Presentation for Shanghai International Symposium on I.C. Engine 2003
by Guenter Elsbett, Elsbett-Technology, Hilpoltstein, Germany
and Michal Bialkowsky. University Edinburgh

Engines running on pure vegetable oil as regrowing fuel
History, Development, Experience, Chances

The idea of using vegetable oils as fuel for diesel engines is not new. With the advent of cheap petroleum, appropriate crude oil fractions were reined to serve as fuel and diesel fuels and diesel engines evolved together. In the 1930s and 1940s vegetable oils were used as diesel fuels from time to time, but usually only in emergency situations. Recently, because of increases in crude oil prices, limited resources of fossil oil and environmental concerns there has been a renewed focus on vegetable oils and animal fats to make biodiesel fuels.

At the beginning of the seventies ELSBETT was the first company to fit a fleet of cars with direct injection diesel engines with extremely low consumption, which were developing their basic models ready to their mass production - 20 years ahead of other companies. More than 1000 engines have been sold – all able to run on vegetable oil as well as on diesel fuel.

This initiated a considerable discussion regarding use of vegetable oil as a fuel similarly to first biodiesel initiatives reported in 1981 in South-Africa and then in 1982 in Austria, Germany and New Zealand.

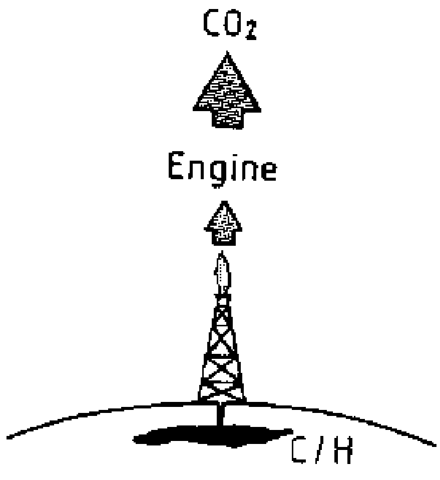
Also Prof. Gao Zonying, Jiangsu University Zhenjiang,where Elsbett engines were tested in the eighties, addressed the concept of using plant “food” for fuel, indicating that petroleum should be the “alternative” fuel rather than vegetable oil and alcohol being the alternatives and some form of renewable energy must begin to take the place of the non-renewable resources. A cooperation between Jiangsu University and ELSBETT for a special engine development was signed.

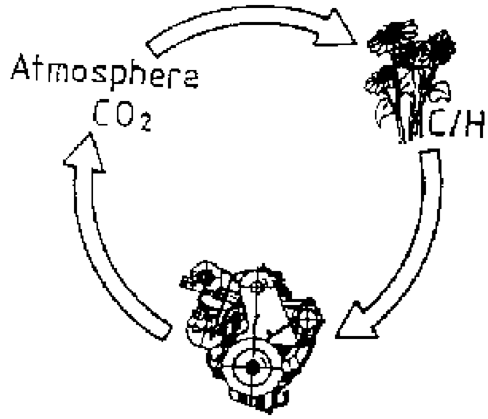
The first International Conference on Plant and Vegetable Oils as fuels was held in Fargo, North Dakota in August 1982. The primary concerns discussed were the cost of the fuel, the effects of vegetable oil fuels on engine performance and durability and fuel preparation, specifications and additives. Oil production, oilseed processing and extraction also were considered in this meeting (ASAE, 1982).

The major advantages of natural vegetable oil are:

- High calorific value: high energy density
- Liquid in form and thus easily to be handled
- When burned it emits less soot
- When burned it has high energy efficiency
- It is neither harmful nor toxic to humans, animals, soil or water
- It is neither flammable nor explosive, and does not release toxic gases
- It is easy to store, transport and handle
- It does not cause damage if accidentally spilt
- Its handling does not require special care to be taken
- It is produced directly by nature: it does not have to be transformed
- It is a recyclable form of energy
- It does not have adverse ecological effects when used
- It does not contain sulphur: it does not cause acid rain when used
- When burned it is neutral in $C0_2$: No contribution to the greenhouse effect.

While our current energy system can be represented by an irreversible, open cycle, an energy system based on natural vegetable oil constitutes a closed cycle.

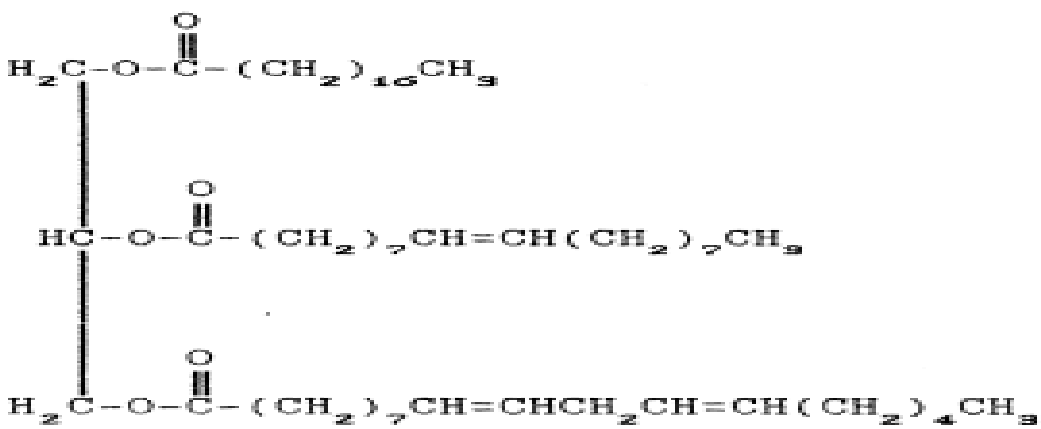




Current:
Open cycle

Natural
closed cycle

Structure of a typical triglyceride molecule



Fatty acids vary in carbon chain length and in the number of unsaturated bonds (double bonds). The triglyceride molecules of vegetable oil consist of three long-chain fatty acids that are ester-bonded to a single glycerol molecule. These fatty acids differ by the length of the carbon chains, as well as the number, orientation, and position of double bonds in these chains. The viscosity of vegetable oils is of the order of 10-20 times that of diesel fuel.

It has been identified more than 1000 oil plants around the World. Some of them are listed below.

List of oil containing seeds (not complete, only a few selected as an example)

English name	Latin name	English name	Latin name	Yearly oil yield kg / ha (average, not intens. agricul-ture)
almond	Prunus communis	Suari fat	Caryocar amyg-	
apricot	Armeniaca vulgaris	sweet chestnut	castanea sativa	
assai-palm	Euterpe edulis	syrian scabious	cephalaria syriaca	
Awarra	Astrocaryum vulgare	tallow tree	Sapium sebiferum	
Bacaba palm	Oenocarpus bacaba	tarweed	madia sativa	
Baobab	Adansonia digitata	tea-oil plant	Camellia oleifera	
borage	Borago officinalis	tucuma	Astrocaryum tucuma	
Borneo tallow	Shorea stenoptera	turpentine tree	Pistacia terebinthus	
butter nut	Caryocar nuciferum	walnut	Juglans regis	
butter tree	Madhuca longifolia	Water-chestnut	Trapa natans	
Carnauba wax	Copernicia cerifera	meadowfoam	Limnanthes alba	20
cohune palm	Attalea cohune	Corn	Zea rnais	143
copaiba tree	Copaifera officinalis	Cashew-nut	Anacardium occidentale	148
corn salad	Valerianella olitora	oat	Avena sativa	183
crabwood	Carapa guineensis	palm	Erythea salvadorensis	189
croton	Croton tiglium	lupine	Lupinus albus	195
earth almond	Cyperus esculentus	rubber seed	Hevea brasiliensis	217
Essang	Ricinodendron hendeloti	calendula	Calendula officinalis	256
Eth. Mahagony	Trichilia emetica	cotton	Gossypium hirsutum	273
evening primrose	Oenothera biennis	soy bean	Glycine max	374
ginkgo	Ginkgo biloba	coffee	coffea arabica	386
gorli seed	Oncoba echinata	line seed	Linum usitatissimum	402
grape	Vitis vinifera	hazel-nut	Corylus avellana	405
hemp	Canabis sativa	Euphorbia	Euphorbia lagascae	440
hunters nuts	Omphalea megacarpa	pumpkin seed	Cucurbita pepo	449
indian almond	Terminalia catappa	coriander	Coriandrum sativum	450
Jaboty Palm	Erisma calcaratum	mustard	Brassica alba	481
Japanese chest-	Castanea crenata	dodder-seed	Camelina sativa	490
Janary Palm	Astrocaryum Januari	sesame	Sesamum indicum	585
Java almond	Canarium comune	Abyssinian kale	Crambe abyssinica	589
Kagne-butter	Allanblackia oleifera	safflower	Carthamus tinctorius	653
malabar-nut~tree	Adhatoda vasica	buffalo gourd	Cucurbita foetidissima	665
malabar-tallow	Vateria indica	rice	Oriza sativa	696
manketti nut	Ricinodendron rautenenii	tung tree	Aleurites spp	790
mururmurupalm	Astrocaryum murmuru	sunflower	Helianthus annus	801
narasplant	Acanthosicyos horridus	cocoa	Theobroma cacao	863
	Antelaea azadirachta	peanut	arachis hypogaea	887
niger	Guizotia abysinnica	Opium poppy	Papaver somniferum	978
nutmeg	Myristica fragrans	rape	Brassica napus	999
oiricurupalm	Syagrus coronata	olive tree	Olea europaea	1019
pachira nut tree	Bombacopsis glabra	Indaia palm	Attalea funifera	1112
papaya	Carica papaya	gopher plant,	euphorbia lathyris	1119
Passion fruit	Passiflora edulis	castor bean	Ricinus communis	1188
pea	Pisum sativum	bacury	Platonia insignans	1197
peach	Amygdalus persica	pecan-nut	Carya illinoensis	1505
peach palm	Bactris gasipaees	jojoba	Simmondsia chinensis	1528
pistachio	Pistacia vera	babassu palm	Orbignya martiana	1541
powder flask-fruit	Afraegle paniculata	purging nut	Jatropha curcas	1588
red pepper	Capiscum annuum	macadamia nut	macadamia terniflora	1887
red-cotton-tree	Bombax malabaricum	Brazil nut	Bertholletia excelsa	2010
rose hip	Rosa pomifera	avocado	Persea americana	2217
sandal beadtree	Adenanthera pavonia	coconut	Cocos nucifera	2260
Scotch pine	Pinus silvestris	oiticica	Licania rigida	2520
seje palm	jessenia bataua	Buriti palm	mauritia flexuosa	2743
shea nut	Vitellaria paradoxa	,,Pequi"	Caryocar brasiliense	3142
sourcherry	Prunus cesarus	Macahuba palm	Acrocomia spp	3775
spruce	Pikea excelsa	Oil palm	Elaeis guineensis	7061

The main source of vegetable oil as fuel still remains rapeseed or canola. Animal fats, although mentioned frequently, have not been studied to the same extent as vegetable oils. Considerable research has been done on these vegetable oils as fuel for diesel engines. That research included palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil and other types of plant oils cultivated locally.

The use of vegetable oils, such as rapeseed, canola, palm, Soya bean, sunflower, peanut and olive oils as alternative fuels for diesel engines dates back almost nine decades and potential use of plant oils had been attracted researchers' attention since long time. As result of these studies and considering the content of the monosaturated oleic acid, the low level of saturated fatty acid and acceptable level of linolenic acid makes the rapeseed oil rather the ideal source of vegetable oil in Europe. Main other sources used are palm oil, sunflower oil and soybean oil are economically the powerful source of fuel in other part of the World however considerable studies on their application still have to be done. Among the vegetable oil seeds that can be grown as domestic field crops, cottonseed and sunflower seed are the major productions [42d] in the World. However, crop productions are inconsistent according to harvest area, climatic conditions, etc.

Although, some permissible results and vast collection of experimental data, the aspect of renewable energy has not been widely applied. Continued and increasing use of petroleum will intensify local air pollution and magnify the global warming problems caused by CO_2. In a particular case, such as the emission of CO_2 in the closed environments of underground mines, vegetable oils have the potential to reduce the level of greenhouse gases.

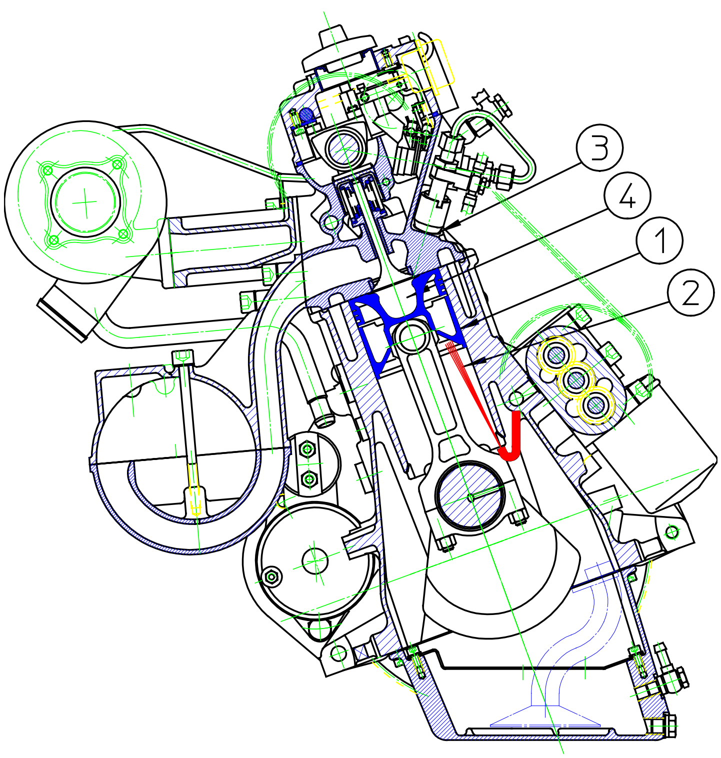
During the last decade many researchers have investigated use of vegetable oils in compression ignition engine fuel. Direct use of vegetable oils and/or the use of blends of the oils has generally been considered to be not satisfactory and problematic for both direct (DI) and indirect (IDI) injection diesel engines. The high viscosity, acid composition, free fatty acid content, as well as gum formation due to oxidation and polymerisation during storage and combustion, carbon deposits and lubricating oil thickening are obvious problems. The probable reasons for the problems and the potential solutions were proposed and are shown below:

Problem	Probable cause	Potential solution
Short-term 1. Cold weather starting	High viscosity, low cetane, and low flash point of vegetable oils	Preheat fuel prior to injection.
2. Plugging and gumming of filters, lines and injectors	Natural gums (phosphatides) in vegetable oil. Other ash	Partially refine the oil to remove gums. Filter to 4-microns
3. Engine knocking	Very low cetane of some oils. Improper injection Timing.	Adjust injection timing. Use higher compression engines. Preheat fuel prior to injection.
Long-term 4. Coking of injectors on piston and head of engine	High viscosity of vegetable oil, incomplete Combustion of fuel. Poor combustion at part load with vegetable oils	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load.
5. Carbon deposits on piston and head of engine	High viscosity of vegetable oil, incomplete combustion of fuel. Poor combustion at part load with vegetable oils	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part loads.
6. Excessive engine wear	High viscosity of vegetable oil, incomplete combustion of fuel. Poor combustion at part load with vegetable oils. Possibly free fatty acids in vegetable oil. Dilution of engine lubricating oil due to blow-by of vegetable oil	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load. Motor oil additives to inhibit oxidation. Use lub oil based on vegetable oil

7. Failure of engine lubricating oil due to polymerisation	Collection of polyunsaturated vegetable oil blow-by in crankcase to the point where polymerisation occurs	Heat fuel prior to injection. Switch engine to diesel fuel when operation at part load. Motor oil additives to inhibit oxidation. Use lub oil based on vegetable oil

In short term engine tests of less than 10h duration, the vegetable oils performed quite well. Problems occur only after the engine has been operating on the vegetable oil for longer periods of time and this has been the main recently highlighted problem. Research that deal with direct use of vegetable oil as alternative diesel fuel are based on the main idea of application problems, clearly suggesting solutions for problems and finally making it possible to apply successfully by the help of these suggestions.

Some researchers have been reporting encouraging engine performance under short-term usage, but again have faced degraded engine performance for prolonged operation with vegetable oils again. They studied some auxiliary parts of diesel engine and looked carefully at combustion chamber. The problems reported include fuel filter clogging, deposit build-up in the combustion chamber, injector coking, piston ring sticking and lubrication oil thickening, which necessitate overhauling the engine with change of some parts. It has been proved again that the cumulative operation hours before overhaul is needed are shorter for vegetable oil than for diesel. One major obstacle in using vegetable oils was their high viscosity, which causes clogging of fuel lines, filters and injectors. Therefore, vegetable oils could not be used directly in diesel engines at room temperatures. In order to reduce the viscosity of the vegetable oils, three methods were found to be effective: transesterification, mixing with lighter oil and heating. In many of successful application, the modifications of diesel engines were applied to the injection system parts like fuel lines, filters and pumps.



The only engine especially developed for successful use of vegetable oil is the Elsbett-Engine.

The distinctive features afforded by the ELSBETT technology, and which relate to specific engine components, are listed below. Each component part can be used separately and many of today's best-known engines are meanwhile fitted with components or systems designed by ELSBETT.

1) The ELSBETT articulated piston
2) The ELSBETT oil cooling system
3) The ELSBETT fuel injection system
4) The ELSBETT duothermic combustion system

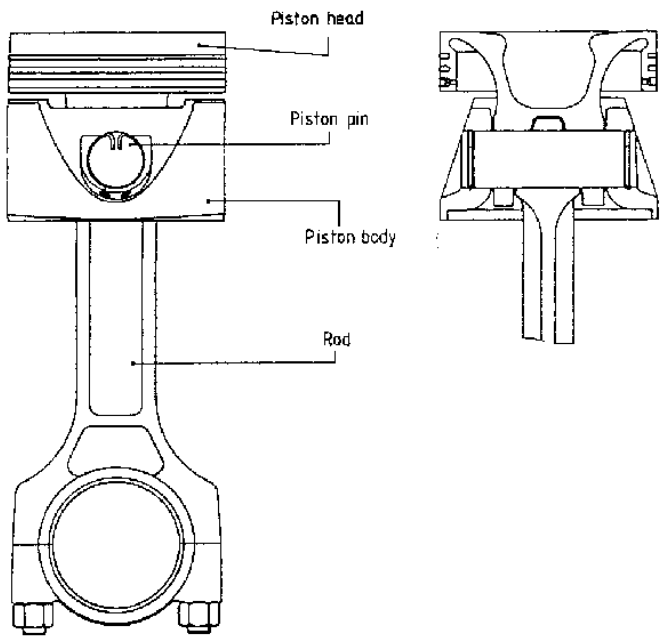
Only by combining the above mentioned elements is it possible to achieve the optimum thermal and mechanical conditions required for the combustion of fuels, such as natural vegetable oils, which are slow to vaporise.

THE ELSBETT ARTICULATED PISTON

The **ELSBETT** piston comprises two interconnected parts:

- the piston head, made from nodular cast iron, and
- the piston body, made from aluminium, which are connected between themselves and to the piston rod by the piston pin.

The piston head houses the rings, and its functions are to seal and compress, and to receive the vertical forces caused by the expansion of the gases. The piston head is made from nodular cast iron, which undergoes minimal thermal expansion and has low heat-conductive properties. Its thermal expansion is identical to that of the material used to construct the block and, therefore, it affords an excellent seal. The surface of the combustion chamber wall is of a reduced size so as to minimise the heat flow and, consequently, prevent the unnecessary overheating of the material.



The piston body provides lateral support (normal forces), and aids the cooling of the internal walls of the cylinder through the distribution of lubricating oil. For this reason it is equipped with guide vanes and is made from aluminium. The static and thermal optimisation of the **ELSBETT** articulated piston enables it to be lighter than its aluminium counterpart.

THE ELSBETT COOLING SYSTEM

In terms of energy, ELSBETT engines in the seventies and eighties performed better than conventional engines having an efficiency of approximately 40% to 43%. This increased performance was made possible by improving the thermal balance of the engine, causing greater availability of useful mechanical energy and substantially reducing the conversion of energy into useless heat.

As the surface of the combustion chamber wall is reduced in size, and thermal insulation is caused by the excess air surrounding the combustion area, the heat flow and the cooling requirements are minimised.

While in a conventional diesel engine with a precombustion chamber approximately 31% of the energy contained in the fuel is removed from the engine through the cooling system and dispelled into the radiator, (26% in direct injection diesel engines, 28% in petrol engines), in the case of the **ELSBETT** engine only around 14% to 16% of the heat has to be removed.

This reduced demand for cooling makes it possible to dispense with conventional cooling systems. In **ELSBETT** engines the cooling process is carried out by the engine's lubricating oil alone. Water radiators and air-cooling devices are thus dispensed with, and this reduces the number of parts, the weight and the volume of the engine.

The absence of water in the engine makes it possible to cast ribless blocks and to dispense with the head joint. Cracks in engines are more often the result of accentuated temperature gradients rather than the temperature itself. For this reason oil allows for the safer cooling of the engine as it works beyond the boiling point of water and reduces thermal tensions in the engine.

Oil does not boil easily, does not cause internal corrosion or cavitation, does not freeze, and quickly reaches its working temperature.

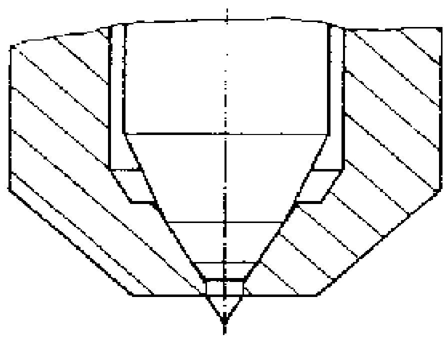
The lower part of the piston is cooled by means of jets of oil. The jets of oil cool the internal walls of the cylinder and, guided by vanes fitted inside the piston body, reach the lower base of the piston head thereby cooling it.

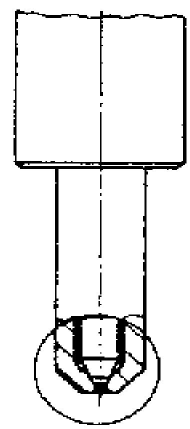
The engine head is cooled by means of the forced circulation of the oil. The oil itself is cooled by an external radiator.

THE ELSBETT FUEL INJECTION SYSTEM

The fuel in the **ELSBETT** engine is injected locally and tangentially inside the central combustion area within the chamber. This process prevents the fuel and its residue from making contact with the walls, thus minimising the loss of heat.

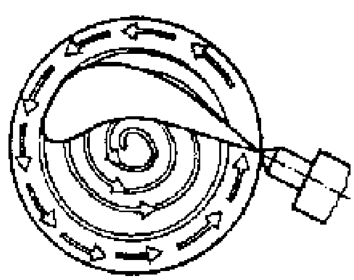
For this reason the injection nozzles have one aperture with a self-cleaning needle, and are arranged in a specific position and at a specific angle.

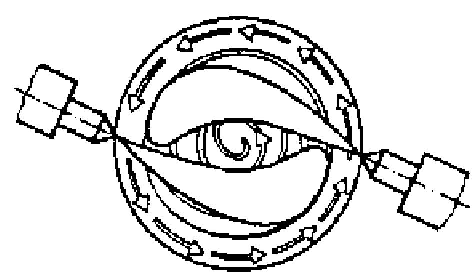




Injector nozzle | Detail of pintle nozzle

The built-in injection control system, which is a feature of **ELSBETT** engines, adjusts perfectly to the specific characteristics of each engine, and renders an additional injection pump unnecessary, thus reducing the number of parts and the weight of the engine.



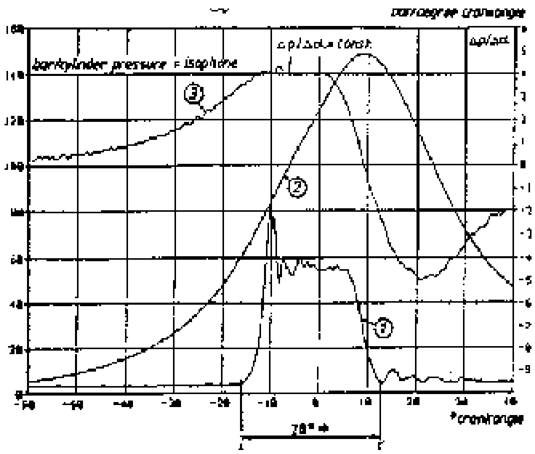


Simple injection | Double injection

Larger engines are fitted with a dual injection system to minimise emissions. Each cylinder is fitted with two injection nozzles which are tangentially symmetrical.

Soot forms when the temperature, caused by the combustion of fuel at the beginning of the injection process, causes the decomposition of the fuel injected at the end of the injection process. The inclusion of a second injection nozzle in each cylinder makes it possible to reduce the injection time by almost 50%, and this substantially reduces the emission of soot and allows soot filters to be dispensed with.

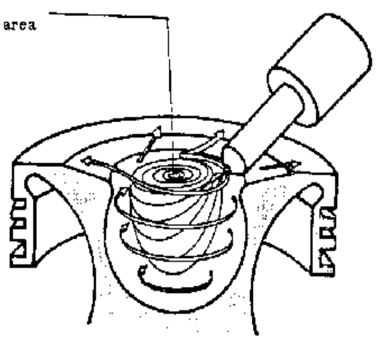
THE ELSBETT DUOTHERMIC COMBUSTION SYSTEM



The aim of the system is to safeguard against the loss of useful energy in the form of heat outside the combustion chamber. For this reason the heat is concentrated inside the chamber so that it cannot reach the surfaces and become lost in a radiator.

The **ELSBETT** duothermic combustion system is based on the principle that the air circulates inside the combustion chamber and arranges itself into different layers according to differences in heat and density, thus forming a central hot air combustion area and an external surrounding layer of cooler excess air. The combustion chamber must be spherical and located in the piston itself. The shape and size of the inlet ducts are such that the inlet air moves in a circular motion.

The fuel is injected tangentially and directed towards the inside of the combustion area, thus causing it to blend perfectly with the air. It does not reach the wall of the combustion chamber and, therefore, the formation of unwanted deposits is avoided. The external layer of cooler, excess air acts as a thermal and acoustic insulator and prevents the fuel from making contact with the chamber walls. The reduced size of the surface of the combustion chamber wall minimises heat flow and the loss of energy.



The noise level is kept low as a result of the internal pressure increase differential remaining constant during the combustion and equal to the pressure differential during the compression of the gases.

APPLICATIONS OF VEGETABLE OIL ENGINES
(and main advantages)

these engines can be used in all types of machinery:

- Tractors, harvesters, and other agricultural machinery (able to produce its own renewable fuel)
- All types of forestry machinery (preservation of ground water)
- Lorries, vans, pick-ups, etc. (fuel efficient)
- Industrial tractors, fork-lifters, and other industrial machinery (non toxic fuel and emissions)
- Cement mixers, diggers, cranes, and other civil engineering machinery (no highly inflammable liquids)
- Buses, taxis, and other public transport vehicles (smoke reduction)
- Private cars (no CO2 increase, save, non inflammable fuel)
- Boats, yachts, tugboats, and other transport and pleasure vessels for sea or river (water preservation)
- Aircraft (lower weight due to lower tank capacity, because of high efficiency)

- Mixers, mills, pumps, ventilators, and other stationary industrial and agricultural machinery (no toxic gases or inflammable liquids)
- Electricity generating plant (efficient, no CO2 increase)
- Combined electricity and heat generating plant (efficient, no CO2 increase)

The **ELSBETT** technology for combustion engines, which has developed over the years, is ready and available to be used. It enables the current energy system to be adapted to a viable model for world development, in which issues which up to now have been neglected, but which are becoming increasingly more important and indispensable - such as environmental health - can be attended to and properly dealt with.

But only one small engine-producer could not bring a break-through in this technology, so a solution must be found for a conversion of most of the conventional diesel engines on the market.

As it had been mentioned, vegetable oils have an ignition quality equivalent to diesel fuel and their combustion characteristics are much the same, but their viscosity is too high for the modern fuel pumps. The development of the modern diesel engines has been tailored to the availability of petroleum derived fuel. Fuel modification may, however, improve the viscosity of vegetable oil fuel but other related problems still exist. Researchers have indicated that higher viscosity resulted in incomplete atomisation of neat vegetable oil fuel, which in turn prevents complete combustion of large fuel droplets resulting in carbon deposits. Knocking, encountered during the test at low load and low cylinder temperature, was due to the low cetane number of vegetable oil. The test results indicate that vegetable oil fuels exhibit longer ignition delay and slower combustion stages, giving rise to a reduction of maximum peak cylinder pressure.

Problems appear only after the engine has been operating on vegetable oils for longer periods of time, especially with direct-injection engines. The problems include coking and soot lump formation on the injectors. This phenomenon is caused by polymerisation of oil causing at the beginning by lacquer formation to such an extent that fuel atomisation does not occur properly or is even prevented as a result of plugged orifices. Carbon deposits, oil ring sticking-thickening and gelling of the lubricating oil as a result of contamination by the vegetable oils are main problems revealed during experiments.

Vegetable oils have been noted to exhibit longer delay periods and slower burning rate especially at low load operating conditions hence resulting in late combustion in the expansion stroke. (However, as an advantage here, slower combustion restrains NO_x formation.) Advanced injection timing was proposed to compensate these effects.

Very important is to know what is mend, when talking about vegetable oil. The standardising of the fuel is a must. So the University Munich in cooperation with oil suppliers and engine manufactorers developed such a quality standard (only for rapeseed oil).

Vegetable oil as a fuel, properties in comparison to diesel fuel

LTV-Work-Session on Decentral Vegetable Oil Production, Weihenstephan

Quality Standard for Rapeseed Oil as a Fuel (RK-Qualitätsstandard)

05/2000

in Cooperation with:

Properties / Contents	Unit	Limiting Value min.	Limiting Value max.	Testing Method
charcteristic properties for Rapeseed Oil				
Density (15 °C)	kg/m³	900	930	DIN EN ISO 3675 DIN EN ISO 12185
Flash Point by P.-M.	°C	220		DIN EN 22719
Calorific Value	kJ/kg	35000		DIN 51900-3
Kinematic Viscosity (40 °C)	mm²/s		38	DIN EN ISO 3104
Low Temperature Behaviour				Rotational Viscometer (testing conditions will be developed)
Cetane Number				Testing method will be reviewed
Carbon Residue	Mass-%		0.40	DIN EN ISO 10370
Iodine Number	g/100 g	100	120	DIN 53241-1
Sulphur Content	mg/kg		20	ASTM D5453-93
variable properties				
Contamination	mg/kg		25	DIN EN 12662
Acid Value	mg KOH/g		2.0	DIN EN ISO 660
Oxidation Stability (110 °C)	h	5.0		ISO 6886
Phosphorus Content	mg/kg		15	ASTM D3231-99
Ash Content	Mass-%		0.01	DIN EN ISO 6245
Water Content	Mass-%		0.075	pr EN ISO 12937

00 1ER 100e

Density: The kinds of vegetable oil do not differ too much in terms of density. On average density is about 10% higher.

Flash Point by P.-M.: Is much higher than with diesel fuel. Makes transportation and handling much more safe.

Colorific Value: Is nearly equal for all vegetable oils, but 10% less in comparison to diesel fuel. Because of higher density the volumetric content of heat value is about the same.

Kinematic Viscosity: For most vegetable oils higher than diesel fuel. Big differences between the different kinds of seeds. If too high, the oil can't pass the fuel circuit. Heating is one of the measures to enable engines to run on vegetable oil.

Low temperature behaviour: No specification defined up to now. But the low temperature behaviour is of importance for engine cold start and low load. Viscosity is such an indicator for low temperature behaviour.

Cetane Number: No sufficient testing method existing, because the engines for the standardising tests are all conventional diesel engines. When measured with conventional method, Cetane number is worse, nevertheless practice shows, that ignition delay is shortened in comparison to diesel fuel.

Carbon Residue: There is a remarkable correlation to the residues in the combustion chamber, piston rings and valves, so carbon residue should be kept low.

Iodine Number: Is an indicator for double bindings in the molecular structure. It influences the long time stability of properties (important for storage).

Sulphur Content: Sulphur reduces the function of catalysts and causes SOx emissions like Diesel engines. Normally vegetable oil does not contain sulphur.

Contamination: That is the most important property. It blocks filters and nozzles and is abrasive all over the fuel circuit. Must be well controlled.

Acid Value: Shows the content of free fatty acids. Can effect the properties of lubrication oil if bigger quantities reach the oil sump.

Oxidation Stability: Describes the pre-aging of the oil. With progressing age the viscosity is also increasing continuously. Can also influence the lub-oil.

Phosphorus Content: Is depending much on production method for the oil. Phosphorus is dangerous for the engine due to its abrasive function. When the oil is cold pressed or refined normally the content of phosphorus is within the limits.

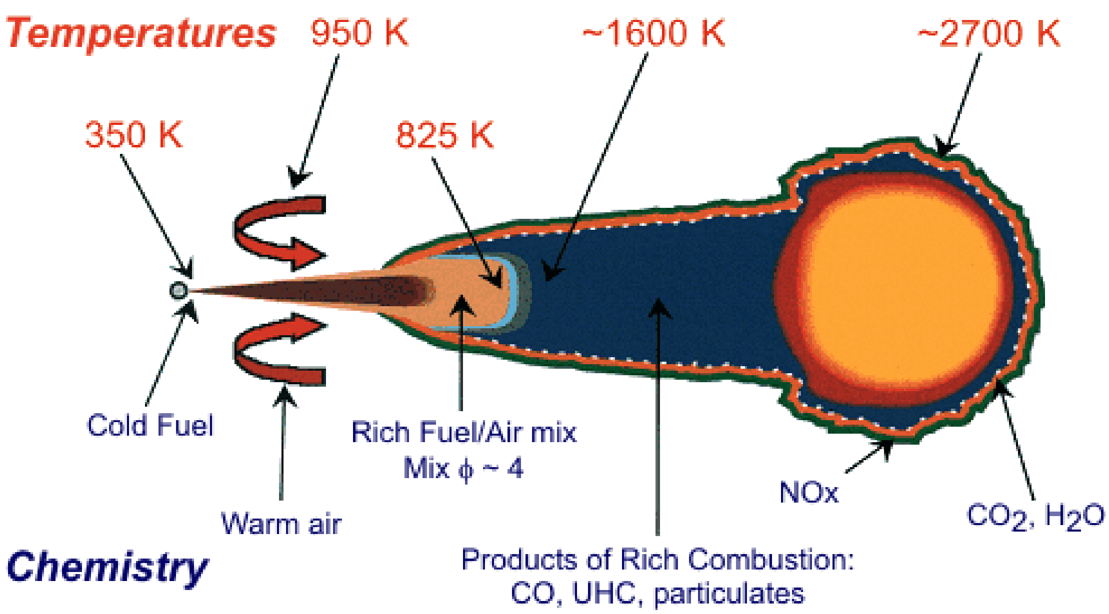
Ash Content: Concerns the content of oxide- and raw-ash. Ash is abrasive.

Water Content: If emulgated, a higher water content is not disadvantageous (as long the emulgation remains stable, which is very difficult). Normally water will cause problems anywhere in the fuel system.

Practical experience shows: **The characteristic properties can anyway not be influenced - but the variable ones. So a rough oil quality check should mainly be focussed on:**

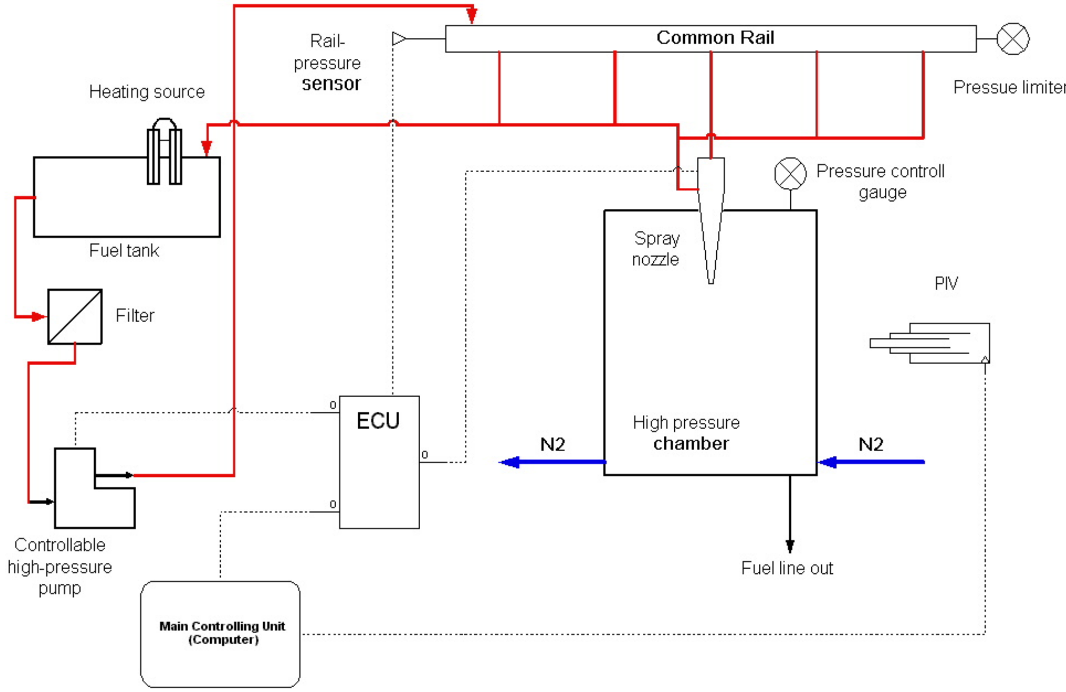
- Contamination
- Phosphorus Content
- Water Content

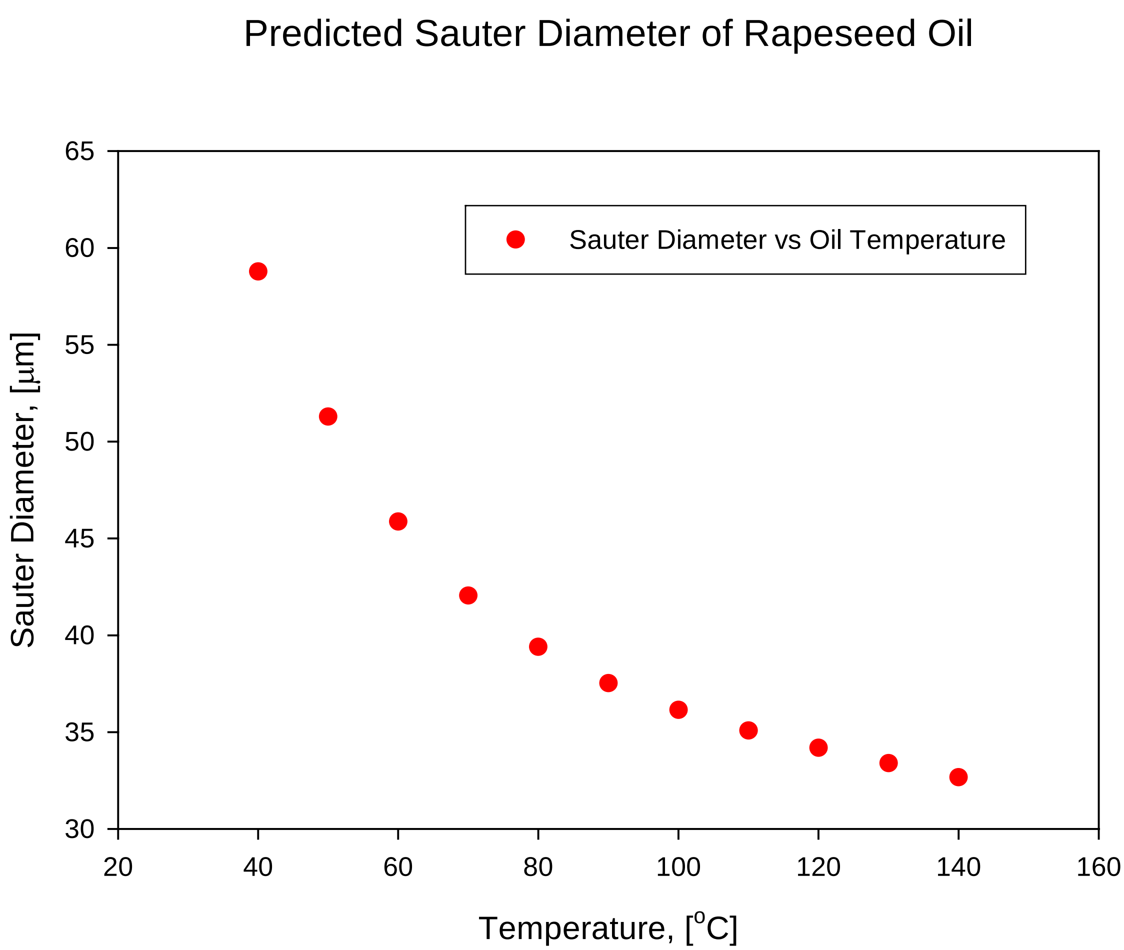
Many tests are carried out at ELSBETT to modify the vegetable oil spray characteristic as close as possible to that of diesel fuel.



Simplified injection- and combustion process

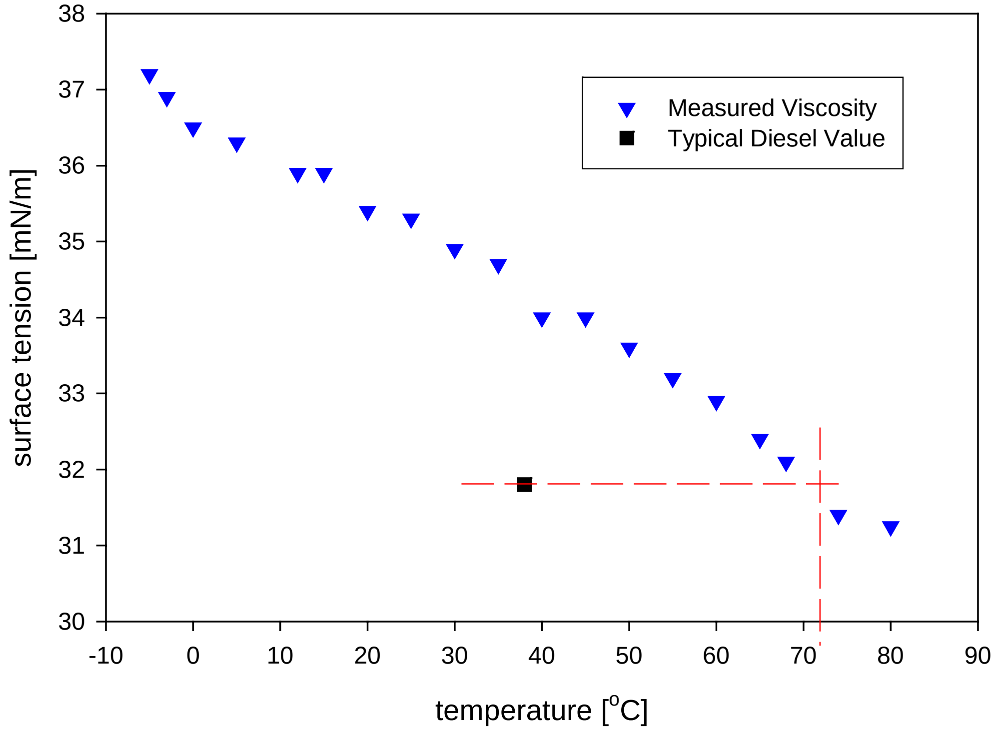
Therefore a special test equipment has been developed in cooperation between the University of Edinburgh and ELSBETT, to measure the relevant spray parameters, evaporation, droplet size and number. A high speed camera and Laser-Doppler will be used. Also some programs showing animated spray distribution were developed.



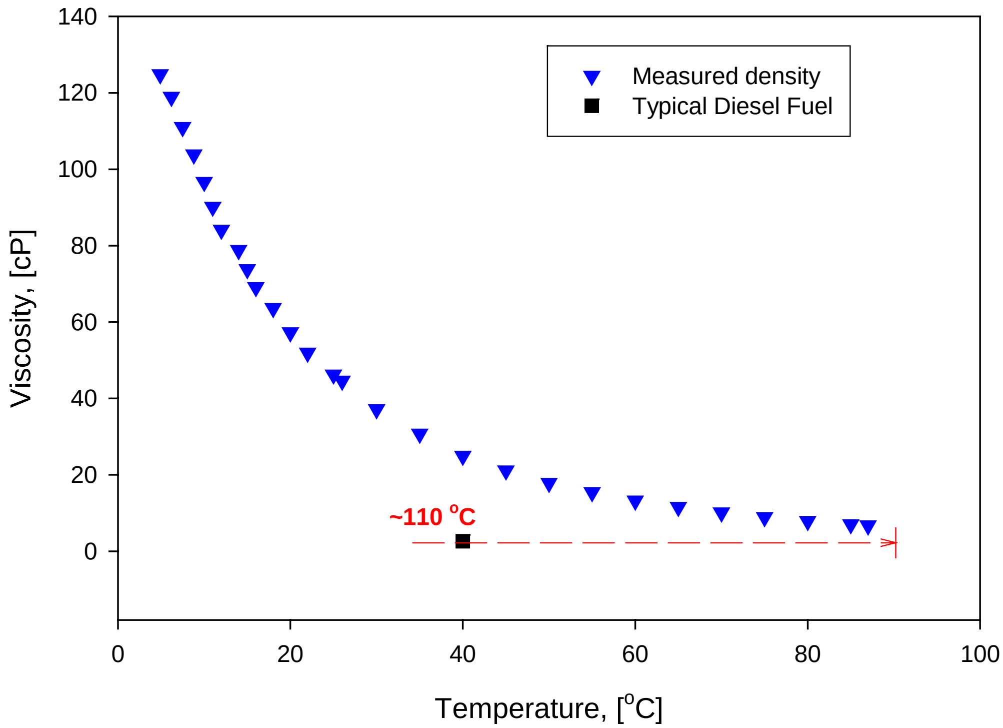


The influence of some parameters is already well known

Surface Tension



Viscosity



CDI-Injection-System, as it was used during the tests

Atomisation

Eq. by Elkotb $$d_{32} = 3.8 \cdot \nu^{0.335} \cdot (\sigma \cdot \rho_L)^{0.737} \rho_A^{0.06} \cdot \Delta P^{-0.54}$$

Diesel fuel

$$\rho_L = 835 \frac{kg}{m^3}$$
$$\nu = 2.7 \cdot 10^{-6} \frac{m^2}{s}$$
$$\sigma = 0.0318 \frac{\mathrm{N}}{\mathrm{m}}$$

Bavarian Sample

$$\rho_L = 900 \frac{kg}{m^3}$$
$$\nu = 2.6 \cdot 10^{-5} \frac{m^2}{s}$$
$$\sigma = 0.034 \frac{\mathrm{N}}{\mathrm{m}}$$

Spray Parameters

$$\rho_A = 42.5 \frac{kg}{m^3} \qquad \Delta P = 1.31 \cdot 10^8 \ Pa$$

The thermodynamic analysis of the engine internal process led to conclusion that when vegetable oil with long chained fatty acids have to be burnt the injection system should be able to alter the injection timing according to both speed and load to get the best engine efficiency. Author suggested that only moderate loads and temperature in the swirl-chamber obstruct the vaporisation and start of burning of long chained fuels. It has been noted that in non-adapted swirl-chamber diesel engines most likely vegetable oil with short fatty acid chains could be burnt without major problems.

Some more typical data are shown in the following:

Fatty acid structure

Vegetable oil	Fatty acid								Reference no
	16:0	16:1	18:0	18:1	18:2	18:3	20:0	Others	
Ailanthus	31.0	0	0	8.1	51.1	7.3	0	2.0	12
Bay laurel[a]	25.9	0.3	3.1	10.8	11.3	17.6	0	31.0	13
Beech	11.6	3.5	1.2	10.4	33.3	16.4	60.0	14.6	7
Beechnut	8.8	0	3.2	30.4	48.9	0	0	6.7	14
Castor[b]	1.1	0	3.1	4.9	1.3	0	0	89.6	5
Corn	11.8	0	2.0	24.4	61.3	0	0.3	0	1
Cottonseed	28.7	0	0.9	13.0	57.4	0	0	0	1
Crambe[c]	2.1	0	0.7	18.9	9.0	6.9	2.1	60.4	5
Hazelnut kernel	4.9	0.2	2.6	83.6	8.5	0.2	0	0	1
Linseed	5.1	0.3	2.5	18.9	18.1	55.1	0	0	1
Peanut	11.4	0	2.4	48.3	32.0	0.9	1.3	3.7	5
Poppyseed	12.6	0.1	4.0	22.3	60.2	0.5	0	0.3	1
Rapeseed	3.5	0	0.9	64.1	22.3	8.2	0	0	5
Safflowerseed	7.3	0	1.9	13.6	77.2	0	0	0	15
H.O. Safflower-seed	5.5	0	1.8	79.4	12.9	0	0.2	0.4	5
Sesame	13.1	0	3.9	52.8	30.2	0	0	0	15
Soyabean	13.9	0.3	2.1	23.2	56.2	4.3	0	0	16
Spruce[d]	5.2	0	1.0	14.7	30.4	5.7	23.2	20.0	6
Sunflowerseed	6.4	0.1	2.9	17.7	72.9	0	0	0	1
Walnut kernal	7.2	0.2	1.9	18.5	56.0	16.2	0	0	1

Fatty acid compositions of vegetable oil, % by weight

Vegetable oil	Iodine value (g I/100g oil)	Saponification value (mg KOH/g oil)	HHV (kJg^{-1})
Ailanthus	107.18	206.34	39.38
Bay laurel[a]	69.82	220.78	39.32
Beech	105.15	202.16	39.59
Beechnut	110.64	193.52	39.82
Castor[b]	88.72	202.71	37.41
Corn	119.41	194.14	39.64
Cottonseed	113.20	202.71	39.44
Crambe[c]	99.83	178.59	40.62
Hazelnut kernel	98.62	197.63	39.83
Linseed	156.74	188.71	39.33
Peanut	119.35	199.80	39.45
Poppyseed	116.83	196.82	39.59
Rapeseed	108.05	197.07	39.73
Safflowerseed	139.83	190.23	39.52
H.O. Safflowerseed	88.57	206.82	39.61
Sesame	91.76	210.34	39.42
Soyabean	120.52	194.61	39.63
Spruce[d]	96.08	207.79	39.44
Sunflowerseed	132.32	191.70	39.57
Walnut kernal	135.24	190.82	39.56

Different vegetable oils compared to Diesel fuel

Fuel type	Caloric value (kJ/kg)	Density (g/dm^3)	Viscosity (mm^2/s)		Cetane number	Flame point (°C)	Chemical formula
			27°C	75°C			
Diesel fuel	43 350	815	4.3	1.5	47[a]	58	$C_{16}H_{34}$
Raw sun¯ower oil	39 525	918	58	15	37.1[a]	220	$C_{57}H_{103}O_6$
Sun¯ower methyl ester	40 579	878	10	7.5	45-52	85	$C_{55}H_{105}O_6$
Raw cottonseed oil	39 648	912	50	16	48.1[a]	210	$C_{55}H_{102}O_6$
Cottonseed methyl es-ter	40 580	874	11	7.2	45±52	70	$C_{54}H_{101}O_6$
Raw soybean oil	39 623	914	65	9	37.9[a]	230	$C_{56}H_{102}O_6$
Soybean methyl ester	39 760	872	11	4.3	37	69	$C_{53}H_{101}O_6$
Corn oil	37 825	915	46	10.5	37.6[a]	270±295	$C_{56}H_{103}O_6$
Opium poppy oil[a]	38 920	921	56	13	-	-	$C_{57}H_{103}O_6$
Rapeseed oil[b]	37 620	914	39.5	10.5	37.6[a]	275-290	$C_{57}H_{105}O_6$

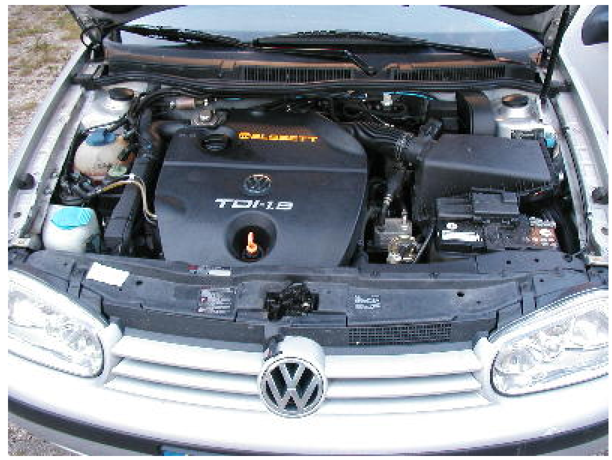
[a] Values for opium poppy oil were taken from Doysan Ltd.
[b] Values for rapeseed oil were taken from Paksoy Ltd

Some photos of conversion examples are following:

Converted Cargo Railway

Converted Railway Bus

Conversion Kit



Converted passenger car (Golf)

Converted
Truck engine
(Scania)

Vegetable oil Filling station in a workshop (not harmful to the ground water, nor explosive), that means the fuel can be stored ever-where without special per-mission

Kitchen oil, 10 liter bags,
bought in a super market, used as fuel for cars

Co-generation Set 300 kW

small generator 2,5 kW