The preparation of biodiesel from rape seed oil – or other suitable vegetable oils worksheet

Method

Stage 1

1. Weigh *ca* 100 g of rape seed oil into a conical flask.
2. Carefully:
   a) add 15 g of methanol;
   b) then slowly add 1 g of a 50% (50 g per 100 cm^3 of solution) potassium hydroxide solution. Take care, potassium hydroxide is very corrosive.

   Adding the chemicals can be done directly into the conical flask on a top pan balance, zeroing the balance after each addition.

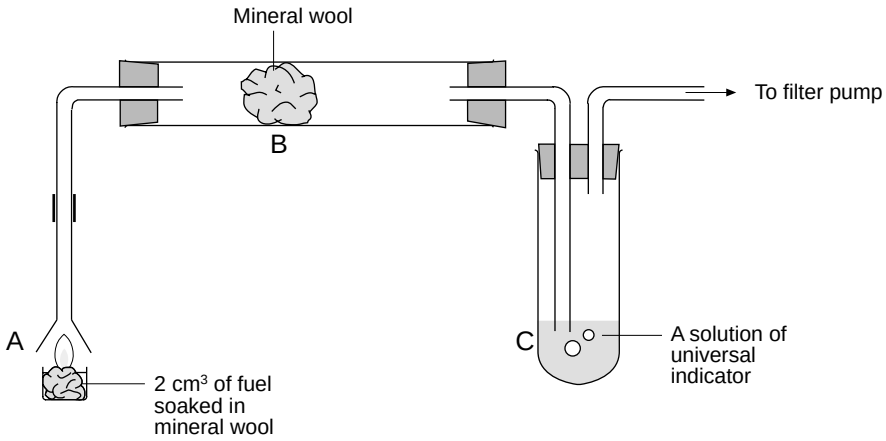
   Stir or swirl for 10 min.

Stage 2

1. Centrifuge the mixture for one minute (you will need several centrifuge tubes to deal with the quantity).
2. Decant off the top layers into a boiling tube and discard the lower layers.
3. Wash the product by adding 10 cm^3 of distilled water to this top layer, with gentle mixing. Do not shake the mixture.
4. Repeat steps 1 and 2 once more.
5. Keep your product for further investigation.

Biodiesel as a fuel worksheet

Set up the apparatus shown below using first biodiesel and then fossil diesel as the fuel.



Burning fuels

Fill in your observations in the table. Record what happens at points A, B and C in the diagram.

	Biodiesel	**Fossil diesel**
A		
B		
C		

Write down your conclusions about differences in flammability, sootiness and acidity.

Extension

Suggest how your observations at B and C could be made quantitative.

Introducing biodiesel information sheets

Alternative Fuels

As the number of petrol- and diesel- powered vehicles on our roads increases, so too does the pollution caused by their exhaust emissions, especially in urban and built up areas.

Increased exhaust emissions are thought to be a factor in environmental problems. These include global warming through increasing carbon dioxide levels in the atmosphere and the formation of acid rain through emissions of sulfur dioxide and nitrogen oxides. The general health of those people living in built up areas may also be suffering.

The fuels we obtain from crude oil – such as petrol and diesel – will eventually run out and the race is on throughout the world to find alternative fuel sources. In Europe most of the interest lies in finding a replacement for *fossil diesel*, (diesel fuel derived from crude oil). It is important that any alternative fuel does not add to the environmental problems. Other alternatives like battery powered vehicles, which do not pollute their immediate environment, are only suitable for short journeys at relatively low speeds.

There are four recognised alternatives for the fossil fuels that we use in our vehicles.

Petrol (gasoline) alternatives	**Diesel alternative**
Methanol Ethanol Compressed natural gas (CNG)	Esterification of vegetable based oils – *eg* rape methyl ester (RME)

The alternatives to petrol – methanol, ethanol and CNG – could also be used to replace diesel, but extensive engine modifications would be needed. The only practical alternative for fossil diesel is *biodiesel* .

An internal combustion engine works by burning fuel in a small chamber. The expansion of the gases produced drives a piston which turns a shaft, which turns the wheels. Petrol engines need a spark to ignite the fuel, whereas diesel engines work by compressing the fuel, which heats it enough to cause ignition. So, the engine construction is different in each case.

A biofuel is a fuel made from a renewable source of growing vegetation. Ethanol, for example, can be produced by fermenting sugar, in which case it is a biofuel. When it is made from crude oil, as most of it is at present, it is not a biofuel.

What is biodiesel?

Biodiesel was first made in the 1940s. It is produced from a renewable source and is designed to replace the diesel used in diesel-powered vehicles.

The term biodiesel describes any biofuel produced from an oil-bearing vegetable feedstock. Biodiesel has been successfully produced from soya oil, sunflower oil, corn oil and rape seed oil but other vegetable oil-bearing crops might also be used. The specification (summary of the relevant properties for use as a fuel) of the biodiesel, varies depending on the feedstock used.

British Biodiesel Ltd uses rape seed oil to produce biodiesel. This is because rape grows well in the UK climate. You may have seen the very bright yellow crop growing in fields in spring and early summer.

The rape is harvested in July, August or September depending on the time of sowing. The collected seed is crushed to extract the rape seed oil, which is then reacted chemically to produce rape methyl ester (RME).

Main stages in biodiesel production

Stage 1 Growth and collection of rape seed

Rape seed is widely grown in the UK with high concentrations around the North East of England. Following recent changes in the European Union agricultural policy, farmers are under pressure to reduce food production through set-aside land. Rape seed is an economical crop that they may grow.

It takes 1 hectare (10 000 m^2, which is slightly less than the size of a football pitch) of land to grow enough rape to produce three tonnes (3000 kg) of rape seed.

Set-aside land is land for which farmers are paid by the government to stop them from growing on it particular crops for food. This means that they may grow food crops as long as the end use is not food!

Stage 2 Extraction of rape seed oil

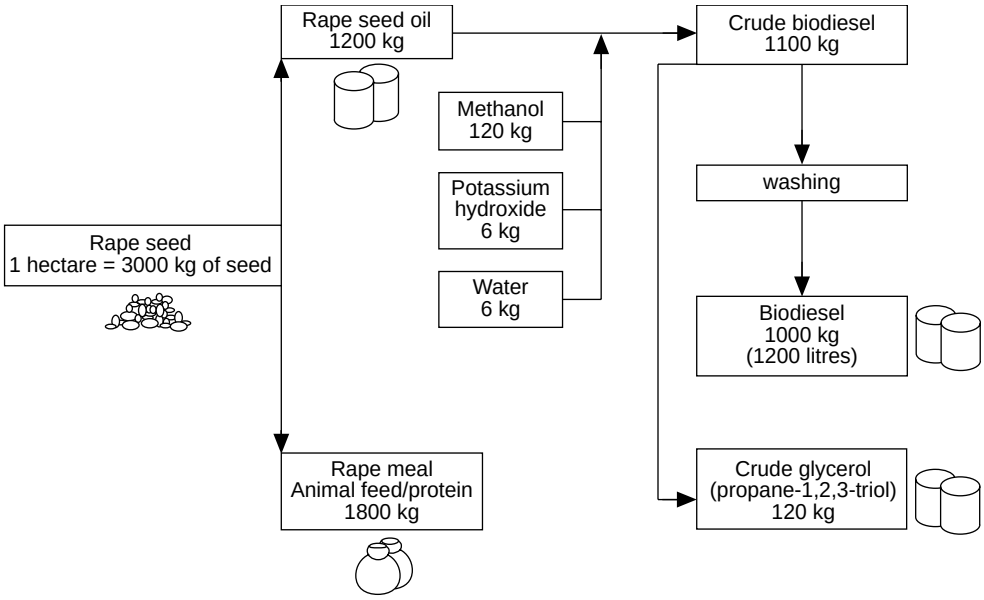
The collected rape seed is crushed to extract rape seed oil. A by-product of this process is rape meal, a high protein animal feed. Rape meal could eventually replace imported soya bean-based animal feed.

From every hectare of rape harvested, about 1.2 tonnes of rape seed oil is extracted and 1.8 tonnes of animal feed produced. Approximately 1200 litres of biodiesel can be produced from the rape seed oil.

Stage 3 Production of rape methyl ester (biodiesel)

The final stage in the production of biodiesel involves a chemical change. This is called transesterification. Using potassium hydroxide as a catalyst, the rape seed oil is reacted with methanol (a type of alcohol) to produce biodiesel and glycerol (propane-1,2,3-triol). Glycerol is a valuable by-product. It is used in the motor industry as antifreeze and is refined for use in the pharmaceutical industry.

A catalyst speeds up a reaction without being used up.



Flow chart showing the stages of biodiesel production (with approximate quantities)

The history of biofuels

Although biodiesel may be a relatively new form of energy, biofuels have existed since the early 1900s. In 1914 Brazil successfully used ethanol manufactured from sugar cane, and in the past 20 years over 50% of the cars in Brazil have been running on an ethanol/petroleum mix.

The first diesel substitutes made from vegetable oils were produced in the US in the early 1950s.

Tests on exhaust emissions of vehicles using blends of biodiesel and fossil diesel in the ratio of 20:80 (biodiesel:fossil diesel) showed that particulate matter (smoke or soot), carbon monoxide levels and the total hydrocarbon levels were all significantly lower compared to those from fossil diesel. Biodiesel (made from soya oil) is used in most of the US.

The use of biofuels in Europe grew as the price of fossil diesel rose in the 1970s.

In France, biodiesel (based on sunflower oil) is available at the pump as a blend of 5% biodiesel with 95% fossil diesel At the moment there is no tax on biofuels.

In Italy, biodiesel is also produced from sunflower oil, as the crop is widely grown there.

Austria has been heavily involved in the production of biodiesel from rape seed oil for over 10 years and has produced the most extensive studies on rape methyl ester (RME). Although the chemistry of biodiesel based on sunflower oil is essentially the same as biodiesel based on rape seed oil, its specification is slightly different.

In the UK, British Biodiesel Ltd uses rape seed oil to produce biodiesel.

British Biodiesel Ltd

In January 1993 the East Durham Biodiesel working group was set up by a group of farmers to start the British Biodiesel industry.

In early 1994 the group formed a successful association with three other North East based companies to bring together representatives from the farming and the chemical industries. The three companies were approached for their specialist skills in the areas of seed collection, crushing and transesterification – the name for the chemical process that changes the rape seed oil to biodiesel.

The three company association consists of:

Farmway, Darlington a farmers cooperative involved with the farming and harvesting of rape;

Unitrition, Selby a specialised seed crushing company; and

Chemoxy International, Middlesbrough, a chemical manufacturer with the facilities for transesterification.

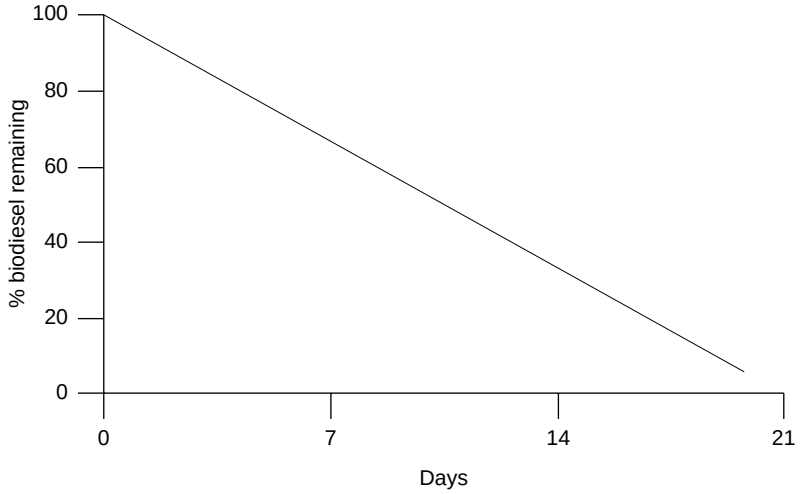
An increasing number of UK companies now use biodiesel.

Ecostatistics of UK biodiesel compared with fossil diesel

Soot and particulate emissions	Reduced by an average of 40%
Hydrocarbon and aromatic* emissions	Reduced by 63%
Sulfur content	Significantly less
Carbon dioxide	Little change
Carbon monoxide	Significantly less
NO_x emissions	Slightly lower
Toxicity	Over 100 times less toxic. Oral (by mouth) and dermal (through the skin) LD_{50}s both exceed 2 g/kg
Biodegradability	Much better, more than 95% biodegrading in 21 days compared with around 50% for diesel. So in an accidental spill, the biodiesel would be digested by bacteria much faster than fossil diesel.

*Aromatic compounds are related to benzene, and can be harmful

LD_{50} stands for lethal dose 50 and is the dose which would kill 50% of a test population of organisms. The larger the number the safer the substance. For example, if biodiesel were spilled in a river, it would take a dose of more than 2 g for each 1 kg of fish, for half the fish population to die. This would compare with half the population of fish being killed off with a dose of fossil diesel of as little as 1/100 to 1/200 g/kg.



Biodegradability

Specifications

The following table compares some relevant properties of the specification for fossil diesel with those of the specification for a biodiesel.

Property	Fossil diesel	Biodiesel
Cetane index*	46–49	49
Density (g/cm^3)	0.820–0.860	0.860–0.890
Viscosity† (mm^2/s)	2.00–4.50	3.50–5.00
Flash point§ (ºC)	55	100
Water content (mg/kg)	200	500 max
Sulphur content (% wt)	0.20	0.01 max
Particulates (g/m^3)	24	20 max
Calorific value (MJ/l)	35–36	33–34
Toxicity	high	low
Biodegradability	50% /21 days	95% /21 days

***** The cetane rating is comparable to the octane rating that is used for petrol. Basically, the larger the number the more evenly the fuel burns in the engine.
†Viscosity measures how treacly the oil is. The larger the number, the slower is the flow.
§ The flash point is the temperature at which the fuel will self-ignite.

Replacement of fossil diesel with biodiesel in the UK

Biodiesel can be used as a replacement for fossil diesel without any engine modifications. Current users have noticed significant reductions in exhaust emissions and a general cleaner running performance with no detrimental effect or loss of acceleration.

British Biodiesel Ltd does not intend to compete with the fossil diesel made by the large petroleum refiners and so biodiesel will not be available to the general public for use in private cars. It will be sold where its ecological advantages are most useful. For example, the use of biodiesel on waterways for leisure craft and barges would reduce the effects caused by spillages of fossil diesel as it is so quickly broken down (95% in 21 days). Urban and inner city areas would significantly benefit from using biodiesel in buses and taxis. Other possible markets include the use of biodiesel in enclosed areas with the use of heavy plant equipment, fork lift trucks and off-shore work.

Even if every arable acre in the UK were to grow rape, it would still only produce between 7 and 10% of our requirements for diesel.

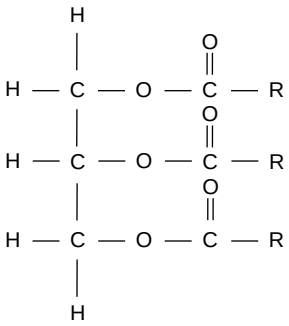
Costs

	Fossil Diesel pence /l	Biodiesel pence /l
Production prices	7.70	38.00
Distribution	6.57	3.94
Excise	30.70	30.74
	44.97	**72.64**
+ VAT @ 17.5%	7.87	12.71
	52.84	**85.35**
+ Retailer's mark up	4.14	4.14
Total	**56.98**	**89.49**

A comparison of fossil diesel and biodiesel retail price 1995

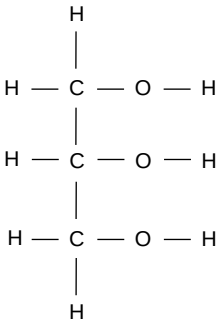
The chemistry of biodiesel production

All vegetable oils are large molecules with the following general form.

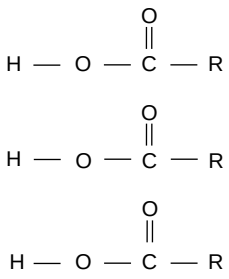


(R is a long chain hydrocarbon. The three R groups may be the same or different).

They have three molecules of long chain fatty acids and are known as triglycerides, because the stem is glycerol (propane -1,2,3-triol).



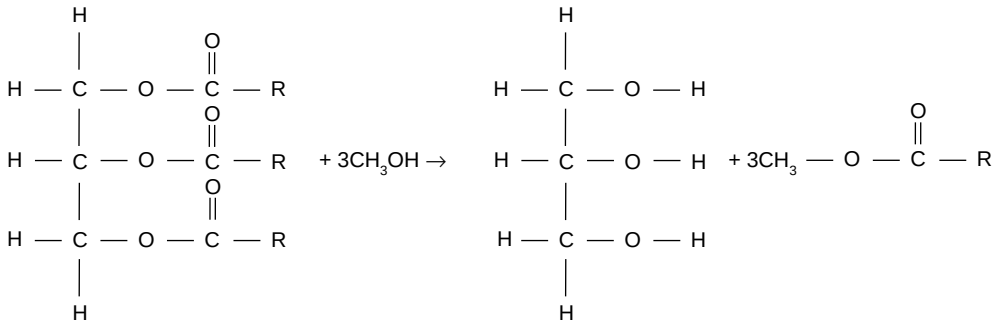
Glycerol



Fatty acids

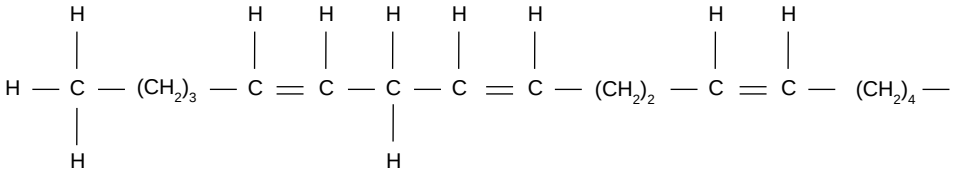
Vegetable oils are *esters* of glycerol and fatty acids. They are called glyceride esters. There are many different fatty acids with different hydrocarbon chain lengths and degrees of unsaturation (number of carbon–carbon double bonds). The compositions of different oils (*eg* rape, olive, sunflower *etc*) and of individual types of oil from crops grown in different areas of the world are different and provide a means of identifying the source of the oil.

Biodiesel is produced by turning the glycerol esters into methyl esters. This is done by mixing the oil with an excess of methanol in the presence of potassium hydroxide (used as the catalyst). Methanol displaces glycerol which is then separated from the resulting methyl esters.



Glycerol ester | Methanol | Glycerol | Methyl ester (biodiesel)

For rape seed oil, one possibility for R is:



although there are others.

Biodiesel and the environment

Use the booklet *Introducing biodiesel* to answer the following questions.

1. What is a biofuel?
2. What is biodiesel?
3. What is a feedstock, and what are the feedstocks for biodiesel?
4. What is meant by set-aside land?
5. Where is biodiesel used at present?
6. Pick two advantages of replacing fossil diesel with biodiesel. For each of your advantages, say where the use might be particularly important. Explain your answer.
7. a) Explain why biodiesel cannot completely replace fossil diesel.

   b) How many miles could a lorry with a diesel consumption of 8 km/l travel on the biodiesel from a year's production from a field of rape of area one hectare?
8. Look at the 1995 prices of diesel and biodiesel. Suggest how biodiesel may be made more similar in price to diesel.
9. Use the graph *Biodegradability* to estimate what percentage of biodiesel would remain in the environment after

   a) 7 days, and

   b) 14 days?

Biodiesel – will you produce it? worksheet

Biodiesel is a fuel. Your company has to decide whether it would be good for the firm to produce large quantities of biodiesel fuel.

There are 20 facts to help your company decide the best thing to do. Your teacher will tell you how many facts you are allowed to collect.

You will be given a fact card and you then decide the next piece of information to collect by choosing one of the words in italics.

Fill in and use the summary sheet provided to gather all the facts together.

Once you have collected enough facts, your group has to produce a two minute presentation of its findings to the rest of the class. The following points should be answered in your presentation:

- whether you will produce the biodiesel or not;
- why you made this decision; and
- if anything might make you change your mind.

Summary sheet

Fact		Keypoints
1 .	Biodiesel	
2.	Government influences	
3.	Rape	
4.	Chemical change	
5.	Uses	
6.	Chemical companies	
7.	Cost	
8.	Other European countries	
9.	Future	
10.	Fuel	
11.	Problems with biodiesel	
12.	Environment	
13.	Ordinary diesel	
14.	Scale	
15.	Cash crops	
16.	Renewable	
17.	More land	
18.	Alternatives	
19.	Diesel and water	
20.	Biodegradability	

Fact cards

Photocopy these facts onto separate pieces of card

Biodiesel

FACT NUMBER 1

Biodiesel is a fuel that can be made from a plant called *rape*. The seeds of the rape plant are similar in many ways to sunflower seeds. Biodiesel could be the fuel of the *future*. It may solve many *environmental problems*.

Government influences

FACT NUMBER 2

In 1995 the government taxed *biodiesel* at the same level as *ordinary diesel*. This added about 31p to the price per litre of biodiesel. In other European countries there is often less tax on biodiesel. The situation may change in the *future*.

Rape

FACT NUMBER 3

Rape plants are grown by farmers as a *cash crop* often on set-aside land. This is land for which the government pays farmers not to grow certain food crops.The seeds are gathered and *chemically changed* into biodiesel. Around 1.5 million tonnes of rape is grown in the UK though more is grown in many other *European countries*.

Chemical change

FACT NUMBER 4

The production of *biodiesel* involves farmers, *chemical companies* and customers. The farmers grow the rape seed and sell it to the chemical companies. The companies then produce the biodiesel by a chemical reaction which is fairly cheap and straightforward and gives a good yield. There are many *uses of biodiesel*.

Fact cards

Uses

FACT NUMBER 5

As a fuel, biodiesel is renewable and the *environmental facts* about biodiesel are interesting. The table gives more information about the energy content in biodiesel. It is interesting to compare biodiesel with *ordinary diesel*.

Fuel	Energy content	Efficiency
Biodiesel	34 MJ/l	40.7%

Biodiesel has many suitable markets where it would be particularly useful. These include national parks, theme parks, off-shore equipment, inner city buses and inland waterways.

Chemical companies

FACT NUMBER 6

As the chemical company you will have to *chemically change* the *rape* seed. Find out

- *how much it costs* to produce;
- the *uses* of biodiesel; and
- if there are any *problems associated with biodiesel*.

Cost

FACT NUMBER 7

The cost of one litre of biodiesel in 1995 was about 89p.
The cost is made up of:

- seeds;
- extraction of the oil;
- transport;
- *chemically changing* the *rape* seed;
- *government influences*; and
- other factors.

Other European countries

FACT NUMBER 8

In other European countries the *government influence* is often positive; the tax on *biodiesel* is low and the governments encourage *rape* seed production because biodiesel has *environmental advantages*.

Fact cards

Future

FACT NUMBER 9

In the future many things might change:

- if the *government* changes the tax rate on biodiesel it should make the price of one litre more competitive;
- if the UK follows the example of other *European countries* which have lower taxes on biodiesel, it could have marked results for biodiesel production;
- if there is a war in any of the fossil fuel-producing countries the need for biodiesel as a fuel might increase; and
- if biodiesel were to be made on a larger *scale*.

Fuel

FACT NUMBER 10

Fuels are store-houses of energy. When fuels burn in plenty of oxygen they normally make carbon dioxide and water along with lots of heat. Some fuels are *renewable*. If the fuel does not burn completely some dangerous gases may be produced which affect the *environment*.

Problems with biodiesel

FACT NUMBER 1 1

There are problems associated with biodiesel – *eg*:

- *rape* pollen may cause hay fever in some people;
- *diesel and water* do not mix;
- some people think that burning *biodiesel* gives off a smell rather like a chip shop;
- *chemically changing* the rape seed is expensive;
- growing rape requires a large scale use of land; and
- with biodiesel there is a slight increase in some *environmental* pollutants.

There are some *alternatives* to biodiesel.

Environment

FACT NUMBER 12

A green fuel is an environmentally friendly fuel, *ie* it causes little damage to the environment. Biodiesel compares very well with *ordinary diesel*. It is a renewable fuel and quickly *biodegrades*.
The following table compares the exhaust emissions from ordinary diesel and those from biodiesel.

	Ordinary diesel	Biodiesel
Nitrogen oxides	100	94.1
Carbon monoxide	100	65.4
Hydrocarbons	100	69.1
Carbon dioxide	100	100.3
Smoke	100	59

Fact cards

Ordinary diesel

FACT NUMBER 13

Fossil diesel (ordinary diesel) was formed from partially decayed organisms that used to live in warm oceans millions of years ago. The organisms died, fell to the ocean bed in deep layers, were covered in mud, squashed and heated and eventually changed into crude oil. Ordinary diesel can be separated from crude oil by fractional distillation.

Ordinary diesel is a non-*renewable fuel* and there are some worries about it causing *environmental problems*. The table tells you some more about the energy in ordinary diesel.

Fuel	Energy content	Efficiency
Ordinary diesel	36 MJ/l	38.2%

Scale

FACT NUMBER 14

If the scale of *biodiesel* production could be increased, larger quantities could be made; it is cheaper to make a lot of a product than to make a small amount. This means that *more land* would be used for growing *rape* seed. A producer must be able to guarantee a supply of biodiesel to customers or they will not risk buying the biodiesel in the first place. It depends on what happens in the *future*.

Cash crops

FACT NUMBER 15

The plants that farmers grow for money are called cash crops. For farmers to grow more *rape* seed the *government influences* must be right.There must also be a *chemical company* to buy the rape seed so that the crop is profitable.

Renewable

FACT NUMBER 16

Fossil *fuels* such as oil and coal take millions of years to form. This means that when we use the fuels they will not be replaced for millions of years. We call these fuels non-renewable. Biodiesel is a renewable fuel because it only takes a few months for the seeds to grow and the seeds can then be *chemically changed* into the fuel.

Fact cards

More land

FACT NUMBER 17

The amount of biodiesel that can be made in the UK is limited and it is not intended to compete with the main markets of *ordinary diesel*. Biodiesel requires a lot of land (1 hectare of rape produces 1200 litres of biodiesel), so to have enough biodiesel to run all the diesel engines in the UK would be impossible. The main areas for biodiesel *use* are decided by the environmental factors and the by-products of *chemicallly changing* the rape seed.

Alternatives

FACT NUMBER 18

Alternatives to biodiesel include:

- using sugar cane to produce alcohol;
- continued use of *ordinary diesel*;
- splitting water to make hydrogen gas;
- using battery-powered engines; and
- using compressed natural gas (a fossil *fuel*).

Each of the alternatives has advantages and disadvantages. Factors like *cost*, availability, technology, demand and pollution levels need to be considered.

Diesel and water

FACT NUMBER 19

Diesel and water do not mix, so both spilt biodiesel and *ordinary diesel* form a thin layer on water through which no oxygen can pass. When diesel spills into water it can cause many problems – *eg*:

- fish die due to lack of oxygen;
- plants die due to lack of air; and
- birds can get covered in diesel and die due to poisoning and cold.

It takes time for the spilt diesel to break down naturally and we describe this as its *biodegradability*.

Biodegradability

FACT NUMBER 20

The biodegradability of a *fuel* describes how long it takes to be broken down by bacteria in the environment. Spilled oil can cause problems so the faster it biodegrades the better. Twenty-one days after spilling ordinary diesel, 50% still remains, 21 days after spilling biodiesel, less than 5% still remains. These results may explain some of the proposed *uses* for biodiesel.