# Biofuel: Technical, Economic and Environmental Impacts

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## ABSTRACT

*The world's primary energy demand has quadrupled since 1950. Great changes and destructions in the environment have been caused by the combustion of huge amounts of fossil fuels. A reduction of the combustion of fossil fuels can be achieved by saving energy as well as by using renewable energies. Vegetable oil is one representative of the renewable fuels. Today the use of vegetable oils is mainly limited to nutrition and the production of cosmetics and detergents. We are witnessing a renaissance of vegetable oils as lubricating and fuel oils, caused by the search for renewable energies as well as by the surplus on many agricultural markets. Pure vegetable oils cannot be used in most conventional diesel engines. They can be made similar in their properties to diesel fuel by means of the esterification process.*

*Within the next years, several 100 000 tonnes per annum of rapeseed oil methyl ester is to be produced in the European Union. To be able to use raw vegetable oil as fuel in diesel engines, precautions have to be considered to prevent the deposition of oil coke. One of the methods to make the use of vegetable oil in direct-injected diesel engines possible is the "duotherm" method invented by Ludwig Elsbett. The author is convinced that the worldwide first car manufacturer to include vegetable oil engines in his series production will enjoy a great economic success. By using vegetable oil fuels, at least part of the energy supply can be provided in an approximate equilibrium between man and environment.*


## WORLD ENERGY DEMAND

The development of the world's primary energy demand since 1950 is shown in *Figure 1*. This energy demand has quadrupled since 1950 from 2.5 to more than 10 billion ($10^9$) tonnes of coal equivalent (tce). Most of this energy comes from the combustion of the fossil fuels - coal, natural gas and mineral oil.

"Smog", "acid rain", "greenhouse effect" and "ozone hole" are slogans known to everyone, describing the changes and destruction in our environment which are caused mainly by the combustion of huge amounts of fossil fuels which have been formed and stored in the earth over millions of years.

One criterion for the changes we have already caused in our atmosphere is the increase of the carbon dioxide concentration *(Figure 2)*. This $CO_2$ concentration has climbed from 280 ppm in the preindustrial epoch to 350 ppm today and is still climbing uninterruptedly.

The urgent obligation for mankind to save fossil energies and to replace them as far as possible by renewable and nuclear energies does not mainly result from the limitations of the fuel resources, but from the environmental risks and pollution caused by the combustion products.

In many developed countries, the increase of the energy demand has come to a stop during the last few years. The heavy increase of energy prices after the first energy crisis in 1973 has caused so many energy conservation measures that the energy consumption has remained constant although the gross domestic product has increased steadily. An example for this is Germany *(Figure 3)* which with 80 million inhabitants holds a little less than one twentieth of the world's energy consumption.

The steady increase worldwide of the energy consumption mainly results from the developing and threshold countries which have a great demand to catch up on as compared to the developed countries. Malaysia, too, belongs to these countries. The primary energy demand of Malaysia *(Figure 4)* has increased during the last 10 years from 12 to 27 million tonnes of oil equivalent (toe), which means it has more than doubled. Nevertheless, on an average each of the 18 million inhabitants of Malaysia consumes only one third of the energy consumed by a German.

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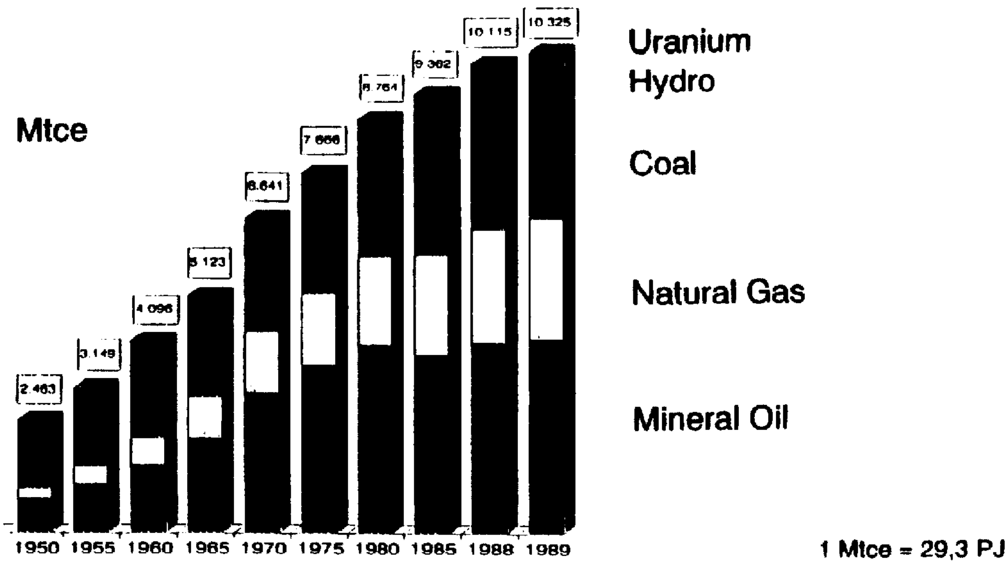



*Figure 1. World energy demand*

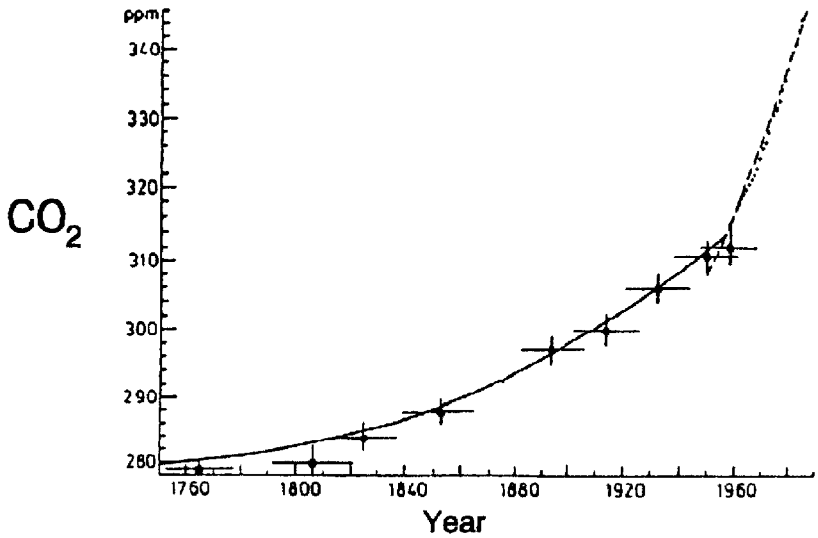



*Figure 2. Increase of CO2 - content of the atmosphere*

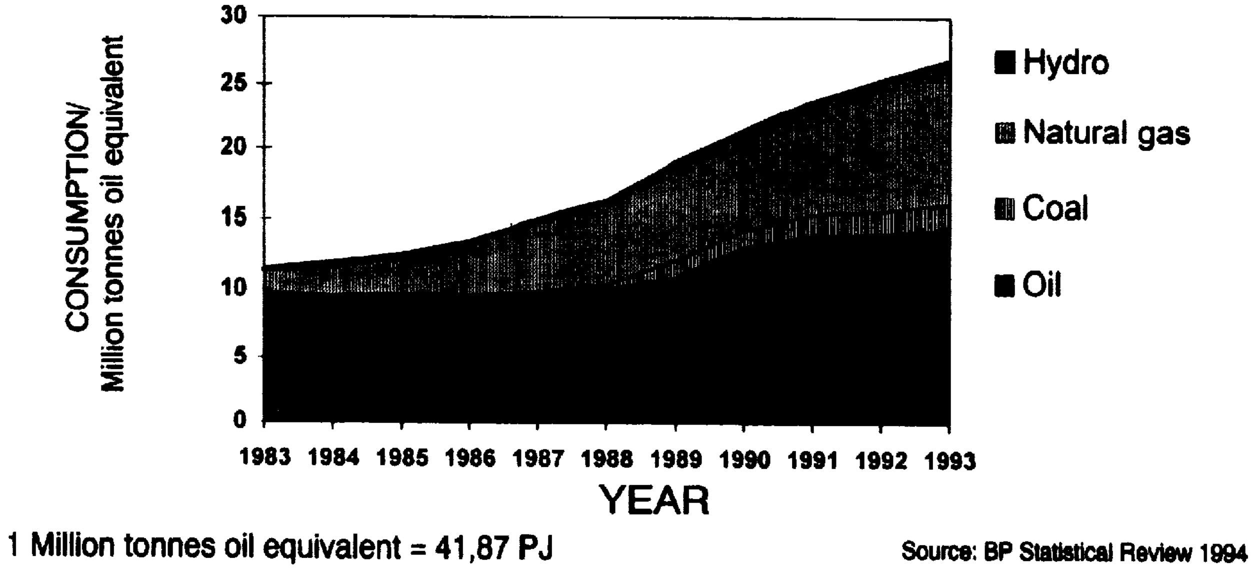



*Figure 3. Primary energy demand of Germany*

**TABLE 3. PRODUCTION OF VEGETABLE OILS IN DIFFERENT REGIONS OF THE WORLD (1990)**

| REGION | MILLION TONNE |
|---|---|
| North America | 16.6 |
| South America | 7.4 |
| China | 3.0 |
| India, Pakistan, Bangladesh | 3.7 |
| USSR | 6.2 |
| Europe (without USSR) | 9.8 |
| Africa | 3.1 |
| Malaysia, Philippines, Indonesia | 8.0 |
| Others | 3.8 |
| **TOTAL** | **61.6** |

**TABLE 4. CHARACTERISTICS OF DIESEL FUEL, RAPESEED OIL AND RME**

| Fuel characteristics | | Diesel fuel average value | Rapeseed oil raw | Rapeseed oil methylester (RME) |
|---|---|---|---|---|
| Average sum formula | | $C_{13}H_{24}$ | $C_{57}H_{101,6}O_6$ | $C_{19}H_{35,2}O_2$ |
| Molar mass | | 120 - 130 | 883 | 296 |
| Cetan number | | >50 | ≈ 44 | 52 - 56 |
| Heat value (20°C) | $MJ/dm^3$<br>MJ/kg | 35,7<br>42,7 | 33,7<br>36,7 | 32,6<br>37,1 |
| Minimum mass of combustion air | kg air/kg fuel | 14,57 | 12,43 | 12,53 |
| Density (15°C) | $kg/dm^3$ | 0,84 | 0,916 | 0,882 |
| Viscosity (20°C) | $mm^2/s$ | 4 - 5,5 | 75 | 6 - 8 |

## RENEWABLE ENERGY SOURCES

The important measure that has to be taken to protect our environment is to reduce the combustion of the fossil fuels, that is coal, natural gas and mineral oil. This can be achieved by saving energy as well as by using renewable and nuclear energies.

Energy can be saved by the following means;

- engines and systems with high efficiency
- energy recovery
- combined generation of mechanic/electric energy and heat (co-generation).

Internal combustion engines are very well suited for co-generation *e.g.* in industrial plants. These engines can be fuelled with natural gas, the most important national energy resource of Malaysia, but also with vegetable oil.

Which renewable energies can be developed further or can be newly recovered in future? The utilization of hydro, wind and geothermal power are well developed technologies. In Malaysia, for example, 23% of the electric energy are generated in hydro power stations. The usable water power resources of Malaysia are 3.5 times larger than the present overall electricity generation of approximately 35 HTWh annually.

Great additional expectations exist in many countries concerning the direct use of solar energy, especially concerning the photovoltaic electricity generation, in the development of which billions of US$ have been invested worldwide, also in Germany. However, no convincing development success is in sight, and will not be in my opinion.

The non-continuous solar radiation is just one reason among others for this statement. At least parts of the generated electric energy will always have to be stored. But all known methods to accumulate electric energy imply extremely high costs and expenditures. One kind of the respective accumulation of photovoltaic current is the generation of hydrogen by means of electrolysis which is being developed at present with high expenditures. But with hydrogen being the lightest element, its density is extremely low. For its storage, *e.g.* as vehicle fuel, it ought to be liquefied. But hydrogen condenses at a temperature of no higher than -252°C. Complicated and costly liquefying plants and cryogenic tanks are necessary. But even after these expenditures for the liquefying, the density of hydrogen is very low, 0.071 kg/dm$^3$ *(Table 1)*.

One litre of liquid hydrogen at -252°C contains 71 g of hydrogen, whereas one litre of vegetable oil contains more than 100 g of hydrogen, however at a normal temperature and easy to handle. The heating value of one litre of vegetable oil is four times higher than the heating value of one litre of liquid hydrogen. The vegetable oil is as well renewable being generated from solar energy as the solar hydrogen, but much cheaper and to be gained without any high technology.

Vegetable oil is one representative of the renewable fuels from biomass. It is very well suited as vehicle fuel because of its very high heating value and ease of handling.

## WORLD VEGETABLE OIL PRODUCTION

Vegetable oils are obtained from the seeds or fruits of oil plants. Edible oils as well as lubricating oils, fuel oils and oils for paints and soaps have always been produced. Since the advent of mineral oil - beginning in the middle of the last century - the use of vegetable oils has been limited mainly to nutrition and for the production of cosmetics and detergents. *Table 2* shows the production figures of the most important vegetable oils. The 61.6 Mt produced in 1990 are, of course, modest as compared to the worldwide consumption of mineral oil of approximately 3300 Mt in the same year *(Figure 5)*.

Today we are witnessing a renaissance of vegetable oil as lubricating and fuel oil, initiated by the search for renewable energies as well as by the surplus on many agricultural markets. The leading producing regions of the world for vegetable oils *(Table 3)* are North America, Europe and South East Asia (Malaysia, the Philippines, Indonesia). The predominant oil plant in South East Asia is the oil palm, the cultivation of which has been considerably enlarged during the last decades and which today is second only to the soyabean, but before the rape plant *(Figure 6)*.

The vegetable oils which are less suited for nutrition have been pushed into the background with the advent of the mineral oil. Only a few of these oil types have been maintained as industrial raw materials because of their specific properties (*Figure 7)*. Oil crops which have hardly been used so far, like the purgier nut (*Jatropha curcas L.*) which grows also on very poor, stony and dry soils, may play an important role in the future - not only in oil production, but also because of their additional ecological and economic advantages like soil conservation, water balance or labour creation.

**TABLE 1. PROPERTIES OF VEGETABLE OIL AND LIQUID HYDROGEN AS VEHICLE FUELS**

| Properties | | Vegetable Oil (20°C) | Liquid Hydrogen (-253°C) |
|---|---|---|---|
| Density | $kg/dm^3$ | 0.92 | 0.0708 |
| Spec. $H^{2-}$ content | $kg/dm^3$ | 0.106 | 0.0708 |
| Heat value | $kJ/dm^3$ | 33700 | 8490 |

**TABLE 2. GLOBAL PRODUCTION OF THE MOST IMPORTANT VEGETABLE OILS AND FATS (1990)**

| OIL CROPS | MILLION TONNE |
|---|---|
| Soybean oil | 12 |
| Rapeseed oil | 8.5 |
| Cottonseed oil | 5 |
| Sunflower oil | 7 |
| Peanut oil | 3.5 |
| Coconut fat | 2.6 |
| Linseed oil | 0.5 |
| Palm oil | 10 |
| Olive oil | 1.6 |
| Other oils and fats | 10.9 |
| Total vegetable fats | 61.6 |

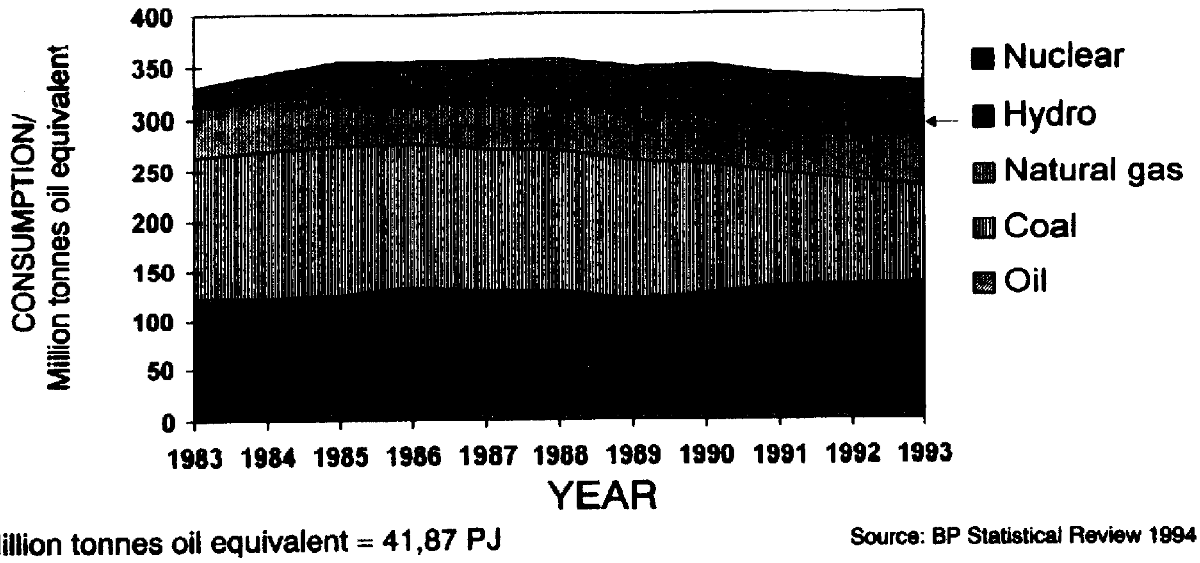



*Figure 4. Primary energy demand of Malaysia*

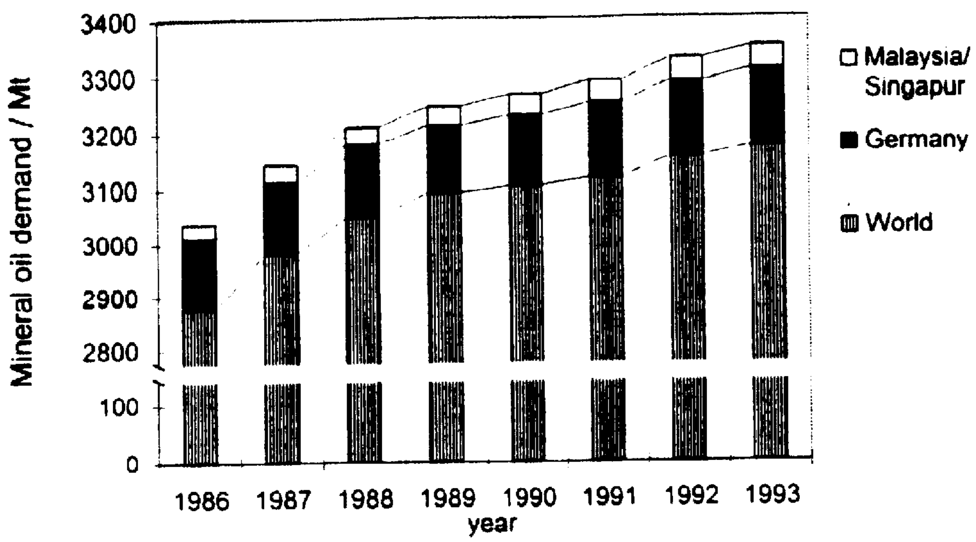



*Figure 5. Mineral oil demand of the world, Germany and Malaysia*

## CHARACTERISTICS OF BIOFUELS (VEGETABLE OILS AND THEIR METHYL ESTERS)

Vegetable oils cannot be used as fuel in most conventional diesel engines. The reason for this is the different behaviour of the vegetable oils as compared to diesel fuel. Natural fats and oils are composed of one trivalent alcohol (glycerol) and three added fatty acids. Natural fats and oils are triacylglycerols (triglycerides). All three OH-groups are replaced by different or identical fatty acids *(Figure 8)*. The triacylglycerols of the natural fats and oils contain at least two different fatty acids. The kind of the fatty acids and their composition in the molecule decisively determine the chemical, physical and biological behaviour of the fats and oils and because of this also their possible use. Oils with a high content of essential fatty acids (*e.g.* linoleic acid) are preferably used for nutrition.

Vegetable oils can be made similar in their properties to diesel fuel by means of a chemical reaction with monovalent alcohols, the so-called esterification process. The glycerol is separated and each fatty acid molecule connects with one monovalent alcohol molecule. The esterification process involves the transformation of the large branched triglyceride molecule into smaller straight-chain molecules. Methyl alcohol is mostly used for the esterification process which results in the formation of vegetable oil methyl esters. The monovalent alcohol esters thus produced can be used as fuel for all "normal" diesel engines without problems provided that the pipes and seals of the fuel system are esters resistant.

In Europe, the vegetable oil methyl esters are called "bio-diesel (fuel)". Within the next years, several 100,000 tonnes per annum rapeseed oil methyl ester will be produced and marketed as "bio-diesel" vehicle fuel inside the European Union, especially in France, Austria and Germany. The main objective is the support for the European farmers who are allowed to produce biofuel oil crops on farmland which would otherwise have to be left fallow. For example European Union regulations require that 15% of the farmland for food supply in Germany has to be left unexploited.

Pilot and demonstration plants for "bio-diesel" are in operation in several European countries. Large-scale plants in the capacity region of 100,000 tonnes per annum are in the planning or construction phase.

Characteristics of diesel fuel, rapeseed oil and rapeseed oil methyl esters (RME) are listed in *Table 4*.

The problems arising when using vegetable oils in conventional diesel engines result in the different characteristics of the fuels. The average molar mass of the vegetable oils as triglycerides is several times higher than the molar mass of the diesel fuel hydrocarbons. As a result also the viscosity of the vegetable oils is many times larger than the viscosity of diesel fuel. Vegetable oils are not filterable from relatively high temperatures downward. An adapted fuel injection system and a heated fuel filter for the use of vegetable oils are necessary. The cetane number as a measure for the ignition quality of the fuel is a little lower for vegetable oil than for diesel fuel. The starting behaviour can be improved by starting with diesel fuel from a special supplementary tank.

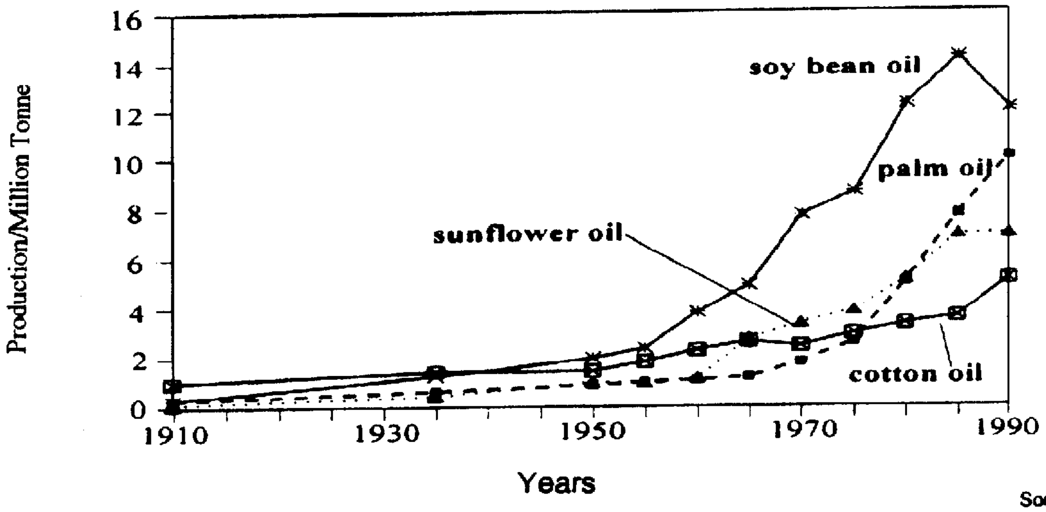
The main problems for the use of vegetable oil as engine fuel results from the thermal cracking of oil particles before the evaporation temperature is reached. The results normally are carbon residues (oil coke) and the formation of coke deposits on the walls of the combustion space.

Diesel fuel is a product of the distillation in the refinery process. The evaporating temperatures of the diesel fuel components range from 170 to 350°C. The oil coke, which is produced due to the decomposition of the crude oil before the evaporation in the distillation columns, remains in the residue of the columns. Vegetable oil - in contrast to diesel fuel - is not distilled and consequently still contains all components which crack before the evaporation and form oil coke.

## TECHNICAL IMPACTS

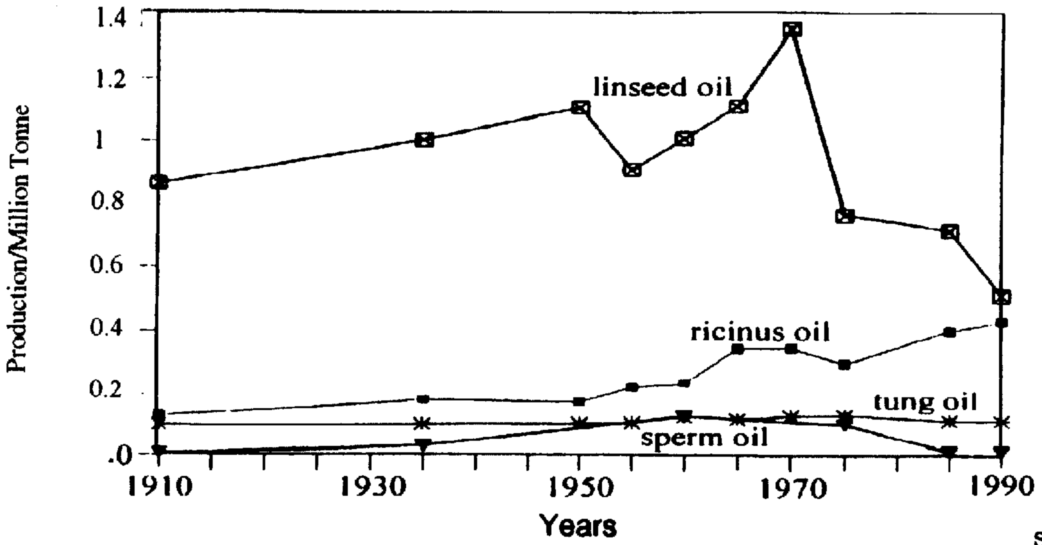
To be able to use raw vegetable oil as fuel in diesel engines, it is necessary to design the fuel supply system accordingly, considering above all the high viscosity and the aggressiveness to many plastic and rubber materials. But most important of all, precautions have to be taken to prevent the deposition of oil coke on the walls of the combustion space and on the fuel-injection nozzles. The combustion of vegetable oil in pre-chamber diesel engines normally proceeds without any problems and without any greater formations of residues or deposits. However, the use of vegetable oil in the more modern direct-injection diesel engines is not possible without taking special measures. In direct-injection diesel engines *(Figure 9)* the fuel jets are normally splashed on the bottom of the piston where they evaporate and begin to burn, and in the case of vegetable oil, the cracking processes cause heavy deposits.

The best known method to make the use of vegetable oil in direct-injection diesel engines possible is




Source: M. Bockisch

*Figure 6. World production of various vegetable oils*




Source: M. Bockisch

*Figure 7. World production of natural oils mainly used in industry*

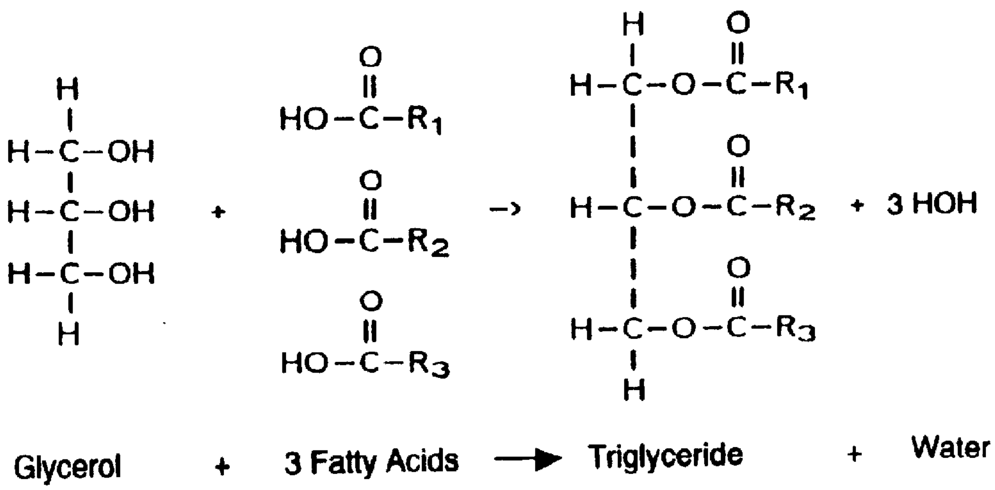



*Figure 8. Composition of a fat molecule*

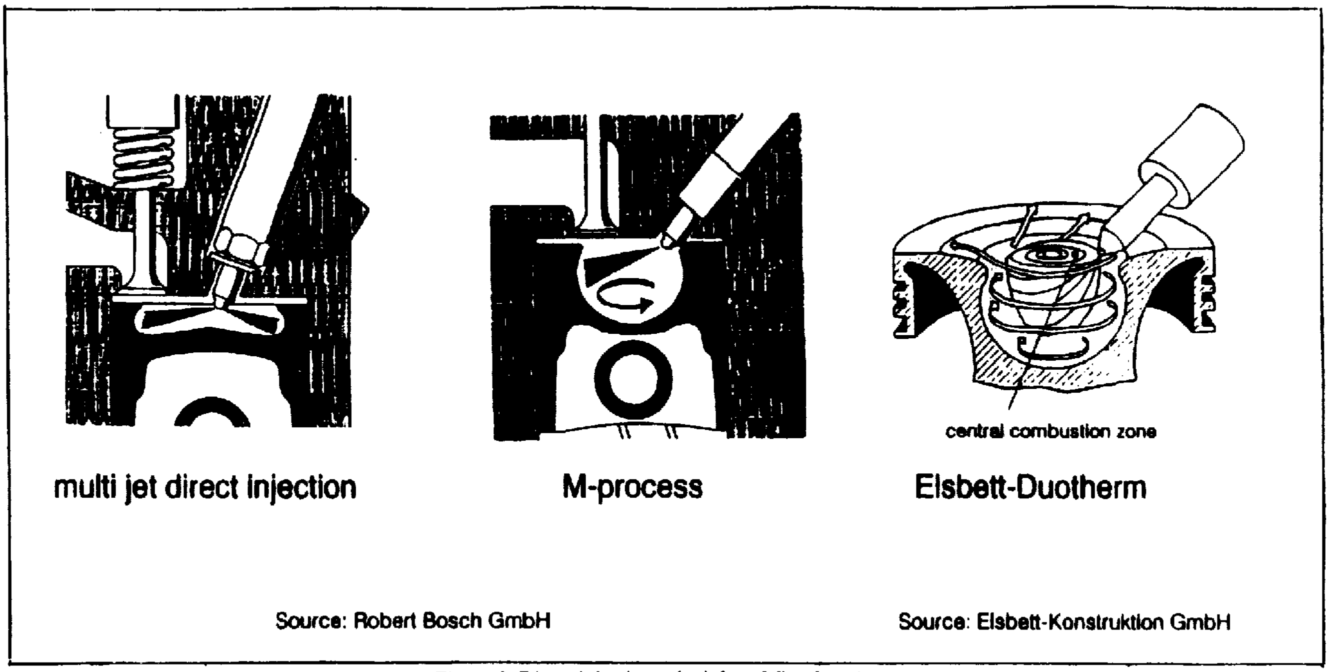



*Figure 9. Direct injection principles of diesel engines*

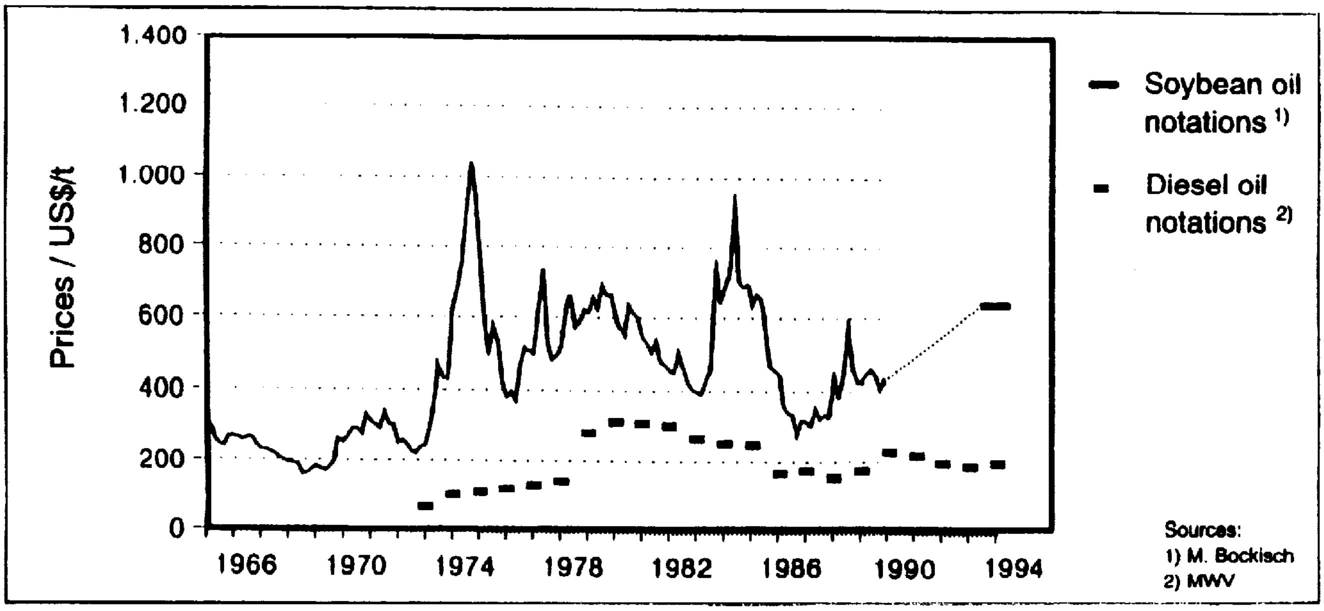



*Figure 10. Comparison between the world market prices for soya bean oil and diesel fuel*

the so-called "duotherm" method. This *duotherm* method for the mixture formation and the combustion was developed by Ludwig Elsbett in Germany. It derives from the MAN-M- direct fuel injection method, in the development of which Ludwig Elsbett took part as well.

In the case of the *duotherm* method *(Figure 9)*, the fuel is injected into a vortex of the combustion air. This prevents wall contact of the fuel particles because of the well known whirlpool effect. Furthermore the heat transfer to the walls of the combustion space is greatly reduced because the combustion takes place in the core of the vortex and because the outer air layer serves as insulation. This results, on the one hand, in a high flame temperature with an intensive combustion and, on the other hand, in a low outgoing heat loss bringing about an outstandingly high thermal efficiency. Some Elsbett engine types do not even need an external air or water cooling system, but only a lubricating oil cooler.

The author can look back upon his own very satisfying operating experience of more than two years with a Mercedes Benz car equipped with a 3-cylinder Elsbett engine. After 92,000 km in operation, the first internal engine inspection showed no oil coke deposits whatsoever, apart from a very thin soot layer.

## ECONOMIC IMPACTS

In many countries of the world, agriculturally useable land is lying fallow, when, at the same time, a part of the population is unemployed. It seems only logical to use these land and labour resources for the production of renewable raw materials in general and for the production of renewable biofuels in particular. According to regulations of the European Union, 15% of the agricultural land in Germany must not be used for agrofood production. The production of renewable raw materials is, however, allowed in those areas. At present, 2.5% of the German agricultural land are used for that purpose. Approximately 50,000 tonnes per annum rapeseed oil for non-food use originate from this cultivation and compare to a total of 380,000 tonnes per annum vegetable fats and oils which are consumed in Germany for non-food purposes.

Vegetable oil is not subjected to the German mineral oil tax (0.61 DM/dm$^3$), even when used as vehicle fuel, and therefore competes favourably with diesel fuel on which tax has to be paid. The vegetable oil would not be able to compete with diesel fuel without the tax preference *(Figure 10)*.

Within the European Union, the introduction of a $CO_2$ emission or energy tax is being discussed in order to reduce the $CO_2$ emission into the atmosphere. Renewable energies are supposed to be exempted from this tax, which would improve the competitiveness of biofuel even further.

The use of pure vegetable oil as vehicle fuel has been extremely hindered up to now. The situation arises because correspondingly suitable engines have not yet been manufactured in great series, and no car manufacturer is standardizing the building-in. Therefore cars which, so far, can only be supplementarily equipped with appropriate prototype engines, suffer the corresponding disadvantages in price, service and spare parts supply.

Up to now, German car manufacturers have shown great reservation towards the use of vegetable oil as vehicle fuel, not to say utter disapproval. The author does not know the reasons for this; perhaps economic consideration for the mineral oil industry plays a role. But the author is convinced that the first car manufacturer worldwide to include vegetable oil engines in his series production, will enjoy great economic success. It would be especially ironic, if in the near future, cars equipped with vegetable oil engines were exported to Germany, that is to the country in which the technology for these engines was invented.

Manufacturing and export chances may result from a resolute introduction of vegetable oil as fuel, not only for the corresponding engines and cars, but also for all kinds of equipment for oilseed processing plants, which are competitive even in small units in industrially developed countries, also.

## ENVIRONMENTAL IMPACTS

The reduction of the $CO_2$ emission into the atmosphere by means of renewable energies has already been mentioned. When burning one liter of vegetable oil, 3 kg $CO_2$ are produced, but the oil plant has withdrawn these 3 kg $CO_2$ from the atmosphere first. Moreover, the oil plant, *e.g.* the oil palm, additionally withdraws $CO_2$ from the atmosphere during its growth, to be precise, 1.8 kg $CO_2$ per one kg dry matter of the plant.

A forced worldwide afforestation or re-afforestation of non-wooded or rooted-out areas, which exist on earth on a gigantic scale, is at present the only realistic possibility to reduce the $CO_2$ content of the atmosphere to a normal level again.

The afforestation, *e.g.* with oil trees, would confer essential additional ecological advantages in many regions of the world in respect to avoiding soil erosion, holding ground water or supplying firewood. Additional ecological advantages of biofuels as opposed to mineral oil fuels are:

- hardly any $SO_2$ emission
- fast biological decomposition, therefore no danger for soils and waters in connection with production, transport and use.

An additional important ecological advantage of pure vegetable oil as fuel in relation to mineral oil fuels, is the possibility to process oil economically also in small oil mills. No huge refinery plants are needed as in the case for mineral oil processing. Therefore vegetable oil fuel can be produced in small mills in the immediate neighbourhood of the cultivation and can be used, if needed, right there.

The great transport distances of raw materials and products which are common for mineral oil, can often be considerably diminished in the case of vegetable oil. Vegetable oil fuels offer the possibility to have almost closed small-area economical and ecological circuits for the energy supply. By using vegetable oil fuels, at least part of the energy supply can be provided in an approximate equilibrium between man and environment, without any essential risks having to be expected.

In many cases this renewable energy production will also be cheaper than the traditional energy supply by means of fossil fuels, at least if the viewpoints of national economy and worlwide ecology are also taken into consideration.

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