Chem Factsheet

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Biofuel Synthesis

To succeed in this topic you need to:

- Be familiar with simple organic structures such as alcohols and esters
- Be familiar with the process of distillation
- Be familiar with the Greenhouse Effect

After working through this Factsheet you will:

- Be aware of the different types of Biofuel
- Know the raw materials and methods of production of some Biofuels
- Know the applications of different Biofuels
- Be aware of the key issues related to the use of Biofuels as alternatives to Fossil Fuels

Introduction

Biofuels are energy sources produced from living matter; usually plants. They are renewable energy sources, as the plants can be regrown. One way of classifying Biofuels is as '1st Generation' or '2nd Generation'. 1st Generation Biofuels are those currently available, which are derived from crops that would otherwise be used as food crops, while 2nd Generation Biofuels are those produced by utilising the whole plant rather than just the sugar/oil component of the food crop. The main impetus behind the development of 2nd Generation Biofuels is that they avoid the 'food vs fuel' controversy discussed below.

Biofuels are receiving growing attention due to the various demands for a change to a low-carbon economy, as they can potentially be carbon-neutral. This is because the CO_2 given off during combustion is matched by the CO_2 absorbed during photosynthesis while the plants are growing. However, this balance is often not as simple as that, and this is discussed in more detail below.

The simplest example of a Biofuel is wood that can be burned to generate heat. However, our main consideration here will be with bioethanol, biodiesel and biogas.

Bioethanol

Bioethanol is ethanol that is produced from plant sources of carbohydrates. Examples include corn, sugar cane, sugar beet, cornstalks and vegetable waste.

1st Generation sources of ethanol, such as sugar beet/cane or corn, are processed to extract the sugars, e.g., glucose, which are then fermented to produce ethanol. The ethanol produced can then be separated and further purified by distillation.

$$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

The above reaction equation summarises the fermentation process which requires yeast, anaerobic conditions and a temperature of about 30 °C.

Advantages of bioethanol	Disadvantages of bioethanol
• Cheap to produce on an industrial scale	• Costs five times as much to produce as petrol
• Easy to store and distribute as a liquid	• Slow rate of production
• Theoretically carbon neutral	• Requires large areas of agricultural land or woodland
• Combustion only produces CO_2 and H_2O with no pollutants such as SO_2	• Farmers may switch from growing food crops – raising food prices and possibly causing food shortages
• Increases octane rating of fuels when mixed with petroleum-derived compounds.	• Burning is fast compared with rate of plant growth, which affects the 'carbon neutral' argument
	• High energy demand for distillation – and not carbon neutral if this energy is derived from fossil fuels.
	• Car engines need modifications

If 2nd Generation sources, such as cornstalks or vegetable waste are used, then, due to the high cellulose content, fermentation with a genetically modified form of *E. coli* can be used instead of yeast fermentation. The optimum conditions for this process are 35 °C and pH 6 and the key advantage over 1st Generation ethanol is that it does not involve competition for land use with food crops.

As it uses waste, that would otherwise be thrown away and decompose, it also reduces the production of CH_4 from decomposition (and CH_4 is a much more potent greenhouse gas than CO_2). The downside is that the amount of waste biomass material available is relatively small so there may be a limit on the large scale production of ethanol by this method.

The main use of bioethanol is as a fuel for cars, mixed with petrol. Almost all petrol used in the USA now contains 10% ethanol while, in the UK, up to 5% of ethanol can be blended with petrol without any requirements for labelling. Such use in the UK will be essential if the UK is to meet the requirements of the EU Renewable Energy Directive, which has set a target of 10% of energy to be from renewable sources by 2020.

Biodiesel

Biodiesel is produced from plant oils or animal fats by a process known as re-esterification or transesterification.

Fats and oils are glycerol esters of long-chain fatty acids. Their general structure can be represented as **Figure 1a**.

Transesterification involves reacting the oil or fat with methanol, in the presence of a base catalyst and can be represented as **Figure 1b**.

Figure 1a:

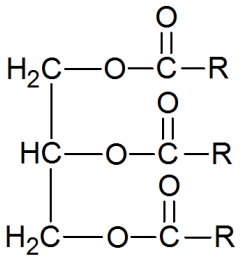
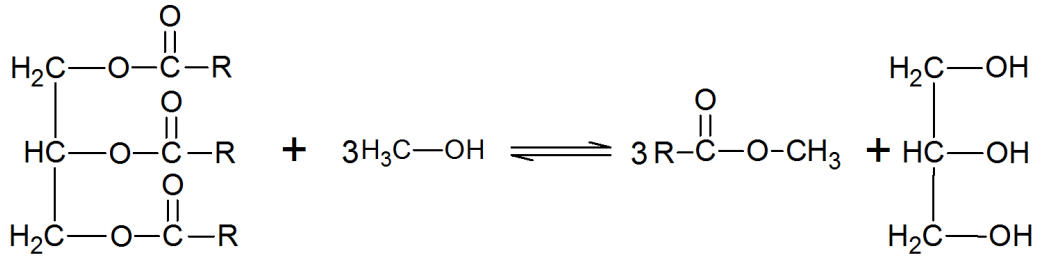


Figure 1b:



The methyl esters produced by this process can either be used directly as biodiesel or mixed with 'normal' diesel. One of the main purposes of transesterification is to reduce the viscosity and lower the melting point of the fuel so that it is more compatible with car engines and flow systems. Vegetable oils are too viscous and freeze at relatively high temperatures (those that a car fuel tank could be exposed to). Untreated oil cannot flow into the cylinders quickly enough to be an effective fuel and on a very cold day the oil may freeze solid in the tank, pipes and engine. The esters produced as a result of transesterification have a much lower molecular mass and consequently weaker intermolecular forces that yield a fuel with lower viscosity and melting point.

Theoretically biodiesel is 'carbon-neutral' and it has the significant advantage of being biodegradable. However, it is expensive to produce and can also lead to 'food vs fuel' problems if farmers switch from food crop production to growing crops to produce oils for biodiesel.

A 2nd generation approach to biodiesel involves the use of recycled cooking oils, but the main problem here is that supply will never be sufficient to allow for a replacement of conventional sources of diesel.

Biogas

Biogas (mainly methane and carbon dioxide) is a by-product of the anaerobic decomposition of plant and animal waste such as that which occurs in landfill sites and waste-treatment facilities, as well as in purpose-built 'digesters'.

An overall equation for the production of biogas (via a series of more complex reactions) is: $C_6H_{12}O_6(aq) \rightarrow 3CO_2(g) + 3CH_4(g)$

The contribution that these gases make to the Greenhouse Effect and Climate Change creates an excellent incentive to prevent them escaping into the atmosphere, but the scale on which it is captured and used is not as great as perhaps it should be.

Biogas can be used as a fuel in small scale electricity generating plants and is also a potential vehicle fuel. A significant advantage of biogas is that its raw material is the waste from other processes such that it avoids the negative implications of the 'food vs fuel' argument.

'Food vs Fuel'

This is a very complex situation, but the basic concern is that (partly due to the availability of government subsidies) farmers might switch the use of their acreage to growing crops for the production of biofuels (principally corn, for ethanol production). This would reduce the acreage used for the production of food crops, so reducing supply and raising prices – and leading to possible food shortages.

Even if non-food crops are used for biofuel production their growth could still reduce land available for growing food crops.

It is this argument that makes the idea of 2nd Generation sources of raw materials so attractive.

An example of how this situation is more complicated than it may at first appear is the fact that, in the USA, a by-product of the production of bioethanol from corn is large quantities of animal feed.

Carbon Neutral Fuels?

Biofuels are often described as carbon neutral on the grounds that the CO_2 given off when the fuel is burned is balanced by the CO_2 absorbed during photosynthesis while the original crop is growing.

For example, for bioethanol, a series of equations can be used to illustrate this balance.

Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Fermentation: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Combustion: $2C_2H_5OH + 6O_2 \rightarrow 4CO_2 + 6H_2O$

So, overall, per mole of glucose, 6 moles of CO_2 are absorbed during photosynthesis and a total of 6 moles of CO_2 are evolved during fermentation (2 moles) and combustion (4 moles).

However, what this does not take into account are any other fuel 'costs' during the growing and manufacturing processes such as transportation, electricity usage, etc. Additionally, if grassland is ploughed to allow for the planting of crops, then this process in itself releases significant amounts of CO_2. Fossil fuels are also used in the production of fertilisers used on the growing crops. Overall the balance is not as straightforward as suggested by the equations.

A combination of low-carbon, renewable energy sources such as solar and wind power alongside sustainable and renewable biofuels would make for an attractive and environmentally sound approach for future generations.

Questions

1. Read the passage below about Gasohol.

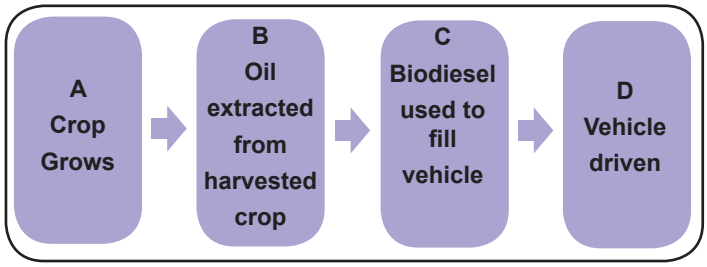
> Brazil is now 'growing' its own fuel for cars. It is growing sugar cane to produce ethanol. This is mixed with petrol to make a fuel called Gasohol. In Brazil, Gasohol contains 25% ethanol. Burning Gasohol releases carbon dioxide into the atmosphere, but it releases much less nitrogen oxide. To grow sugar cane for fuel, Brazil has cleared large areas of rainforest.

Is using Gasohol better or worse for the environment than using petrol?

Use information from the passage and your own knowledge and understanding to explain the reasons for your answer. (4)

2. Biodiesel is an alternative to diesel obtained from fossil fuels. It can be made from plant oils and burned in normal diesel engines.

Figure 2 The production of biodiesel from plant material



(a) (i) Where does the energy for growth of the crop come from? (1)
(ii) What has happened to this energy during stage D? (1)
(iii) Why is biodiesel a renewable fuel? (1)

(b) Biodiesel can be thought of as 'carbon neutral' because the carbon dioxide released when it burns does not result in an overall increase in the amount of carbon dioxide in the atmosphere.
(i) At which stage in Figure 1 is carbon dioxide removed from the air? (1)
(ii) What happens to the carbon in the carbon dioxide when it is removed from the air? (1)

(c) Discuss the advantages and disadvantages of the use of biofuel as a way of reducing Britain's greenhouse gas emissions from transport.

Compare the use of biofuel to at least one other way of reducing greenhouse gas emissions. (6)

Total 11 marks

Answers

1. (better)
less nitrogen oxides released (1)
less use of petrol / non-renewable resource (1)
can grow energy source (1)
CO_2 released is equivalent to that taken in by plants (1)

2. (a) (i) Sun/photosynthesis (1)
(ii) converted to heat (in the vehicle and surroundings)
converted to kinetic energy
energy transferred to environment (1)
(iii) more plants can be produced in short time /plants can be replaced (1)

(b) (i) A (1)
(ii) It ends up as plant chemicals (e.g. sugars or starch) (1)

(c) **Advantages of biodiesel**
- good short term solution/ can use existing vehicles
- conserves fossil fuel/ renewable
- less reliance on imports
- improves farm income

Disadvantages
- does not reduce other exhaust pollutants/example
- land use/monoculture
- will still need to be imported if a high proportion of total

Comparisons
- cheaper than hydrogen /electric car/ photovoltaic
- more expensive than hybrid
- hydrogen fuel less polluting
- example of other renewable
- encourage energy saving/ reduce use of fuel for transport/ example of any energy saving measure

Many other points that relate to ways of reducing CO_2 emissions would be accepted

no marks for discussion of need to reduce CO_2 (6)

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