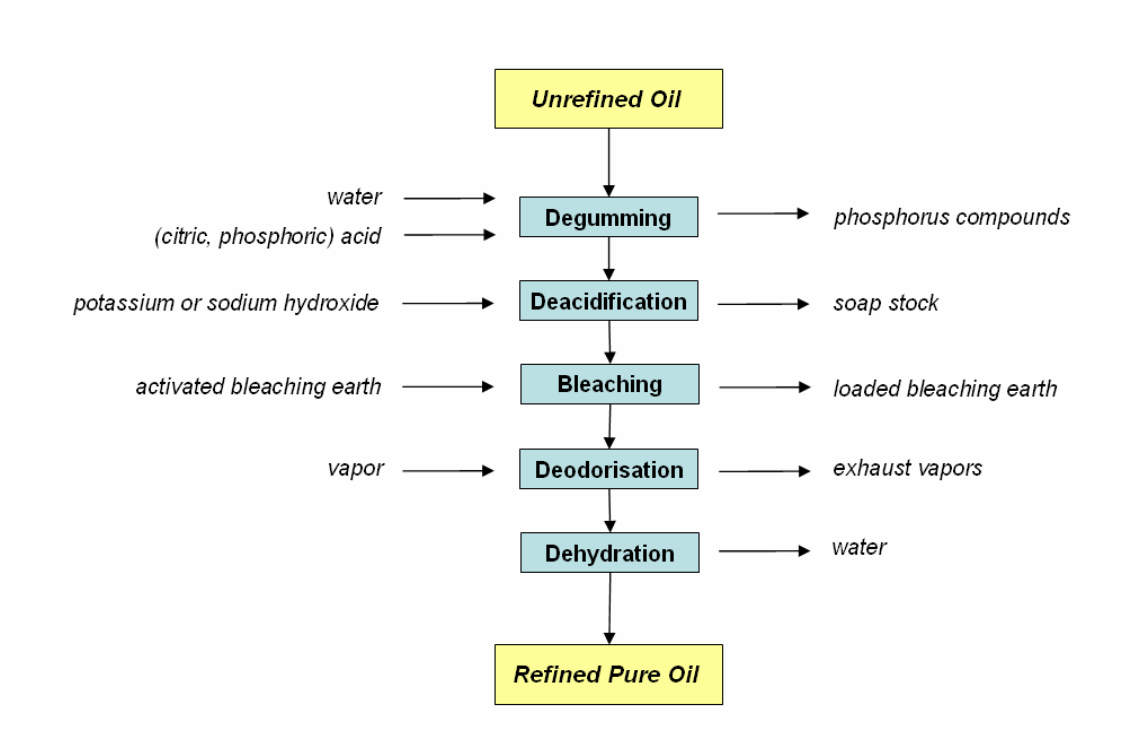

Figure 31: Chemical plant oil refining process

In the third step **bleaching**, colorants are removed. This process step enhances storage life of the biofuel. Bleaching is mainly conducted by adsorbing substances, such as bleaching earth, silica gel or activated carbon. But also oxygen, ozone, hydrogen peroxide and heat (200°C) can be used for bleaching.

In the **deodorization** step odorous substances (ketone, aldehyde) are removed by steam distillation.

Finally a **dehydration** step has to be conducted, as traces of water may decrease conversion in the transesterification process of biodiesel production. The removal of water is either accomplished by distillation under reduced pressure or by passing a stream of nitrogen through the fatty material (MITTELBACH & REMSCHMIDT 2004 p. 46).

6.2.3 Transesterification

The chemical transesterification process during biodiesel production changes the molecular structure of lipid molecules. Thereby the physical properties change. Although even refined pure plant oil (PPO) can be used in refitted diesel engines, biodiesel, which is created by a transesterification step, has several advantages. One advantage is the lower viscosity of biodiesel when compared to PPO. Increased viscosity adversely affects fuel injection duration, pressure, and atomization of diesel engines. Biodiesel is very similar to fossil diesel and thus can be consumed in common diesel engines which are refitted with only small efforts.

Transesterification, also called **alcoholysis**, is the process by which the refined oil molecule is “cracked” and the glycerin is removed, resulting in glycerin soap and methyl- or ethyl esters (biodiesel). Organic fats and oils are triglycerides which are three hydrocarbon chains connected by glycerol. The bonds are broken by hydrolyzing them to form free fatty acids. These fatty acids are then mixed or reacted with methanol or ethanol forming methyl or ethyl fatty acid esters (monocarbon acid esters). The mixture separates and settles out leaving the glycerin on the bottom and the biodiesel (methyl-, ethyl ester) on the top. Now the separation of these two substances has to be conducted completely and quickly to avoid a reversed reaction. These transesterification reactions are often catalyzed by the addition of an acid or base. The chemical transesterification reaction is shown in Figure 32.

For the transesterification process, mainly the alcohols methanol and ethanol are used. Theoretically transesterification can be also processed with higher or secondary alcohols.

Transesterification with methanol, also called **methanolysis**, is the most commonly method for biodiesel production. Methanol is characterized by its lower prices and its higher reactivity as compared to other alcohols. This reaction can happen by heating a mixture of 80–90 percent oil, 10–20 percent methanol, and small amounts of a catalyst. For the reaction it is necessary to mix all ingredients well, as the solubility of methanol in vegetable oil is relatively low. The received biodiesel after methanolysis is **fatty acid methyl ester** (FAME).

As methanol usually is a fossil product, the utilization of bioethanol in an **ethanolysis** reaction is often discussed as the more environmentally friendly alternative, since it allows the production of an entirely renewable fuel. In addition, ethanol is much less toxic and slightly increases the heat contents and cetane numbers of the resulting fuel. But, on the other hand, for ethanolysis much more energy is needed and problems with the separation of the ester and glycerin phases are reported more frequently (MITTELBACH & REMSCHMIDT 2004 p. 46). The process energy costs seem to be higher as well (WWI 2006 p. 15). Biodiesel which is received by ethanolysis is also called **fatty acid ethyl ester** (FAEE).

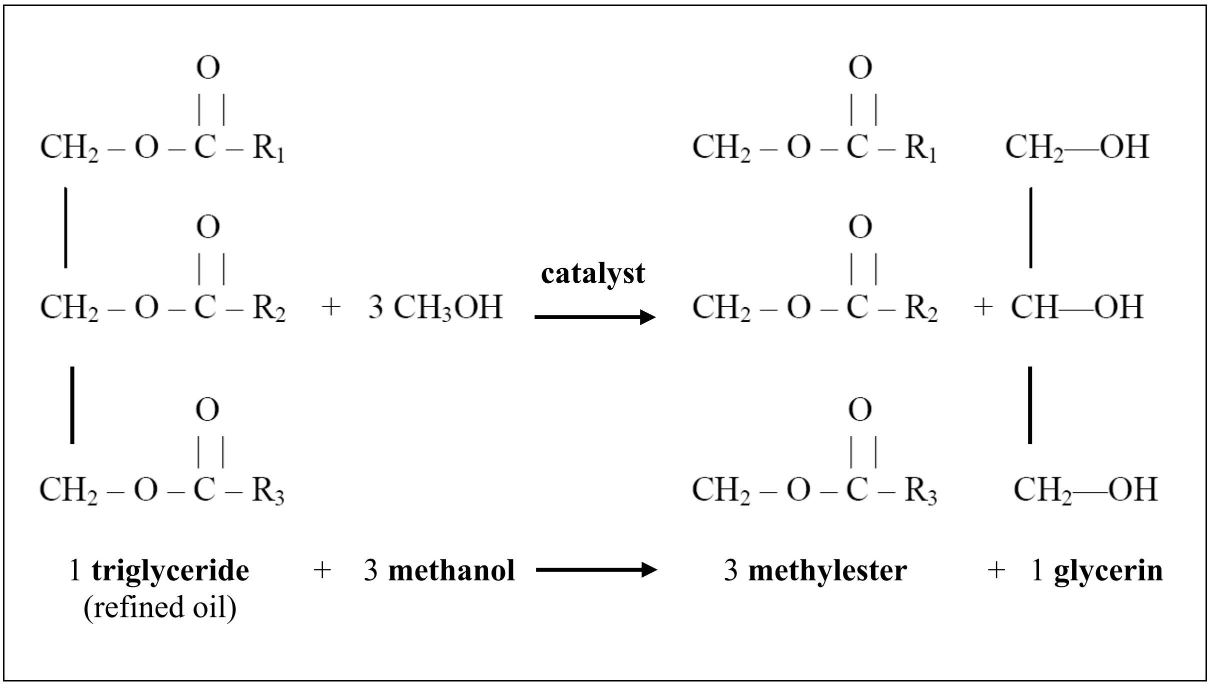

Figure 32: Transesterification reaction of biodiesel production by using methanol

Although the transesterification process proceeds in the absence of **catalysts** as well, the reaction usually is conducted by using catalysts due to economic reasons. Non-catalytic reacting too slowly and high energy inputs are required. The advantage of a non catalytic process would be the creation of purer esters and soap-free glycerin. Several types of catalysts can be used:

- Alkaline material
- Acidic material
- Transition metal compounds
- Silicates
- Lipases

Acidic and alkaline catalysis can be divided between homogeneous and heterogeneous catalysis. Thereby, alkaline catalysis by far is the most commonly used reaction type for biodiesel production. Sodium hydroxide (NaOH) and potassium hydroxide (KOH) are the most common alkaline catalysts, in part because with them, transesterification can happen at a lower temperature. Typical processes produce a volume of biodiesel equivalent to the volume of the original plant oil (WWI 2006 p. 15).

A description of the transesterification processes which is more detailed is given by MITTELBACH & REMSCHMIDT (2004 p. 46ff).

In conclusion, due to the wide variety of oils and fats that can be used to produce biodiesel, there is a greater range in the characteristics of biodiesel fuels than for ethanol fuel. Ethanol is actually one very specific molecule, whereas biodiesel is a mix of molecules that varies somewhat, depending on the initial oil or fat source used to produce the fuel. For example some oils are shorter or more saturated which are characteristics that affect the viscosity and combustibility of the biodiesel (WWI 2006 p. 15).

Figure 33: Biodiesel plant for animal fat (grease) in Brazil

6.3. Properties and Use of Lipid Biofuels

Generally the characteristics of lipid derived fuels are much more variable than propertyes of bioethanol, due to its different conversion process and due to the wide variety of feedstock sources of oils and fats. Ethanol is actually one very specific molecule. In contrast, the molecules of pure plant oil, animal fat and biodiesel vary, depending on the origin of the feedstock type. Nevertheless, PPO and biodiesel must meet certain properties and standards after refining and transesterification, respectively.

Before detailed properties of biodiesel and PPO will be described in the following chapters, a general comparison of rapeseed oil, biodiesel and BtL fuels is given in Table 11. These biofuels are also compared to fossil diesel. The table shows the high viscosity and flashpoint of rapeseed oil. It shows further, that the properties of biodiesel and BtL fuels are very similar to fossil diesel.

Table 11: Parameters of biodiesel and PPO in comparison with fossil diesel and BtL (PAUL & KEMNITZ 2006)

	Density [kg/l]	Viscosity [mm²/s]	Flashpoint [°C]	Caloric value [at 20°C MJ/kg]	Caloric value [MJ/l]	Cetane-number	Fuel-equivalence [l]
Diesel	0.84	5	80	42.7	35.87	50	1
Rapeseed oil	0.92	74	317	37.6	34.59	40	0.96
Biodiesel	0.88	7.5	120	37.1	32.65	56	0.91
BtL	0.76	4	88	43.9	33.45	> 70	0.97

6.3.1 Properties of Pure Plant Oil (PPO)

Properties of pure plant oil (PPO) largely differ in its properties when they are compared to the properties of fossil diesel. For example the viscosity of PPO is much higher, especially at cooler temperatures. It is up to ten times higher than the viscosity of fossil diesel. This property leads to technical challenges in winter running and when cold starting in conventional engines. Since PPO tends to gum up at colder temperatures, it has been difficult to blend it with conventional diesel fuel. However, different types of plant oil have different properties that affect engine performance. Some tropical oils with more saturated, shorter-chained fatty acids, such as coconut oil, can be blended directly with diesel fuel, offering the potential for the use of PPO-diesel blends in unmodified engines in tropical locations (WWI 2006 p.14).

Also the flashpoint of pure plant oil is significantly higher than that of normal diesel. It lies at around 240 ºC (Pensky-Martens Method, DIN EN 22719) (often cited flashpoints over 300 °C are received by Open-Crucible method; see Table 11) and is therefore particularly safe in storage and transport and easy to handle. Consequently, in Germany for example, pure plant oil is not included in any hazard classes according to the “Ordinance for Flammable Liquids”. Additionally, PPO is biodegradable in a short time in soil and waters and e.g. in Germany, it is not classified in any water hazard class. A detailed description of PPO properties is given by REMMELE (2000).

Because of its specific properties, the refined PPO usually cannot be used in normal diesel engines. In order to run on pure plant oil, diesel engines must either be refitted, which is often done by attaching a mechanism for preheating the oil, or a dedicated engine must be used such as the Elsbett engine.

It can be concluded that in temperate counties, technical barriers generally limit the use of PPO to niche markets. However, fuel quality standards have been defined for pure rapeseed oil in Europe, and there has been some experience with the use and handling of PPO in daily operation (WWI 2006 p.14).

6.3.2 Properties of Biodiesel

Generally, the properties of biodiesel and especially its viscosity and ignition properties are similar to the properties of fossil diesel.

Although the energy content per liter of biodiesel is about 5 to 12 % lower than that of diesel fuel, biodiesel has several advantages. For example the cetane number and lubricating effect of biodiesel, important in avoiding wear to the engine, are significantly higher. Therefore the fuel economy of biodiesel approaches that of diesel. Additionally, the alcohol component of biodiesel contains oxygen, which helps to complete the combustion of the fuel. The effects are reduced air pollutants such as particulates, carbon monoxide, and hydrocarbons. Since biodiesel contains practically no sulfur, it can help reducing emissions of sulfur oxides.

Biodiesel is sensitive to cold weather and may require special anti-freezing precautions, similar to those taken with standard diesel. Therefore winter compatibility is achieved by mixing additives, allowing the use down to minus 20 °C. Another problem is that biodiesel readily oxidizes. Thus long-term storage may cause problems, but additives can enhance stability.

Biodiesel also has some properties similar to solvents. Therefore it can attack plastic and rubber components such as seals and fuel lines. This causes problems in vehicles which have not been approved or which are filled with biodiesel for the first time after a long mileage with fossil diesel. In this case biodiesel acts like a detergent additive, loosening and dissolving sediments in storage tanks. Residues of the fossil fuel are released, causing the filter to become blocked. It is therefore advisable to change the fuel filter after several tank fillings with biodiesel.

Conventional diesel engines operate readily with up to 100 % biodiesel fuel, but using blends above 20 % may require modest costs in order to replace some rubber hoses that are sensitive to the solvent character of biodiesel (WWI 2006 p. 16).

6.4. Technology Applications for Lipid Biofuels

Generally, for using biodiesel and pure plant oil, much less technological applications are suitable than technology applications for ethanol. Nevertheless, engine technologies for lipid biofuels are already well established. The appropriate technology for lipid biofuels is the compression ignition engine, also called diesel engine.

These engines are internal combustion engines in which the fuel is ignited by high pressure and temperature, rather than by a separate source of ignition, such as a spark plug, as is the case in the spark ignition engine. The German pioneer Rudolf Diesel invented this type of engine in 1892. He also demonstrated that this engine is running with peanut oil, as well.

6.4.1 Compression Ignition Engines for Biodiesel Use

Biodiesel has some characteristics that can cause damages on conventional engines. For example biodiesel has solvent properties that break down deposits in the fuel supply system and fuel filters may clog. Consequently, compression ignition engines which are constructed for the use of fossil diesel have to be refitted.

The appropriate measures depend on the blending ratio of biodiesel with fossil diesel. Biodiesel can be used in compression ignition engines either blended with fossil diesel or unblended (B100). Biodiesel mixes easily and completely with fossil diesel at any concentration. Typical blends are B5, B20, and B30 with 5%, 20%, and 30% biodiesel content respectively. Nevertheless, most diesel vehicles are able to run on blends of up to B20 with few or no modifications, particularly if the vehicle was manufactured after the mid-1990s. For older models susceptible plastic and rubber components must be replaced by more resistant materials.

Today, manufacturers have declared many of their models to be suitable for biodiesel. The automotive industry prefers blends of up to 5 percent biodiesel content (B5) for use in existing vehicle fleets because it enhances lubricity, especially of ultra-low-sulfur diesel. Most original equipment manufacturers (OEM) guarantee a warranty of B5, as long as the pure product conforms to an approved quality standard. Many OEM fear that higher blend levels could degrade fuel lines, filters, o-rings, and seals and damage fuel injector orifices, among other potential problems. Another concern expressed by the automotive industry is the higher viscosity of biodiesel, especially at higher blends. This property could affect fuel flow and fuel spray in the combustion chamber, particularly in colder conditions. However, if proper care of fuel handling and use is adopted, no problems should be experienced (WWI 2006).

While the use of low blends requires no or only minor technology modifications, the use of higher blends, such as B100, need more efforts. It may require modification of engine or fuel system components as well as some fine tuning. Due to the high viscosity of B100, tank heaters and anti-gel additives have to be applied in colder climates.

More recently, approvals for B100 have been granted only in conjunction with special biodiesel packages. The main reason is the new EU exhaust gas standard EURO IV. This standard came into force in 2005. Due to the higher nitrogen oxide emissions (NO_x), biodiesel as a pure fuel can no longer comply with the stricter values of this standard without further measures. Using a sensor, which detects the different fuels or mixtures, the engine management system can be adjusted to the respective fuel mix ratio and combustion can be optimized accordingly. In this way, the exhaust gas limits of EURO IV can be fulfilled without difficulty. The biodiesel sensor is now available as extra equipment for several new VW models (PAUL & KEMNITZ 2006 p. 22f).

6.4.2 Compression Ignition Engines for PPO Use

Pure plant oil can be used in diesel engines, but due to its relatively high viscosity (approximately 12 times higher than ordinary diesel), engines should be refitted. When PPO is used in unmodified engines, the results can be poor atomization of the fuel in the combustion chamber, incomplete combustion, coking of the injectors, and accumulation of soot deposits in the piston crown, rings, and lubricating oil (WWI 2006 p. 220).

In Germany, several suppliers have developed different refitting concepts. These either pre-heat the fuel and the injection systems or are equipped with a so-called “2-tank system”. By using this latter technology, the engine is started with diesel and only changes to PPO when the operating temperature has been reached. It is then switched back to diesel shortly before being turned off to ensure that it contains no PPO when it is restarted. The other method by pre-heating the fuel requires an electric preheating system for the fuel (including lines and filters), an upgraded injection system, and the addition of glow plugs in the combustion chamber.

The various methods of refitting currently used in practice cost between over one thousand and several thousand Euros according to the engine type. A guarantee is not always granted on the modifications to the engine. In particular, modifications to older precombustion chamber diesel engines are well proven, whereas all problems are not regarded as fully solved in modern common-rail or pump/injector systems. Also, PPO escaping into the engine oil often requires substantially shorter oil change intervals. PPO should not be used either in pure form or mixed with diesel in unadapted engines, as its combustion properties differ too widely from those of diesel and damage to the injection systems and deposits in the engine may occur (PAUL & KEMNITZ 2006 p. 16f).

6.5. Standardization of Lipid Biofuels

6.5.1 Standardization of PPO

Germany is the leader in research of pure plant oil (PPO) as fuel. A quality standard for rapeseed oil as fuel was in operation since 2000: **RK 5/2000**. Due to climatic and yield reasons, rapeseed is the almost exclusively grown oil plant in Germany.

The RK standard is currently being improved and the standard **DIN V 51605** (2006-07) “Fuels for vegetable oil compatible combustion engines - Fuel from rapeseed oil - Requirements and test methods“ will be published by the end of 2006. This new standard can already be ordered from the German Institute for standardization (DIN Deutsches Institut für Normung e. V.) under www.normung.din.de. On the European or international level currently no standard for PPO exists.

6.5.2 Standardization of Biodiesel

European Union

Compared to ethanol, specifications for biodiesel are much further advanced. There exists a common European standard for biodiesel: **EN 14214** “Automotive fuels - Fatty acid methyl esters (FAME) for diesel engines - Requirements and test methods”. The requirements for biodiesel properties in this standard include:

- Test methods
- Ester Content
- Density at 15 °C
- Viscosity at 40 °C
- Flash Point
- Sulfur Content
- Carbon Residue (10 % Bottoms)
- Cetane Number
- Sulfated Ash Content
- Water Content
- Total Contamination
- Copper Strip Corrosion (3hr at 50 °C)
- Thermal Stability
- Oxidation Stability, 110 °C
- Acid Value
- Iodine Value
- Linolenic acid methyl ester
- Polyunsaturated (≥ 4 double bonds) methyl esters
- Methanol Content
- Monoglyceride Content
- Diglyceride Content
- Triglyceride Content
- Free Gylcerol
- Total Gylcerol
- Alkaline Metals (Na + K)
- Phosphorus Content

The European standard for biodiesel EN 14214 removed several national standards in different countries. For example the former standards have been ÖNORM C1191 in Austria, CSN 65 6507 in the Czech Republic, standard of the Journal Officiel in France, DIN E 51606 in Germany, UNI 10635 in Italy and SS 155436 in Sweden.

Apart from the official European norm there may exist additional national standards and quality examinations. For example in Germany the Arbeitsgemeinschaft Qualitätsmanagement Biodiesel e. V. (AGQM, Association for the Quality Management of Biodiesel) offers a complex quality assurance system. The association was founded in 1999 on initiative of the UFOP (Union for the Promotion of Oil and Protein Plants). This was a time when the necessity of organized quality protection emerged through the increased number of biodiesel producers and trading enterprises. Its members are manufacturers, biodiesel traders, filling stations as well as further prospective customers such as additive manufacturers, constructors etc. The aims of AGQM are:

- guaranteeing the minimum quality requirements according to EN 14214,
- guaranteeing the supply of bulk consumers and filling stations with quality biodiesel and
- presenting biodiesel as a high-quality product for establishing confidence with consumers and the automobile industry.

Basically it can be observed that the requirements for biodiesel in the AGQM quality assurance system are stricter than those defined by EN 14214 (AGQM 2006). For example, according to AGQM, some parameters are more detailed to avoid degradation of the product in the whole life cycle (HAUPT 2006). The main criterion for these parameters always is the fuel quality that is received by consumers. The most appropriate feedstock to guarantee this quality fuel is rapeseed. Therefore at the moment mainly RME (Rapeseed oil methyl ester) is labeled by AGQM.

For gaining a higher public recognition in Germany biodiesel fuel pumps are labeled after DIN EN 14214. Additionally fuel pumps may also be marked by the German AGQM label (Figure 34).

Figure 34: Labels for biodiesel in Germany after AGQM (left) and DIN EN 14214 (right)

Besides the general standard for biodiesel there also exists a standard which regulates the blending of fossil diesel with biodiesel. According to the European standard **EN 590**

"Automotive fuels, diesel, requirements and test methods" additions of up to 5 % biodiesel (FAME) to diesel fuel are permissible without labeling. Higher blends (except for 100 % biodiesel) may be sold, but are to be labeled accordingly. When mixed together, biodiesel always has to be in accordance with EN 14214. In Germany the EN 590 standard is in operation since March 2004. As opposed to biodiesel PPO are not authorized as blends in standardized fuels.

USA

The most common standard referenced in the United States is standard **ASTM D 6751** for pure biodiesel used in blends of up to 20 percent with diesel fuel.

Similar to the additional quality management program AGQM in Germany, the respective quality system in the US is the **BQ-9000** standard by the National Biodiesel Accreditation Commission. This BG-9000 program is a cooperative and voluntary program for the accreditation of producers and marketers of biodiesel fuel. The program is a combination of the ASTM standard for biodiesel, ASTM D 6751, and a quality systems program that includes storage, sampling, testing, blending, shipping, distribution, and fuel management practices. BQ-9000 is open to any biodiesel manufacturer, marketer or distributor of biodiesel and biodiesel blends in the United States and Canada.

6.6. Energy Balance of Lipid Biofuels

The energy balances of lipid biofuels from different feedstock sources are shown in Table 12 and compared to the energy balance of fossil diesel. As described in chapter 4.1, energy balances are drawn up to illustrate the relationship between the input of fossil energy necessary for the production of the energy carrier and the usable energy contained. The energy balance is better, the higher the value.

Table 12: Estimated fossil energy balances of selected fuel types from several studies (summarised by WWI 2006 p.136 and MITTELBACH & REMSCHMIDT 2004 p. 254)

Fuel type (feedstock)	Estimates of Fossil Energy Balance
Biodiesel (palm oil)	~ 9
Biodiesel (WVO)	5 - 6
Biodiesel (soybeans)	~ 3
Biodiesel (sunflower)	~ 3
Biodiesel (rapeseed)	1.9 – 2.9
Biodiesel (castor)	~ 2.5
PPO	3 - 5
Diesel (crude oil)	0.8 – 0.9

Conspicuous is the high energy balance for biodiesel from palm oil and from waste vegetable oils (WVO). This is due to the fact that energy inputs for fertilizing, cultivation, harvesting, and oil recovery are not accounted to the energy balance of biodiesel from WVO. In contrast, fossil diesel fuel has even negative energy balances. Pure plant oil has an energy balance of approximately 3-5.

The energy balance of lipid biofuels is mainly determined by fossil energy input for the manufacture of nitrogen fertilizers, agriculture, transportation, and oil recovery via pressing and extraction. Additionally, fossil energy is required for the refining process of PPO and for the transesterification process of biodiesel. In the transesterification process fossil energy is mainly utilized for the methanol production.

6.7. Emissions of Lipid Biofuels

6.7.1 Greenhouse Gas Emissions

The GHG balance for lipid biofuels mainly includes emissions of biofuel production, as it was described in chapter 4.2.1. Thus, reductions depend on the type of feedstock, agricultural practices, site productivity, conversion technology, and finally on the design of the study.

Nevertheless, for biodiesel most studies show a net reduction in emissions. A short summary of GHG studies is given by WWI (2006 p. 153f) and OECD/IEA (2004 p. 63f). For instance, up to 78 % reductions in CO_2 are estimated by SHEEHAN et al (1998 p.19) by using soybeans in the United States. Also the estimates for net GHG emissions reductions from rapeseed-derived biodiesel range from about 40% to 70% when compared to conventional diesel fuel. In the framework of the Carbon Labelling project which is supported by the European Commission, RUTZ et al. (2007) and JANSSEN et al. (2007) promote 60% CO_{2equiv}. reduction for RME produced in Germany. Besides many studies showing GHG reductions for biodiesel, the study of DELUCCHI (2003) shows an increase of GHG emissions for biodiesel from soybeans.

For PPO far fewer studies on GHG balance exist. But, as the process step of transesterification is not applied to PPO, some GHG emissions can be saved. On the other hand, the consideration of glycerin, a co-product of biodiesel production, reduces GHG emissions of biodiesel (DREIER & TZSCHEUTSCHLER 2001). QUIRIN et al. (2004 p. 20) mention that biodiesel from rapeseed is generally more favorable in regard of GHG emissions then pure rapeseed oil, since glycerin can be used to substitute technically produced glycerin.

If the feedstock source for biodiesel or pure plant oil is waste cooking oil, the GHG balance for these fuels is even greater than for all other lipid biofuels. This is due to the fact, that no emissions of ecologically relevant compounds during fertilizer manufacture, cultivation, harvesting and oil recovery are considered for waste oils. Also other negative effects, such as eutrophication, acidification and stratospheric ozone depletion, that are associated with dedicated grown energy crops, may be mitigated or even reversed by using waste vegetable oil as feedstock source (MITTELBACH & REMSCHMIDT p.278f).

6.7.2 Toxic Exhaust Emissions

The major part of engine exhaust streams consists of the components nitrogen, carbon dioxide and water which are non-toxic. However, about 0.2% of diesel engine exhaust emissions are composed of more or less harmful substances to human health (MITTELBACH & REMSCHMIDT 2004 p. 185). These substances can be divided into those which are **limited** by national authorities and those which are **not limited**. In the European Union limited emissions are carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM). Unlimited emissions for instance are aldehydes and various polycyclic aromatic compounds (PAH).

Limited emissions

Since the use of PPO is not yet widely promoted in Europe, studies on pure plant oil emissions are rare. In contrast, biodiesel is much more used and thus more studies on biodiesel emissions are available than for PPO. Therefore mainly emissions of biodiesel are treated in the following sections.

Although emission of biodiesel combustion is a complex result of fuel quality, engine design and vehicle condition, it can be summarized that most pollutants are generally reduced when compared to fossil diesel. Lower emissions of particulates, sulfur, hydrocarbons, CO and toxins can be observed. Only NO_x emissions slightly increase (WWI 2006 p. 195).

These reductions e.g. ´have been observed in a detailed evaluation of emission results and potential health effects by the U.S. Environmental Protection Agency (EPA 2002). EPA has surveyed the large body of biodiesel emissions studies and averaged the health effects testing results with other major studies. Since the majority of available data was collected on heavy-duty highway engines, this data formed the basis of the analysis. The average effects are shown in Figure 35.

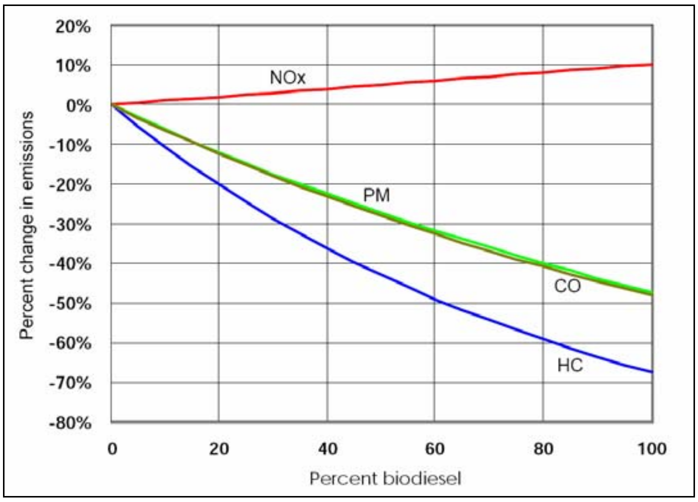

Figure 35: Average emission impacts of biodiesel for heavy-duty highway engines (EPA 2002)

In this EPA study it is shown that several pollutants which also affect human health are reduced by the use of biodiesel instead of fossil diesel (BIODIESEL 2006). For example the ozone forming potential of biodiesel hydrocarbons is less than diesel fuel. Sulfur emissions are essentially eliminated with pure biodiesel. Further, the use of biodiesel in diesel engines results in substantial reductions of unburned hydrocarbons, carbon monoxide, and particulate matter. Emissions of nitrogen oxides slightly increase (BIODIESEL 2006):

Besides this EPA survey, also MITTELBACH & REMSCHMIDT (2004 p. 192) compared several studies on biodiesel combustion emissions. These studies attest reductions in CO and HC emissions as well, which is attributed to the oxygen content of fatty acid methyl esters, amounting to about 11 %, which leads to more complete combustion. Regarding NO_x emissions, all studies report a slight increase for biodiesel-fuelled engines. The reason for this is uncertain.

MITTELBACH & REMSCHMIDT (2004 p. 195ff) further mention that opposed to the other regulated exhaust emissions (CO, HC, NO_x), diesel particulate matter is a complex, chemically and structurally inhomogeneous mixture of organic and inorganic compounds. The amount of PM can be measured by its mass on Teflon®-coated glass fiber filter or on Teflon®-based membrane filters. The amount of total particulate mass differs widely depending on the test fuels, test cycles, test engines and exhaust gas after treatment systems used. But it has become apparent that size distribution and particle number may be far more important than mass, since smaller particles can reach the alveolar regions of the lung, whereas larger particles are effectively eliminated by the ciliated epithelium of the airways. Thereby ultrafine particles with aerodynamic diameters of less than 100 nm pose far higher risks to human health than larger particles.

Unlimited emissions

When compared to fossil diesel, the emissions of biodiesel also contain substances that are **unlimited** by national authorities. Some of them increase; others decrease by using biodiesel, depending on different studies and different testing designs. Nevertheless, sulfates are reduced dramatically due to the fact that most biodiesel fuels contain no sulfur. Also emissions from aromatic compounds, polycyclic aromatic compounds (PAC) and nitro-PAC are generally reduced. In contrast to this compliance, studies about aldehyde emissions show different results. Thus, on the one side reductions in aldehydes were reported, but on the other side also rising emissions of formaldehyde, acroleine, and acetaldehyde ere demonstrated (MITTELBACH & REMSCHMIDT 2004 p. 205f).

Apart from these different results of tailpipe emissions from neat biodiesel combustion, it was investigated whether an optimum blending ratio for minimum emissions can be recommended. But no single blending concentration was found which could lower all regulated exhaust emissions.

6.8. Sustainability of Lipid Biofuels

Environmental effects of using lipid fuels such as PPO and biodiesel vary, depending on the fuel itself, vehicle technology, vehicle tuning and driving procedure. To enable the full evaluation of a certain fuel, also environmental effects of producing feedstock and processing the fuel have to be considered.

6.8.1 Water Issues

The consumption of biodiesel not only reduces tailpipe emissions when compared to fossil diesel. It also has the advantage, that biodiesel itself is much less harmful to water and soil. Therefore, biodiesel is e.g. classified in class 1 after the German system of water pollution classes by the Federal Environment Agency (UBA), whereas fossil diesel is classified in class 2 “water hazard”[21]. The reason for this classification of biodiesel is that it is biodegradable and breaks down readily (WWI 2006 p. 191). It has been shown, that RME can biodegrade in less than half the time required for fossil diesel degradation. ZHANG et al. (1998) observed that RME was biodegradable to about 88 % within 28 days as opposed to only 26 % degradation for fossil diesel fuel over the same period of time. Additionally biodiesel is far more water-soluble than fossil diesel, enabling marine animals to survive in far higher concentrations if fuel spills occur. This is not only important to maritime shipping, but also to groundwater and biodiversity, agriculture and drinking water issues. Nevertheless leakage must be avoided in any case as biodiesel is the result of the transesterification process in which vegetable oil reacts with toxic methanol.

Since PPO is entirely made from plant materials (it contains no methanol), it is even less harmful than biodiesel. PPO is completely risk-free and no special precautions are needed as it is biodegradable in a short time in soil and water. In the German system of water pollution classes, rapeseed oil is not even classified in the lowest class 0.

Besides the direct influences of biodiesel and PPO themselves on water and soil, also feedstock production and fuel processing influences water issues. For feedstock production pesticides and fertilizers are need, like for any agricultural crop. Runoff from pesticides can find its way in the groundwater, causing contamination and affecting water quality. Enhanced fertilization can cause eutrophication. In some regions and for some crops also water is needed for irrigation. This causes problems in areas where water is scarce. All these water issues of feedstock production largely depend on the various agricultural practices and have to be evaluated separately.

Processing of biodiesel and PPO can consume large quantities of water. The total water consumption for B100 is three orders of magnitude higher than petroleum diesel on a life cycle basis (Figure 36). Water is mainly consumed for washing plants and seeds as well as for removing soap and catalysts from the oil (WWI 2006 p. 189). Thereby wastewater is produced and has to be cleaned. Calculations of SHEEHAN et al. (1998) show that

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[21] For comparison: petrol is classified as class 3 “high water hazard” according to the German system of water pollution classes.

wastewater flows over the whole life-cycle of biodiesel from soybean are almost 80% lower than those of petroleum diesel (Figure 37).

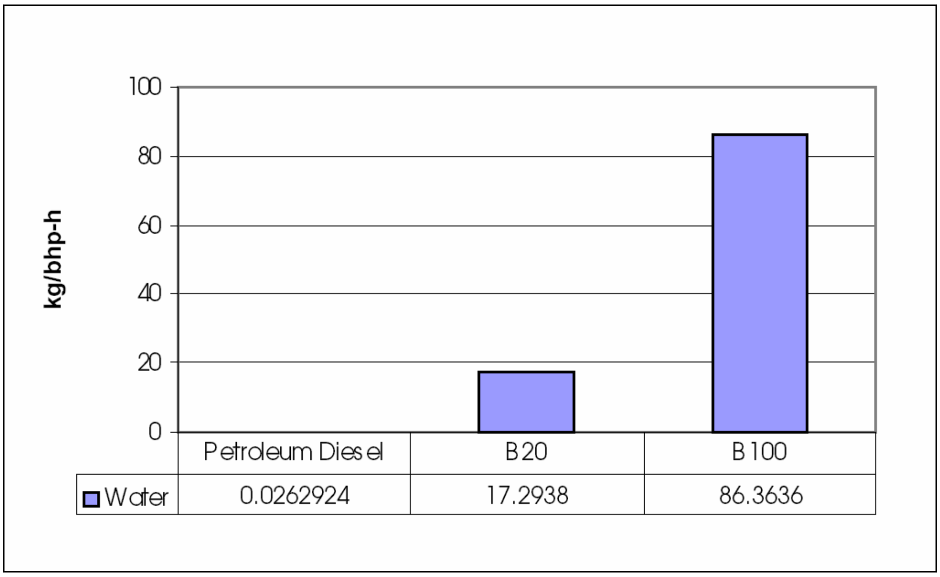

Figure 36: Water use for petroleum diesel, B20, and B100 (SHEEHAN et al. 1998)

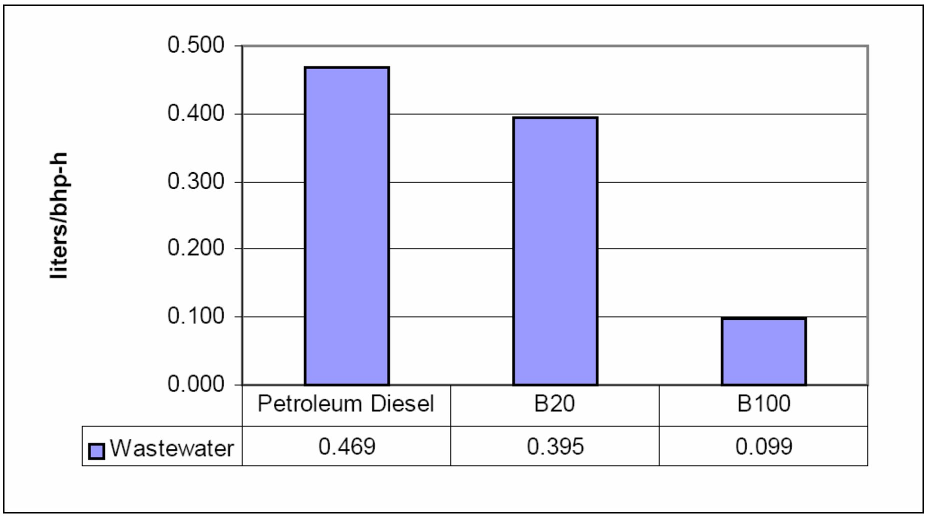

Figure 37: Comparison of total wastewater flows for petroleum diesel and biodiesel life cycles (SHEEHAN et al. 1998)

6.8.2 Land Use and Biodiversity

Environmental problems associated with cultivating feedstock for pure plant oil and biodiesel can be very serious and it is may be the most environmentally disruptive stage of lipid biofuel production. Thereby the environmental impact of land use for PPO and biodiesel production mainly affects habitat and biodiversity as well as soil, water and air quality. It depends on a variety of factors such as the choice of feedstock, what the feedstock replaces and how it is managed (WWI 2006 p. 168).

Considerable amounts of land have to be used for feedstock production. The key factors in determining how much land is needed to produce biodiesel are crop yields and the resulting biodiesel yields. Crop yields are usually measured in kilogram or tons per hectare and biodiesel yields are measured per ton of crop input and consequently in liter per hectare.

Average crop yields vary considerably due to the cultivated region, climate, weather condition and growing season. Nevertheless, agricultural yields and conversion yields have been slowly but steadily improved in the most regions. It appears likely that yields in most regions will continue to improve in the future at an overall rate of some 1% to 2% per year in terms of liters of biofuels per hectare of land (OECD/IEA 2004 p.126).

When compared biodiesel with bioethanol, larger volumes of ethanol can be typically produced from a hectare of cropland than biodiesel. In the EU, average typical yields for biodiesel production per hectare are 1.200 liters for rapeseed, 1.100 liters for barley, 1.000 liters for sunflower seed and 700 liters for soybean. For comparison ethanol yield per hectare is 5.500 liters for sugar beets in the EU and up to 6.500 liters for sugar cane in Brazil (OECD/IEA 2004 p.127).

If biodiesel production is dramatically expanded in the future, the cropland requirements could become quiet significant and puts limits on biodiesel production potential. Therefore degraded lands, wastelands and set-aside lands can be further used for feedstock production. Increased biodiesel and PPO consumption would also support the agricultural sector since it represents a new distribution channel for farmers. On the other hand, set-aside land is a very useful habitat for several plant and animal species and therefore the biodiversity would be reduced if all set-aside land would be converted into fields for biofuel production, such as rapeseed or sunflower.

6.8.3 Human Health

Arguments about impacts on human health can be effective political instruments either for or against biofuels since it influences public opinion. Therefore this topic has to be treated very sensitive. However, it has to be clarified that the use of pure plant oil and biodiesel poses indeed several risks to humans, but that the impacts of using fossil diesel are usually much larger.

For PPO and biodiesel the toxicity of the unburned fuel is generally lower than the toxicity of fossil diesel. Many vegetable oils are even edible and used for cooking purposes.

Unlike this, toxic exhaust emissions of both, biodiesel and fossil diesel are suspected of having acute adverse effects on human health. The most obvious affects are irritation of the eyes and upper respiratory tract and the induction and enhancement of allergic responses (MITTELBACH & REMSCHMIDT 2004 p. 228). However, impacts can be reduced by gas after treatments like catalytic converters and when compared to the emissions of fossil diesel, many tailpipe emissions of biodiesel combustion are reduced (see chapter 6.7.2). Correspondingly biodiesel also reduces many health risks associated with fossil diesel. For instance, biodiesel combustion emits fewer polycyclic aromatic hydrocarbons (PAH) and nitrated polycyclic aromatic hydrocarbons (nPAH), which have been identified as potential cancer causing compounds. A detailed comparison of the carcinogenic toxicity of exhaust emissions between fossil fuels and lipid biofuels is given by the EPA (U.S. ENVIRONMENTAL PROTECTION AGENCY (2002b) and by MITTELBACH & REMSCHMIDT (2004).

6.9. Economy of Lipid Biofuels

Despite continuous improvements in the production of lipid biofuels, relatively **high production costs** remain a critical barrier against commercial development, though technologies for PPO and biodiesel production from oilseed crops are already fairly mature (OECD/IEA 2004 p.67).

For lipid fuels from first generation feedstock the **costs of oil crops** are a major component of overall costs. As crop prices are highly volatile, the overall production costs of lipid fuels are varying as well. In particular, the cost of producing oil-seed derived biodiesel is dominated by the cost of the oil and by competition from high value uses like cooking (OECD/IEA 2004 p.67).

Since the feedstock price for waste grease and oil is lower, costs for biodiesel produced from these **waste sources** are lower, too. This is especially valid in cases where the waste oil is free or where it even has negative prices. But, due to its impurity, additional processing costs for cleaning waste oils are needed. Furthermore the quantity of waste oils is limited. It can be increased by organized collection practices as it is performed in Graz and other Austrian cities.

Similar to ethanol production also the **production scale** of biodiesel has significant impact on cost, but since processing is a smaller share of overall cost, it is less significant than for ethanol.

The **value of co-product sales** largely influences the production costs of lipid biofuels. During biodiesel production glycerin is received and can be sold as co-product. Currently the sale of glycerin improves the economies of biodiesel production significantly. But since glycerin markets are limited, increasing supply of glycerine, which is caused by increased biodiesel production, could cause glycerine prices to fall near zero. In the case of collapsing glycerin prices, biodiesel prices would increase drastically. This only affects biodiesel production, but not PPO production, since glycerine is only a co-product of biodiesel production. Net production costs for PPO are lower since the expensive transesterification process in not applied for PPO.

An example for a detailed cost calculation over the whole life cycle of biodiesel production is given by Dreier & Tzscheutschler (2001) for Germany. Thereby especially tax incentives and the agricultural subsidies for set-aside land largely contribute to the **competitiveness** of biodiesel in Germany. The competitiveness of PPO and biodiesel today still largely depends on the national legislative frameworks and subsidies in EU member states. Subsidies can be both agricultural aids and market incentives for the biofuel itself. Tax exemptions also have considerable impacts on end-user costs for pure plant oil and biodiesel.

However, generally PPO and biodiesel offer large economic advantages over fossil fuels, but direct cost comparisons are difficult. Negative **externalities** associated with fossil fuels tend to be poorly quantified. The most important negative externalities among others are military expenditures and costs for health and environment. However, PPO and biodiesel have the potential to generate many positive externalities, such as reduced greenhouse gas emissions, decreased air pollution, and job creation. Additionally PPO and biodiesel decrease dependency from crude oil imports. Consequently PPO and biodiesel are a more socially and environmentally desirable liquid fuel, a fact that is often neglected in direct-cost calculations. Therefore biofuels often look uncompetitive although a biofuel market may actually provide long-term economic benefits when comparing environmental and social costs (WWI 2006 p. 91f).

The **biodiesel market** in the European Union is the biggest biodiesel market worldwide by producing 95 % of the global capacity. In the EU, Germany is a leader in biodiesel production and marketing. As Figure 38 shows, Germany produced 1 669 000 tons biodiesel in 2005 with a growth rate of 61.3 % over 2004 (EurObserv'ER 2006). Also important biodiesel markets were established in France with 493 000 tons and Italy with 396 000 tons in 2005. Totally 3 184 000 tons biodiesel were produced 2005 in the EU, compared to 1 933 400 tons in 2004 (EurObserv'ER 2006). Outside Europe there are only two larger markets, in Indonesia and Malaysia (Arnold et al. 2005). Also in the USA recently a viable biodiesel market emerges. In contrast to biodiesel, the global **PPO market** is minor.

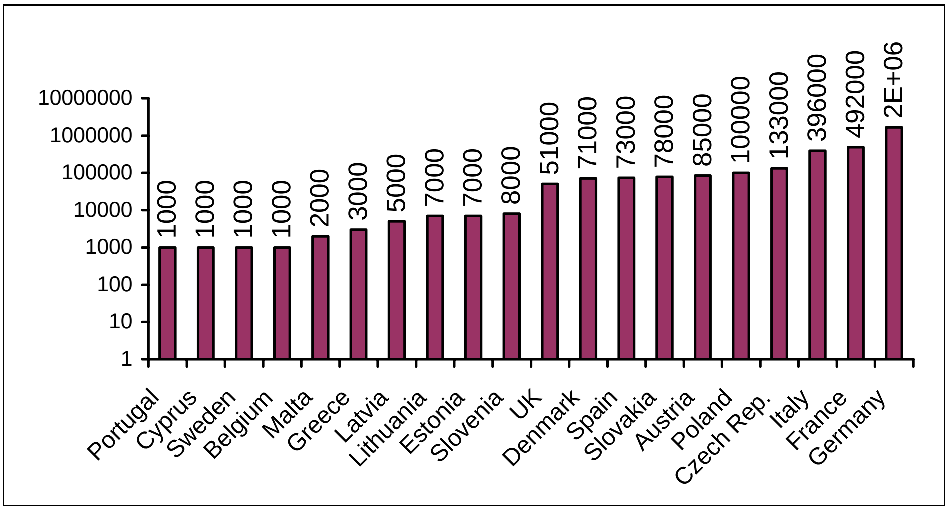

Figure 38: Biodiesel production in the European Union in 2005 (estimates in tons) (EurObserv'ER 2006)

7. BtL Fuels

The development of BTL-fuels is a relatively new. BTL stands for Biomass-to-Liquid and like GTL (Gas-to-Liquid) and CTL (Coal-to-Liquid) BtL-fuels belong to the group of synthetic fuels. Therefore BtL-fuels are also called Synfuel or Sunfuel®. Their components are designed for the requirements of modern motor concepts. Synthetic fuels can be ideally adapted to current engine concepts. Since BtL-fuels are not yet produced on the large scale, they belong to second generation biofuels. Nevertheless, the great advantage of BtL-fuels is that they can be made from various vegetable sources, such as e.g. agricultural remnants like straw, remainders of waste wood and energy crops which are only grown for the production of fuels.

7.1. Feedstock Production

Generally, the great advantage of second generation biofuels is that they can be produced from many different raw materials. The feedstock ranges from waste materials already produced, such as straw, biological wastes and wood offcuts, to energy crops which are only cultivated for fuel production.

Whereas only parts of a crop (mostly the seed) can be used for the production of first generation biofuels, the complete crop can be used for the production of BTL-fuels. Compared to conventional starch and oilseed crops perennial energy crops for BtL production can supply much more biomass per hectare of land, since essentially the entire biomass growth can be used as feedstock. It can be assumed that about 4 000 liters of BtL-fuel can be produced from one hectare of agricultural land.

As already mentioned in chapter 5.1.3, cellulosic biomass such as wood and energy grasses as well as forestry and crop residues are expected to significantly expand the quantities and types of biomass feedstock available for biofuel production in the future. In contrast to the production of ethanol from cellulose, for BtL-fuels also lignin can be used. Lignin can be readily gasified and is therefore suitable as BtL feedstock. Over the next 10–15 years, it is expected that lower cost of cellulosic biomass will contribute to the large scale cultivation of these “next generation” feedstock types. Cellulosic energy crops are expected to begin supplying feedstock for biofuel production toward the end of this timeframe, then expanding substantially in the years beyond (WWI 2006 p. 37).

7.2. BtL Production

The production of BtL-fuels is based on experiences of producing CtL-fuels (coal-to-liquid) which are made from coal and GtL-fuels (gas-to-liquid) which are made by synthetic natural gas liquidisation. The first large-scale production of CtL fuels was implemented in Germany in 1938 due to the shortage of mineral oil. The synthesis was done by the Fischer-Tropsch synthesis which was developed in 1925 at the Kaiser-Wilhelm Institute for Coal Research. Today's plants for GtL and CtL fuels are operated by the mineral oil industry in South Africa, China, Malaysia and other countries.

All three fuels, BtL, GtL and CtL, are characterized by similar process steps, but only BtL is renewable. As it is shown in Figure 39, the transformation-process of BtL-fuels has three main steps: gasification, gas cleaning and synthesis. These process steps are described in detailed sub-chapters.

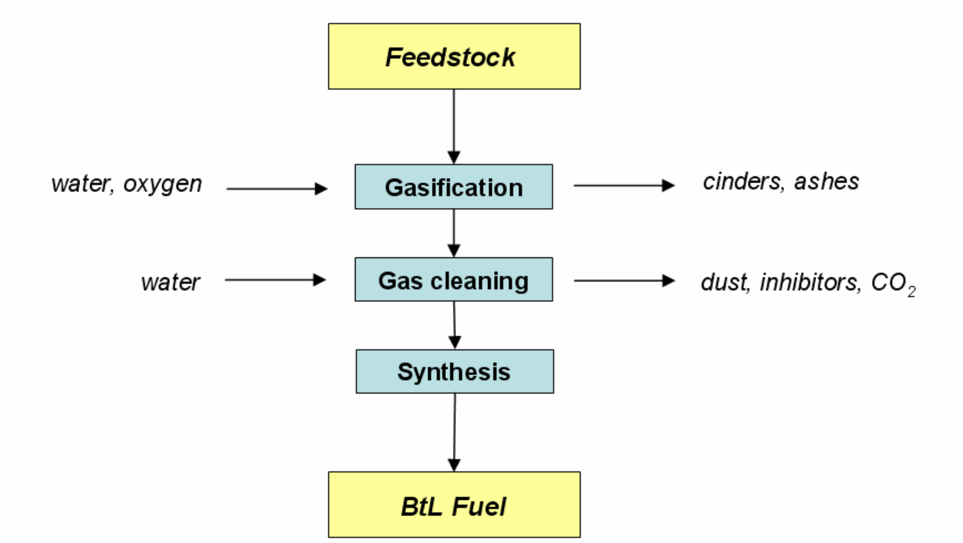

Figure 39: Simplified process of BtL fuel production[22]

7.2.1 Gasification

The first step of the BtL process is the gasification process. Thereby, the biomass is put in a reactor and broken down into a synthetic gas. This is done in the presence of heat and pressure. A gasification agent such as oxygen has to be added, too. The produced synthetic gas is composed mainly of hydrogen, carbon monoxide and carbon dioxide.

The types of gasifiers are various, but VESSIA (2005 p. 33) divides them into three main groups: entrained flow gasifiers, fluidized bed gasifiers (bubbling/circulating) and fixed bed gasifiers, where the last is subdivided into: counter-current (updraft), co-current

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[22] Source: www.btl-plattform.de (FNR, Fachagentur Nachwachsende Rohstoffe e.V.)

(downdraft) and cross-current moving bed. The main differences concern how reactants and products are moved around in the reactor, and the resulting reaction conditions. The reactors may be operated at atmospheric pressure or at higher pressures, but the latter is only available to bubbling or circulating fluidized bed reactors, but at considerable higher cost. The higher cost may be earned downstream due to smaller equipment size and higher reactivity.

The produced gas consists mainly of H_2, CO, CO_2 and CH_4. The desired products are high yields of H_2 and CO (in the case of using them in a downstream FT reactor). This can be achieved by reformation of CH_4 and gas shift reactions, where CO is converted to H_2 and CO_2. Both processes occur with the help of steam. A reduction of CO_2 which decrease the amount of inert gas might also be wanted. A higher reactivity is obtained with lower amounts of inert gas, but the cost may be considerable (VESSIA 2005 p. 33f).

An example for the gasification process is given by Choren Industries[23] which has developed the so called Carbo-V® Process. This is a gasification process involving the following steps: low temperature gasification, high temperature gasification and endothermic entrained bed gasification.

The **low temperature gasification** continuously carbonizes biomass (with a water content of 15 – 20 %) through partial oxidation (low temperature pyrolysis) with air or oxygen at temperatures between 400 and 500 °C. Thereby the biomass is broken down into gas containing tars (volatile parts) and solid carbons (char).

During the **high temperature gasification**, the gas containing tar is post-oxidized hypostoichiometrically by using air and/or oxygen in a combustion chamber.

Finally, during the **endothermic entrained bed gasification**, the char is ground down into a pulverized fuel and is blown into the hot gasification medium. The pulverized fuel and the gasification medium react endothermically in the gasification reactor and are converted into a raw synthesis gas. Once this has been treated in the appropriate manner, it can be used as a combustible gas for generating electricity, steam and heat or as a synthesis gas for producing e.g. SunDiesel.

Another approach is made by the Forschungszentrum Karlsruhe (FZK) and Lurgi AG which have built a fast-pyrolysis pilot plant. The **decentralised fast-pyrolysis** step consists of heating the biomass in the absence of air to a temperature of 500°C after which pyrolysis oil and tar is obtained which is called “slurry” which is shipped to the gasification and Fischer-Tropsch plant where the slurry is gasified in an entrained flow gasifier at temperatures of up to 1200 °C and pressures of 80bar to obtain a tar-free synthesis gas, which consists mainly of hydrogen and carbon monoxide.

The two-stage “bioliq” process tries to overcome the main bottleneck in the production chain of BtL fuels: the low energy density of biomass feedstocks such as wood chips, straw, paper, pulp and other residues from agriculture, forestry and industry. By placing fast-pyrolysis plants near the biomass source the residues can be transformed into bio-oil (pyrolysis oil) the energy density of which is 13 to 15 times higher. Transporting raw

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[23] A description of the Carbo-V® Process from Choren Industries is available at: http://www.choren.com/en

biomass over distances larger than 25 kilometres is economically unattractive, with producing slurry the range can be extended by a factor of 10 and more.

Figure 40: Slurry produced with the bioliq process

7.2.2 Gas Cleaning

In the second step of BtL production the gas is cleaned. The gas cleaning is the linkage between gas production and its use and can be seen as the bottleneck in the gasification process. Subsequently, this step is described according to VESSIA (2005 p. 34ff).

The continual build up of condensable organic compounds (known as tars) in the producer gas may cause blockages, corrosion and reduce efficiency. Not all the liquids from the pyrolysis are converted to syngas, due to physical limitations of the reactor and chemical limitations of the reactions. These residues form contaminant tars in the product gas and have to be removed prior to the synthesis process. The pyrolysis of the solid fuel occur in the temperature range of 300 – 500 °C, but as the gasification takes place at higher temperature, the tars in the product gas tend to be refractory and hard to remove by catalytic, thermal or physical processes. This aspect of the tar cracking or removal in gas cleaning is one of the most important technical barriers to implement the gasification of biomass technology. Other impurities in the producer gas is the organic BTX (benzene, toluene and xylene), and inorganic impurities as NH_3, HCN, H_2S, COS and HCl. There are also volatile metals, dust and soot. The tars have to be cracked or removed first, to enable the use of conventional low temperature wet gas cleaning or advanced high temperature dry gas cleaning of the remaining impurities. Cracking or recycle of the tar back to the gasifier is preferred as the tar has a high content of chemical energy.

There are three basic ways to destroy tars: thermal cracking, catalytic cracking and scrubbing. The thermal cracking operates at temperatures between 1000 – 1200 °C where tars are cracked without catalyst, usually by adding steam or oxygen. Drawbacks are low thermal efficiency, soot production and the need of expensive materials. Catalytic cracking consists of a catalyst that decomposes the unwanted hydrocarbons into CO and hydrogen. The use of advanced low temperature scrubbing, with an oil-based medium is another option. The tars are subsequently separated from the oil and returned into the gasifier.

Now tars are almost absent and the remaining inorganic impurities are NH_3, HCN, H_2S, COS, HCl and also volatile metals, dust and soot, which may be removed by conventional low temperature dry gas cleaning or advanced high temperature wet gas cleaning.

7.2.3 Synthesis Process

During the third step of processing BtL fuels, the fuel components are synthesized from the cleaned gas. The final BtL fuel can be processed optionally with diesel or petrol properties. The best known synthesizing process is the Fischer-Tropsch (FT) synthesis.

During FT synthesis, the reactive parts of the synthesis gas (CO and H_2) interact with a catalyst to form hydrocarbons. FT synthesis was developed in Germany in the 1920s and it is particularly used in South Africa on a large scale to produce automotive fuels from coal. In order to maximize the output of diesel (= SunDiesel), the waxes formed during the FT synthesis process are further processed using hydrocracking techniques, a standard process that is used in the petrochemical sector to recycle waste substances at refineries.

Apart from FT synthesis, the methanol-to-synfuels synthesis is also regarded as a promising option for the production of BtL fuels.

7.3. Properties and Emissions of BtL Fuels

The chemical properties of the hydrocarbons in BtL fuels permit efficient and complete combustion with low exhaust gas emission. In particular, the properties of the fuel can be influenced by changes in specific parameters such as pressure, temperature and catalysts during synthesis and the subsequent treatment and can be “fine-tuned”. Synthetic fuels are therefore also known as tailored fuels or as designer fuels.

For example, the increased cetane number of BtL fuels ensures an optimal combustion in the engine. Future emission standards, which are not reachable with the recent biogenic fuels without technical adaptations, can be easily reached with BtL fuels. The noxious emissions, especially the nitric oxide (NO_x) and the particle output, could clearly be reduced. Moreover, it is emissions-free of sulfur and flavor.

In contrast to CtL and GtL fuels, BtL fuels are synthesized from renewable resources and therefore permit substantial savings in climate gas emission. Further, BtL fuel can be used without technical modifications to the engine and logistics are possible using the existing infrastructure.

8. Biomethane

Since today’s infrastructure for transport is based on liquid fuels, the introduction of gaseous fuels into the transport sector is slow and challenging for future transport strategies. Nevertheless, there exists already a market for vehicles which use gaseous fuels in place of liquid fuels. Today, most of them run on natural gas. Many automotive manufacturers already offer pure or bivalent natural gas vehicles as standard models. One of the promising future options for sustainable transport fuels is the subsidization of natural gas by biomethane[24]. Biomethane is the most efficient and clean burning biofuel which is available today. It can be produced from nearly all types of biomass including wet biomass which is not usable for most other biofuels. Another motivation for using gaseous biofuels for transport applications is the opportunity of diversifying feedstock sources.

8.1. Feedstock Production

The raw material for the production of biomethane is biogas, which can be processed from various feedstock sources. For biogas production much more different feedstock sources can be used than for common liquid biofuels. For instance biodiesel can be only made from plant materials containing certain amounts of oil. In contrast, biogas is produced from nearly all types of organic materials including vegetable and animal feedstocks.

The origin of the feedstock can vary, ranging from livestock waste, manure, harvest surplus, to vegetable oil residues. Dedicated energy crops are becoming more and more practice as feedstock source for biogas production. Recently, wastewater sludge, municipal solid wastes and organic wastes from households have been introduced as feedstock. Another feedstock source is the collection of biogas from landfill sites. In Germany biogas is produced in agricultural facilities, mainly by the fermentation of manure and maize silage (Figure 41).

One main advantage of methane production is the ability to use so-called “**wet biomass**” as feedstock source. Wet biomass can not be used for the production of other biofuels such as PPO, biodiesel or biomethane. Examples for wet biomass are sewage sludge, manure from dairy and swine farms as well as residues from food processing. They all are characterized by moisture contents of more than 60–70 %.

The use of **waste materials** is not only excellent suitability for biogas production it also creates some additional benefits. Thus, it contributes to reduce animal wastes and odors. Digestion effectively eliminates environmental hazards, such as overproduction of liquid manure. Therefore biogas production is an excellent way for livestock farmers to comply with increasing governmental regulations of animal wastes. In addition it destroys disease-

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[24] In this handbook the term „biomethane“ is used fort the final gaseous fuel after digestion of biomass AND purification. It contains more than 95% methane. The term „biogas“ is referred to the intermediate product after digestion, but which is not yet purified.

causing pathogens existing in waste materials. Nevertheless, using animal feedstock can be critical as well. For instance anaerobic degradation of poultry excrements with high contents of organic nitrogen produce high concentrations of undesirable ammonium. Furthermore, new economical and ecological solutions for the treatment of animal by-products are required due to the BSE-crisis (PRECHTL & FAULSTICH 2004). However, it is often the combination of environmental, economical and legal reasons that motivates farmers to use digester technology for waste treatment.

Apart from waste materials wet biomass also includes dedicated **energy crops** or any other vegetable materials with high moisture contents. Even grass can be used as feedstock. The suitability of energy crops for biogas production was received through improvements in the fermentation process. The main disadvantage of energy crops when compared to waste materials is their need for additional agricultural land as it is needed also for PPO, biodiesel and bioethanol production. Nevertheless, energy crops for biogas production have several advantages which make them very promising for the future. One main advantage is the production of considerably high yields of energy crops, even when they are cultivated extensively. Chemical fertilizers and pesticides are not required or only in small amounts. Damaged and uneatable harvests resulting from unfavorable growing and weather conditions, as well as from pest contaminations are suitable for biogas production, too. In addition, cultivations do not have to become fully ripe, since the whole plant can be used for biogas production. Harvests do not have to be dried.

The quality and yield of biogas heavily depends on the feedstock type. According to (BENSMANN 2005) the average yield of biogas is 4 100 liters per hectare. This is equivalent to approximately 127 GJ/ha, being nearly three times as high as for RME and one and half times higher than for ethanol. Much higher yields can be expected from energy crop optimization (ARNOLD et al. 2005).

Figure 41: Waste materials (waste potatoes) (left) and maize silage (right) for biogas production

8.2. Biomethane Production

The production of biomethane includes two steps. Firstly, biogas has to be produced from feedstock sources. Secondly, the biogas has to be further processed and cleaned in order to receive biomethane which is suitable for transport applications.

8.2.1 Digestion Process

Biogas is produced by means of **anaerobic digestion**. Organic matter is broken down by microbiological activity and in the absence of air. Symbiotic groups of bacteria perform different functions at different stages of the digestion process in order to break down complex organic materials. 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.

Since these bacteria are sensitive to **temperature**, this has to be considered in the digestion process. In order to promote bacterial activity, temperatures of at least 20° C are required. Generally, higher temperatures shorten processing time and reduce the required volume of the digester tank by 25 % to 40 %. Table 13 shows different classification options for digestion pathways. Regarding the temperature, bacteria of anaerobic digestion can be divided into psychrophile (25 °C), mesophile (32 – 38 °C) and termophile (42 – 55 °C) bacteria. The choice of the process temperature depends on the feedstock and of the utilized digester type. Thus, digesters have to be heated in colder climates in order to encourage the bacteria to carry out their function.

Digestion time ranges from a couple of weeks to a couple of months depending on feedstock and digester type as well as on the digestion temperature.

8.2.2 Digester Types

The common technology for biogas production is the digestion of feedstock in specially designed digesters. These must be strong enough to withstand the buildup of pressure and must provide anaerobic conditions for the bacteria inside. In addition, anaerobic digester systems can reduce fecal coliform bacteria in manure by more than 99 %, virtually eliminating a major source of water pollution. Further, the ability of the digester to produce and capture methane from the manure reduces the amount of methane that otherwise would enter the atmosphere. Methane gas in the atmosphere is a contributor to global climate change.

Today, there are many different technologies and digester types available. Generally, the **size of biogas plants** can vary from a small household system to large commercial plants of several thousand cubic meters. Digester size also influences logistics and vice versa. For instance, for larger scale digesters feedstock has to be collected from individual farms and transported to central digester facilities. However, independent from the type of digester, they are often built near the source of the feedstock, and several are often used together to provide a continuous gas supply.

Nevertheless, apart from their size, digester types can be classified by using several criteria as it is shown in Table 13.

Table 13: Digestion classification by several criteria (adapted from SCHOLWIN et al. 2006 p. 36)

criterion	classification characteristics
Process temperature	- psychrophile (optimum: 25 °C) - mesophile (optimum: 32 - 38 °C) - termophile (optimum: 42 - 55 °C)
Water content of substrate	- wet digestion (dry mass: < 15 %) - dry digestion (dry mass: 20 – 40 %)
Number of process steps	- single-stage - two-stage - multi-stage
Filling procedure	- discontinuous - quasi-continuous - continuous

A classification after the **process temperature** was already described in the previous chapter. Digesters have to fulfill requirements in order to guarantee a certain process temperature which should be as continuous as possible. Therefore the digester has to be insulated and equipped with heaters, especially in colder climates.

The **water content of substrate** also influences the design and type of digester. One of the most common classifications regarding the water content of the substrate is the classification into wet digestion which is fed with dry mass contents lower than 15 % and into dry digestion which is fed with dry mass content between 20 and 40 %. Wet digestion usually is applied to manure and sewage sludge, whereas dry digestion is often applied to the fermentation of energy crops.

Digesters can be classified after the **number of process steps**. Single-stage and two-stage digesters are the most common technologies today whereas the focus is on single-stage digesters. These are characterized by no special separation of different process steps (hydrolysis, acidification, methanisation). All process steps are conducted in one single digester. Process steps of two-stage and multi-stage technologies are conducted in two or more different digesters (SCHOLWIN et al. 2006 p. 36).

However, digesters can be also classified after their **filling procedure** and after the filling interval. Digester types include following technologies:

- **Batch type**: the digester is filled at once, the feedstock digests and subsequently the whole system is emptied
- **Continuously expanding type**: firstly, the digester is filled up to 1/3, then it is continuously filled until it is full and finally the digester is emptied
- **Continuously flow type**: the digester is initially filled completely, then the feedstock is continuously added and digested material is continuously removed
- **Pug flow type**: the feedstock is added regularly at one end and overflows the other end
- **Contact type**: this is a continuous type, but a support medium is provided for the bacteria

Figure 42: Biogas installation with two digesters (continuously flow type on the left and pug flow type container on the right) in Germany

8.2.3 Biogas purification

The product of digestion is Biogas, a combination of methane and carbon dioxide, typically in the ratio of 6:4 (55-80 % methane). In addition, there are small quantities of hydrogen sulfide and other trace gases. Since only the methane is usable as transport fuel, methane has to be separated from CO_2 and the remaining components of biogas. The final product is biomethane, which has methane content between 95 and 100%. Therefore it is very similar to natural gas and suitable for all natural gas applications.

The most common technologies for biogas upgrading are the water scrubber technology and the PSA technology (pressure swing adsorption). Gas upgrading is normally performed in two steps where the main step is the process that removes the CO_2 from the gas. Minor contaminants (e.g. sulphurcompounds) are normally removed before the CO_2-removal and the water dew point can be adjusted before or after the upgrading (depending on process).

Another promising technology is the membrane technologies which has a potential to be energy efficient.

Biomethane can be also produced by the gasification process. Nevertheless, it has to be recognized that the process of biomass gasification is distinctly different form that of biogas production. Gasification is the process by which solid biomass materials are broken down using heat to produce a combustible gas, commonly known as producer gas. Since this process was already described in chapter 7, it will not be described here further.

8.3. Properties and Use of Biomethane

The simplest hydrocarbon, methane, is a gas at standard temperature and pressure (STP). Its chemical formula is CH_4. Further, methane is a combustible and odorless gas. It is also a greenhouse gas with a global warming potential (GWP) of 23 in 100 years (IPCC 2001). That means that each kg of methane warms the earth 23 times as much as the same mass of CO_2 when averaged over 100 years.

After the digestion and purification process of biomass, biomethane is obtained. In contrast to neat NH_4, biomethane also has small amounts of other compounds than NH_4. Nevertheless, the methane content of biomethane is 95-100%. For fuel purposes it can be concluded, that the higher the methane content the higher is the fuel quality.

Biomethane from biogas is chemically identical with natural gas and therefore does not differ in parameters. The most important characteristic values are listed in Table 14.

Table 14: Parameters of methane (from biogas or natural gas) (PAUL & KEMNITZ 2006)

	Density [kg/l]	Caloric value at 20°C [MJ/kg]	Caloric value at [MJ/l]	Octane number (ROZ)	Fuel-equivalence [l]
Methane	0.72	50	36	130	1.4

8.4. Technology Applications for Biomethane

8.4.1 Infrastructure Requirements for Biomethane

Gaseous energy sources are far more difficult to store and transport than liquid fuels and require more storage space due to their substantially lower energy density. For transport purposes biomethane must be stored in specially installed pressure tanks at a pressure of 200 bars. However, these fundamental disadvantages are offset by positive combustion properties. In comparison with petrol and diesel, the emission of several toxic substances such as nitrogen oxides and reactive hydrocarbons can be reduced by up to 80 % (PAUL & KEMNITZ 2006).

Generally, biomethane can reach the consumer by two routes. One means is to feed it into the existing natural gas network, to which the natural gas filling stations are connected.

The difficulty of this are the technical barriers, as treatment to reach the quality of natural gas and supply into the natural gas network still present high requirements. Also, the gas infeed must be provided with a stable legal basis. Biogas plant operators therefore currently choose a second route: the construction of decentralized biomethane filling stations directly at biogas plants. (PAUL & KEMNITZ 2006)

8.4.2 Vehicle Technologies for Biomethane

Untreated biogas is usually unsuitable for transport applications as its methane content is relatively low (60–70 %). Additionally, untreated biogas typically has high concentrations of contaminants. Therefore biogas is purified and the resulting fuel is biomethane (see chapter 8.2.3).

Biomethane can be used in engines for all types of vehicles which are suitable for natural gas, since biomethane is very similar to natural gas. The real methane content of both fuels, biomethane and natural gas, is above 95%. Also engine performance, drivability, emissions, and maintenance are considered to be equivalent. Moreover, no differentiation in warranty coverage is required as long as the biomethane characteristics fulfill the vehicle manufacturer's requirements.

A number of vehicle options can therefore be considered: dedicated compressed natural gas (CNG) or liquefied natural gas (LNG) vehicles, bi-fuel (gasoline/CNG) vehicles, and dual-fuel (LNG/diesel or CNG/diesel) vehicles. Sweden is currently the leading user of biomethane in transportation. Its CNG/biomethane urban bus fleet comprises approximately 4.500 vehicles (WWI 2006 p. 222).

8.5. Standardization of Biomethane

For biomethane as transport fuel no common standardization in the European Union exists. This is attributed to the low level of applications and on the lower complexity of biomethane compared to bioethanol or biodiesel. Biomethane consists, after different purification treatments, mainly of methane (> 80 %Vol) and CO_2.

Nevertheless there is a Swedish Standard (SS) on biomethane **SS 155438** "Motor fuels – Biogas as fuel for high-speed otto engines" as a reaction to the growing demand of biomethane in Sweden. The methane content of biomethane according to this standard is 97 % (+/- 1-2 %). This Swedish standard was developed by STG Technical Group number 85 (TK 85). It is applied for the use in otto engines, which includes converted diesel engines provided with glows or spark plugs. A high-speed engine is defined as an engine with at least 16 revolutions per minute, at maximum performance (ATRAX ENERGI 2005). This Swedish standard has been adapted in such a way that, from a material-technical point of view, fuelling and engine equipment developed for natural gas may also be used for biomethane. In this standard, biomethane is defined as: "gas produced from microbial fermentation of organic material in an anaerobic (oxygen free) environment" (ATRAX ENERGI 2005).

In Germany already 650 filling stations for natural gas are field tested. There, natural gas for transport is divided by the German Technical and Scientific Association for Gas and Water (DVGW Deutsche Vereinigung des Gas- und Wasserfaches e.V.) into two classifications: natural gas of **group H** (high caloric gas) which contains 87 – 99.1 vol% methane and natural gas of **group L** (low caloric gas) which contains 79.8 – 87 vol% methane (Figure 43).

Figure 43: Labels for gas pumps with natural gas in Germany

Since the existing filling infrastructure for natural gas could be easily modified for the use of biomethane, a similar labeling for biogas would be useful. Such a standard for biomethane does not exist at the moment, as the first biomethane filling station in Germany opens in June 2006.

8.6. Biomethane Emissions

8.6.1 Greenhouse Gas Emissions

There exist two types of GHG emissions which are influenced by the production and utilization of biomethane: methane and carbon dioxide.

Methane itself is a greenhouse gas with a relatively high global warming potential (GWP) of 23 in 100 years (IPCC 2001) (chapter 4.2.1). Each kg of methane warms up the earth 23 times as much as the same mass of CO_2 when averaged over 100 years.

Methane is emitted from a variety of both human-related (anthropogenic) and natural sources. Human-related activities include fossil fuel production, animal husbandry (enteric fermentation in livestock and manure management), rice cultivation, biomass burning, and waste management. These activities release significant quantities of methane to the atmosphere. It is estimated that 60% of global methane emissions are related to human-related activities (IPCC 2001). Natural sources of methane include wetlands, gas hydrates, permafrost, termites, oceans, freshwater bodies, non-wetland soils, and other sources such as wildfires.

In regard of biomethane production for transport purposes, the natural fermentation of manure from livestock is of special interest as these methane emissions can be reduced by the controlled digestion process of manure in a digester. Manure which is stored in not covered agricultural storage tanks and manure which is deposited on fields and pastures emit methane. These emissions can be reduced by the use of a controlled digestion facility. Therefore biomethane is not only a renewable energy source, but it also contributes to the reduction of agricultural methane emissions. Nevertheless, it always has to be guaranteed, that the digester does not leak.

As for all other biofuels, **carbon dioxide** emissions have to be considered when evaluating biomethane as transport fuel. Therefore emissions of all life cycle steps of biomethane have to be included. These CO_2 emissions largely depend on the feedstock. If biomethane is produced from waste materials such as manure, emissions during feedstock production can be kept minor. This advantage will be abolished if dedicated energy crops are used as feedstock source.

However, it can be concluded that the carbon dioxide reduction of biomethane can be 65-85 % when compared to fossil fuels (LINNÉ & JÖNSSON 2004). It largely depends on the choice of the feedstock source.

8.6.2 Toxic Exhaust Emissions

In addition to the positive greenhouse gas balance, also the toxic exhaust emissions from biomethane combustion are reduced, when compared to liquid fuels. According to several sources[25] visible reductions of exhaust emissions can be received. Table 15 shows these reductions of combusting natural gas in comparison to fossil diesel and petrol. Since natural gas and biomethane have the same properties, the data can be used for both fuels.

Table 15: Reductions of toxic emissions (in %) from biomethane combustion in comparison with petrol and diesel

emission	*petrol*	*diesel*
NO_x	55 %	80 %
CO	55 %	50 %
PM	-	98 %
HC	80 %	80 %
Ozone formation	65 %	85 %

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[25] Sources: http://www.gibgas.de/german/umwelt/index.html [10.08.2006]
http://www.erdgasfahren.ch/index.php?id=30 [10.08.2006]
http://www.erdgasfahrzeuge.de/appFrameset.html [10.08.2006]

8.7. Sustainability of Biomethane

Biomethane is not toxic to human health. Nevertheless, biomethane is an asphyxiant and may displace oxygen in a workplace atmosphere. Asphyxia may result if the oxygen concentration is reduced to below 18 % by displacement.

Since biomethane is mostly produced from wastes, such as manure, it does not have any negative impact on land use and biodiversity. If dedicated energy crops are taken for bioethanol production, the impact on land use and biodiversity depends on the feedstock type. But as nearly any feedstock can be used for biogas production, biodiversity aspects can be easily considered. Figure 44 shows the energy yield of different biofuels in Germany for one hectare in transport kilometres. When compared to biodiesel, bioethanol and BtL, biomethane receives the most effective yields per hectare and thus is a very economical way in using agricultural land for energy purposes.

Additionally, the use of biomethane has several positive and comfortable side effects to humans. Firstly, due to the impermeability of digesters, far less odors are emitted than if animal manure is collected in open storage facilities. Secondly, vehicles running on biomethane are generally not as noise intensive as other vehicles. This is due to good combustion properties of biogas.

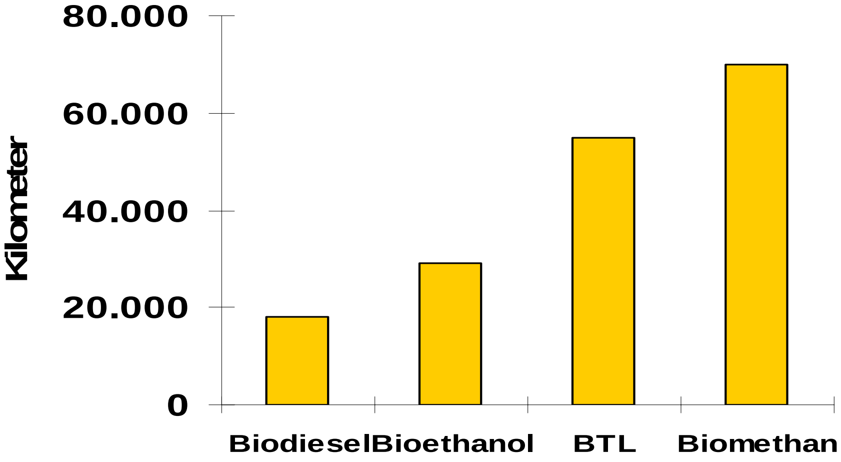

Figure 44: Energy yield of different biofuels in Germany for one hectare in transport kilometres (COSTA GOMEZ 2006)

8.8. Economy of Biomethane

The main problem of using biomethane for transport is the lack of infrastructure. Vehicles running on biogas are not compatible with common vehicles running on liquid fuels. Nevertheless a remarkable infrastructure for natural gas was created in several European countries. This existing infrastructure can be used for natural gas and for biomethane at the same time.

Upgrading of biogas into biomethane is a relatively new technology but experience from Sweden and other countries shows that it is possible now to upgrade biogas with high reliability and at reasonable costs. The Swedish experience shows that biogas can be an economical sustainable fuel with a potential to drastically reduce emissions in urban transport (JÖNSSON & PERSSON 2003).

Today 8 000 vehicles use methane as fuel in the Sweden. During 2005 biogas accounted for 45 % of the total volume of methane delivered to vehicles, the rest being natural gas. The market for biogas as vehicle fuel is growing in Sweden. This is shown by the fact that the sale of biogas for vehicles was 25 % higher 2005 than 2004 (PERSSON 2006).

9. Biohydrogen

Hydrogen is the most abundant element in the Universe and very common on earth. Its atomic structure is the simplest of all atoms, since it is composed of one proton and one electron. Usually, pure hydrogen, which is diatomic (H_2), does not exist naturally since it easily combines with other elements. Hydrogen is mainly chemically bound in water, biomass or fossil fuels. In order to get hydrogen into a useful form, it must be extracted from one of these substances. This process requires energy. Accordingly, the cleanliness and renewability of this energy is of critical importance. While hydrogen fuel cells operate without producing emissions, making hydrogen can produce significant greenhouse gases and other harmful byproducts. Nevertheless, once obtained, hydrogen is a nearly ideal energy carrier.

9.1. Biohydrogen Processing

There exist various ways for hydrogen processing which are briefly described below although hydrogen from biomass is focused in this handbook:

- **Electrolysis**: Water electrolysis involves passing an electric current through H_2O to separate it into hydrogen (H_2) and oxygen (O_2). Hydrogen gas rises from the negative cathode and oxygen gas collects at the positive anode. Electrolysis produces extremely pure hydrogen, but a large amount of electricity is required. Ideally, this would come from renewable sources like wind and photovoltaic.
- **Steam-Methane Reformation**: Hydrogen can be reformed from natural gas by a two-step process at temperatures reaching 1100 °C in the presence of a catalyst. This is a relatively efficient and inexpensive process, especially in case of cogeneration.
- **Photoelectrolysis**: Photoelectrolysis uses sunlight to split water into its components via a semi-conducting material. It is roughly like immersing a photovoltaic cell in water, whereby the incoming light stimulates the semiconductor to split H_2O directly into its constituent gases. Though promising, this is still an experimental method of hydrogen production that has not evolved beyond the laboratory.
- **Hydrogen from Coal**: Coal contains hydrogen, and techniques are being developed to sequester hydrogen and carbon. Nevertheless, coal mining pollutes and despoils the landscape, and burning coal produces many harmful emissions.
- **Bio-Hydrogen**: Certain species of green algae produce hydrogen in the presence of sunlight. Researchers manipulated the photosynthetic process of spinach plants to produce hydrogen. But these biological means of hydrogen production, like the photoelectrolytic process described above, are known only as immature lab

experiments. Intense research persists to better understand ways to improve these hydrogen production methods.

- **Biohydrogen**: Apart from the above mentioned technologies, the conversion route from biomass to hydrogen gains on interest, as it is a pathway based on renewable energy that can therefore contribute to the reduction of GHG. The conversion routes for hydrogen from biomass are therefore described below.

There are currently two possible production routes for biohydrogen, the gasification of solid biomass and the digestion of (usually water rich) biomass, both with following purifying and reforming of the produced syngas to hydrogen. For both conversion routes there is a strong competition to the direct use of biomass (ARNOLD et al. 2005 p. 52).

Using **biomass gasification**, hydrogen-rich biomass sources converts to synthesis gas when heated in a controlled atmosphere. This synthesis gas (see chapter 7.2.1) primarily consists of carbon monoxide (CO), carbon dioxide (CO_2), and hydrogen (H_2). It is often composed of several compounds from which the H_2 must be extracted afterwards. Gasification can be conducted using a variety of low, medium or high-temperature methods. These methods differ in several aspects, including required pre-treatment and post-gasification treatment. Gasification technology has been under intensive development in recent times. Large-scale demonstration facilities have been tested and commercial units are starting worldwide. Nevertheless, the barriers for biomass gasification have been economic rather than technical. If biomass gasification to hydrogen is combined with carbon sequestration, biomass could even serve as a measure for returning CO_2 from the atmosphere into the earth (OECD/IEA 2004 p. 46).

The other method of gaining hydrogen from biomass is the **digestion of biomass**. In traditional biochemical conversion (digestion) processes, wet feedstock such as manure is digested to produce primarily CH_4 and CO_2 (see chapter 8.2). In order to produce hydrogen, the CH_4 has to be converted by using a thermochemical process, such as steam reforming. By manipulation of process conditions, methane formation can be suppressed and hydrogen can be directly produced along with organic acids. These acids can then be converted into methane and post-processed to yield additional hydrogen, increasing the overall efficiency of the process. Overall, this approach is well developed, though innovations to increase efficiency and lower costs are still needed in order to bring the cost of hydrogen production with this method closer to that of hydrogen production from other sources (OECD/IEA 2004 p. 46).

However, hydrogen is not expected to be available before the year 2020, although demonstration fleets are announced to be in operation earlier. The biggest obstacle for an earlier large-scale implementation is the missing environmental friendly, and economically and technically mature developed source for hydrogen production (ARNOLD et al. 2005 p. 51f).

9.2. Use of Biohydrogen

As cited in 'An EU Strategy for Biofuels', "advanced biofuel technologies could also provide a stepping stone to renewably-produced hydrogen, which offers the prospect of virtually emission-free transport. However, hydrogen fuel cells require new engine technology as well as a big investment in plants to produce the hydrogen and a new distribution system. In this context, the sustainability of hydrogen has to be carefully assessed. Any shift to hydrogen-based transport would therefore call for a major decision, embedded in a large-scale, long-term strategy" (EC 2006b p. 29).

In particular, energy effective use of hydrogen requires the introduction of fuel cells instead of internal combustion engines and therefore, adds another technology and cost challenge. The implementation of fuel cell vehicles is promising a much higher TTW efficiency than hydrogen combustion engines. Hydrogen from renewable sources for fuel cell driven vehicles might be a long term option, but its introduction will take a long time, needs breakthroughs in technology and cost and will require intermediate steps to enable a gradual growth of both fuel and vehicle availability. (EC 2006 p. 20)

The use and logistics of hydrogen becomes a difficult problem, since hydrogen in its gaseous state takes up a very large volume when compared to other fuels. One possible solution is to use ethanol to transport the hydrogen, then liberate the hydrogen from its associated carbon in a hydrogen reformer and feed the hydrogen into a fuel cell. Alternatively, some fuel cells (DEFC Direct-ethanol fuel cell) can be directly fed by ethanol or methanol.

Experiences with infrastructure of hydrogen applications have been made in several countries. For example in Germany a hydrogen filling station opened at Munich Airport[26] in May 1999.

In April 2003 the first hydrogen refueling station was opened in Reykjavík, Iceland. This station serves three buses that are in service in the public transport net of Reykjavík. The station produces the hydrogen it needs by itself, with an electrolyzing unit, and does not need refilling: all that enters is electricity and water.

Probably the most prominent worldwide project of hydrogen application for transport purposes is the establishment of the hydrogen highway in California, USA, promising 100 hydrogen fuel stations and 2000 hydrogen vehicles till the end of 2010. Other regions, as for example British Columbia (Canada) and Norway have joint the idea of the "hydrogen highway" (ARNOLD et al. 2005 p. 52).

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[26] For further details see: http://www.h2argemuc.com

PART C: THE FUTURE OF BIOFUELS

Since several years, the demand and price for crude oil are increasing continuously. The price of light crude oil even scratched the 100 US Dollar per barrel in autumn 2007. Discoveries of new oil fields are rapidly decreasing. New solutions have to be found to guarantee the high standard of daily life in Europe and worldwide.

As shown in the previous chapter, the development of new technologies for processing and using biofuels is steadily progressing. Biofuels are becoming more and more competitive compared to fossil fuels. The use of biofuels features a number of advantages suitable for achieving energy, environmental, agricultural and trade policies. As a result, biofuels are emerging as a popular step towards a more sustainable transportation sector, and several European countries have introduced advanced policies to support the production and use of biofuels. The Vision Report of the European Commission presents a vision for biofuels in 2030 in the European Union (see chapter 3.1).

The future of biofuels depends on the one hand on supportive policies but on the other hand on technical developments. In order to demonstrate potential future technical developments, three important issues were selected and are presented in the following chapters of Part C. The first issue describes the current discussion about 1st versus 2nd generation biofuels, the second issue gives an overview about integrated biorefinery concepts and the third issue scribe strategies for new vehicle technologies.

10. 1st vs. 2nd Generation Biofuels

In the current discussion biofuels are often divided into so-called first and second generation biofuels. Biofuels already established in fuel markets, such as PPO, biodiesel and bioethanol are denoted as **first generation biofuels**. They are usually produced from food crops. For instance, bioethanol is processed from sugar-bearing crops such as sugarcane and sugar beet, and from starchy crops such as cereals and potatoes. Rape seed, sunflower, soybean and palmoil are examples of feedstocks for biodiesel and pure plant oil production. Also biomethane already established in some European countries is usually referred to first generation biofuel.

Second generation biofuels are not yet commercial on large scale since their conversion technologies are still in the developmental stage. A wide range of feedstocks can be used for the production of these biofuels including lignocellulosic sources such as short-rotation woody crops (SRWC). Second generation biofuels are e.g. bioethanol from cellulosic material and BtL-fuels (chapters 5.2.3 and 7.2).

The 'Technology Roadmap' elaborated in the 'Vision Report' (EC 2006a) summaries the future development of biofuels (Figure 45) in the following three main phases:

Phase I Short term (until 2010)

- Improving existing technologies;
- R&D into 2nd generation biofuels (from lignocellulosic biomass). First 2nd generation biofuels demonstration plants;
- R&D into the biorefinery concept.

Phase II Medium term (2010 - 2020)

- Deployment of 2nd generation biofuel production
- Demonstration of biorefinery concept; continued R&D to improve lignocellulosic biofuel; and integrated biorefinery processes;
- Development of options for energy crops and sustainable agriculture.

Phase III Long term (beyond 2020)

- Large-scale production of 2nd generation biofuels; deployment of integrated biorefining complexes

Both, first and second generation biofuels have several **advantages and disadvantages**. The main advantage of first generation biofuels is that they are available with today's technologies. The production and use of bioethanol, biodiesel and PPO is already well established and a further promotion of these fuels mainly depends on non-technical issues, such as policies and cost-effectiveness. The main disadvantage of first generation biofuels is that only specific crops can be used for the biofuel production.

In contrast, for the production of second generation biofuels a much larger variety of feedstock can be used. This raises the available potential of usable biomass in Europe. Furthermore, the energy input for agriculture and feedstock production could be drastically reduced. In large conversion facilities second generation feedstock are expected to be efficiently converted into biofuels. But, although they offer high future potentials, it is not yet proved that second generation biofuels will have a better energy, economic and carbon performance than first generation production pathways.

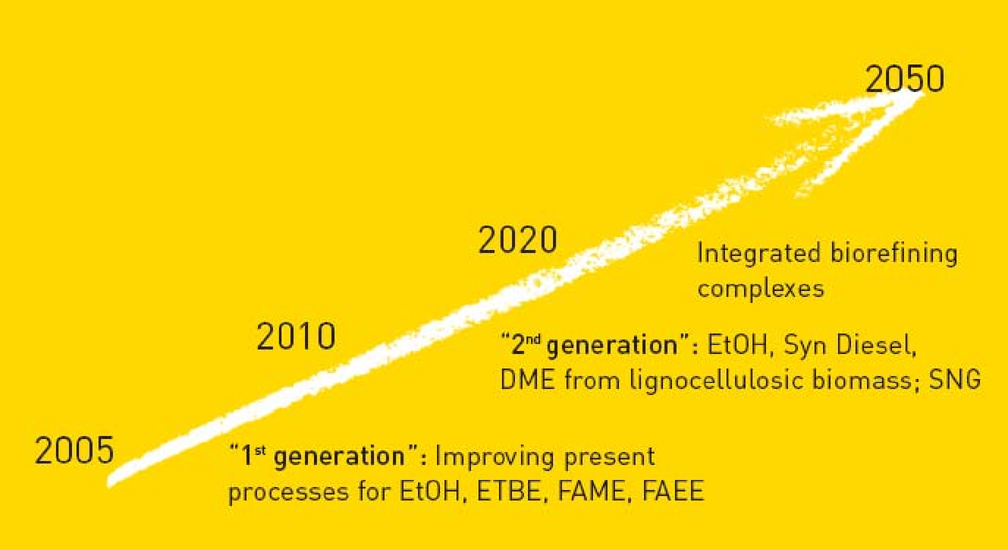


Figure 45: Future European Roadmap for Biofuels (EC 2006a)

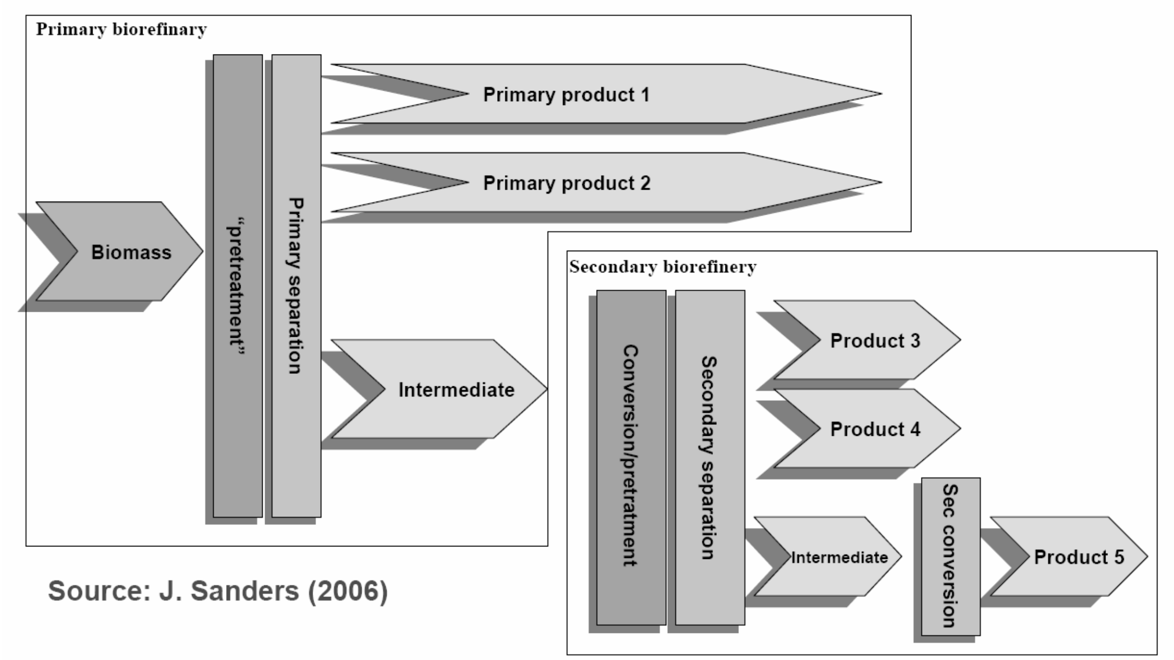
An advantage of first generation compared to second generation biofuels is that first generation biofuels (especially PPO and biodiesel) can be produced in **decentralized facilities**. For example, rapeseed farmers can press the seeds after harvesting either themselves or in small co-operational organized oil mills, and sell their own final products on the market. This encourages farmers and additional benefits are transferred to rural areas. In contrast, second generation biofuels can only be produced competitively in large facilities. The larger the conversion factory, the better are the scale effects and the economies of scale. Therefore large investments are needed which can only be taken by large companies. As a result, these companies will have a dominant market position with significant control over feedstock prices, and the benefits for rural areas may be limited.

In conclusion and with respect to the described advantages and disadvantages it is **recommended to further promote both, first and second generation biofuels with large ambition**. In the view of the authors of this handbook it is thereby necessary to avoid conflict between promoters of first and second generation biofuels. A sustainable transport sector in the foreseeable future will most likely depend on a successful development of a large variety of different biofuels.

11. Integrated Refining Concepts

The integrated refining concept is a holistic approach for the production of biofuels. So called "biorefineries" produce both biofuels and high value co-products. These co-products are further processed in the same refinery in order to add value. This model is similar to petroleum refineries where fuels are produced simultaneously with chemicals and materials. Similar to fossil fuel refineries, biofuels would represent the majority of total production in a biorefinery, while chemicals and other materials would generate most profits.

A general biorefinery model is show in Figure 46. Biomass is fractioned into various products that possibly undergo further biological, chemical or physical refinement. In these processes relatively high value chemicals, such as pharmaceuticals and polymers, can be produced as co-products of biofuels and thereby contributing to higher competitiveness of biofuels.



Source: J. Sanders (2006)

Figure 46: General concept of biorefinery (SANDERS 2006[27])

Although synergies between the production of chemicals and fuels from biomass are expected to be high, one complicating factor is the size of markets for organic chemicals, which tend to be relatively small compared to markets for liquid fuels. This will create a challenge in identifying chemical co-products for biorefinery production that will not

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[27] Source: http://ec.europa.eu/research/energy/pdf/gp/gp_events/biofuels/askew_en.pdf [03.08.2006]

exceed the market demand, as large quantities of liquid fuels are produced at these facilities (WWI 2006 p. 63f).

An example of how the biorefinery concept can be applied to ethanol production is presented in Figure 47. It shows that a large variety of feedstock sources can be used as input into the biorefinery. The output of the plant, besides the main product ethanol, includes solid fuel pellets, green pellets, beet pellets, enzymes, flavorings, colorings, proteins, amino acids, organic acids, and biodegradable plastics.

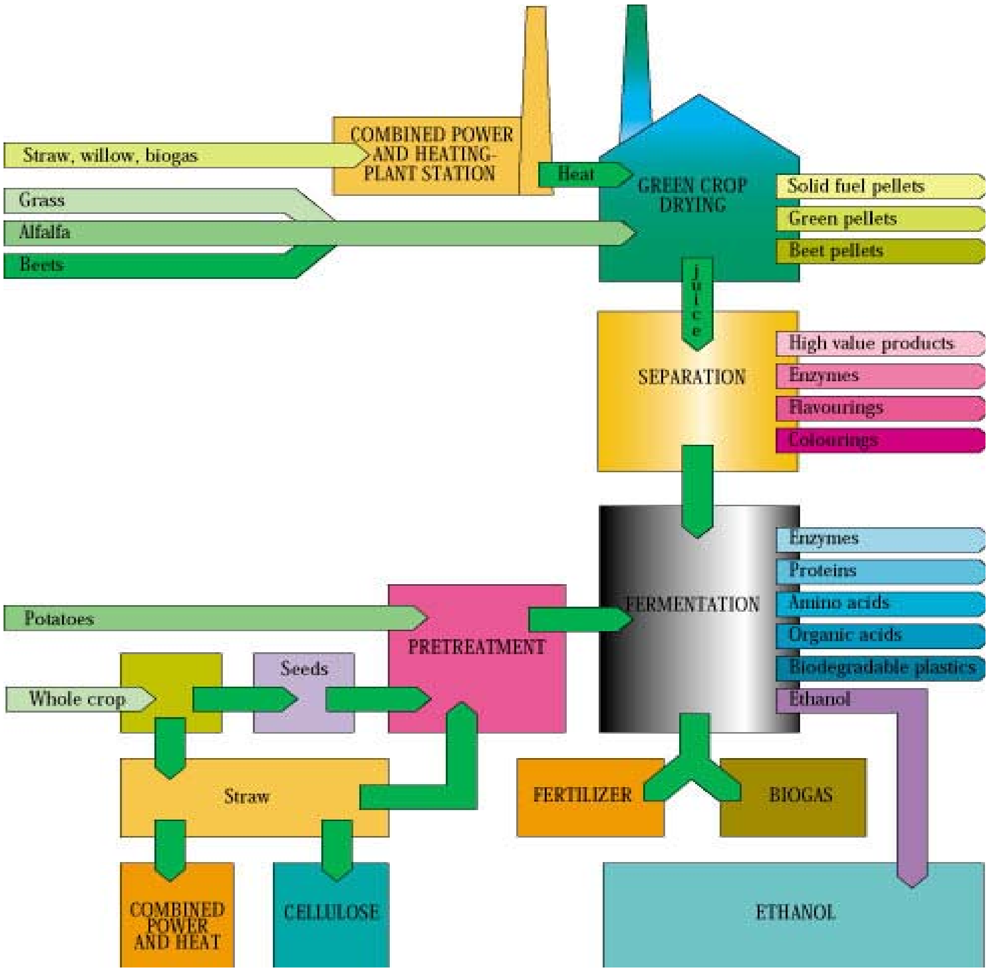

Figure 47: Example of a biorefinery concept for the production of ethanol (PAULI KIEL et. al. 1994[28])

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[28] Source: PAULI KIEL et al. (1994) in http://websrv5.sdu.dk/bio/Cropgen/JBHN.pdf [03.08.2006]

12. Strategies for New Vehicle Technologies

The use of biofuels is closely linked to available and future engine technologies. To replace conventional engine concepts which are based on mineral oil, two alternative strategies are principally pursued at the moment (short and long term strategy). These concepts differ mainly in the philosophy of the engines.

In the **short term** the concept is based on further developments of today’s combustion engine and the use of biofuels. Today this is the most promising approach. It is efficient and sustainable, as no additional infrastructure and no principally different engine technology is needed.

The **long-term** approach favors a change to electric engines driven by fuel cells and high efficient batteries which work without producing emissions during vehicle use. However, numerous technical and economical challenges need to be overcome and today only few manufacturers produce **hybrid vehicles** (combinations of electric and combustion engines) already available on the market.

Both approaches can use renewable energy as input. However, they must be available at reasonable prices and contribute to the reduction of CO_2 emission. As stated in the Vision Report “in 2030, biofuels will mostly be used in internal combustion engines, as these technologies will still prevail. However it is possible that specialized drivetrains, e.g. fuel cells, will be used in certain applications or in dedicated fleets.” (EC 2006 p. 18)

13. Glossary and Abbreviations

Acidity: The presence of acid-type constituents whose concentration is usually defined in terms of neutralization number. The constituents vary in nature and may or may not markedly influence the behavior of e.g. oils.

Additives: Chemicals added to fuel in very small quantities to improve and maintain fuel quality. Detergents and corrosion inhibitors are examples of gasoline additives.

Advanced Technology Vehicle (ATV): A vehicle that combines new engine, power and drivetrain systems in order to significantly improve fuel economy. This includes hybrid power systems and fuel cells, as well as some specialized electric vehicles.

AFV: Alternative Fuel Vehicle

Air-Fuel Ratio: The ratio of air weight to fuel weight consumed in an internal combustion engine or furnace.

Air Toxics: Toxic air pollutants including benzene, formaldehyde, acetaldehyde, 1-3 butadiene, and polycyclic organic matter (POM). Benzene is a constituent of motor vehicle exhaust, evaporative, and fueling emissions. The other compounds are exhaust pollutants.

AKI: Anti-Knock Index

Alcohols: Organic compounds that are distinguished from hydrocarbons by the inclusion of a hydroxyl group. The two simplest alcohols are methanol and ethanol.

Aldehydes: A class of organic compounds derived by removing the hydrogen atoms from an alcohol. Aldehydes can be produced from the oxidation of an alcohol.

Aliphatic: A class of saturated or unsaturated carbon compounds, in which the carbon atoms are joined in open chains.

Alternative Fuel: Fuel which is not broadly applied today and which is a niche product in the fuel market.

Alternative Fuel Vehicle (AFV): Any dedicated, flexible-fuel, or dual-fuel vehicle designed to operate on at least one alternative fuel.

American Society for Testing and Materials (ASTM): An American nonprofit organization that provides a management system to develop published technical information. ASTM standards, test methods, specifications, and procedures are recognized as definitive guidelines for motor fuel quality as well as a broad range of other products and procedures.

Anhydrous: Describes a compound that does not contain any water.

Anhydrous alcohol: Alcohol that is free of water and at least 99% pure. This ethanol may be used in fuel blends. Hydrous alcohol on the other hand contains some water and usually has a purity of 96%. In Brazil, this ethanol is being used as a 100% gasoline substitute in cars with dedicated engines. The distinction between anhydrous and hydrous alcohol is of relevance not only in the fuel sector but may be regarded as the basic quality distinction in the ethanol market.

Aniline Point: The aniline point of a petroleum product is the minimum equilibrium solution temperature with an equal volume of freshly distilled aniline.

Anti-Knock Index (AKI): It is the average of the Motor Octane Number (MON) and the Research Octane Number (RON). This is the number posted on the retail gasoline pumps normally indicating 87, 89, or 92 octane. Racing gasoline have AKI's from 100 to 118.

API: American Petroleum Institute

API Gravity: Gravity (weight per unit volume) of oils as measured by the API scale. This standard was adopted by the API 5/4/22 as the standard for the American petroleum industries.

Aromatics: Hydrocarbons based on the ringed six-carbon benzene series or related organic groups. Benzene, toluene and xylene are the principal aromatics, commonly referred to as the BTX group. They represent one of the heaviest fractions in gasoline.

Ash: Inorganic residue remaining after ignition of combustible substances determined by definite prescribed methods.

Asphaltenes: Insoluble, semi-solid, or solid particles which are combustible and are highly aromatic. Asphaltenes contain a high carbon to hydrogen ratio and entrap water, fuel ashes and other impurities.

ASTM: American Society for Testing and Materials

Atomization characteristics: The ability of an oil to be broken up into a fine spray by some mechanical means.

ATV: Advanced Technology Vehicle

B100: Is pure biodiesel since it is 100% (neat) biodiesel.

B20: A blend of biodiesel fuel with petroleum-based diesel where 20% of the volume is biodiesel.

Bagasse: By-product of sugarcane production. It is the biomass remaining after sugarcane stalks are crushed to extract their juice. Bagasse is often used as a primary fuel source for sugar mills; when burned in quantity, it produces sufficient heat energy to supply all the needs of a typical sugar mill, with energy to spare.

Barrel: A unit of volume measurement used for petroleum and its products. 1 barrel (bbl) = 42 U.S. gallons or 35 British gallons.

BAT: Best available technology

bbl: Abbreviation for barrel

Benzene: An aromatic hydrocarbon which is a colorless, volatile, flammable liquid. This common gasoline component is identified as being toxic. Benzene is a known carcinogen.

BHP: Brake horsepower

Bi-Fuel Vehicle: A vehicle with two separate fuel systems designed to run on either an alternative fuel, or gasoline or diesel, using only one fuel at a time.

Biochemical Conversion: The use of enzymes and catalysts to change biological substances chemically to produce energy products, for example the digestion of organic wastes or sewage by microorganisms to produce methane.

Biodiesel: Biodiesel is composed of monoalkyl esters (methyl/ethyl esters), a long chain of fatty acids derived from renewable lipid sources. It is an ester based, renewable fuel made from vegetable oils, recycled fryer oils, tallow and other biological products which have had their viscosity reduced using a process called tranestrification. The by-product of this process is glycerin, the thick component of vegetable oil. Biodiesel is biodegradable, non-toxic, and essentially free of sulfur and aromatics. Originally biodiesel was considered a by-product of glycerin soap production.

Bio-DME: Dimethylether produced from biomass, for use as biofuel

Bio-ETBE: Ethyl-Tertio-Butyl-Ether produced from bioethanol. ETBE is used as a fuel additive to increase the octane rating and reduce knocking.

Bioethanol: Ethanol produced from biomass and/or the biodegradable fraction of waste, for use as biofuel E5 contains 5% ethanol and 95% petrol E85 contains 85% ethanol and 15% petrol

Biofuel: Liquid or gaseous fuel for transport produced from biomass: Alcohols, esters, ethers, and other chemicals (biodiesel, ethanol, and methane) made from biomass sources (herbaceous and woody plants, animal fats, agricultural and forest waste, or municipal solid and industrial waste) within an active carbon cycle. Production and combustion of biofuels take and replenish the CO_2 in a circular, sustainable fashion. These fuels are used for stationary and mobile applications, i.e., electricity and transportation. Two commonly used biofuels are ethanol and biodiesel.

Biogas: A fuel gas produced from biomass and/or the biodegradable fraction of waste, which can be purified to natural gas quality (biomethane) for use as biofuel or woodgas.

Biohydrogen: Hydrogen produced from biomass or biodegradable waste for use as biofuel.

Biomass: Renewable organic matter such as agricultural crops, crop waste residues, wood, animal waste, animal fat, municipal waste, aquatic plants; fungal growth; etc., used for the production of energy.

Biomass-to-Liquid (**BTL)**: This second-generation fuel belongs to the group of synthetic fuels. Its components are designed for the requirements of modern motor concepts. For the production of BTL-fuels many types of feedstock can be used.

Biomethane: Methane produced from biogas production. This fuel can be used in vehicles running on natural gas.

Biomethanol: Methanol produced from biomass, for use as biofuel.

Bio-MTBE: Methyl-Tertio-Butyl-Ether produced from biomethanol. MTBE is used as a fuel additive to increase the octane rating and reduce knocking.

Blending: Mixing of two compatible fuels having different properties in order to produce an intermediate fuel.

Brake horsepower (bhp): It is the measure of an engine's horsepower without the loss in power caused by the gearbox, generator, differential, water pump and other auxiliaries. The actual horsepower delivered to the driving wheels is less. An engine would have to be retested to obtain a rating in another system.

British Thermal Unit (Btu): A standard unit for measuring heat energy. One Btu represents the amount of heat required to raise one pound of water one degree Fahrenheit (at sea level).

BS&W: Bottom sediment and water.

BS&W Monitor: An instrument which detects entrained water content in petroleum products wherein the water changes the capacitive reactance as a function of the dielectric constant.

BTL: Biomass-to-Liquid

BTU: British Thermal Unit.

BTX: Industry term referring to the group of three aromatic hydrocarbons: benzene, toluene and xylene.

Bunker Fuel Oil: Heavy, residual fossil fuel oil used in ships.

Butane: A gas, easily liquefied, recovered from natural gas. Used as a low-volatility component of motor gasoline, processed further for a high-octane gasoline component, used in LPG for domestic and industrial applications and used as a raw material for petrochemical synthesis.

Butyl Alcohol: Alcohol derived from butane that is used in organic synthesis and as solvent.

Bxx: (where xx is a number e.g. B5, B10 etc.) biodiesel blend with petroleum diesel, with biodiesel volume percentage indicated by the number

CAI: Controlled auto-ignition combustion technology

Calorie: The amount of heat required to raise the temperature of 1 gram of water by 1 degree centigrade, at or near maximum density.

Calorific Value: Amount of heat produced by the complete combustion of a unit weight of fuel. Usually expressed in calories per gram or BTU's per pound, the latter being numerically 1.8 times the former.

CAP: Common Agricultural Policy in the EU

Carbon Dioxide (CO_2): A product of combustion that has become an environmental concern in recent years. CO_2 does not directly impair human health, but is a greenhouse gas that traps the Earth's heat and contributes to the potential for global warming.

Carbon Monoxide (CO): A colorless, odorless gas produced by the incomplete combustion of fuels with a limited oxygen supply, as in automobile engines. CO contributes to the formation of smog ground-level ozone, which can trigger serious respiratory problems.

Carbon Sequestration: The absorption and storage of CO_2 from the atmosphere by the roots and leaves of plants. The carbon builds up as organic matter in the soil.

Carcinogens: Chemicals and other substances known to cause cancer.

Catalyst: A substance whose presence changes the rate of chemical reaction without itself undergoing permanent change in its composition. Catalysts may be accelerators or retarders. Most inorganic catalysts are powdered metals and metal oxides, chiefly used in the petroleum, vehicle, and heavy chemical industries.

CBP: combined bioprocessing

CCR: Conradson carbon residue

CCs: EU candidate countries

CDM: Clean Development Mechanism

Centigrade: Temperature based on 0 for the temperature at which water freezes and 100 for the temperature at which water boils.

Centrifuge: A machine using centrifugal force produced by high-speed rotation for separating materials of different densities. Applied to Diesel engine fuels and lubricating oils to remove moisture and other extraneous materials.

Cetane Number (Cetane Rating, Cetane Index): A measure of ignition quality of diesel fuel. The higher the cetane number, the easier the fuel ignites when it is injected into the engine. Biodiesel has a higher cetane number than petrol diesel because of its higher oxygen content. This means that engines run smoother and create less noise when running on Biodiesel. It is the equivalent to the octane number of gasoline.

CFV: Clean Fuel Vehicle

CGH_2: Compressed gaseous hydrogen.

CH_4: Methane

C/H Ratio: Carbon/Hydrogen ratio

Clean Development Mechanism (CDM): Countries can engage under the Kyoto Protocol in projects through which an entity in one country partially meets its domestic commitment to reduce GHG levels by financing and supporting the development of a project in another country. CDM projects are between an industrial and a developing country.

Closed-Loop Carburetion: System in which the fuel/air ratio in the engine is carefully controlled to optimize emissions performance. A closed-loop system uses a fuel metering correction signal to optimize fuel metering.

Cloud Point: Temperature at which wax begins to crystallize from a distillate fuel.

CNG: Compressed natural gas

CO: Carbon monoxide

CO_2: Carbon dioxide

Combined bioprocessing (CBP): technology for cellulosic ethanol production

Common Agricultural Policy (CAP): The CAP is a system of European Union agricultural subsidies. These subsidies work by guaranteeing a minimum price to producers and by direct payment of a subsidy for crops planted. This provides some economic certainty for EU farmers and production of a certain quantity of agricultural goods.

Co-solvents: Heavier molecular weight alcohols used with methanol to improve water tolerance and reduce other negative characteristics of gasoline/alcohol blends. Tertiary butyl alcohol (TBA) was used commercially as a co-solvent for methanol/gasoline blends during the 1980s.

Compressed Natural Gas (CNG): Natural gas that has been compressed under high pressures, typically 2000 to 3600 psi and which is held in a container. The gas expands when used as a fuel.

Compression Ignition: The form of ignition that initiates combustion in a diesel engine. The rapid compression of air within the cylinders generates the heat required to ignite the fuel as it is injected.

Converted Vehicle: A vehicle originally designed to operate on gasoline or diesel that has been modified or altered to run on an alternative fuel.

Copra: It is the dried meat, or kernel, of the coconut. The name copra is derived from the Malayalam word kopra for dried coconut. Copra is not to be mistaken as the scientific name for coconut (*Cocos nucifera* Linnaeus, Arecaceae or palm family).

Corrosion: Detrimental change in the size or characteristics of material under conditions of exposure or use. It usually results from chemical action either regularly and slowly, as in rusting (oxidation), or rapidly, as in metal pickling.

Corrosion Inhibitors: Additives used to inhibit corrosion (e.g., rust) in the fuel system.

Cracked: Refers to a petroleum product produced by a secondary refining process such as thermal cracking or vis-breaking processes which yield very low quality residue.

Cryogenic Storage: Extreme low-temperature storage.

cSt: Centistokes at 50 Centigrade

CTL: Coal-to-Liquid

DDGS: Distillers dry grains soluble

Dedicated Natural Gas Vehicle: A vehicle that operates only on natural gas. Such a vehicle is incapable of running on any other fuel.

Dedicated Vehicle: A vehicle that operates solely on one fuel. Generally, dedicated vehicles have superior emissions and performance results because their design has been optimized for operation on a single fuel.

Demulsibility: The resistance of an oil to emulsification, or the ability of an oil to separate from any water with which it is mixed. The better the demulsibility rating, the more quickly the oil separates from water.

Denatured Alcohol: Ethanol that contains a small amount of a toxic substance, which cannot be removed easily by chemical or physical means. Alcohols intended for industrial use must be denatured to avoid federal alcoholic beverage tax. There are diverse industrial uses for ethanol, and therefore literally hundreds of recipes for denaturing ethanol. Typical additives are methanol, isopropanol, methyl ethyl ketone, methyl isobutyl ketone, denatonium, and even aviation gasoline. In this sense of the word, denatured means "a specific property of ethanol, its usefulness as a beverage, is removed". The ethanol molecule is not denatured in the sense that its chemical structure is altered.

Density: Density is the term meaning the mass of a unit of volume. Its numerical expression varies with the units selected.

Detergent: Additives used to inhibit deposit formation in the fuel and intake systems in automobiles.

Detonation: A violent explosion involving high-velocity pressure waves; in a gasoline engine, the spontaneous combustion of part of the compresses charge after spark occurs. Detonation usually produces a characteristic metallic sound, or knock.

Distillation: Distillation is a method of separating substances based on differences in their volatilities. In the distillation process a liquid is heated up to its boiling point and the vapors are collected after condensing. This process is used for ethanol production.

Dimethyl Ether (DME): An oxygenated hydrocarbon, which is the simplest compound in the class of ethers. It is generally produced from natural gas but almost any carbon-based feedstock can be used, including crude oil, coal, crop residues, oil sands, wood, or straw.

Distillers dry grains soluble (DDGS): High value and protein rich feed consisting of wheat mash which is a co-product from ethanol production.

DME: Dimethyl ether

Dual-Fuel Vehicle: Vehicle designed to operate on a combination of an alternative fuel and a conventional fuel. This includes vehicles using a mixture of gasoline or diesel and an alternative fuel in one fuel tank, commonly called flexible-fueled vehicles; and vehicles capable of operating either on an alternative fuel (usually compressed natural gas or propane), a conventional fuel, or both, simultaneously using two fuel systems. These are commonly called bi-fuel vehicles.

E10 (Gasohol): Ethanol mixture that contains 10% ethanol, 90% unleaded gasoline.

E85, E93, E95: Ethanol/gasoline mixture that contains 85% (93%, 95%) denatured ethanol and 15% (5%, 2%) gasoline, by volume.

EC: European Commission

E-diesel: ethanol-diesel blends

Electric Vehicle (EV): A vehicle powered by electricity, generally provided by batteries.

Electricity: Electric current used as a power source. Electricity can be generated from a variety of feedstocks, including oil, coal, nuclear, hydro, natural gas, wind, and solar. In electric vehicles, onboard rechargeable batteries power electric motors.

Electrolytic process: A process that causes the decomposition of a chemical compound by the use of electricity.

Emulsion: A liquid mixture of two or more liquid substances not normally dissolved in one another, one liquid held in suspension in the other. Water-in-oil emulsions have water as the internal phase and oil as the external, while oil-in-water have oil as the internal phase and water as the external.

Engler viscosity: A viscosity obtained by dividing the out-flow time in seconds for 200 ml. of the material being tested, by the time in seconds for 200 ml. of water at 68F (20C) to flow out of an Engler viscosimeter.

Ester: An organic compound formed by reacting an acid with an alcohol, always resulting in the elimination of water. In the biodiesel reaction, esters are formed as a result of combining fatty acids and methanol or ethanol. Methyl Acetate (CH_3COOCH_3) is the simplest ester.

ETBE: Ethyl tertiary butyl ester

Ethane (C_2H_6): A colorless hydrocarbon gas of slight odor having a gross heating value of 1,773 Btu per cubic foot. It is a normal constituent of natural gas.

Ethanol: (also known as Ethyl Alcohol, Grain Alcohol, CH_3CH_2OH) Can be produced chemically from ethylene or biologically from the fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood.

Ether: A class of organic compounds containing an oxygen atom linked to two organic groups.

Etherification: Oxygenation of an olefin by methanol or ethanol. For example, MTBE is formed from the chemical reaction of isobutylene and methanol.

Ethyl Ester: A fatty ester formed when organically derived oils are combined with ethanol in the presence of a catalyst. After water washing, vacuum drying, and filtration, the resulting ethyl ester has characteristics similar to petroleum-based diesel motor fuels.

Ethyl Tertiary Butyl Ether (ETBE): A fuel oxygenate used as a gasoline additive to increase octane and reduce engine knock.

EU: European Union

Evaporative Emissions: Hydrocarbon vapors that escape from a fuel storage tank or a vehicle fuel tank or vehicle fuel system.

Exx: (where xx is a number e.g. E10, E20) ethanol blend with gasoline, with ethanol volume percentage indicated by the number

FAEE: Fatty acid ethyl ether

Fahrenheit: Temperature scale based on 32F for the temperature at which water freezes and 212F for the temperature at which water boils (180 difference). Conversion to Fahrenheit from Celsius (centigrade) temperature scale is by the following formula: F = 9/5C + 32, where C is the temperature in Celsius degrees.

FAME: Fatty acid methyl ether

Fatty acid ethyl ether: (FAEE, biodiesel) Are ethyl esters produced from vegetable oils or recycled cooking oils or animal fats. Producing ethyl ester rather than methyl ester is of considerable interest because it allows production of an entirely agricultural fuel, and the extra carbon brought by ethanol molecule slightly increases the heat and the cetane number.

Fatty acid methyl esters (FAME, biodiesel): Are methyl esters produced from vegetable oils or recycled cooking oils or animal fats.

Feedstock: Any material converted to another form of fuel or energy product. For example, cornstarch can be used as a feedstock for ethanol production.

Fermentation: The enzymatic transformation by microorganisms of organic compounds such as sugar. It is usually accompanied by the evolution of gas as the fermentation of glucose into ethanol and CO_2.

FFV: Flexible fuel vehicle

Final Boiling Point (FBP): The highest temperature indicated on the thermometer inserted in the flask during a standard laboratory distillation. This is generally the temperature at which no more vapor can be driven over into the condensing apparatus.

Fire Point: The lowest temperature at which an oil vaporizes rapidly enough to burn for at least 5 seconds after ignition, under standard conditions.

First-generation feedstock: Feedstock which is used to produce first generation biofuels. Usually, this feedstock was originally cultivated for food production. It comprises only parts of the plants, such as stalks, kernels and tubes. Examples are rape-seed, cereals, potatoes, sugar-cane etc.

First generation biofuels: Biofuels which are available on todays fuel markets, such as PPO, biodiesel and bioethanol.

Fischer-Tropsch: A method discovered in 1923 by the German coal researchers Franz Fischer and Hans Tropsch, for the synthesis of hydrocarbons and other aliphatic compounds. A mixture of hydrogen and carbon monoxide is reacted in the presence of an iron or cobalt catalyst. Much heat is evolved and products such as methane, synthetic gasoline and waxes, and alcohols are made. Water or carbon dioxide is its by-product.

Flashpoint: The lowest temperature in °C at which a liquid will produce enough vapor to ignite, if the vapor is flammable and when exposed to a source of ignition. The lower the flashpoint is the higher is the risk of fire. Biodiesel has an abnormally high flashpoint (for a fuel), making it very safe to handle and store.

Flexible-Fuel Vehicle (FFV): A Vehicle with a common fuel tank designed to run on varying blends of unleaded gasoline with either ethanol or methanol.

Fluorinated Polyethylene/Polypropylene: Two types of plastic that have been specially modified to withstand certain chemicals, including biodiesel.

Fossil Fuel: A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter of a previous geologic time and used for fuel. Combustion of fossil fuels emits large amounts of CO_2 into the atmosphere.

Fuel Cell: An electrochemical engine with no moving parts that converts the chemical energy of a fuel, such as hydrogen, and an oxidant, such as oxygen, directly to electricity. The principal components of a fuel cell are catalytically activated electrodes for the fuel (anode) and the oxidant (cathode) and an electrolyte to conduct ions between the two electrodes.

FT: Fischer-Tropsch process for making synthetic fuels.

Fusil alcohol (fusil oil): Fusel alcohols, also sometimes called fusel oils, are higher order (more than two carbons) alcohols formed by fermentation. During distillation, fusel alcohols are concentrated in the "tails" at the end of the distillation run. They have an oily consistency, which is noticeable to the distiller, hence the other name fusel oil. If desired, these heavier alcohols can be almost completely separated in a reflux still.

Gas to Liquid Technology: Gas-to-liquid conversion technologies use chemical or physical means to convert natural gas to a liquid form suitable for ready transport or direct use.

Gasohol: In the United States, gasohol (E10) refers to gasoline that contains 10% ethanol by volume. This term was used in the late 1970s and early 1980s but has been replaced in some areas of the country with E10, super unleaded plus ethanol, or unleaded plus.

Gasoline Gallon Equivalent (gge): A unit for measuring alternative fuels so that they can be compared with gasoline on an energy equivalent basis. This is required because the different fuels have different energy densities.

GE: genetic engineering (or genetically engineered)

GHG: Greenhouse gas

Global Warming: The theoretical escalation of global temperatures caused by the increase of greenhouse gas emissions in the lower atmosphere.

Glycerin: ($CH_2OHCHOHCH_2OH$): The "thick" component of all biodiesel feedstocks. It is separated from the esters during the biodiesel reaction process, combining together with the catalyst to form glycerin soap, the by-product of making biodiesel.

GMO: Genetically modified organisms

Greenhouse Effect: A warming of the Earth and its atmosphere as a result of the thermal trapping of incoming solar radiation by CO_2, water vapor, methane, nitrogen oxide, chlorofluorocarbons, and other gases, both natural and man-made.

GTL: Gas-to-Liquid

GWP: Global warming potential

H_2: Hydrogen

HC: Hydrocarbons

Heat of Combustion Gross: Total heat evolved during complete combustion of unit weight of a substance, usually expresses in BTU per pound.

Heat of Combustion Net: Gross heat of combustion minus the latent heat of condensation of any water produced.

Heavy crude: Crude oil with a high specific gravity and a low API gravity due to the presence of a high proportion of heavy hydrocarbon fractions and metallic content.

HHV: Higher heating value

High Compression Ignition Engine: Also know as Diesel engine. Unlike gasoline engines which use a spark plug to ignite the fuel, there is no external ignition spark in a high compression engine. Air is compressed, driving its temperature up to a point that it ignites fuel which has been injected into the chamber.

Homogenizer: A mechanical device which is used to create a stable, uniform dispersion of an insoluble phase (asphaltenes) within a liquid phase (fuel oil).

HP: Horsepower

HTU: Hydrothermal upgrading

Hybrid Electric Vehicle (HEV): A vehicle powered by two or more energy sources, one of which is electricity. HEVs may combine the engine and fuel of a conventional vehicle with the batteries and electric motor of an electric vehicle in a single drivetrain.

Hydrocarbons: Compounds containing various combinations of hydrogen and carbon atoms. Hydrocarbons contribute heavily to smog.

Hydrogen (H_2): A colorless, highly flammable gaseous fuel.

Hydrometer: An instrument for determining the gravity of a liquid.

Hydrous alcohol: Alcohol that contains some water and usually has a purity of 96%. In Brazil, this ethanol is being used as a 100% gasoline substitute in cars with dedicated engines. The distinction between anhydrous and hydrous alcohol is of relevance not only in the fuel sector but may be regarded as the basic quality distinction in the ethanol market.

IBP: Initial Boiling Point.

Infrastructure: In transportation, this term generally refers to the charging and fueling network necessary to successful development, production, commercialization, and operation of alternative fuel vehicles. It includes fuel supply, public and private charging and fueling facilities, standard specifications for fueling outlets, customer service, education and training, and building code regulations.

Initial Boiling Point (IBP): In a standard laboratory distillation, the temperature on the distillation thermometer at the moment the first drop of distillate falls from the condenser.

JI: Joint Implementation

Joint Implementation (JI): Countries can engage under the Kyoto Protocol in projects through which an entity in one country partially meets its domestic commitment to reduce GHG levels by financing and supporting the development of a project in another country. JI projects are between two industrial countries.

Kinematic Viscosity: The ratio of the absolute viscosity of a liquid to its specific gravity at the temperature at which the viscosity is measured. Expressed in Stokes or Centistokes.

Latent heat: Heat required changing the state of a unit weight of a substance from solid to liquid or from liquid to vapor without change of temperature.

Layering: This occurs in tanks when a high density fuel is mixed with a low density fuel.

LH_2: Liquid hydrogen. (stored at very low temperatures).

LHV: Lower Heating Value

Light crude: Crude oil with a low specific gravity and high API gravity due to the presence of a high proportion of light hydrocarbon fractions and low metallic compound.

Light Ends: The more volatile products of petroleum refining; e.g. butane, propane, gasoline.

Liquefied Natural Gas (LNG): Compressed natural gas that is cryogenically stored in its liquid state.

Liquefied Petroleum Gas (LPG): A mixture of hydrocarbons found in natural gas and produced from crude oil, used principally as a feedstock for the chemical industry, home heating fuel, and motor vehicle fuel.

LNG to CNG Station: A station, supplied with LNG, that pumps and vaporizes the liquid supply to vehicles as CNG fuel, generally at the correct pressure and temperature (i.e., the temperature effect of compression is factored into the design).

LPG: Liquefied petroleum gas

LRP: Lead replaced petrol

Lubricity: Capacity to reduce friction. The higher the lubricity, the easier a fuel can move through an engine, resulting in longer engine life. Lubricity is measured as "kinetic viscosity."

M100: 100% (neat) methanol.

M85: 85% methanol and 15% unleaded gasoline by volume, used as a motor fuel in FFVs.

Mercosur or **Mercosul**: (Spanish: Mercado Común del Sur, Portuguese: Mercado Comum do Sul, English: Southern Common Market) is a trading zone between Brazil, Argentina, Uruguay, and Paraguay, founded in 1991 by the Treaty of Asunción. Its purpose is to promote free trade and the fluid movement of goods, peoples, and currency. Bolivia, Chile, Colombia, Ecuador and Peru have associate member status. On 9 December 2005, Venezuela was accepted as a new member, but it will be publicized in late 2006.

Methane (CH_4): The simplest of the hydrocarbons and the principal constituent of natural gas. Pure methane has a heating value of 1,012 Btu per standard cubic foot.

Methanol (Methyl Alcohol, Wood Alcohol, CH_3OH): A liquid fuel formed by catalytically combining CO with hydrogen in a 1 to 2 ratio under high temperature and pressure. Commercially, it is typically manufactured by steam reforming natural gas. Also formed in the destructive distillation of wood. It is commonly used in biodiesel for its reactivity.

Methoxide: In biodiesel production, methoxide is a product of mixing methanol and sodium hydroxide (or potassium hydroxide). This is then mixed with the vegetable oil in a reaction known as transesterification.

Methyl Alcohol: See Methanol.

Methyl Ester: A fatty ester formed when organically derived oils are combined with methanol in the presence of a catalyst. Methyl Ester has characteristics similar to petroleum-based diesel motor fuels.

Methyl Tertiary Butyl Ether (MTBE): A fuel oxygenate used as an additive to gasoline to increase octane and reduce engine knock.

Middle Distillate: Term applied to hydrocarbons in the so-called "middle range" of refinery distillation. Examples: heating oil, diesel fuels, and kerosene.

MJ: Megajoule

MON: Motor Octane Number

Motor Octane: The octane as tested in a single-cylinder octane test engine at more severe operating conditions. Motor octane number (MON) affects high-speed and part-throttle knock and performance under load, passing, climbing, and other operating conditions. Motor octane is represented by the designation M in the (R+M)/2 equation and is the lower of the two numbers.

MTBE: Methyl tertiary butyl ether

Mutagenicity: The property of chemical or physical agents inducing changes in genetic material that are transmitted during cell division. Fundamentally, a measure of cancer risk. The mutagenicity of biodiesel emissions is 75% - 90% less than its petroleum counterpart.

N_2O: Nitrous oxide

Natural Gas: A mixture of fossil gaseous hydrocarbons, primarily methane, occurring naturally in the Earth and used principally as a fuel.

Natural Gas Distribution System: This term generally applies to mains, services, and equipment that carry or control the supply of natural gas from a point of local supply, up to and including the sales meter.

Natural Gas Transmission System: Pipelines installed for the purpose of transmitting natural gas from a source or sources of supply to one or more distribution centers.

Natural Gas Vehicle: Vehicles that are powered by compressed or liquefied natural gas.

Neat Alcohol Fuel: Straight or 100% alcohol (not blended with gasoline), usually in the form of either ethanol or methanol.

Neat Fuel: Fuel that is free from admixture or dilution with other fuels.

Neutralization number: The number that expresses the weight in milligrams of an alkali needed to neutralize the acidic material in one gram of oil. The neutralization number of an oil is an indication of its acidity.

NH_3N: Ammonia nitrogen

Nitrile: Also called "Buna-N." Nitrile is a low grade rubber common in older vehicles' fuel systems and is not as ideal for use with biodiesel as the higher grade synthetics. For this reason, it is recommended that nitrile and natural rubber fuel system components be replaced with more suitable fluoropolymers.

NO_x: Oxides of nitrogen

OECD: Organization of Economic Co-operation and Development

OEM: Original equipment manufacturer.

Octane Enhancer: Any substance such as MTBE, ETBE, toluene, or xylene that is added to gasoline to increase octane and reduce engine knock.

Octane Rating (Octane Number): A measure of a fuel's resistance to self-ignition, hence a measure as well of the antiknock properties of the fuel.

Olefins: Class of unsaturated paraffin hydrocarbons recovered from petroleum. Typical examples include: butene, ethylene and propylene.

Open-Loop Fuel Control: System in which the air/fuel mixture is preset by design with no feedback correction signal to optimize fuel metering.

Original Equipment Manufacturer (OEM): The original manufacturer of a vehicle or engine.

Oxidation: Combining elemental compounds with oxygen to form a new compound. A part of the metabolic reaction.

Oxides of Nitrogen (NOx): Regulated air pollutants, primarily NO and NO_2 but including other substances in minute concentrations. Under the high pressure and temperature conditions in an engine, nitrogen and oxygen atoms in the air react to form various NOx. Like hydrocarbons, NOx are precursors to the formation of smog. They also contribute to the formation of acid rain.

Oxidizing agent: Any substance (oxygen, chlorine) that can accept electrons. When oxygen or chlorine is added to wastewater, organic substances are oxidized. These oxidized organic substances are more stable and less likely to give off odors or to contain disease bacteria.

Oxygenate: A term used in the petroleum industry to denote fuel additives containing hydrogen, carbon, and oxygen in their molecular structure. It includes ethers such as MTBE and ETBE and alcohols such as ethanol and methanol.

Oxygenated Fuels: Fuels blended with an additive, usually methyl tertiary butyl ether (MTBE) or ethanol to increase oxygen content, allowing more thorough combustion for reduced carbon monoxide emissions.

Oxygenated Gasoline: Gasoline containing an oxygenate such as ethanol or MTBE. The increased oxygen content promotes more complete combustion, thereby reducing tailpipe emissions of CO.

Ozone(O_3): Tropospheric ozone (smog) is formed when volatile organic compounds (VOCs), oxygen, and NOx react in the presence of sunlight (not to be confused with stratospheric ozone, which is found in the upper atmosphere and protects the earth from the sun's ultraviolet rays). Though beneficial in the upper atmosphere, ground-level ozone is a respiratory irritant and considered a pollutant.

Ozonation: The application of ozone to water, wastewater, or air, generally for the purposes of disinfection or odor control.

PAH: Polycyclic aromatic hydrocarbons.

PAN: Peroxyacetyl nitrate

Paraffins: Group of saturated aliphatic hydrocarbons, including methane, ethane, propane, and butane and noted by the suffix "-ane".

Particulates: Very small liquid and solid particles floating in the air and a component of smog.

Particulate Matter (PM): A generic term for a broad class of chemically and physically diverse substances that exist as discrete particles (liquid droplets or solids) over a wide range of sizes.

Particulate Trap: Diesel vehicle emission control device that traps and incinerates diesel particulate emissions after they are exhausted from the engine but before they are expelled into the atmosphere.

PCB: Polychlorinated biphenyls

Petrochemical: An intermediate chemical derived from petroleum, hydrocarbon liquids or natural gas, such as: ethylene, propylene, benzene, toluene and xylene.

Petroleum: A generic name for hydrocarbons, including crude oil, natural gas liquids, natural gas and their products.

pH: pH is an expression of the intensity of the basic or acidic condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion concentration. The pH may range from 0 to 14, where 0 is most acidic, 14 most basic, and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5.

Phase Separation: The phenomenon of a separation of a liquid or vapor into two or more physically distinct and mechanically separable portions or layers.

Phenol: An organic compound that is an alcohol derivative of benzene.

PM: particular matter

Polymer: A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to form larger chemical flocs for easier removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

Polymerization: Process of combining two or more simple molecules of the same type, called monomers, to form a single molecule having the same elements in the same proportion as in the original molecules, but having increased molecular weight. The product of the combination is a polymer.

Portable Fueling System: A system designed to deliver natural gas to fueling stations. Such systems are usually configured as tube trailers and are mobile. Fuel delivery usually occurs via over-the-road vehicles.

Potassium Hydroxide (KOH): A metallic alkaline salt that can be used instead of sodium hydroxide for methoxide production. When KOH is used in Biodiesel production the by-product can be used as a fertilizer.

Pounds Per Square Inch (psi): A unit of measure for pressure.

Pour Point: Lowest temperature at which an oil will pour or flow under certain prescribed conditions.

ppm: Parts per million

PPO: Pure plant oil

Private Fleet: A fleet of vehicles owned by a non government entity.

Proof: Alcoholic proof is a measure of how much ethanol is in an alcoholic substance, and is approximately twice the percentage of alcohol by volume (ABV, the unit that is commonly used presently). After distillation 190 proof ethanol is received and after dehydration 200 proof ethanol is received.

Propane (C_3H_8): A gas whose molecules are composed of three carbon and eight hydrogen atoms. Propane is present in most natural gas in the United States, and is refined from crude petroleum. Propane contains about 2,500 Btu per standard cubic foot. Propane is the principal constituent in liquefied petroleum gas (LPG).

Pure vegetable oil (PVO): Oil produced from oil plants through pressing, extraction or comparable procedures, crude or refined but chemically unmodified, which can be used as biofuel when compatible with the type of engine involved and the corresponding emission requirements.

Purifier: A machine used for a liquid-liquid separation in which the two intermixed liquids which are insoluble in each other have different specific gravities. Solids with specific gravities higher than those of the liquids can be separated off at the same time. A purifier bowl has two outlets; one for the light phase liquid and one for the heavy phase liquid.

R&D: Research and development

Reagent: A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

Reducing agent: Any substance, such as the base metal (iron) or the sulfide ion that will readily donate (give up) electrons. The opposite of an oxidizing agent.

Redwood viscosity: The number of seconds required for 50 ml. of an oil to flow out of a standard Redwood viscosimeter at a definite temperature; British viscosity standard.

Refinery: A plan used to separate the various components present in crude oil and convert them into usable products or feedstock for other processes.

Reid Vapor Pressure (RVP): A standard measurement of a liquid's vapor pressure in psi at 100°F. It is an indication of the propensity of the liquid to evaporate.

Renewable Energy: Designated commodity or resource, such as solar energy, biodiesel fuel, or firewood, that is inexhaustible or replaceable by new growth.

Research Octane Number (RON): The octane as tested in a single-cylinder octane test engine operated under less severe operating conditions. RON affects low-to medium-speed knock and engine run-on.

Retrofit: To change a vehicle or engine after its original purchase, usually by adding equipment such as conversion systems.

RFG: Reformulated gasoline

RFO: Recycled frying oil

RFO-ME: Recycled frying oil methyl ester

RME: Rapeseed methyl ester (a type of FAME)

RVP: Reid vapor pressure

Second generation biofuel: Biofuel which is not yet competitive and available on the fuel market. It is made from second generation feedstock, such as cellulosic materials and plants. An example is BtL fuel.

SHF: Separate hydrolysis and fermentation (technology for cellulosic ethanol production)

Silicon and Teflon: Fluoropolymers that can withstand high heat, especially useful in replacing older rubber fuel lines.

SIT: Spontaneous Ignition Temperature. The temperature at which an oil ignites of its own accord in the presence of air or oxygen under standard conditions.

Slagging: Formation of hard deposits on boiler tubes and piston crowns which is usually due to the presence of sodium, vanadium and sulfur.

Sludge: Deposits in fuel tanks and caused by the presence of wax, sand, scale, asphaltenes, tars, water, etc.

SME: Soy methyl ester (a type of FAME)

SME: Small and medium sized enterprise

SNG: Synthetic natural gas

Sodium Hydroxide (Caustic Soda, Lye, NaOH): It is a metallic alkaline salt that is extremely corrosive and is used in Biodiesel production to make methoxide.

Soluble: Matter or compounds capable of dissolving into a solution.

Solvent: A substance, normally a liquid, which is capable of absorbing another liquid, gas, or solid to form a homogeneous mixture.

SO_x: Oxides of sulfur

Specifications: Term referring to the properties of a given crude oil or petroleum product, which are "specified" since they often vary widely even within the same grade of product. In the normal process of negotiation, seller will guarantee buyer that product or crude to be sold will meet certain specified limits, and will agree to have such limits certified in writing.

Specific gravity: Weight of a particle, substance or chemical solution in relation to an equal volume of water at 15°C. Abbreviated as Sp.Gr.

Specific heat: The quantity of heat required to raise the temperature of a unit weight of a substance by 1 degree; usually expresses as calories/gram/C or BTU/lb./F.

Smog: A visible haze caused primarily by particulate matter and ozone. Ozone is formed by the reaction of hydrocarbons and NOx in the atmosphere.

Spark Ignition Engine: Internal combustion engine in which the charge is ignited electrically (e.g., with a spark plug).

SRWC: short rotation woody crops

SSF: Simultaneous saccarification and fermentation (technology for cellulosic ethanol production)

Stoke: The unit of kinematic viscosity

Straight Vegetable Oil (SVO): Pure oil which is made from plant materials.

STP: Standard Temperature (25°C) and Pressure (300 mm Mercury).

Sulfur (S): An element that is present in crude oil and natural gas as an impurity in the form of its various compounds.

Surfactant: Surface-active agent. It is the active agent in detergents that possesses a high cleaning ability.

SWAP: In finance a swap is a derivative, where two counterparties exchange one stream of cash flows against another stream. These streams are called the legs of the swap. The cash flows are calculated over a notional principal amount. Swaps are often used to hedge certain risks, for instance interest rate risk. Another use is speculation.

Synthetic biofuels: Synthetic hydrocarbons or mixtures of synthetic hydrocarbons produced from biomass, e.g. SynGas produced from gasification of forestry biomass or SynDiesel

Synthetic natural gas (SNG): A manufactured product, chemically similar in most respects to natural gas, resulting from the conversion or reforming of petroleum hydrocarbons that may easily be substituted for or interchanged with pipeline-quality natural gas.

Tag-Robinson Colorimeter: An instrument used to determine the color of oils. Also a scale of color values.

Tax Incentives: In general, a means of employing the tax code to stimulate investment in or development of a socially desirable economic objective without direct expenditure from the budget of a given unit of government. Such incentives can take the form of tax exemptions or credits.

Tertiary Amyl Ethyl Ether (TAEE): An ether based on reactive C_5 olefins and ethanol.

Tertiary Amyl Methyl Ether (TAME): An ether based on reactive C_5 olefins and methanol.

Thermal Value: Calories per gram of BTU per pound produced by burning fuels.

Toluene: Basic aromatic compound derived from petroleum and used to increase octane. The most common hydrocarbon purchased for use in increasing octane.

Topped Crude Oil: Oil from which the light ends have been removed by a simple refining process. It is also referred to as "reduced crude oil".

Toxic: A substance which is poisonous to a living organism.

Toxic Emission: Any pollutant emitted from a source that can negatively affect human health or the environment.

Transesterification: The process by which the vegetable oil molecule is "cracked" and the glycerin is removed, resulting in glycerin soap and methyl/ethyl esters (biodiesel). Organic fats and oils are triglycerides which are three hydrocarbon chains connected by glycerol. The bonds are broken hydrolyzing them to form free fatty acids. These fatty acids are then mixed or reacted with methanol or ethanol forming methyl or ethyl fatty acid esters. The mixture separates and settles out leaving the glycerin on the bottom and the methyl/ethyl ester or biodiesel on the top. The glycerin is then used for soap or any one of several hundred other products and the biodiesel is filtered and washed to be used as a fuel in a diesel engine.

Ullage: The amount which a tank or vessel lacks of being full.

USDA: US Department of Agriculture

Vapor Pressure or Volatility: The tendency of a liquid to pass into the vapor state at a given temperature. With automotive fuels, volatility is determined by measuring RVP.

Variable Fuel Vehicle (VFV): A vehicle that has the capacity of burning any combination of gasoline and an alternative fuel. Also known as a flexible-fuel vehicle.

Vehicle Conversion: Retrofitting a vehicle engine to run on an alternative fuel.

Vehicle Miles Traveled: The miles traveled by motor vehicles over a specified length of time (e.g. daily, monthly, or yearly) or over a specified road or transportation corridor.

Viscosimeter: A device for determining the viscosity of oil. There are several methods or devices in general use. Basically, a fixed quantity of oil is allowed to pass through a fixed orifice at a specified temperature over a measured time span and then compared to a standard liquid such as a calibration oil or water.

Viscosity: Measure of the internal friction or resistance of an oil to flow. As the temperature of an oil is increased, its viscosity decreases and it is therefore able to flow more readily. Biodiesel is much less viscous than the oil from which it is made. Viscosity is measured on several different scales, including Redwood No. 1 at 100F, Engler Degrees, Saybolt Seconds, etc. The most common method for designation of viscosity is kinematic viscosity, measured in centistokes.

VOCs: Volatile Organic Compounds.

Volatile: A volatile substance is one that is capable of being evaporated or changed to a vapor at a relatively low temperature. Volatile substances also can be partially removed by air stripping.

Volatile Organic Compound (VOC): Reactive gas released during combustion or evaporation of fuel. VOCs are a major component of air pollution and react with NOx in the presence of sunlight and form ozone. A wide range of carbon-based molecules, such as aldehydes, ketones, and hydrocarbons are VOC's.

Volatility: Ability of a substance (gasoline) to turn from a liquid to a vapor. Low volatility refers to low RVP, indicating less light hydrocarbons in the gasoline front end.

WTO: World trade organization

WVO: Waste Vegetable Oil

Xylene: An aromatic hydrocarbon derived from petroleum and used to increase octane. Highly valued as a petrochemical feedstock. Xylene is highly photochemically reactive and, as a constituent of tailpipe emissions, is a contributor to smog formation.

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