RAPESEED OIL AS FUEL FOR FARM TRACTORS

Prepared for

IEA Bioenergy Task 39, Subtask „Biodiesel"

Prepared by

BLT Wieselburg, www.blt.bmlfuw.gv.at

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IEA Bioenergy, an international collaboration in Bioenergy, aims to accelerate the use of environmentally sound and cost-competitive bioenergy on a sustainable basis, and thereby achieve a substantial contribution to future energy demands. The work of IEA Bioenergy is carried out through a series of Tasks, each having a defined work program. (*www.ieabioenergy.com/*)

The objectives of Task 39 “Liquid Biofuels” are to work jointly with governments and industry to identify and eliminate non-technical barriers which impede the use of fuels from biomass in the transportation sector, and to identify technological barriers to Liquid Biofuels technologies. The Task is composed of 10 members (Austria, Canada, Denmark, European Union, Finland, Ireland, The Netherlands, Sweden, USA and UK) interested in working together for a successful introduction of biofuels. Under the leadership of the US Department of Energy this Task reviews technical and policy issues and provides participants with information that will assist them with the development and deployment of biofuels for motor fuel use. (www.forestry.ubc.ca/task39/)

The extent to which biofuels have entered the marketplace varies by country. The reasons are complex and include policy and market issues. While biofuels offer significant potential, the prices of biofuels are higher than their petroleum equivalents. As a result, biofuels have been successfully implemented only in those countries that have recognized the value of those benefits and have made appropriate policy decisions to support biofuels.

(www.liquid-biofuels.com/FinalReport1.html)

The overall goal of this Task is to provide participants with comprehensive information that will assist them with the development and deployment of biofuels for motor fuel use. The Task:

- Provides information and analyses on policy, regulatory and infrastructure issues that will help participants to encourage the establishment of the infrastructure for biofuels
- Catalyzes cooperative research that will help to develop processes for converting lignocellulosic biomass to ethanol.
- Provides information and analyses on specialized topics relating to the production and implementation of biodiesel technologies.

Work is carried out in three subtasks:

- Policy, regulative and infrastructure issues to assist with the implementation of liquid biofuels (Subtask leader Dr. Don Stevens, Pacific Northwest National Laboratory, USA)
- R & D & D issues used to expand the use of technologies that convert lignocellulosics to ethanol (Subtask leader Dr. Jack Saddler, UBC, Canada)
- Specialized topics and Information exchange on biodiesel (Subtask leader Manfred Wörgettel, BLT Wieselburg, Austria)

In the Biodiesel Subtask Denmark an Ireland showed interest on cold-pressed vegetable oils for modified diesel engines. Whereas at the beginning of the Task period neither research projects nor demonstration programs were implemented in the participating countries, the situation changed during the period. Driven by Austrian farmers a demonstration project was proposed. BLT Wieselburg reviewed the use of pure vegetable oil as fuel for modified diesel engines. The work was carried out as a diploma thesis at “Fachhochschule Wiener Neustadt/ Wieselburg and is based mainly on results of the “100 farm tractors demonstration project” financed by the German government and the comprehensive research work on vegetable oil fuel quality of “Landtechnik Weihenstephan” in Bavaria.

Wieselburg, January 2004 Manfred Wörgetter

Table of contents

1 Introduction

The idea of using vegetable oil as a fuel is almost as old as the diesel engine itself. The limited availability of the raw material, competition regarding its use as food, the development of the oil industry and a lack of interest by the stakeholders might be the reasons which have impeded the development of a transport system based on vegetable oil.

The use of pure vegetable oil or vegetable oil – diesel fuel mixtures in unaltered, marketable diesel engines has been tested since 1973 with very similar results. Vegetable oil as a fuel shows very promising results at the test bench. Its practical use, however, leads to severe damage to the engine after a certain time. The reasons given are the characteristics of vegetable oil which differ from fossil diesel fuels and the inadequate level of development of the engines run on vegetable oil.

During recent decades much has been achieved concerning the adaptation of the characteristics of vegetable oil to the requirements of marketable engines, but efforts to adapt engines to vegetable oil have only been minimal.

The following reasons support the development of engines running on vegetable oil:

- Vegetable oil is available worldwide as a pure product of high quality and with very similar characteristics.
- The energy and the amount of auxiliary substances needed for pressing the seeds is low.
- The technology used for pressing the oil is highly developed on all imaginable scales (from the press in the laboratory to industrial plants).
- Vegetable oil fuel can be sold on the market but also used in agricultural enterprises without involving middlemen.

In decentralised plants at agricultural enterprises and in small co-operatives the oil cake could be used as high-quality fodder.

So far, development has been impeded by technological and non-technological barriers. The 100-tractors-demonstration-programme in Germany has revived the interest of farmers in the use of pure vegetable oil. As a consequence farmers have started an initiative for an Austrian rape seed oil fuel demonstration project ("35-tractors-programme Austria").

The present report summarises the current level of development. First, basic information on rapeseed oil and diesel engines is given. Next, the possibilities for using vegetable oil in diesel engines are discussed, activities in Austria and Germany are described and first results of the German demonstration project are provided.

2 Rapeseed oil

2.1 Introduction and basics of rape

Currently the most important plant for the production of vegetable oil fuel is rape. Rape is a cruciferous plant and is cultivated in Europe as summer and winter rape. The varieties cultivated today reach a height of 80 to 150 cm. Rape ripens 30 to 40 days after pollination of the flower. The crops are 5 to 10 cm long pods. The oil is part of the seed contained in the pod. The ripe seed has a diameter of 1.5 to 3.0 mm. The varieties used today are harvested 180 to 240 days after sowing of the winter varieties and 85 to 125 days after sowing of the summer varieties. The crops are harvested with combine harvesters. Usual losses amount to 5 to 10%. Seeds with a water content below 10% can be stored without drying. Crops with a higher water content have to be dried. A water content below 6% makes the seed brittle and prone to damage.

The storable seed has the following components:

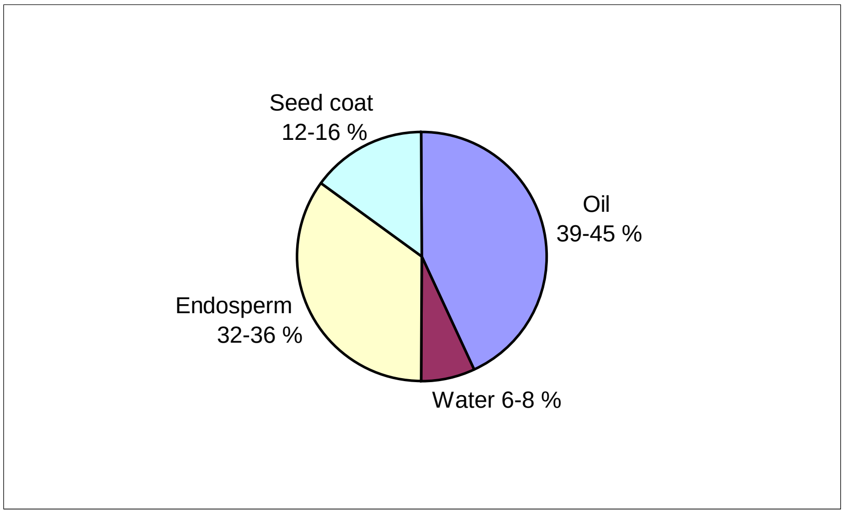

Illustration 1: Components of rape seeds, source: Apfelbeck, 1989

The oil content of rape ranges between 39 and 50%, varying considerably according to genetic differences and environmental influences. The yield potential of winter rape ranges between 2.8 and 4.8 t/(ha.a). This corresponds to 1.1 – 2.0 t oil. For summer rape the yield is from 2.0 to 2.8 t/(ha a).

2.2 Characteristics of rapeseed oil

Rapeseed oil is a glyceride which consists of the trivalent alcohol propantriol (glycerine) and three fatty acids. The fatty acids consist of carbon chains with an even number of carbon atoms and they can be saturated, mono-unsaturated or polyunsaturated. Saturated means that no double bonds between adjacent carbon atoms exist.

Fatty acids therefore primarily differ in the length of the chain and the degree of saturation.

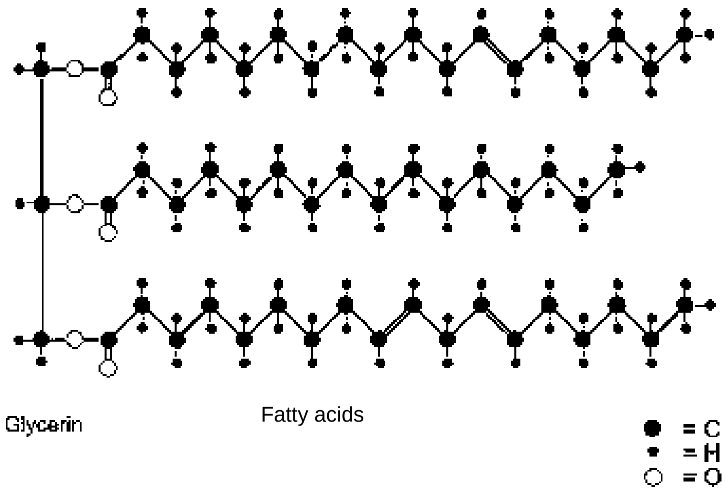

Illustration 2: Schematic representation of a triglyceride, source: Widmann, 1999

The fatty acids in an oil seed are fixed genetically, the distribution is called the fatty acid profile. The structure of the fatty acids influences the physical characteristics considerably.

Table 1: Fatty acid profile of rapeseed oil, source: Lewandowski, 2001

Fatty acid		high in erucic acid	low in erucic acid
		% of the total content of fatty acids	
Palmitic acid	C16:0	2	4
Oleic acid	C18:1	19	58
Linoleic acid	C18:2	15	22
Linolenic acid	C18:3	10	12
Gadoleic acid	C20:1	2	2
Erucic acid	C22:1	52	2

In older varieties of rapeseed oils erucic acid amounted to 40 – 64% and was one of the main components. Due to the unhealthy effect of erucic acid, the oil could not be used for food or fodder purposes. Thanks to the cultivation of varieties low in erucic acid, rape seed oil has become valuable as a food.

Apart from saturated fatty acids you can also find free fatty acids and di- or monoglycerides in vegetable fat or oil. They are cleavage products of fat catabolism. Furthermore, oils contain fat-accompanying substances such as tocopheroles, waxes, chlorophylls or phospholipids.

2.3 Oil production

Rapeseed oil can be produced in decentralised small-scale plants with a processing capacity of approx. 0.5 to 25 t/d or in central large-scale plants with up to 4,000 t/d oil seed. The energy consumption in central plants amounts to approx. 1.7 GJ/t oil seed; 0.7 GJ are used for refining. The energy consumption for rape oil production in small-scale plants only amounts to 0.1 to 0.5 GJ/t oil seed. Further advantages of decentralised processing are the logistics and the low transport costs. Besides, such small-scale plants economically favour transactions in regional material cycles. Below, both production possibilities are described.

2.3.1 Vegetable oil production in small-scale plants

The following scheme explains the process in a decentralised small-scale plant.

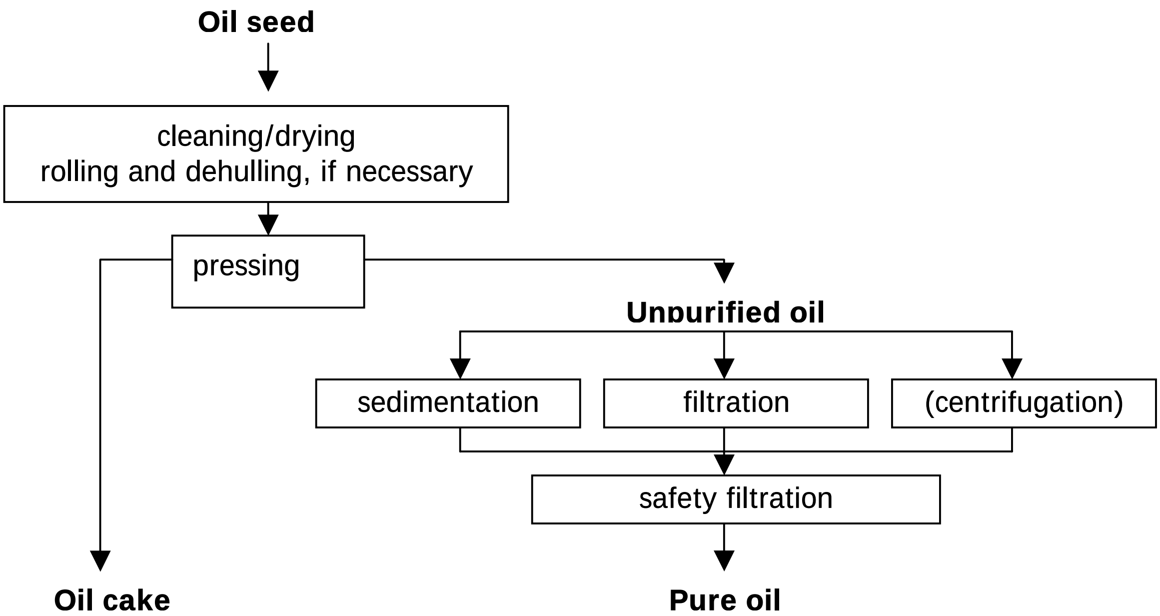

Illustration 3: Vegetable oil production – Process in decentralised plants, source: Widmann, Thuneke, 2002

In a first step the rape seed is cleaned. This is very important regarding the quality of the final product. For sufficient storage stability, a high oil yield and high quality the seed has to be dried until it has a water content of approx. 7% by weight.

In some cases the pressing is preceded by prior crushing by means of a roller mill and dehulling. The oil is mostly extracted in screw presses. A residual oil content of 11 – 18% can be achieved in the oil cake.

The unpurified oil extracted by pressing contains approx. 0.5 – 0.6% solid matter which has to be removed. Procedures such as sedimentation, filtration and centrifuging can be used. Chamber filter presses or frame filter presses or vertical pressure filters are suitable filtration devices.

2.3.2 Vegetable oil production in large-scale plants

The processes of large-scale production are illustrated below.

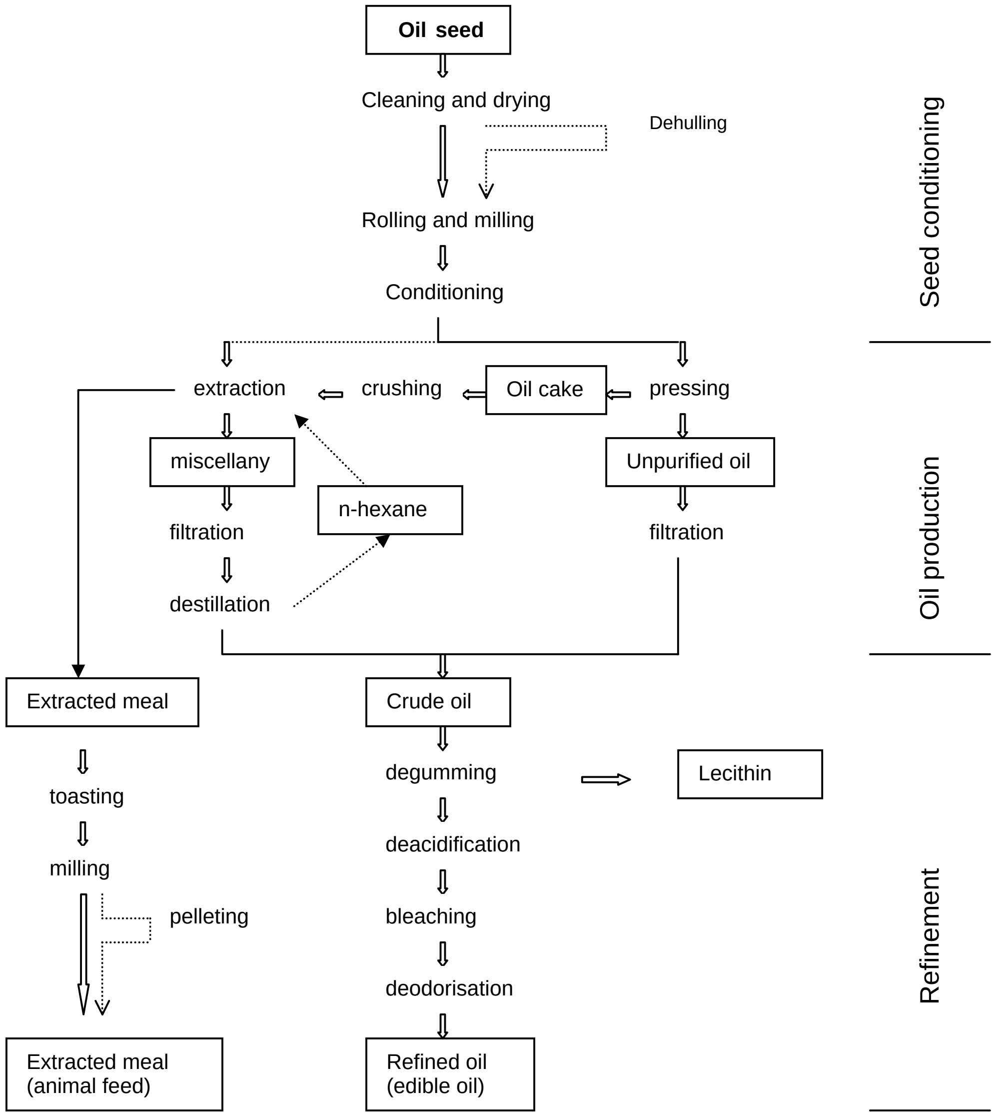

Illustration 4: Vegetable oil production – procedures in central plants, source: Widmann, 1999

Pretreatment of the oil seed: Before pressing the oil seed may be dehulled, crushed and conditioned. During the conditioning process the crushed oilseed is subjected to thermal treatment by means of steam and the water content and temperatures are regulated.

Oil production: Vegetable oils can be produced by means of pressing (finished pressing), exclusive extraction (direct extraction) or by a combination of these procedures (pressing/extraction). In the case of exclusive pressing the oil yield is rather low. Extraction can lead to a yield of up to 99%.

Subsequent treatment of the extraction meal is used for the recovery or removal of the solvent (mostly hexane).

Refining: Because of the pretreatment the crude oil contains unwanted related substances such as dirt, phosphatides, carbohydrates, proteins, fatty acids and their oxidation products, colourants, trace metals, etc. These substances might affect the taste, the storage life and the technical usability. By means of refining, disruptive substances are removed. Refining includes:

- degumming for the removal of phospholipids
- deacidification for the removal of free fatty acids
- bleaching to minimise colourants and trace metals
- deodorisation for the removal of aromatic substances and oxidation products

After the refining process the oil is called fully refined oil and has edible oil quality.

2.4 Oil storage

Both, for the storage of the oilseed and the oil quality assurance measures have to be taken. Quality is influenced during storage by:

Table 2: Unfavourable influences on storage, source: Widmann, 1999

Influence	**Effect**
oxygen	oxidation
water	hydrolysis
high temperatures	oxidation, hydrolysis
light	oxidation
metals (Cu, Fe)	catalysts for oxidation

The main processes which cause the chemical breakdown of vegetable oil are hydrolysis and oxidation. They can also lead to polymerisation. This means that single molecules are linked anew, complex molecules are formed and the viscosity increases.

2.4.1 Storage of rapeseed and rapeseed oil

Measures for the storage of the seed and the oil can be derived from the processing methods.

Measures for the storage of the oilseed:

- high degree of maturity
- low water content
- low extraneous matter
- low temperatures

Measures for the storage of the vegetable oil:

- low total contamination
- low temperature, low variations in temperature
- avoid influence of light
- avoid incidence of oxygen and water
- avoid non-ferrous metals
- clean storage tanks very carefully

2.5 Quality standard for rapeseed oil as a fuel (“RK-Standard”)

The Bavarian State Research Centre for Agriculture in Freising-Weihenstephan has developed a quality standard for vegetable oil fuels within a research programme financed by the Bavarian State Ministry of Food, Agriculture and Forestry in cooperation with the company ASG Analytik-Service Gesellschaft, Augsburg and the State Office for Agricultural Machines and Construction, University Hohenheim. This standard is supposed to create the basis for the safe operation of diesel engines with vegetable oil and can serve as a basis for the development of engines which can be operated with vegetable oil. By determining the quality, guarantees can be given, e.g. for sustained engine operation or for compliance with emission limits.

The developed standard (“RK-Standard”) determines the requirements and test procedures and applies to fuels used in combustion engines working on the diesel principle which have been designed or retrofitted for operation with rapeseed oil fuel. The standard does not have the status of a national or international standard. The contents described in this section are mostly derived from research results gained in the above mentioned project.

Table 3: Quality standard for rapeseed oil as a fuel (RK-quality standard), source: Remmele, Thuneke, Widmann, Wilharm, Schön

Quality standard for rapeseed oil as a fuel (RK-quality standard, 05/2000)				
characteristics/ substances	**units**	**limiting values**		**test procedure**
		min.	**max.**	
characteristic properties				
density (15°)	kg/m^3	900	930	DIN EN ISO 3675 DIN EN ISO 12185
PM flash point	° C	220		DIN EN ISO 22719
calorific value	kJ/kg	35,000		DIN 51900-3
kinematic viscosity (40 °C)	Mm^2/s		38	DIN EN ISO 3104
behaviour at low temperatures				rotation viscosimetry
cetane number (ignition quality)				process is being evaluated
coke residues	% by mass		0.40	DIN EN ISO 10370
iodine number	G/100g	100	120	DIN 53241-1
sulphur content	mg/kg		20	ASTM D 5453-93
variable characteristics				
total contamination	mg/kg		25	DIN EN 12662
neutralisation value	Mg KOH/g		2.0	DIN EN ISO 660
oxidation stability	h	5.0		ISO 6886
phosphor content	mg/kg		15	ASTM D3231-99
ash content	% by mass		0.01	DIN EN ISO 6245
water content	% by mass		0.075	pr EN ISO 12937

The characteristic properties are natural and only subject to minor variations. The variable characteristics are influenced by the procedure (cultivation, harvesting, storage), the seed and oil, the oil extraction and are subject to bigger variations.

The density describes the mass of a substance per unit volume. By means of a density measurement blendings can be detected.

The flash point is the temperature of a liquid at which vapours develop to such amount that they can be ignited by a flame. The flashpoint has to be at least 220°C and it is used to detect blendings with other fuels.

The calorific value describes the amount of heat which is released in complete combustion without taking into consideration the latent heat of vaporisation of the steam created in the combustion process. The calorific value of rapeseed oil is subject to minor variations and is used as a descriptive variable for the energy content.

The kinematic viscosity (40°C) describes the flow resistance of a liquid. It is determined by the composition of the fatty acids and strongly depends on the temperatures. The viscosity can change during storage due to oxidation and polymerisation processes.

Behaviour at low temperatures: In order to describe the behaviour at low temperatures the dynamic viscosity, which is the product of kinematic viscosity and the density of the liquid, is used. In the RK-quality standard test conditions and limiting values have not been determined. The determination of the cold filter plugging point (CFPP) used for fossil fuels is not suitable for rapeseed oil.

The cetane number describes the ignition quality of the diesel fuel. Petrochemical test procedures are not necessarily suitable for vegetable oils.

The coke residue describes the tendency of a fuel to form carbonaceous deposits during combustion.

The iodine number describes the average number of double bonds of fatty acid molecules. A high number of double bonds decreases the oxidation stability.

Sulphur content: Rapeseed oil has a lower sulphur content than fossil diesel, a fact which has positive effects on the emission values of the combustion process.

The total contamination is determined by filtering the sample through a membrane filter with a mesh width of 0.8 µm and determining the filtration residue. It is an important criterion for its use as a fuel. The main part of the total contamination are rape grain particles as a result of the pressing process, which were not separated from the oil during the cleaning process.

The neutralisation number is used to measure the share in free fatty acids and permits conclusions as regards the ageing state of the oil.

The oxidation stability is used to measure the pre-ageing of the rapeseed oil and it is a parameter for interactions, if any, between the fuel and the engine oil. The stability largely depends on the fatty acid profile. Oils with a high share of unsaturated fatty acids are prone to oxidation. The oxidation stability can be influenced negatively if the seed and the oil are stored at high temperatures, because of the influence of light, through water and through metals with catalytic effects, e.g. copper. Ketones[1] and aldehydes[2] created through autoxidation[3] might influence the emission behaviour of engines.

Phosphor in rapeseed oil might lead to mineral deposits in the engine. Furthermore, phosphor might damage exhaust catalytic converter systems. The phosphor content is influenced by the process parameters of the oil production.

The ash content is the inorganic residue after the ashing of the oil.

Water content: With an increasing water content the activity of the micro-organisms rises. Thus, water and the existence of micro-organisms or enzymes can cause hydrolysis and oxidation processes can be accelerated.

2.6 Fuel-relevant characteristics of rapeseed oil

The following table compares fossil diesel, rapeseed oil and rapeseed oil methyl ester.

Table 4: Characteristics of diesel, rapeseed oil and rapeseed oil methyl ester, source: Krammer, 2000

	Unit	Diesel	Rapeseed oil	Rapeseed oil methyl ester
Calorific value	MJ/kg	42.4	37.6	37.2
Density at 20°C	kg/dm³	0.83	0.91	0.88
Calorific value (vol.)	MJ/dm³	35.2	34.2	32.7
Viscosity at 20°C	mm²/s	5	70	7.2
Flash point	°C	>55	>220	>100
Ignition quality	CZ	>49	-	>49

Power output and consumption of an engine depend on the energy content of a fuel. The calorific value of diesel fuel is approx. 42 MJ/kg. The calorific value of vegetable oil is 4 MJ/kg less, due to the oxygen share. Because of the higher density of rapeseed oil, the calorific value, which depends on the volume, is only 3% less. As a consequence, operating at the same efficiency with rapeseed oil results in a loss of output or an increase in consumption.

[1] Organic compound with one or more CO groups, which are bound to hydrocarbon radicals
[2] Chemical compounds created through dehydrogenation from alcohols
[3] Oxidation of a substance caused by the catalytic effect of oxygen compounds

An advantage for the combustion is the oxygen content and the low sulphur content. Disadvantages are the high viscosity, the tendency of large molecules to crack, a mediocre ignition quality and the phosphor content.

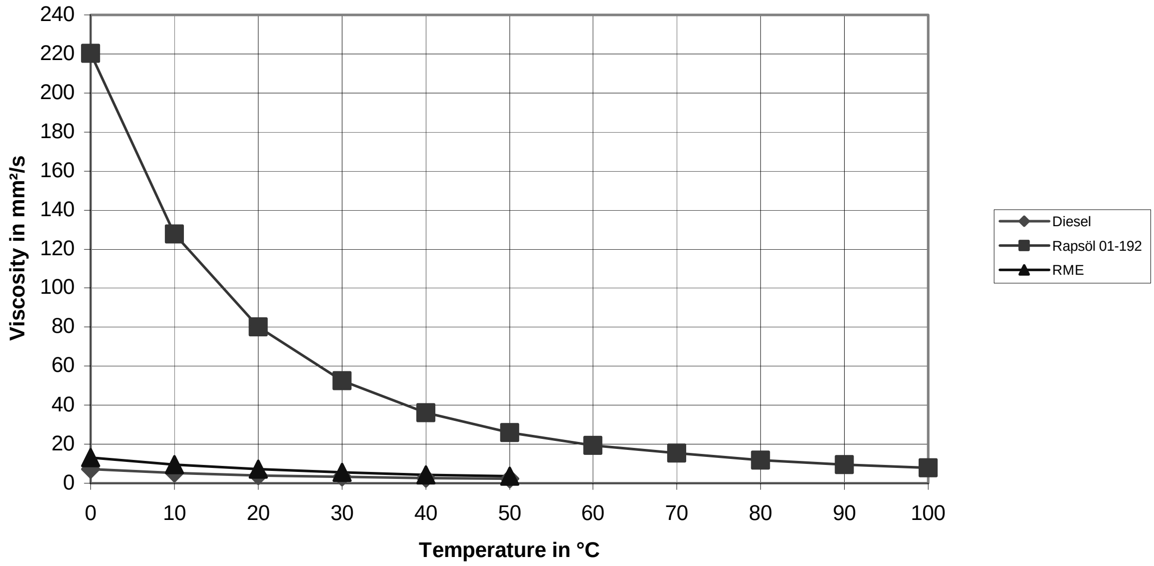

Illustration 5: Viscosity development of rapeseed oil, diesel and RME, source: Krammer, 2000

The viscosity of rapeseed oil is almost the same at high temperatures (90°C) as the viscosity of diesel at 20°C.

Cold pressed oils are much closer to the limiting values of the RK-standard than fully refined oils. Differences can be found in the sulphur and phosphor content and the total contamination. The neutralisation number and the oxidation stability of cold pressed rapeseed oil also show more unfavourable values.

2.7 Potentials and cultivated areas

Awareness of the short- and medium-term availability of raw materials is very important for market developments. Subsequently an overview of the situation is given.

2.7.1 Worldwide

More than three quarters of the Earth's surface cannot be used as arable land. More than 80% of the arable land reserves, which amount to more than 2,500 million ha, are in South America or Africa. 12% of this land has good prerequisites for arable farming. In Asia most arable land is already in use.

The following table 5 shows the current cultivated areas worldwide and the harvest yields of rape:

Table 5: Cultivation and harvest of rape, rapeseed oil production worldwide, source: Mielke, 2002

Worldwide	unit	1980	1990	2000	2001-2005*	2016-2020*
area-rape	1,000 ha	11,617	17,129	27,334	27,102	31,942
harvest rape	t/ha	0.87	1.29	1.56	1.56	1.91
production-rapeseed oil	1,000 t	3,485	8,176	14,388	15,336	22,689

* expected 5-year-average

The main cultivation areas for rape are Canada, China and India, which had 68% of the worldwide cultivated area for rape in the year 2000. In the past years Australia has also increased its cultivation (1.92 million ha in the year 2000).

2.7.2 European Union

Rape cultivation: The rape cultivation area, the yield situation and the rapeseed oil production since 1980 as well as the expected development until 2020 are shown below.

Table 6: Cultivation and harvest of rape, rapeseed oil production in EU-15, source: Mielke, 2002

EU-15	unit	1980	1990	2000	2001-2005*	2016-2020*
area rape	1,000 ha	820	2,059	3,562	3,197	3,500
harvest rape	t/ha	2.1	2.89	3.22	3.08	3.3
Production – rape-seed oil	1,000 t	953	2,652	3,770	3,905	4,490

* expected 5-year-average

The average harvest yield rose continuously between 1980 and 2000 and amounted to 3.22 t/ha in 2000. With this value the EU is well above the average of other cultivation countries.

The cultivation areas increased considerably between 1980 and 1990. From 1990 until 2000 an increase in cultivation areas was also recorded. As of 2000, cultivation areas will decrease for a short time. Very important for future cultivation areas will be frameworks of energy and agricultural policies, which will be discussed in detail below.

Frameworks of energy policy: The European Union supports the development of biofuels. The reasons are to guarantee supply, to reduce the impairment of the environment and social advantages. Currently, 90% of the petroleum consumed in the EU is imported. In order to reach the aim to strengthen biofuels an action plan has been developed. Furthermore, a directive supporting the use of biofuels has been drawn up. The following aims have been suggested:

Table 7: EU- directive for the use of biofuels – minimum share biofuels[4]

Minimum share of sold biofuels in the sold petrol and diesel fuels						
year	2005	2006	2007	2008	2009	2010
%	2	2.75	3.5	4.25	5	5.75

The aims are indicative, which means they cannot have sanctions imposed. A second directive on the tax exemption for biofuels was also made[5].

Framework of agricultural policy: In 1992 the Blair House Agreement on oilseeds was concluded within the GATT[6]. The Agreement intended to limit cultivation areas for oilseeds for food purposes in the European Union to 5.482 million ha. Besides, the setting aside of at least 10% of the areas was determined as a prerequisite for compensatory payment. The cultivation of oilseeds for industrial use on areas lying fallow has been limited with a maximum of one million t soybean meal equivalent.

In the CAP[7] reform within the Agenda 2000 alterations of the EU support system for oilseeds are envisaged, in order to abolish the specific character of the support of oilseed production and to free the producers from the area limitations of the Blair House Agreement. Part of it is the gradual decrease of compensation payments for oilseeds to the level of corn and fallow areas. This means a payment of € 63/t as of the economic year 2002/2003.

Currently, oilseed plants can still be cultivated on the fallow areas provided for technical purposes. On January 21, 2003 the Commission published a suggestion for a regulation of the Council for the determination of common rules for direct payments within the Common Agricultural Policy and support rules for the producers of certain cultivated plants. According to this suggestion energy plants may not be cultivated on fallow areas. The financial support for the cultivation of energy plants is to amount to € 45/ha.

[4] Commission of the European Community, 2002, p. 16
[5] Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity
[6] The General Agreement on Tariffs and Trade, founded in 1947, was incorporated in the successor organisation WTO (World Trade Organisation) in 1995. The task of the WTO is to organise international trade relations within binding regulations, to monitor trade practices and to mediate effectively in case of trade conflicts, Fischer Weltamanach 2002, 2001, p. 996
[7] Common Agricultural Policy

3 Diesel engine

A diesel engine is a high-density combustion engine with auto-ignition. In the combustion process of a diesel engine, air is sucked in and has been compressed. The air is heated up and the thoroughly distributed fuel self-ignites. The first diesel engine was developed by Rudolf Diesel (1858-1913). With this invention Diesel accomplished his aim to develop the most economic thermal engine of his time. The superiority of the diesel engine as regards fuel consumption is still valid today.

3.1 Fuel system

The fuel is sucked in from the fuel tank by means of a pump, it passes through filters and is injected into the combustion chamber by the injection pump through injection nozzles. In order to ensure the fuel supply and to cool the engine, the fuel pump boosts more fuel than required at full load. The surplus fuel is returned to the fuel tank via an overflow valve and a by-pass.

3.2 Combustion and injection system

The combustion systems are categorised into direct and indirect injection systems. With indirect injection (prechamber and swirl chamber procedure) the combustion chamber is divided into a prechamber and a main combustion chamber.

In recent years a completely new generation of direct injection diesel engines has been created. They have replaced the indirect injection engines on the market because of their efficiency. The fuel is injected into the combustion chamber in the piston via a multi-hole injection nozzle. The form of the injection nozzle, the injection pressure and the arrangement in the combustion chamber decisively influence the fuel–air mixture formation and thus the combustion quality. State-of-the-art developments in the field of injection systems such as “unit injector” and “common rail” are explained below.

3.2.1 Unit injector system

Every cylinder is equipped with a unit comprising a pump and a nozzle. At the injection element very high pressure (approx. 2,050 bar) is created. This is only possible as no tube between the pump and the nozzle is required. Because of the high pressure the fuel is sprayed very thinly, the engine performance is improved and the formation of harmful substances is reduced.

3.2.2 Common rail diesel engine

In this injection system the pressure is produced independent of the injection cycle through a high-pressure pump. The fuel, which is subject to high pressure (up to 1600 bar), is transported via a rail common to all cylinders. The rail is connected with short high-pressure lines to the injectors of the engine cylinders. The injection is implemented through electronically operated control valves at the right time in the necessary amount.

3.3 Fuel requirements

The diesel engine originally had comparably modest requirements concerning fuel quality and permitted operation with fuels with strongly varying characteristics. As a result of the development of engines and the reduction of emission limits the fuel quality has gained importance. The optimisation of the engine is based on a carefully designed combination of injection system, mixture preparation and combustion of a certain fuel. A prerequisite for optimisation is the constant quality of the fuel used.

Fuel Standards: In May 1993 the first European Diesel Standard, EN 590, was published, which was also adopted in Austria and which was revised in early 2000 with improved key values. As a consequence of globalisation the automobile associations have drawn up a worldwide fuel charter, which was published in its second edition in April 2000. This fuel charter contains laboratory methods and engine test procedures with the respective limiting values.

4 Rapeseed oil in diesel engines

In principle, the following possibilities for operating a diesel engine with vegetable fuels exist:

- adapt the fuel to the engine
- blending with fossil fuels
- adapt the engine to the fuel

4.1 Adapting the fuel to the engine

The most frequent method used to adapt rapeseed oil to conventional diesel engines is the esterification to rapeoil methyl ester (RME). In the esterification process the trivalent alcohol of the rapeseed oil (glycerin) is replaced by three monovalent alcohols by means of catalysts. Mostly, methanol is used for this purpose. One of the by-products is glycerine.

4.2 Blending with fossil fuels

By blending vegetable oil and diesel the disadvantage of the higher viscosity can be improved. Illustration 6 shows the alterations of the kinematic viscosity of the diesel fuel in blendings with rapeseed oil.

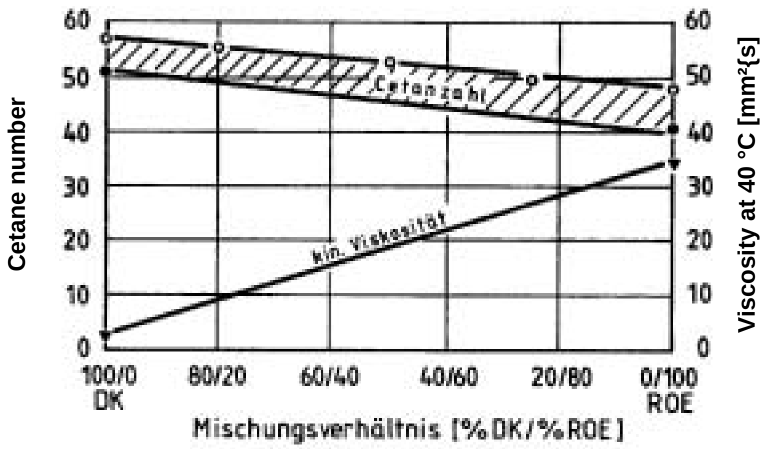

Illustration 6: Cetane number and viscosity in rapeseed oil blendings, source: Maack, Maurer, 2002

In the early 80s a series of studies on the blending of fuels were conducted. Short-term tests proved successful in most cases. Long-term tests, however, often led to engine failures due to deposits and carbonisation phenomena. This could above all be observed with fuels with vegetable oil shares of more than 20%. A rough prognosis shows, for instance, that a 20% blending of rapeseed oil would decrease the useful life of an engine to approx. 80% of the usual period of use if operated with diesel fuels.

At the university of Hohenheim fuels based on rapeseed oil such as RME and rapeseed oil blends were used in a direct-injection production line engine between 1992 and 1995. The fuels used apart from diesel RME were rapeseed oil water emulsions with 2 to 14% water, rapeseed oil blends made of 80% rapeseed oil and 20% gasoline-alcohol blends and of 60% rapeseed oil, 35% RME and 5% alcohol. The operating behaviour of the test engine was unsatisfactory at low engine load, which can frequently be found, for example, in agricultural tractors. At a higher load, however, better results were achieved.

Table 8: Fuel-specific characteristics of blends, source: Maack, Maurer, 2002

	unit	RG 4A	Tessol I		Tessol II	Emulsion	Rapeseed oil	Diesel
			a	b				
Density at 15 °C	kg/m³	864	895	895	891	924	918	834
Kin. viscosity at 40 °C	mm²/s	6.3	14.0	15.2	11.7	39.2	34.7	2-3.5
Flash-point	°C	55	15.0	77	100	>200	246	74
Conradson carbon residue	Masse-%	-	0.33	0.35	0.42	0.45	0.34	<0.01
Cetane number	-	47	(39)	(38)	(45)	(21)	(40)	~51
Water content	mg/kg	380	470	350	500	77,600	460	<200
Calorific value	kJ/g		37.2	37.7	38.6	34.9	37.5	42.8
	MJ/dm³		33.3	33.7	34.4	32.2	34.5	35.5
Deviation of the calorific value comp. to diesel	%		-6.2	-5.1	-3.1	-9.3	-2.8	-
Results of the engine test bench and engine field tests:								
Suitability as diesel-substitute		(yes)	no	no	no	no	no	-

RG4A 50% rapeseed oil + 50% kerosene Jet A-1 + 0.1 % DK plus
Tessol I, a 80% rapeseed oil + 14% test fuel (TB 180/210) + 6 % alcohol C_3H_8O
Tessol I, b 80% rapeseed oil + 14% test fuel (TB 180/210) + 6 % alcohol $C_8H_{18}O$
Tessol II 60% rapeseed oil + 35% RME + 5 % alcohol $C_8H_{18}O$
Emulsion 93.8% by weight rapeseed oil + 6.0% by weight demineralised water + 0.2% by weight emulsifier
Rapeseed oil cold pressed, natural rapeseed oil
Diesel fuel according to DIN EN 590

The characteristic values of the blends differ decisively from the diesel fuel in their viscosity and the Conradson Carbon Residue. A blend of 50% rapeseed oil and 50% kerosene tested in Switzerland showed good combustion properties and few deposits.

S. Jones and C. Peterson have reviewed the literature concerning the use of vegetable oils as a replacement for diesel fuel. The oils studied include virgin and used oils of various types including soy, rapeseed, canola, sunflower, cottonseed and similar oils. In general, raw vegetable oils can be used successfully in short term performance tests in nearly any percentage. When tested in long term tests blends above 20% nearly always result in engine damage or maintenance problems. Some authors report success in using vegetable oils as diesel fuel extenders in blends less then 20% even in long term durability studies. It is apparent that few, if any, engine studies using low-level blends of unmodified vegetable oils have been conducted[8].

4.3 Adapting the engine to the fuel – vegetable oil engine

If unmodified vegetable oil is used as a fuel, the technology of the engine has to be adapted to the characteristics of the fuel.

4.3.1 Historical development

The idea of using vegetable oil as a fuel is as old as the diesel engine itself. One hundred years ago Rudolf Diesel was already running his first engines, among other, on vegetable oil. Because of the development of the oil industry and the range of oil products offered vegetable oils soon became non-competitive. Only in the economically difficult years after World War I did biogenous fuels became interesting once more because of the shortage of foreign exchange in Europe. After World War II the idea was again forgotten. Only with the oil crisis in 1973 did alternative fuels come to the fore again.

4.3.2 Problem

As vegetable oil differs considerably from diesel in its physical properties, using vegetable oil in unmodified engines leads to deviations in the injection and combustion process. Important parameters are the boiling characteristics, the ignition quality and the viscosity. A higher viscosity leads, for instance, to cold start problems and deterioration of the spray through the injection nozzle.

Basically, there are two solutions:
- development of vegetable oil engines
- adaptation of conventional engines by retrofitting measures.

4.3.3 Engine concepts

In this section especially developed vegetable oil engines are described. Indirect injection procedures are not dealt with as they only play a minor role, for tractors.

4.3.3.1 Elsbett – Duotherm

Ludwig Elsbett developed the first vegetable oil engine with direct injection. The engine has four typical construction characteristics:

The piston: The piston consists of two parts which are linked through the piston pin in an articulated way. The upper part consists of nodular cast iron and takes the me-

[8] Using Unmodified Vegetable Oils as Diesel Fuel Extender. The 10th Biennial Bioenergy Conference "Bioenergy 2002", Sept. 2002, Boise, Idaho

chanical and thermal load. The lower part of the piston consists of light metal and takes the lateral forces.

Duothermal combustion: The combustion chamber is located at the upper part of the piston and has the form of a sphere. Through temperature and density differences the combustion air which moves in circles is divided into diverse hot zones. The hot air sphere is in the middle and is surrounded by a cooler air shell. Only the hot air is part of the combustion, the cool shell should insulate thermally, acoustically and mechanically.

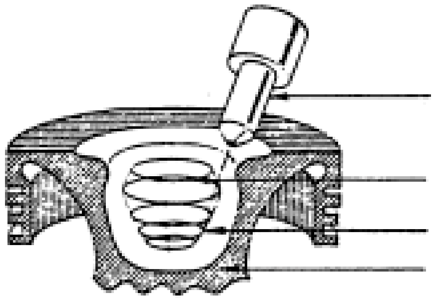

Illustration 7: Elsbett engine – Duothermal combustion procedure, source: Grandl, 1996

Tangential injection: is made through a single hole pintle-type injector with self-cleaning needle. The injection is carried out tangentially to the movement of the air in the combustion chamber without there being any contact of the fuel with the combustion chamber wall.

Internal oil cooling: This procedure is to reduce heat losses and the thermal load of the components. The engine is mainly cooled through oil at the base of the piston, further cooling through air or water is not provided for.

This development was not successful on the market. A conversion set for Daimler Benz engines (among others used in the MB-Trac and Unimog) was also unsuccessful on the market. Production of the engine has been discontinued in the meantime.

4.3.3.2 Mahler multifuel engine

The essential characteristic of the Mahler concept as compared to other engines is that the combustion chamber is located in the cylinder head instead of in the piston. The inlet valve is recessed into the combustion chamber. Injection is carried out almost tangentially at two opposite points within the cylindric combustion chamber. The injection of the fuel is implemented in a way that even rapeseed oil with a relatively high viscosity is prepared for clean combustion.

4.3.3.3 AMS Antriebs- und Maschinentechnik

The company AMS Antriebs- und Maschinentechnik, Schönebeck (formerly: DMS Dieselmotoren- und Gerätebau GmbH, Schönebeck) has further developed a licence of the Duotherm-procedure of Elsbett. The construction characteristics are similar to the Elsbett engine. AMS engines are primarily used in stationary applications, e.g. in cogeneration plants.

4.3.3.4 AAN Anlagen- und Antriebstechnik Nordhausen

The main characteristics of the vegetable oil engine of the company AAN Anlagen- und Antriebstechnik Nordhausen (formerly: Thüringer Motorenwerke GmbH, Nordhausen) are a semi-spherical combustion chamber in the piston and the use of a single hole injection nozzle. The Ferrotherm piston used was developed in co-operation with the company Mahle GmbH, Stuttgart.

4.3.4 Retrofitting concepts

In order to adapt conventional engines to the characteristics of vegetable oil adaptations are made. The measures include adaptations of the fuel supply, combustion and injection. Retrofitting measures for serial engines in Germany are carried out by:

- AAN Anlagen- und Antriebstechnik Nordhausen GmbH (Nordhausen)
- ATG Autozubehör-Technik Glött GmbH (Glött)
- Auto Pielmeier (Falkenstein)
- Bio Car Lohmann Prototypenbau (München)
- Elsbett Technologie GmbH (Thalmässing)
- Biodrive KWS (Mägenwil)
- Giese Energie- und Regeltechnik GmbH (Puchheim)
- Graml Landtechnik (Kößlarn)
- Hausmann Lackiererei Karosserie (Wülfershausen)
- Henkelhausen GmbH & Co KG (Krefeld)
- Konrad Weigel Energietechnik (Freystadt-Sulzkirchen)
- KPM Pflanzenöl-Marine-Motoren (Lahnstein)
- KTV-Greenpower (Rieden)
- MANN Naturenergie GmbH & Co KG (Langenbach/Westerwald)
- Max Stangl Landtechnik (Langenisarhofen)
- Natur-Energie-Technik Dosch & Stumpf G.b.R. (Dettelbach)
- Naturpower Pflanzenöltechnik (Zossen)
- OIKO Energy GmbH (Hollfeld)
- Raps Bio Power System (Seligenporten)
- TCB Technik-Center Bastorf GmbH (Bastorf)
- Thomas Gruber KG (Ampfing)
- VWP Vereinigte Werkstätten für Pflanzenöltechnologie GbR (Allersberg)
- Wolf Pflanzenöl-Technik (Untereuerheim)
- 3-E-GmbH (Nortorf/Wilster)

Most of the companies specialise in retrofitting private cars, some also retrofit lorries or tractors. Common to all concepts is an increased cross-section of lines on the low pressure side of the fuel system. Some of the retrofitters use one-tank systems, others use two fuel tanks. As examples, descriptions of each type of construction are given below.

4.3.4.1 One-tank systems

In one-tank systems the vehicle is adapted to being run exclusively on rapeseed oil. One example of this system is the concept of the Hausmann company.

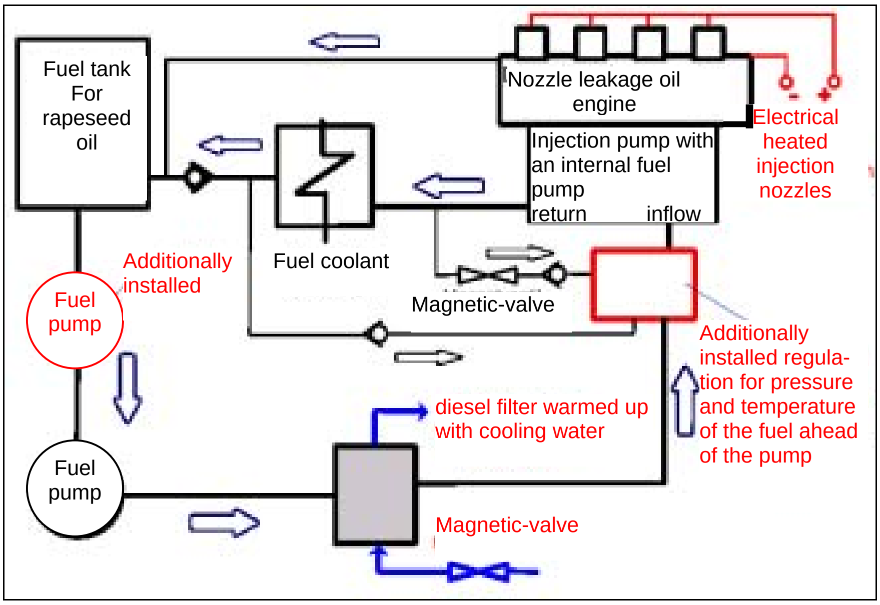

Illustration 8: Retrofitting concept of the Hausmann company, source: Hassel, Berndt, Golisch, Harkner, Schümann, Wichmann, 2003

An additional electrically operated fuel pump is installed. The main fuel filter is heated by means of the cooling water in order to reduce the viscosity of the rapeseed oil. The pressure and temperature are regulated before the injection nozzle. An essential characteristic of the Hausmann system is the electrical heating of the injection nozzles. This is to produce an optimal spray pattern and optimal lubrication of the nozzle needles independent of the engine temperature.

The extent of the retrofitting measures differs considerably in the diverse companies. In this connection the company VWP Vereinigte Pflanzenöltechnologie has to be mentioned, it being the only retrofitter of tractors which also alters engine conditions.

4.3.4.2 Dual tank systems

When starting and switching off the engine diesel fuel is used. Operation inbetween or under optimal conditions is with vegetable oil. In illustration 9 the system of the company Gruber Landtechnik is described:

In addition to the second tank an electric fuel pump and supplementary electric heating in front of the main fuel filter is used. The starting process uses diesel, the change to rapeseed oil is made at 60°C cooling water temperature. As a consequence the fuel pump and the additional heating are activated. The driver has to implement the change back to diesel fuel. One of the advantages is that cold start problems in winter are obviated (by starting with diesel fuel); on the other hand operation is dependent on another (fossil) material.

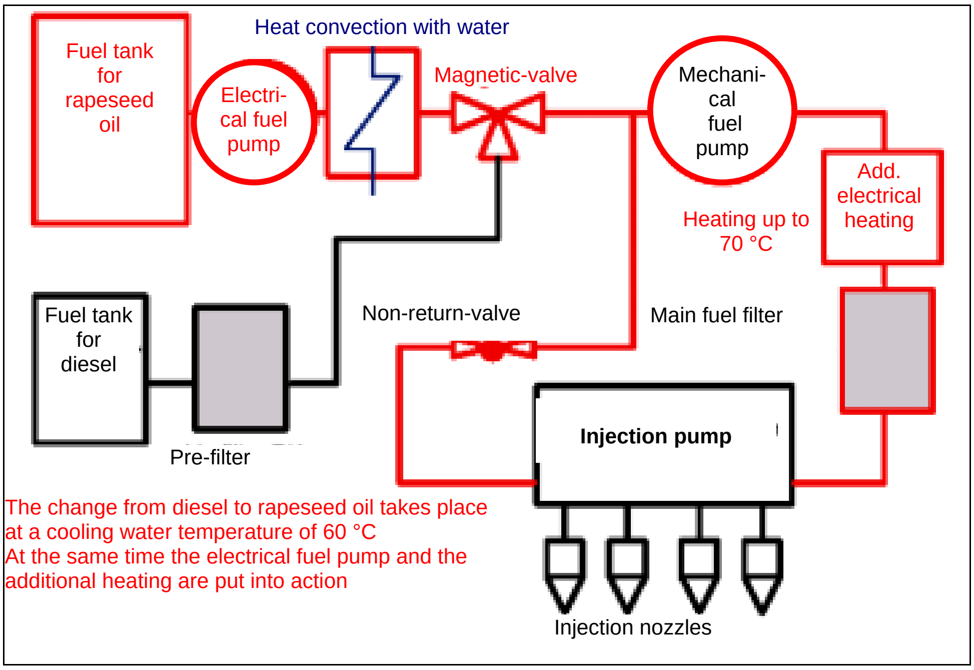

Illustration 9: Retrofitting concept of the company Gruber GmbH – dual tank system, source: Hassel, Berndt, Golisch, Harkner, Schümann, Wichmann, 2003

5 Current activities in Germany and Austria

5.1 Introduction

The introduction of biofuels requires suitable framework conditions. Germany and Austria have favourable tax prerequisites for vegetable oil fuels, including the use of pure vegetable oil.

5.2 Austria

5.2.1 Agricultural framework

The total area of Austria amounts to 83,900km², of which 34,000 km² are used agriculturally. Arable land is decreasing continuously and currently amounts to 1.38 million ha. The following table shows the cultivation areas for oilseeds.

Table 9: Cultivation areas for oilseeds and arable land in Austria, source: Grüner Bericht, 2001, table taken from: http://www.awi.bmlf.gv.at/gb/tabellen/Tab_5101.xls, 17.04.2003

Oilseeds [ha]	1980	1990	1995	2000	2001
Winter rape	3,941	40,844	87,307	51,334	55,811
Summer rape and turnip rape	-	-	1,939	428	287
Sunflower	291	23,336	28,550	22,336	20,329
Soybean	-	9,271	13,669	15,537	16,336
Pumpkin	-	-	8,957	10,376	11,540
Poppy	-	-	2,567	654	806
Other oilfruits (saflor,..)	5,831	6,871	1,415	7,866	5,504
Fallow land*	14,522	20,541	123,866	110,806 rape: 6,085[9]	107,881 rape: 8,673[10]
Total arable land	1,487,598	1,406,394	1,403,191	1,381,996	1,379,951

*as of 1996 plants growing on fallow areas have been attributed to fallow land (until 1995 they were attributed to the respective oilfruit)

Table 10: Oilseed hectare yields in Austria, source: Grüner Bericht, 2001, Table taken from: http://www.awi.bmlf.gv.at/gb/tabellen/Tab_5103.xls, 17.04.2003

yields [dt/ha]	1990	1995	2000	2001
winter rape	24.9	30.1	24.3	26.2
summer rape and turnip rape	23.8	23.4	18.3	19.3
sunflowers	24.6	21.4	24.6	24.9

In crop rotation rape should not exceed 25%. If this value is considered, the maximum cultivation area amounts to approx. 345,000 ha. At an oil yield of 1,000

[9] source: Agrarmarketing Austria
[10] source: Agrarmarketing Austria

kg/ha (1,087 L/ha) a potential of 345,000 t can be calculated. This is only a theoretical value, as basic structural conditions and the use of land for food and fodder cultivation have not been considered.

In Austria approx. 3.8 million t diesel were consumed in 2000. 371,200 t were used in agriculture and forestry; basically this corresponds to the above mentioned potential.

5.2.2 Legal frameworks

In Austria, biogenous fuels, which are used purely as fuels, are exempt from the mineral oil tax. If biogenous substances (e.g. biodiesel) are blended with diesel up to a mixture of 2% the mineral oil tax is refunded or reimbursed completely.

Besides, agricultural enterprises are exempt from tax declaration if the production of biogenous substances is primarily used for the self-sufficiency of agricultural enterprises and if the substances are exclusively used in agricultural enterprises. A reimbursement of the mineral oil tax for traditional diesel for farmers has been discussed repeatedly, but has not been implemented so far.

Vegetable oil as a fuel is not defined in the body of legislation, its use in vehicles, however, is currently not punished.

5.2.3 Fuel provision – oil production plants

Vegetable oil is produced in small-scale plants, co-operatives and industrial plants. The co-operatives and the industrial plants are sometimes combined with biodiesel production. The following table gives an overview of plants in Austria:

Table 11: Vegetable oil production plants in Austria, source: Rathbauer, Krammer, Prankl, 2002

Agricultural undertakings	▪ Approx. 20 to 30 small-scale plants with continuous screw presses, above all rape, edible oil – direct sales ▪ Unknown number of discontinuous presses fort he production of edible oils
Agricultural co-operatives/ industrial plants	▪ Asperhofen: Press output approx. 800 kg/h, currently not oil extraction; AME-production ▪ Mureck: approx. 3,000 t/a rape, RME ▪ Güssing: approx. 3,000 t/a rape, rapeseed oil, RME ▪ Starrein: approx. 3,000 t/a rape, RME, rapeseed oil ▪ Höhmbach: approx. 1,000 t/a rape, plus other small amounts, edible oil, rapeseed oil for technical purposes ▪ Heidenreichstein: approx. 1,000 t/a rape, edible oil, rapeseed oil ▪ Kautzen: 610 t/a Raps (2001), fuel ▪ Oberwaltenreith: 3,200 t/a milk thistle, oil as a by-product
Large-scale plants	Bruck/Leitha: 250,000 t/a rape and sunflower mechanic pressing with subsequent extraction, fully and partly refined, edible oil, vegetable oil for technical purposes, biodiesel Aschach: 40,000 t/a rape Mechanical pressing, fully refined, edible oil

5.2.4 Current level of development

As a consequence of the energy crisis, intensive research in the biofuels sector has been carried out in Austria since the 70s. Initially, most tests were on vegetable oils. In the early 80s the focus moved to vegetable oil methyl ester (“biodiesel”).

In the year 2002 an estimated number of 25 retrofit private cars and small transporters as well as three tractors run with vegetable oil were in operation. The technology used is from Germany, the retrofitting measures are implemented by the company Waldland, in co-operation with the German Vereinigte Werkstätten.

Currently, an Austrian **“35-vegetable-oil-tractors-programme”** is planned, in which 35 tractors from three regions will be retrofitted for operation with vegetable oil and examined scientifically. The project will be financed by the Federal Government and the participating Provinces. The Federal Institute of Agricultural Engineering will implement the scientific accompanying research. On the basis of this research the use of rapeseed oil as a fuel for tractors and the practical suitability of tractors operated with rapeseed oil is to be evaluated.

5.3 Germany

5.3.1 Agricultural conditions

In the year 2001 Germany had 17.3 million ha of agriculturally used land, 11.8 million ha were used as arable land. 1.3 million ha of the 11.8 million ha were cultivated with oilseeds, which corresponds to a share of 11%. Rape, sunflower and flax seed predominate.

Table 12: Cultivation areas, area yields and harvest amounts in Germany for rape, sunflower and flax seed in 2000, source: Brenndörfer, 2002

Oil plant	Cultivation area in ha	Area yields in dt/ha	Harvest in 1,000 t
Rape	1,078,010		
Divided between			
Winter rape	1,046,216	33.7 (23.8 – 39.5)	3,525.9
Summer rape and turnip rape	31,794	18.3 (11.9 – 30.5)	58.3
Sunflower	25,794	24.7 (10.1 – 34.8)	63.6
Flax seed	32,000		

Winter rape has the biggest share with more than 1 million ha cultivation area. On 332,350 ha rapeseed oil for technical and chemical products were cultivated.

5.3.2 Political frameworks

The introduction of biofuels is supported by the Federal Government. By exempting biofuels from the mineral oil tax an important measure has been taken. For comparison, fossil diesel mineral oil tax amounts to 0.47€/L as of 2003. As one component of the ecological tax reform the mineral oil tax was increased between 1999 and 2003 in five steps by 0.15 €/L.

Since 2001 agricultural diesel has been regulated specifically with a reduced tax of 0.26 €/L in Germany. From 2003 it will be 55% of the mineral oil tax.

Table 13: Mineral oil tax comparison diesel/agricultural diesel/biodiesel, source: Graf, Vetter, Reinhold, Breitschuh, 2002

	Mineral oil tax in €/L (indirect taxes with VAT)						
Fuel	Before 31.3.99	As of 1.4.99	2000	2001	2002	2003	2004
Diesel	0.32	0.35	0.38	0.41	0.44	0.47	0.47
Agricultural diesel	-	-	-	0.26	0.26	0.26	0.26
Biodiesel/rapeseed oil	no tax						

By exploiting the agriculturally feasible rapeseed cultivation potential fuel demand of agriculture could almost be fulfilled by rapeseed oil. In reality however, the use of rapeseed oil in agriculture is considerably lower because of tax-reduced diesel fuel (agricultural diesel).

5.3.3 Quality assurance

In early 2002 about 200 decentralised oil presses were operated. In 1998 the decentralised plants were registered by the KTBL (Association for Technology and Structure in Agriculture), for the period between 1998 and 2002 a 2.3-fold increase in plants was noted.

Rapeseed oil fuel is mostly offered by the operators of decentralised oilseed processing plants. The qualities of rapeseed oil fuel partly differ from the requirements of the RK-standard (Section 2.5). As a remedy a project has been initiated to assure the quality of decentralised vegetable oil production for the non-food industry “Qualitätssicherung bei der dezentralen Pflanzenölerzeugung für den Nicht-Nahrungsbereich – Erhebung der Ölqualität und Umfrage in der Praxis“.

5.3.4 Rapeseed oil for technical use

In Germany most rapeseed oil used technically is used in the fuel sector. The use of esterified fuels (biodiesel) is increasing continuously. In the year 2001, for instance, already 450,000 t of biodiesel were sold. The amounts of natural rapeseed oil fuel have not yet been recorded, but they seem to be low.

5.3.5 Current activities

The State Office for Agricultural Machines and Construction of the University of Hohenheim was instructed by the Federal Ministry of Consumer Protection, Food and Agriculture to investigate the influence of rapeseed oil-diesel blends on the useful life of engines. For the engine test runs, blends with a rapeseed oil share of 20, 50 and 75% are envisaged.

The most important current project is the **100-tractors demonstration project**, which is explained in detail below.

5.4 100-Tractors Demonstration Project

5.4.1 Introduction

In September 2000 the Federal Government initiated the demonstration project “Practical use of new production line tractors running on rapeseed-oil” (100-Tractors Demonstration Project). In the three year test period more than 100 tractors were modified for rapeseed oil operation. The most important arguments in favour of the implementation of the project were:

- fuels made from renewable raw materials have environmental advantages
- the cultivation of rape is an income alternative for agriculture

- the price differences between rapeseed oil and diesel fuel in the year 2000
- statements of retrofitter companies that modifiying devices are ready to go into the market

The aim is to prove practical suitability, environmental compatibility and long-term stability. The results will be documented and evaluated scientifically. When the project has been completed the results will be made available to the wide public.

5.4.2 Modification

From April 2001 until September 2002 109 tractors were modified. The tractors were new and each tractor should run at least 800 hours per year. The vegetable oil fuel has to comply with the RK quality standard.

The tractors were modified by six companies. Five companies use one-tank systems, one company uses dual tank systems.

Table 14: Modified tractor types in the 100-tractors-demonstration project, source: Hassel, Berndt, Golisch, Harkner, Schümann, Wichmann, 2003

Modifying company	Tractor type	number	Modifying company	Tractor type	number
Vereinigte Werkstätten für Pflanzenöl-technologie	Deutz-Fahr	41	Gruber KG	Case	**10**
	No entry	7	LBAG Lüchow	Fendt	4
	Fendt	6		New Holland	1
	Welte	1		*sum*	***5***
	New Holland	1	TC Bastorf	Case	1
	sum	***56***		Renault	1
Firma Hausmann	Fendt	17		Fendt	1
	John Deere	7		John Deere	1
	Case	4		*sum*	***4***
	Deutz-Fahr	1	Stangl-Landtechn.	John Deere	**2**
	Claas	1			
	Same	1			
	Lamborghini	1			
	sum	***32***			

Most of the tractors are used in Bavaria. The performance range of the modified tractors ranges from 50 to more than 200 kW, 81% range between 70 and 120 kW.

5.4.3 Scientific accompanying research

The scientific accompanying research will run for three years and is being implemented by the University Rostock (Chair For Piston Machines and Combustion Engines). The main tasks are:

- registration and documentation of the initial condition of the tractors
- registration and documentation of the respective modification concept

- registration of the condition of the tractors (emission and performance tests) immediately after modification and constant tests after 800 operation hours or once a year
- in-depth tests of 20 tractors
- quality assurance of the tractor and of the engine oil through sampling
- registration and systematisation of faults

The research will be concluded with a technical and economic evaluation of the modification measures and the use.

5.4.4 First interim results

In March 2003 a seminar was held in Berlin in which first **interim** results were presented. Below the most important points are discussed:

Fuel: Until November 2002 350 rapeseed oil samples were tested. 320 samples were cold-pressed oils, 30 were fully refined oils. The samples were tested as regards total contamination, neutralisation number, oxidation stability, phosphor content and water content.

Approx. 59% of the storage tank samples showed deviations from the RK-standard. The standard values of the oxidation stability, total contamination, neutralisation number and phosphor content were exceeded. Reasons are the low rapeseed oil quality, which is caused by low seed quality, missing refining steps and missing quality assurance measures during production. Problems are also caused by bad storage conditions. Cold-pressed oils showed the worst results.

Engine oil: 55 different engine oil varieties are used in the programme. The engine oil tests are an important component of the scientific accompanying research, as potential damage can be detected early. By determining the vegetable oil content of the engine oil, problems caused by the decrease of the viscosity and the inclination to polymerisation of the fuel in the oil can be predicted.

In one-tank systems samples are taken after 60 to 80 operation hours, in dual tank systems after 80 to 100 hours. The following criteria have been determined for an (early) oil change:

- kinematic viscosity – maximum alteration one SAE-class[11] (approx. 25%)
- soot content and total contamination – maximum of 3 or 4% by mass
- total base number[12] - maximum alteration 50%
- fuel content less than 30%.

The density at 15°C, the kinematic viscosity at 40°C, the total contamination, the total base number and the saponification number. The rapeseed oil content is determined

[11] SAE = Society of Automotive Engineers. Defines internationally recognised classifications for the viscosity of engine and gearbox oils, http://www.westfalen-ag.de/1024/fachbegrife/s.php4, 23. April 2003
[12] Information on the alkaline reserve of the lubricating oil. It shows the degree of the neutralisation ability of acid combustion and oxidation products, Schümann, 2003

by means of the saponification number and IR-spectroscopy (alteration of the C=O-bonds).

By November 2002 620 engine oil samples had been tested; limiting values were exceeded 127 times, 77 of them concerned the saponification number. All modification concepts showed a drag-in of rapeseed oil into the lubricating oil. The required oil change intervals differed a lot and ranged from 100 to 350 operating hours in the examples given.

Performance and emission measurements, combustion chamber examinations
After modification minor performance reductions but also performance increases as compared to the operation with diesel fuel were observed. With rapeseed oil NO_x emissions as well as CO emissions increased with most tractors.

Components of the 20 test tractors were examined by endoscopy, including the injection nozzles, exhaust valves, cylinder walls and piston bases. The pictures mostly showed a crusty coat of the valves and deposits on the injection nozzles. Sometimes, traces of wear were also found on the valve shanks.

Faults recorded so far
The damage recorded so far can be divided into four categories (damage which is in no relation to the fuel up to damage which can clearly be attributed to modification measures).

Faults in the first category, which are not related to operation with rapeseed oil, such as faulty head gaskets or loose screws, apply to almost the same extent to all modifying companies. Their share within the total failure statistics amounted to **10%.**

Faults in the second category would in all probability have also occured in the case of conventional operation with diesel fuel and can thus not be clearly attributed to operation with rapeseed oil. These faults include cracks in injection nozzles and nozzle fittings or embrittlement of seals, which results in a leakage in the fuel system and thus in an increased drag-in of rapeseed oil into the lubricating oil. The share within the total failure statistics amounted to approx. **40%** and applied to almost the same extent to all modifying companies.

Faults in the third category include those pertaining to improvements of modification, such as measures which improve the cold-start behaviour, adapt the engine performance, but also repairs made by the modification components. They occurred primarily in the initial phase. Not all modifying companies are affected by these faults. The share within the total failure statistics amounted to **45%.**

Faults in the fourth category demonstrate severe technological deficits of the respective modification concept and mostly lead to severe damage to the engine, such as piston seizure after thermal overload of the combustion chamber. The share of these faults amounted to approx. **5%.** Not all modifying companies are affected by these failures.

6 Summary

In the development of vegetable oil fuels the adaptation of the fuel to conventional engines has been preferred in the last decade. Programmes for the alteration of the engines have only been supported to a low extent. Obvious advantages of changes in engine technology (low expense of oil production, decentralised solutions) are above all stressed by proponents in the agricultural and environmental sector.

If pure rapeseed oil is used as a fuel for tractors technical changes are required. For a market introduction technical and non-technical barriers have to be overcome.

The agricultural centre Weihenstephan has developed a rapeseed oil quality standard which could support the development of rapeseed oil as a fuel. A demonstration project (“100-tractors-project”) supported by the German Federal Government is to provide results on the current state of technology of modification devices. First results show some problems, however, the difficulties seem to be fewer than expected.

In Austria a vegetable oil tractors project is also planned on the basis of the results of the German demonstration project. In this project which could already start in 2003, 35 modified tractors are to be operated with accompanying scientific reasearch.

7 List of links

IEA und IEA Bioenergy

http://www.iea.org/: The IEA is an autonomous agency linked with the OECD and it was founded directly after the energy crisis in 1973 to stabilise the world energy markets

http://www.iea.org/techno/renew/index.htm offers a detailed reference to more than 150 legislative acts that support the development of renewable energy sources

http://www.iea.org/impagr/imporg/imagpub/listof.htm contains a list of the "Implementing Agreements".

http://www.ieabioenergy.com/ informs on IEA Bioenergy

http://www.forestry.ubc.ca/task39/GT4/Frames/indexN4.html is the web page of the current IEA Bioenergy Task 39 "Liquid Biofuels"

http://www.liquid-biofuels.com/publicat.htm includes all reports of the past IEA Bioenergy Liquid Biofuels Program

Education and research institutions, institutions, associations

www.blt.bmlfuw.gv.at – The **Federal Institute of Agricultural Engineering** has been dealing with the topic "biogenous fuels" for years and is involved in many research projects.

www.fnr.de – The **Agency of Renewable Resources** supports as one of the project implementing organisations of the German Federal Ministry of Consumer Protection, Food and Agriculture research, development and market introductions in the field of renewable resources.

http://www.tec.agrar.tu-muenchen.de/ - The **Bavarian State Research Centre for Agriculture** is involved in many reasearch projects in the field of vegetabel oil, e.g. the development of the RK standard for vegetable oil.

www.ufop.de – The **Union for the Promotion of Oil and Protein Plants (UFOP)** was founded in 1990 following an initiative of the Association of German Farmers and the Federal Society of German Plant Breeders in order to support local oil and protein plants comprehensively and to open new perspectives for German agriculture.

http://www.uni-hohenheim.de – At the **University Hohenheim** some research projects on vegetable oil have been implemented, such as "Forschungsprojekt Eignung von Pflanzenölschleppern und Gewinnung von Pflanzenöl in landwirtschaftlichen Betrieben" (01/1990-12/1997), University Hohenheim http://www.uni-hohenheim.de/i3v/00217110/00731841.htm www.uni-rostock.de – The **University Rostock**, Chair for Piston Machines and Combustion Engines, is responsible for the scientific accompanying research of the 100-tractors-demonstration project.

Information portals

www.biomasse-info.net,

www.energieportal24.de, an information portal for alternative energy

www.energytech.at, platform for innovative technologies in the field of renewable energies and energy efficiency

www.fmso.de, a technology and information forum for the operation and retrofitting of diesel vehicles run on vegetable oil

www.high-oleic.de, vegetable oils for industry

www.inaro.de, information system renewable resources

www.inaro.de, information system renewable resources

www.nachwachsende-rohstoffe.info, news portal dealing with renewable resources by the NOVA Institute

www.pflanzenoel-initiative.de, market introduction programme in the field “biogenous fuels and lubricants”,

www.Pflanzenoeltankstellen.de. directory of vegetable oil service stations

www.rerorust.de, directory of vegetable oil service stations

Retrofitters

www.biocar.de

www.elsbett.de

www.gruber-landtechnik.de

www.landtechnik-graml.de

www.pflanzenoel-motor.de

www.wolf-pflanzenoel-technik.de

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9 List of illustrations

10 List of tables