International resource costs of biodiesel and bioethanol

Contents

Executive Summary

AEA Technology was commissioned to investigate international resource costs for biodiesel and bioethanol by the Department for Transport. This short study has looked at a range of possible feedstocks, processing routes and distribution options for biodiesel and bioethanol in both 2002 and 2020, including some routes where intermediate products are imported to the UK and processed here (see Tables A and B below). The production of biofuels from UK has not been addressed. Instead the study has focused on other European Union sources and those regions of the world which may be able to produce bioethanol and/or biodiesel for export at a competitive price due to advantageous growing conditions or cheap labour costs, i.e.:

- EU countries for biodiesel from oil seeds and for bioethanol from wood, straw, wheat or corn.
- North America for biodiesel from oil seeds and for bioethanol from wood, straw, wheat or corn.
- South America for bioethanol from sugar cane.
- Eastern Europe for bioethanol from wood, straw, wheat or corn.

Table A: Fuel pathways considered for both 2002 and 2020

Option	Fuel type	Raw material	Processing overseas	Processing in UK
1	Biodiesel	Oil seeds	Esterification	-
2	Biodiesel	Oil seeds	-	Esterification
3	Bioethanol	Wood	Acid hydrolysis + fermentation	-
4	Bioethanol	Straw	Acid hydrolysis + fermentation	-
5	Bioethanol	Wheat	Malting + fermentation	-
6	Bioethanol	Corn	Fermentation	
7	Bioethanol	Sugar cane	Fermentation	-
8	Bioethanol	Sugar cane	-	Fermentation
9	Bioethanol	Sugar beet	Fermentation	-

Table B: Additional fuel pathways considered for 2020

Option	Fuel type	Raw material	Processing overseas	Processing in UK
10	Biodiesel	Wood	Gasification + Fischer-Tropsch	-
11	Biodiesel	Straw	Gasification + Fischer-Tropsch	-

12	Bioethanol	Wood	Enzymic hydrolysis + fermentation	-
13	Bioethanol	Straw	Enzymic hydrolysis + fermentation	-

Tables C and D show estimated resource costs in £/GJ and pence/litre respectively for each pathway for 2002, where resource costs are defined as the costs before taxation of liquid transport fuels delivered to the car driver at a UK filling station. They therefore include costs associated with raw materials, processing, distribution and supply of fuels, and take account of any income from the sale of co-products.

Figure A shows these same resource costs in £/GJ and compares them with pre-tax costs for petrol and diesel.

Table C: Estimated resource costs for 2002 in £/GJ

Option &	Feedstock	Source	Costs, £/GJ		
Fuel type			Product	Fuel type	
1. Biodiesel	Oil seeds	US	9.86	1. Biodiesel	Oil seeds
		EU15	12.22		
2. Biodiesel	Oil seeds - UK production	US	9.86	2. Biodiesel	Oil seeds - UK production
		EU15	12.22		
3. Bioethanol	Wood - Acid hydrolysis	US	10.18	3. Bioethanol	Wood - Acid hydrolysis
4. Bioethanol	Straw - Acid hydrolysis	EU15	19.52	4. Bioethanol	Straw - Acid hydrolysis
5. Bioethanol	Wheat	EU15	14.20	5. Bioethanol	Wheat
6. Bioethanol	Corn	US	7.41	6. Bioethanol	Corn
7. Bioethanol	Sugar cane	Brazil	5.98	7. Bioethanol	Sugar cane
8. Bioethanol	Sugar cane - UK production	Brazil	20.75	8. Bioethanol	Sugar cane - UK production
9. Bioethanol	Sugar beet	EU15	16.16	9. Bioethanol	Sugar beet

Table D: Estimated resource costs for 2002 in pence/litre

Option &	Feedstock	Source	Costs, p/litre		
Fuel type			Product	Fuel type	
1. Biodiesel	Oil seeds	US	33.24	1. Biodiesel	Oil seeds
		EU15	41.19		
2. Biodiesel	Oil seeds - UK production	US	33.24	2. Biodiesel	Oil seeds - UK production
		EU15	41.19		
3. Bioethanol	Wood - Acid hydrolysis	US	21.45	3. Bioethanol	Wood - Acid hydrolysis
4. Bioethanol	Straw - Acid hydrolysis	EU15	41.12	4. Bioethanol	Straw - Acid hydrolysis
5. Bioethanol	Wheat	EU15	29.91	5. Bioethanol	Wheat
6. Bioethanol	Corn	US	15.61	6. Bioethanol	Corn

7. Bioethanol	Sugar cane	Brazil	12.60	7. Bioethanol	Sugar cane
8. Bioethanol	Sugar cane - UK production	Brazil	43.71	8. Bioethanol	Sugar cane - UK production
9. Bioethanol	Sugar beet	EU15	34.04	9. Bioethanol	Sugar beet

Costs are expected to fall by 2020 due to improvements in process efficiencies and the development of new process options. Resource costs for 2020 are shown in Table E below.

Table E: Estimated resource costs for 2020 in £/GJ

Option &	**Feedstock**	**Resource Cost £/GJ**			
Fuel type		**US**	**Fuel type**		**US**
1. Biodiesel	Oil seeds	10.72	1. Biodiesel	Oil seeds	10.72
2. Biodiesel	Oil seeds - UK production	11.58	2. Biodiesel	Oil seeds - UK production	11.58
3. Bioethanol	Wood - Acid hydrolysis	11.49	3. Bioethanol	Wood - Acid hydrolysis	11.49
4. Bioethanol	Straw - Acid hydrolysis	20.00	4. Bioethanol	Straw - Acid hydrolysis	20.00
5. Bioethanol	Wheat	14.17	5. Bioethanol	Wheat	14.17
6. Bioethanol	Corn	8.15	6. Bioethanol	Corn	8.15
7. Bioethanol	Sugar cane	7.88	7. Bioethanol	Sugar cane	7.88
8. Bioethanol	Sugar cane - UK production	27.82	8. Bioethanol	Sugar cane - UK production	27.82
9. Bioethanol	Sugar beet	16.95	9. Bioethanol	Sugar beet	16.95
10. Biodiesel	Wood - FT processing	6.49	10. Biodiesel	Wood - FT processing	6.49
11. Biodiesel	Straw - FT processing	6.49	11. Biodiesel	Straw - FT processing	6.49
12. Bioethanol	Wood - Enzymic hydrolysis	10.18	12. Bioethanol	Wood - Enzymic hydrolysis	10.18
13. Bioethanol	Straw - Enzymic hydrolysis	10.18	13. Bioethanol	Straw - Enzymic hydrolysis	10.18

The following conclusions can be drawn from the above results, from sensitivity analyses and from a brief review of wider issues such as land availability and agricultural policy.

1. Currently, the lowest cost routes are to produce bioethanol from US corn or Brazilian sugar cane and to produce biodiesel from oil seeds in the US. Process options which involve the importation of intermediate products (oil seeds or sugar concentrate) prior to processing in the UK are less cost-effective.

2. None of the biofuel options addressed in this study are currently cost competitive with petrol or diesel on a pre-tax £/GJ basis. The lowest cost biofuel, bioethanol from Brazilian sugar cane, is about 40% more expensive than gasoline on an energy basis.

3. By 2020, minimum costs of bioethanol are expected to fall by about 10% compared to 2002 values while biodiesel costs could fall by nearly 50% due to the development of a new process route based on Fischer-Tropsch technology.

4. Resource costs are sensitive to changes in feedstock cost, processing cost and co-product value. For example, for bioethanol production from corn a 10% change in each of these parameters is estimated to lead to changes of 8.4%, 4.4% and 4.4% respectively in the resource cost of ethanol produced.

5. There are considerable uncertainties in the resource cost estimates and a more detailed, location-specific engineering study would be required to get a full understanding of the cost components for any particular process route.

6. Import tariffs, which are not included in resource costs, would affect the cost of biodiesel imported from outside the EU, but only by about 5%. No import tariffs are applicable for bioethanol at present.

7. Estimated resource costs inherently include subsidies for the production of agricultural crops, although they exclude subsidies on biofuel sales. The Common Agriculture Policy is currently being reviewed and agricultural subsidies are likely to reduce in future, thus increasing feedstock costs for many of the biofuel options considered in this report.

8. Estimated resource costs are based on the current availability of land for growing energy crops and current markets for co-products. If biofuel production is increased then this will put additional pressures on land availability, which could force prices up. Markets for co-products such as animal feeds could also become less valuable as a result of additional biofuel production.

The study team would like to thank the many stakeholders, listed in Appendix A, who provided an invaluable input to this study.

Introduction

AEA Technology was commissioned to investigate international resource costs for biodiesel and bioethanol by the Department for Transport. This study has looked at a range of possible feedstocks, processing routes and distribution options for biodiesel and bioethanol, including some routes where intermediate products are imported to the UK and processed here. The production of biofuels from UK has not been addressed in this study. Instead it has focused on other European Union (EU) sources and those regions of the world which may be able to produce bioethanol and/or biodiesel for export at a competitive price due to advantageous growing conditions or cheap labour costs, i.e.:

- EU countries for biodiesel from oil seeds and for bioethanol from wood, straw, wheat or corn.
- North America for biodiesel from oil seeds and for bioethanol from wood, straw, wheat or corn.
- South America for bioethanol from sugar cane.
- Eastern Europe for bioethanol from wood, straw, wheat or corn.

Other regions of the world such as Africa, South-East Asia and China are also suitable for growing these crops but biofuels production is not so well established there. These regions may offer marginally lower raw material and processing costs in the longer term, perhaps offset by higher costs for transporting the products to the UK.

1.1 Study methodology

Information gathering was carried out over a 6 week period in January/February 2003. Information was obtained from a wide range of literature sources (see Section 7) and from telephone interviews with international biofuels experts including representatives of the US Department of Energy and International Energy Agency.

A full list of stakeholders who contributed is given in Appendix 1. Many stakeholders agreed to participate in this study only if comments and statistics were not attributed directly to them. Therefore, there are very few specific references to individual stakeholders in the text, but where comments and statistics from stakeholders are given, it is made clear that these were derived from stakeholders and not from written sources.

The study investigated 2 options for the production and distribution of biodiesel and 9 options for bioethanol for both 2002 and 2020, as shown in Table 1.1. These options all use processing technology which is already demonstrated on a commercial scale. In addition, resource costs for 2020 have been estimated for biodiesel using Fischer-Tropsch processing and for bioethanol production through enzymic hydrolysis. These options (shown in Table 1.2) are not yet fully developed but may offer lower cost routes to liquid biofuels in the longer term.

Table 1.1: Fuel pathways considered for both 2002 and 2020

Option	Fuel type	Raw material	Processing overseas	Processing in UK
1	Biodiesel	Oil seeds	Esterification	-
2	Biodiesel	Oil seeds	-	Esterification
3	Bioethanol	Wood	Acid hydrolysis + fermentation	-
4	Bioethanol	Straw	Acid hydrolysis + fermentation	-
5	Bioethanol	Wheat	Malting + fermentation	-

6	Bioethanol	Corn	Fermentation	
7	Bioethanol	Sugar cane	Fermentation	-
8	Bioethanol	Sugar cane	-	Fermentation
9	Bioethanol	Sugar beet	Fermentation	-

Table 1.2: Additional fuel pathways considered for 2020

Option	Fuel type	Raw material	Processing overseas	Processing in UK
10	Biodiesel	Wood	Gasification + Fischer-Tropsch	-
11	Biodiesel	Straw	Gasification + Fischer-Tropsch	-
12	Bioethanol	Wood	Enzymic hydrolysis + fermentation	-
13	Bioethanol	Straw	Enzymic hydrolysis + fermentation	-

Resource costs are defined as the costs before taxation of liquid transport fuels delivered to the car driver at a UK filling station. They therefore include costs associated with raw materials, processing, distribution and supply of fuels, and take account of any income from the sale of co-products. Resource costs exclude any subsidies to biofuel producers or duties on the sale of biofuels; in this way they can be compared directly to the pre-tax costs of gasoline and diesel on an energy (£ per GJ), volumetric (pence per litre) or driving cost (pence per km) basis.

Resource costs for 2020 assume improvements in processing technology and the efficiency of distribution vehicles, but make no assumptions about changes in feedstock price. This is because future trends in feedstock costs are very uncertain and will depend on factors such as land resource constraints, competition for land from food production and commodity prices for oil seeds and sugar.

No account has been taken of the indirect/external cost implications of increased employment in the biofuel processing sector or improved air quality from the replacement of petrol and diesel with cleaner fuels. Some of these wider issues are discussed briefly later in this report.

1.2 Introduction to this report

This report comprises seven sections in addition to this introduction. **Section 2** describes the different fuel pathways considered for biodiesel and bioethanol, including current process efficiencies and likely trends to 2020. **Section 3** reviews the information available from literature and expert interviews on the costs of biofuel production, including feedstock costs, processing costs and co-product values. **Section 4** reviews available information on the costs of distribution and supply. **Section 5** summarises the resource costs (production + distribution costs) for each fuel pathway and compares the estimated resource costs for biodiesel and bioethanol with those of conventional petrol and diesel. **Section 6** discusses the implications of these results, explores their sensitivity to key assumptions and considers the cost implications of blending biofuels with conventional fuels rather than distributing them separately. **Section 7** briefly discusses wider issues associated with biofuel production and use such as resource constraints, agricultural subsidies and environmental impacts; the cost implications of such issues fall outside the scope of this study. Finally, **Section 8** presents the conclusions from this work.

Process descriptions

This section describes the processes involved in the different fuel pathways shown in Tables 1.1 and 1.2, namely:

Production processes:

- Options 1 & 2: Production of biodiesel from the esterification of vegetable oils.
- Options 3 & 4: Production of bioethanol from wood or straw using acid hydrolysis and fermentation.
- Option 5: Production of bioethanol from wheat using malting and fermentation.
- Option 6: Production of bioethanol from corn using fermentation.
- Options 7, 8 & 9: Production of bioethanol from sugar cane or sugar beet using fermentation.
- Options 10 & 11: Production of biodiesel from wood or straw using gasification and Fischer-Tropsch processing.
- Options 12 & 13: Production of bioethanol from wood or straw using enzymic hydrolysis and fermentation.

Distribution processes:

- Option 2: Transport of oilseeds or vegetable oil to the UK.
- Option 8: Transport of raw sugar to the UK.
- All other options: Transport of bioethanol or biodiesel to the UK.
- All options: Distribution of biodiesel or bioethanol within the UK.

Process diagrams are provided for each of the production processes (Figures 2.1 to 2.7). These show feedstocks in green, co-products in blue and main products in red.

There are three main feedstock types for ethanol production: sugar cane or beet; grains such as wheat or corn, and lignocellulosic materials such as wood and straw. These three types are increasingly difficult to break down into liquid biofuels, due to differences in their chemical structures. Sugar cane and sugar beet can be fermented with minimal pre-processing as they contain C6 sugars such as glucose which have 6 carbon atoms in each molecule. Corn and wheat require pre-treatment to break down starches in the grain into C6 sugars. Cellulosic materials require still more aggressive processing to extract C5 and C6 sugars and then ferment them. The fermentation of C5 sugars, such as xylose, is currently a much less efficient process than the fermentation of C6 sugars.

Production processes

Options 1 and 2: biodiesel from oilseeds

Biodiesel may be produced from a variety of vegetable oil feedstocks including rapeseed oil, soybean oil and sunflower oil. At present, rapeseed accounts for over 80% of global biodiesel production, with sunflower oil providing 13% and small contributions from other vegetable oils.

The production route is shown in Figure 2.1. Oilseeds are crushed to produce oil, which after filtering is mixed with ethanol or methanol at about 50°C. The resultant esterification reaction produces fatty acid methyl esters (FAME), which are the basis for biodiesel, and the co-product glycerine which can be used in soap manufacture. Approximately 100kg of glycerine is produced per tonne of biodiesel. Another co-product is the residue "cake" from he crushing of the oilseeds, which is rich in protein and is used for animal feed.

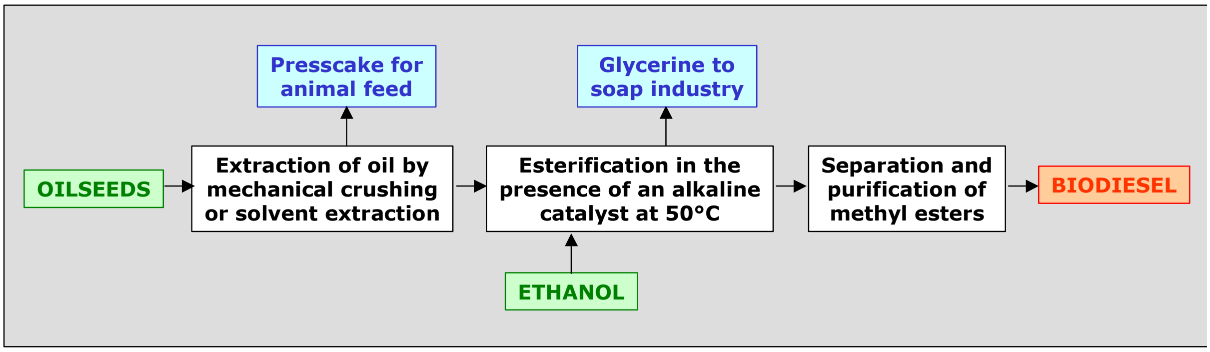


Figure 2.1: Production of Biodiesel by esterification of vegetable oil

The technology for extracting oil from oilseeds has remained the same for the last 10-15 years and is not likely to change significantly. Similarly, biodiesel production from the oil is a relatively simple process and so there is little potential for efficiency improvement. There is, however, ongoing research into the better utilisation of co-products.

Options 3 and 4: Bioethanol from wood or straw using acid hydrolysis and fermentation

The process of producing ethanol from wood or straw feedstocks is shown in Figure 2.2. It requires the production of ethanol from both C5 and C6 sugars - unlike the only the C6 sugars in conventional ethanol production from sugar cane (see Section 2.6).

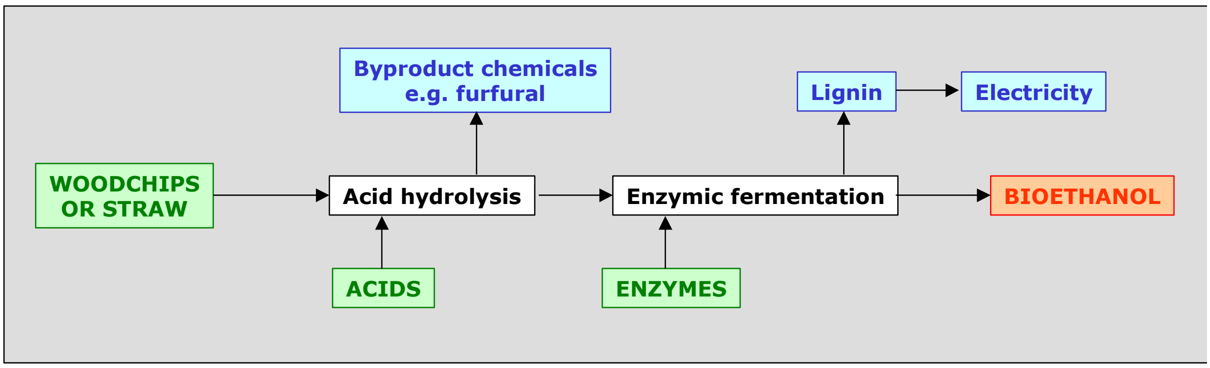


Figure 2.2: Production of bioethanol from wood or straw by acid hydrolysis and fermentation

This process is technically feasible but is complex and expensive and there are few industrial examples. Ongoing research and development in the US aims to address cost issues and develop a more efficient process. This is thought by many to be a step on the way to the eventual goal of an enzyme hydrolysis process (see Section 2.1.7).

Option 5: Bioethanol from wheat from malting and fermentation

The process here is similar to that for other methods producing bioethanol by fermentation, but an initial milling and malting (hydrolysis) process is necessary (see Figure 2.3). The wheat is first crushed or milled. In its passive form, malting is a process by which under controlled conditions of temperature and humidity, enzymes present in the wheat break down starches into C6 sugars. However, this process is very slow, and the commercial process introduces artificial enzymes to break down the starch into sugar. These sugars are washed out of the wheat with water, whilst the leftover residue can be sold for animal feed. The C6 sugars are then fermented using yeast at between 32 and 35^{o}C and pH 5.2. Ethanol is produced at 10-15% concentration and the solution is distilled to produce ethanol at higher concentrations.

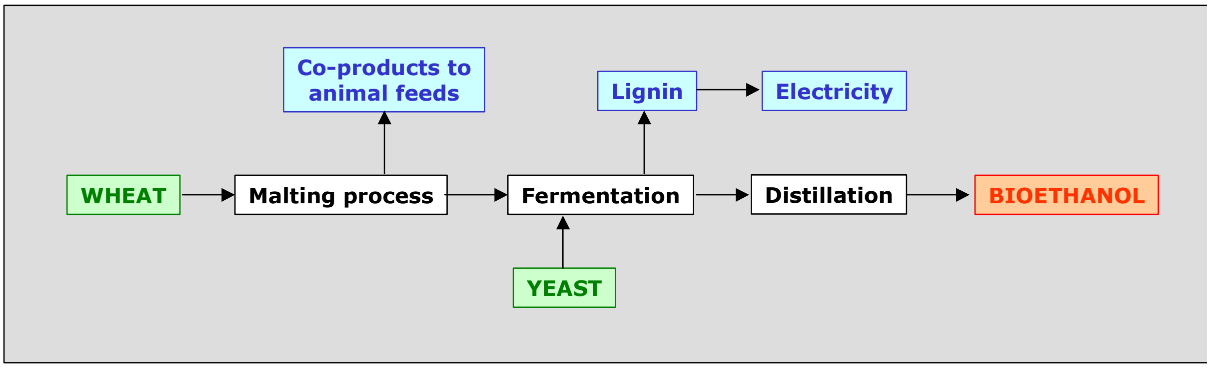


Figure 2.3: Production of bioethanol from wheat using malting and fermentation

The current conversion efficiency of the process is about 0.55 GJ of ethanol per GJ wheat (Reith 2002). The process is well established so there is limited scope for efficiency improvements.

Option 6: Bioethanol from corn using fermentation

This is similar to the process for wheat, but with small differences in the initial processing of the corn (see Figure 2.4). Firstly, the corn must be milled, either by wet milling or dry milling. The United States is the main producer of alcohol from corn, and the split between the use of wet and dry milling is fairly even. The milling produces co-products of residues which can be sold as animal feed. For wet milling, several types of residues are produced; dry milling produces only one type of animal feed product. Enzymes are used to break down the starches in the corn into C6 sugars which are then fermented and distilled using the same process as for wheat.

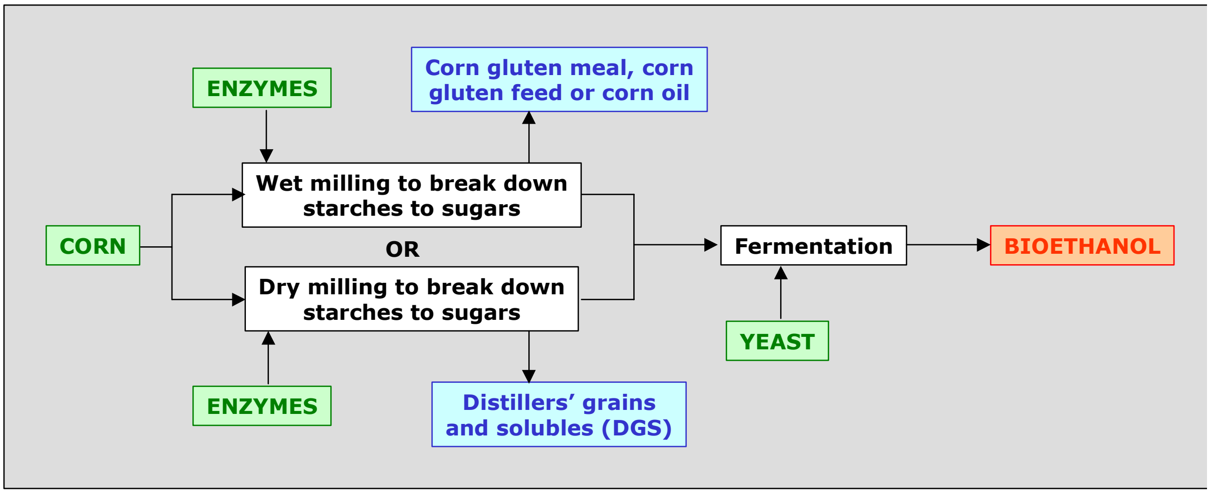


Figure 2.4: Production of bioethanol from corn using wet or dry milling

The current conversion efficiency of both wet and dry milling process routes is about 0.55 GJ of ethanol per GJ wheat (USDA 2002). The processes are well established but there is some limited scope for efficiency improvements.

Options 7, 8 & 9: Bioethanol from sugar cane or sugar beet using fermentation

This is the simplest of all the processes for producing bioethanol by fermentation (see Figure 2.5). The harvested sugar cane or sugar beet is crushed and then soluble sugars are extracted by washing through with water. Yeast is added and fermentation takes place under similar conditions to that in the above processes.

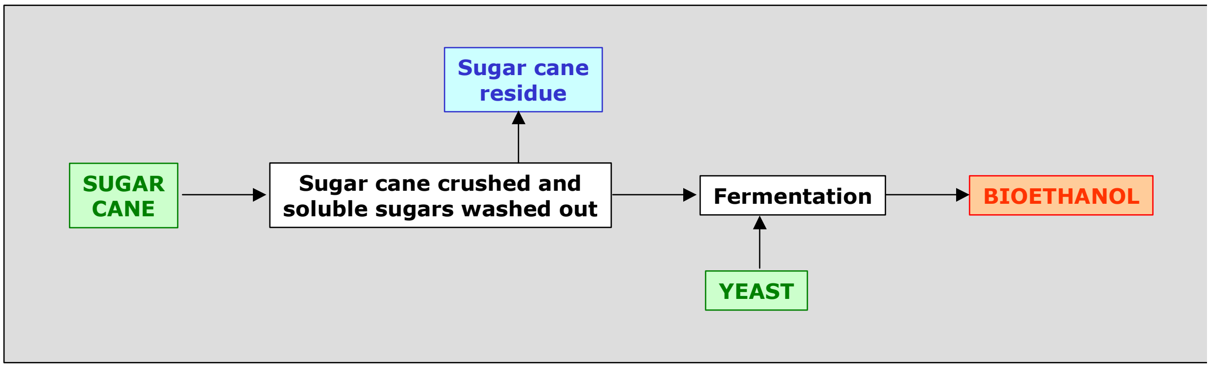


Figure 2.5: Production of bioethanol from sugar cane or sugar beet

Sugar cane has an energy production per hectare that is substantially higher than the other feedstocks considered here, but the process conversion efficiency is only about 0.35-0.40 GJ bioethanol per GJ feedstock. The sugar cane residue or bagasse can be burned to generate electricity, producing about 0.08 GJ electricity per GJ feedstock.

Options 10 and 11: Biodiesel from wood or straw using gasification and Fischer-Tropsch (2020 only)

The Fischer-Tropsch process was pioneered for the purpose of converting solid fuels, mainly coal to liquid fuels, in countries where there was a very limited indigenous supply of oil. The first stage of the process involves the gasification of the feedstock to a "synthesis gas", which is primarily a mixture of hydrogen and carbon monoxide. This gas can, in turn, be converted to liquid fuel in the Fischer-Tropsch reactor, which makes use of a catalyst (usually iron-based). The reactor also produces significant heat which can be used to generate electricity as a significant co-product of the process.

There is little information in the literature about Fischer-Tropsch processing of biofuels, although the process should very similar to the fossil fuel process. The key challenge for biofuels is to adapt and optimise the whole system to a scale that is appropriate to the availability of the biomass feedstock. A large refinery would not be practical as it would require wood to be transported long distances to the processing facilities.

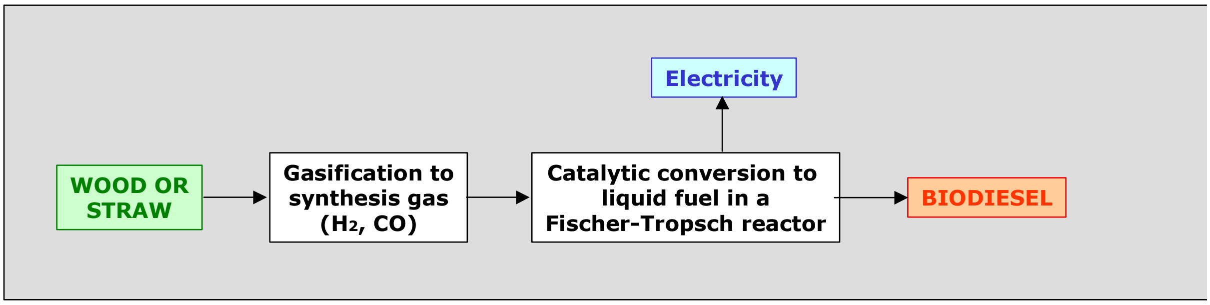


Figure 2.6: Production of biodiesel by gasification and Fischer-Tropsch

Options 12 & 13: Bioethanol from wood or straw by enzymic hydrolysis and fermentation (2020 only)

This process is not yet well developed enough to be put into practice, but is expected to be commercially viable by 2020. It is essentially similar to the process in Section 2.3, by which ethanol is produced from wood and straw through acid hydrolysis and fermentation, except that enzymes instead of acids are used for the hydrolysis process of converting lignocellulose to C5 and C6 sugars. This process is not yet proven as hydrolysis enzymes have not been developed yet and enzymes for the C5/C6 sugar conversion to ethanol are also too costly at present. However, intensive research efforts are underway and the USDOE has stated that enzymic hydrolysis offers good prospects for cost-effective bioethanol production in the longer term.

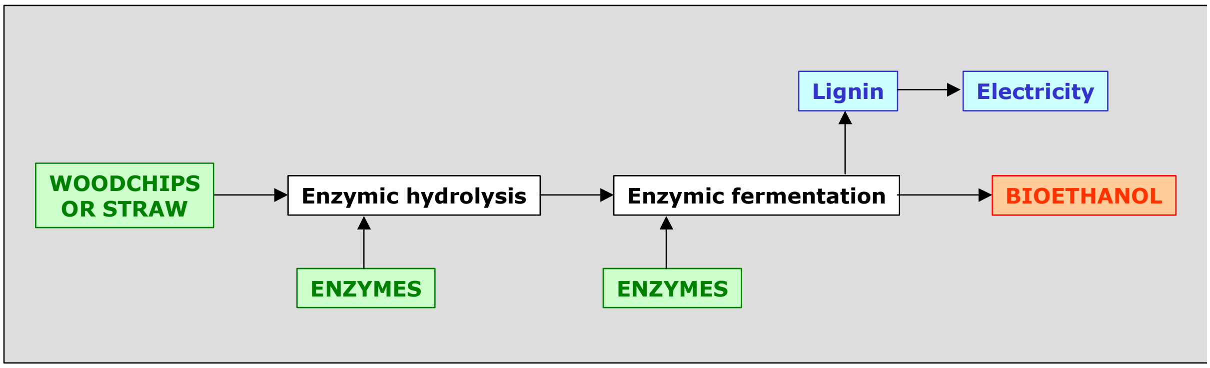


Figure 2.7: Production of bioethanol from wood or straw by enzymic hydrolysis and fermentation

Summary of process conversion efficiencies

Table 2.1 summarises the data available on current process conversion efficiencies (product yields) for the developed biodiesel and bioethanol pathways (options 1 to 9). Efficiencies are expressed in original units from the literature and as GJ biofuel per GJ feedstock. The latter were used to estimate feedstock costs where feedstock costs were not available on a cost per unit biodiesel/bioethanol basis (see Section 3). Conversion efficiencies do not take account of any energy outputs, such as electricity produced from the combustion of co-products.

Table 2.1: Current process conversion efficiencies

Option	Fuel type	Process	Conversion Efficiency (original units)	2002 Efficiency (GJ biofuel per GJ feedstock)
1/2	Biodiesel	Oil seed esterification	28-30% [CSIRO 2000]	0.29
3	Bioethanol	Wood - acid hydrolysis	47% [Reith 2002]	0.47
4	Bioethanol	Straw - acid hydrolysis	40% [Reith 2002]	0.40
5	Bioethanol	Wheat	55% [Reith 2002] 349 l/tonne [IEA 2002] 305 kg/tonne [NDDC 2002]	0.55* 0.53 0.59
6	Bioethanol	Corn - wet milling	2.682 gall/bu [USDA 2002]	0.56
6	Bioethanol	Corn - dry milling	2.636 gall/bu [USDA 2002]	0.55
7/8	Bioethanol	Sugar cane	80 l/tonne [stakeholder]	0.38
9	Bioethanol	Sugar beet	85 kg/tonne [NDDC 2002]	0.12

** Value used in subsequent cost analysis.*

No distinction is made between UK and overseas production efficiencies as no data were available. UK facilities for processing imported feedstocks are likely to be larger than average facilities overseas, and hence potentially more efficient, but this could be offset by lack of operational experience in the UK.

Table 2.2 shows projected improvements in process conversion efficiencies for these production options between 2002 and 2020. These are fairly conservative estimates, based on the relative maturity of different production processes, potential efficiency gains from larger scale production (economies of scale) and stakeholder views on future technology developments. This is discussed further in Appendix 3.

Table 2.2: Future process conversion efficiencies

Option	Fuel type	Process	Estimated efficiency improvement to 2020 (% improvement)	2020 Efficiency (GJ biofuel per GJ feedstock)
1/2	Biodiesel	Oil seed esterification	+5%	0.30
3	Bioethanol	Wood - acid hydrolysis	+5%	0.49
4	Bioethanol	Straw - acid hydrolysis	+5%	0.42
5	Bioethanol	Wheat	+10%	0.59

6	Bioethanol	Corn - wet milling	+20%	0.67
6	Bioethanol	Corn - dry milling	+20%	0.66
7/8	Bioethanol	Sugar cane	0%	0.38
9	Bioethanol	Sugar beet	+5%	0.13

We have been unable to find any information on process conversion efficiencies for prospective 2020 process routes to biodiesel and bioethanol (options 10-13).

Summary of co-product yields

Our original intention was to estimate co-product values for each process route from relevant co-product yield (kg or GJ co-product per GJ biofuel) and the selling price of the co-product. This method would have allowed us to explore regional differences, e.g. different prices for electricity, and to estimate the cost implications of increases in co-product yield over time. However, there is insufficient data available on either co-product yields or co-product prices for this estimation method to be used. Furthermore, co-product yields vary widely, depending on market conditions for the co-product and the configuration of the processing plant. For these reasons, co-product values (or credits) have been taken directly from the literature on a £(co-product) per £(biofuel) basis, and so co-product yields are not used in the overall cost estimates (see Section 3 for details).

The information that has been obtained on co-product yields is summarised in Table 2.3; these should be considered as illustrative values only, for the reasons given above. Data for options 2, 4, 5 and 9 were taken from a report by Sheffield Hallam University which considered co-product yields (but not co-product values) for UK production.

Table 2.3: Co-product yields

Option	Fuel type	Process	Co-product	Co-product yield
2	Biodiesel	Rapeseed esterification	Rape straw	2.78 tonne/tonne biodiesel
			Rape meal	1.575 tonne/tonne biodiesel
			Crude glycerine	0.1 tonne/tonne biodiesel
4	Bioethano l	Acid hydrolysis of straw	Electricity	1.829 GJ/tonne bioethanol
			Ash	0.384 tonne/tonne bioethanol
			Acetic acid	0.115 tonne/tonne bioethanol
5	Bioethano l	Wheat	Straw	18.54 tonnes/tonne bioethanol
			Bran	0.121 tonne/tonne bioethanol
			Animal feed	1.507 tonnes/tonne bioethanol
6	Bioethano l	Corn - wet milling	Corn oil	1.886 kg/GJ corn
			Corn feed	12.851 kg/GJ corn
			Corn meal	3.065 kg/GJ corn
7	Bioethano l	Sugar cane	Electricity	100 kWh/tonne sugar cane

8	Bioethanol	Sugar beet	Pulp	22.75 tonnes/tonne bioethanol
			Animal feed	0.75 tonne/tonne bioethanol

The effects of co-product values on the economics of biofuel production are discussed in Section 6.

Distribution processes

1.1.1 Transport of oil seeds or vegetable oil to the UK

For the purposes of estimating international distribution costs associated with option 2 (biodiesel production in the UK from imported feedstocks), we have assumed that vegetable oil is imported through current distribution channels to a processing facility near to a UK port. A substantial proportion of UK demand for vegetable oil is already met by imports, with most imports derived from the United States or Europe. Distribution is primarily by road tanker and bulk ship, although there is some potential for rail distribution from Europe via the Channel tunnel.

It would not be economic to transport oil seeds to the UK for biodiesel production as the energy density of seeds is much lower than the energy density of vegetable oil, and UK processing costs are unlikely to be significantly lower than processing costs in other countries. Therefore this option has not been explored further.

Transport of raw sugar to the UK

For the purposes of estimating international distribution costs associated with option 8 (bioethanol production in the UK from imported feedstocks), we have assumed that raw sugar is imported through current distribution channels to a processing facility near to a UK port. Raw sugar derived from sugar cane is presently imported in bulk for processing in refineries to make sugar for food; bulk carriers are used and port facilities are close to refineries, such as those in the Thames estuary. Ethanol production plants might be established on the same site as sugar production, to minimise costs. However, ethanol production facilities will also require good road and/or rail links to facilitate inland distribution to fuelling stations.

Transport of bioethanol or biodiesel to the UK

For the purposes of estimating international distribution costs associated with importing biodiesel or bioethanol, we have assumed the same costs as for the import of petroleum products, adjusted for the different energy densities of biodiesel and bioethanol. Almost identical tankers could be used, although stakeholders have suggested that the transport of ethanol may require improved vapour control systems, since it is more volatile than petrol. Any such modifications should be fairly minimal in terms of cost. There may also be some need for careful sealing of tanks against water, due to the potential for water to dissolve in ethanol.

Distribution of bioethanol or biodiesel in the UK

The inland distribution costs for bioethanol and biodiesel were also assumed equivalent to petrol/diesel distribution costs, adjusted for relative density. Distribution would by road tanker, and again there may be some need for additional vapour control equipment and protection against water egress. Rickeard and Thompson (1993) argue that biodiesel fuelling costs could be lower than those for conventional diesel as less rigorous safety procedures would be required to prevent land contamination, because biodiesel is biodegradable.

Production Costs

This section reviews and analyses information available from literature on the costs associated with the production of biodiesel and bioethanol for each of the fuel pathways described in Section 2. It comprises four parts:

Section 3.1 summarises available information on product costs for each biodiesel and bioethanol pathway. Product costs include feedstock and processing costs, and take account of co-product values. This section also provides estimated product costs for 2020, based on assumed efficiency improvements. This information is used to derive the resource cost estimates given in Section 4 (resource costs include both production and distribution costs).

Section 3.2 presents information on feedstock costs, i.e. the purchase price of feedstocks such as wheat and sugar cane. This information is used to estimate the proportion of the production cost which is attributable to feedstock costs for each pathway. This allows us to explore sensitivities of resource costs to feedstock price changes, including regional differences, later in the report in Section 5.

Section 3.3 presents information on processing costs (capital and operating costs). This information, which is not available for all pathways, is used to estimate the proportion of the production cost which is attributable to those operational costs (i.e. labour costs) which vary significantly between different regions of the world. This allows us to explore how resource costs might be affected by relocating biofuels production to different regions (in Section 5).

Section 3.4 presents information on co-product values or credits. As discussed in Section 2.1.9, there are considerable uncertainties over co-product yields and co-product selling prices, and so it has not been possible to determine accurate figures for co-product values. Furthermore, co-product values are not available for many of the processes considered in this report. Nevertheless, the indicative values in Section 3.4 are useful in illustrating the importance of co-products in the overall economics of biofuels production, which is discussed further in Section 6.

Where possible, costs are presented in two ways: as £ per GJ of final product and as pence per litre of final product. The following conversion factors have been used:

Energy content of biodiesel: 40.128 GJ/tonne

Energy content of bioethanol: 26.7 GJ/tonne

Density of biodiesel: 0.840 kg/litre

Density of bioethanol: 0.789 kg/litre

These costs can be converted to pence per kilometre data, if required, by using the following assumptions on fuel economy:

- Biodiesel: The fuel efficiency of a biodiesel fuelled car is expected to be similar to that of a conventional diesel car. The average efficiency of a new diesel car registered in the UK was 2.31 MJ/km in 2000 (ACEA, 2001). This efficiency is likely to improve by about 30% to around 1.62 MJ/km by 2020, assuming further improvement beyond the targets set by the ACEA agreement (25% CO_2 emissions reduction for new cars between 1995 and 2008). This is a fairly conservative estimate and Ricardo (2002) has projected greater efficiency gains through the use of hybrid technology.
- Bioethanol: The fuel efficiency of a bioethanol fuelled car in 2002 is expected to be similar to a conventional gasoline car. The average efficiency of a new gasoline car registered in the UK was 2.98 MJ/km in 2000 (ACEA, 2001). Again a 30% improvement in efficiency can be assumed to 2020, so the 2020 efficiency is expected to be about 2.09 MJ/km.

The following currency exchange were used for converting overseas costs into sterling (exchange rates around 1st March 2003):

1 US$ (USD) = 0.63
1 € (EUR) = 0.681
1 Swedish Kronor (SEK) = 0.07477

Product costs

Estimated product costs for biodiesel and bioethanol in 2002 are summarised in Table 3.1. These costs have been derived from literature sources and discussions with stakeholders (see references and Appendix 1 for details). Where a range of costs was presented in a reference, the average (mean) cost was taken. Where costs were available in a number of references, the lowest costs were taken (provided the reference was considered reliable). Lowest costs were used because countries and states with the lowest production costs are considered most likely to supply to export markets, as long as there is sufficient feedstock resource.

Table 3.1 Estimated product costs for biodiesel and bioethanol in 2002 (£/GJ product)

Option & Fuel type	Feedstock	Product Cost [1]		Source country	Data source/ assumption
		£/GJ	p/l		
1. Biodiesel	Oil seeds	9.86	33.2	US (soy, likely export price)	Stakeholder
		12.22	41.2	EU15 (Belgian rape)	Stakeholder
2. Biodiesel	Oil seeds - UK production	9.86	33.2	US	Assumed equal to US price above
		12.22	41.2	EU15	Assumed equal to EU15 price above
3. Bioethanol	Wood - Acid hydrolysis	10.18	21.4	US	DiPardo (2000)
4. Bioethanol	Straw - Acid hydrolysis	19.52	41.1	EU15 (Sweden)	Stakeholder
5. Bioethanol	Wheat	14.20	29.9	EU15	Reith et al (2002)
6. Bioethanol	Corn - wet mill	7.41	15.6	US	USDA (2002)
	Corn - dry mill	7.51	15.8	US	USDA (2002)
7. Bioethanol	Sugar cane	5.98	11.0	Brazil (likely export price)	Stakeholder

8. Bioethanol	Sugar cane - UK production	20.75	43.7	Brazil	Sugartech (2003) Ouwens & Faaij (2002)
9. Bioethanol	Sugar beet	16.16	34.1	EU15 (France)	Ouwens & Faaij (2002)

These figures exclude any Government subsidies for biofuel production but it is not possible to establish the degree to which agricultural subsidies influence the figures. Costs quoted by studies and stakeholders are based on current costs of feedstocks which will take account of any subsidies for growers of oil seeds, sugar cane etc.

The production of bioethanol from corn (option 6) is well established in the US but there is no evidence of production in Europe. This may be because climatic conditions are more favourable for corn growing in the mid-West region of the USA.

The cost of bioethanol from sugar cane with UK processing (option 8) is expected to be much higher that the cost when the processing is undertaken in Brazil (option 7). The UK cost has been calculated from the price of raw sugar imported to the UK (£15.88/GJ ethanol) plus the cost of processing that sugar into ethanol (£4.87/GJ ethanol). Processing costs are estimated from the UK processing cost of ethanol from sugar beet, which may give a slight overestimate as it includes the initial processing of sugar beet into sugar concentrate.

Table 3.2 shows estimated product costs for 2020 in £/GJ for each region; Table 3.3 presents the same data in pence/litre. These estimates are based on:

- Estimated improvements in processing efficiency (see Section 2.1.8 and Appendix 3).
- Estimated increases in crop yield (see Section 3.2, below).
- Regional differences in feedstock costs (see Section 3.2, below).
- Regional differences in plant operating costs due to different labour costs (see Section 3.3, below).

Cost data for options 12 and 13 are based on targets set by the US National Renewable Energy Laboratory (NREL 2002), rather than bottom-up cost projections, as this was the only data available. These costs may be aspirational rather than realistic.

Table 3.2: Estimated product costs for 2020 in £/GJ

Option &	**Feedstock**	**Product Cost £/GJ**			
Fuel type		**US**	**EU15**	**Eastern Europe**	**South America**
1. Biodiesel	Oil seeds	9.76	12.10	10.26	-
2. Biodiesel	Oil seeds - UK production	9.76	12.10	10.26	-
3. Bioethanol	Wood - Acid hydrolysis	10.08	10.68	9.83	-
4. Bioethanol	Straw - Acid hydrolysis	18.58	18.95	13.49	-
5. Bioethanol	Wheat	12.76	13.39	9.97	-

6. Bioethanol	Corn	6.74	7.07	5.27	-
7. Bioethanol	Sugar cane	6.46	-	-	5.23
8. Bioethanol	Sugar cane - UK production	25.63	-	-	20.75
9. Bioethanol	Sugar beet	15.54	16.00	13.01	-
10. Biodiesel	Wood - FT processing	5.54	5.65	4.21	-
11. Biodiesel	Straw - FT processing	5.54	5.65	4.21	-
12. Bioethanol	Wood - Enzymic hydrolysis	8.77	9.21	6.86	-
13. Bioethanol	Straw - Enzymic hydrolysis	8.77	9.21	6.86	-

Table 3.3: Estimated product costs for 2020 in pence/litre

Option & Fuel type	**Feedstock**	**Product Cost p/litre**			
		US	**EU15**	**Eastern Europe**	**South America**
1. Biodiesel	Oil seeds	32.91	40.78	34.57	-
2. Biodiesel	Oil seeds - UK production	32.91	40.78	34.57	-
3. Bioethanol	Wood - Acid hydrolysis	21.23	22.50	20.70	-
4. Bioethanol	Straw - Acid hydrolysis	39.14	39.93	28.42	-
5. Bioethanol	Wheat	26.87	28.22	21.01	-
6. Bioethanol	Corn	14.19	14.90	11.10	-
7. Bioethanol	Sugar cane	13.62	-	-	11.03
8. Bioethanol	Sugar cane - UK production	53.99	-	-	43.71
9. Bioethanol	Sugar beet	32.73	33.71	27.40	-
10. Biodiesel	Wood - FT processing	18.68	19.05	14.19	-
11. Biodiesel	Straw - FT processing	18.68	19.05	14.19	-
12. Bioethanol	Wood - Enzymic hydrolysis	18.47	19.39	14.44	-

13. Bioethanol	Straw - Enzymic hydrolysis	18.47	19.39	14.44	-

Feedstock costs

Feedstock costs are taken as the price that biofuels producers must pay for oilseeds, wood etc. delivered to their factory gate. With the exception of wood and straw, these raw materials are sold on the commodity market and so their price will fluctuate depending on market conditions and expectations of future harvest yields. The price of oilseeds, corn and wheat will also depend on the demand for foodstuffs and any subsidies provided to farmers. Furthermore, costs to biofuels producers will depend on the size of the order that they are able to place and the contractual terms agreed. It is therefore very difficult to get accurate estimates of feedstock costs.

The table below shows costs for the different feedstocks from literature values and stakeholder interviews. Those costs exclude government subsidies where possible (it was not always apparent from the literature whether subsidies had been included). The original cost units have been converted to costs per GJ of biodiesel or bioethanol using the conversion efficiency data in Section 2.1.8.

Table 3.4: Feedstock costs for 2002

Feedstock	**Region**	**Feedstock Cost (original units)**	**Feedstock cost (£/GJ feedstock), 2002**	**Feedstock cost (£/GJ biofuel), 2002**	**Source of cost data**
Oilseeds - Soy	US	$5.91/bu	6.57	22.64	MDA (2002)
Oilseeds - Soy	EU15	€17.2/100kg	5.58	19.23	Eurostat (2002)
Oilseeds - Rapeseed	EU15	€16.3/100kg	3.99	13.75	Eurostat (2002)
Wood	US	$2-4/GJ	3.00	6.38	Bioenergy
Wood	EU15	€33-99/t	5.01	10.65	Biobase (2002)
Straw	EU15	£35/t	2.30	5.75	Environment Agency (2003)
Wheat	EU15	€120/t	5.88	10.69	Stakeholder
Wheat	Eastern Europe	0.65Skr/kg	3.5	6.36	Stakeholder
Corn - Dry Mill	US	$1/bu	1.62	7.15	USDA (2002)
Corn - Wet Mill	US	$1/bu	1.62	6.43	USDA (2002)
Sugar Cane	Brazil	$180/t raw sugar	-	10.09	Stakeholder
Sugar Cane for export	Brazil	0.081$/lb	-	15.88	Sugartech (2003)

Sugar Beet	EU15	-	5.88	43.23	Stakeholder

For biodiesel production, rapeseed offers a cheaper feedstock than soy but the overall product costs (see Table 3.1) are higher because soy contains protein which can be converted into valuable animal feedstock as a co-product.

Table 3.4 gives a range of values for many feedstocks, in part because of the uncertainties over subsidy rates and whether subsidies are included in prices. Based on these values, we have estimated the ratio between product costs and feedstock costs for each fuel pathway (see Table 3.5).

Table 3.5: Feedstock costs vs product costs, 2002

Option & Fuel type	Feedstock	Feedstock Source	Product costs £/GJ	Feedstock costs £/GJ	% of product cost due to feedstock cost
1/2. Biodiesel	Oil seeds	US	9.86	22.64	230%
3. Bioethanol	Wood - Acid hydrol.	US	10.18	6.38	63%
4. Bioethanol	Straw - Acid hydrol.	EU15	19.52	5.75	29%
5. Bioethanol	Wheat	EU15	14.20	10.69	75%
6. Bioethanol	Corn	US	7.41	7.15	96%
7/8. Bioethanol	Sugar cane	Brazil	5.98	10.09	169%
9. Bioethanol	Sugar beet	EU15	16.16	43.23	268%

Ratios of greater than one are counterintuitive as they suggest product costs are lower than feedstock costs, i.e. the process loses money. There are a number of possible reasons for this: (a) the two data sets are from different sources, and hence the data is incomparable, (b) co-product values are sufficient to make up the difference in cost, or (c) some of the product costs include subsidies. The value of co-products can have a substantial impact on the economics of the process. For example, about 1.2 kWh of electricity is generated per litre of ethanol produced from sugar cane, which equates to a co-product credit of about £2.28/GJ ethanol assuming a typical UK electricity price of 4p/kWh.

The information in Table 3.4 is not sufficiently extensive or reliable to compare costs of the same feedstock grown in different regions. Therefore we have used the following estimated factors to derive costs in 2020 of producing biofuels in different regions:

EU15: 1.0

US: 1.0

Brazil: 0.7 (sugar cane only)

Eastern Europe: 0.8

These reflect lower labour costs for Brazil and Eastern Europe compared to the EU and USA, and better growing conditions for sugar cane in Brazil.

Crop yields may increase by about 10% by 2020 due to the introduction of genetically modified crops, which in turn would reduce feedstock costs if all other parameters (energy costs, fertiliser costs etc.) remain unchanged. In practice there are many unknown variables which contribute to the price of feedstocks, such as the level of agricultural subsidies, so we have assumed that 2020 feedstock costs are equal to 2002 feedstock costs for the same region. The potential for feedstock cost reduction is discussed further in Appendix 2.

Processing costs

This section discusses the costs of processing feedstocks into biofuels. As explained in the introduction to Section 3, there are few information sources on processing costs and so it has not been possible to derive product costs from a bottom-up assessment of feedstock and processing costs in most cases.

Table 3.6 shows the breakdown of processing costs for the production of bioethanol from corn in North America using wet- or dry-milling, which are the only processes for which data is available.

Table 3.6: Breakdown of processing costs for bioethanol from corn (USDA, 2002)

	Energy	Labour & maintain'	Overheads	Capital recovery	Total
Wet-milling: Cost £/GJ	1.03	0.86	0.29	1.50	3.68
Wet milling: % of total cost	28%	23%	8%	41%	100%
Dry-milling: Cost £/GJ	0.88	0.98	0.30	1.50	3.65
Dry-milling: % of total cost	24%	27%	8%	41%	100%

These figures suggest that labour costs constitute about 25% of total processing costs, while the largest cost component (41%) is capital recovery, i.e. the cost of raising finance to pay for capital equipment. The total processing cost for corn wet milling is £3.68/GJ of product, which represents about 50% of the total product cost of £7.51/GJ. This is relatively high because of the complexity of the process; processing costs are estimated to contribute only about 20% of the product costs of biodiesel from oilseeds (stakeholder comment).

Tables 3.7 and 3.8 summarise the assumptions made for the purpose of assessing the sensitivity of product costs to regional cost differences. Table 3.7 shows the assumed contribution of processing costs to total product costs, while Table 3.8 shows factors applied to processing costs to account for regional differences, with US costs as an index value of 100. More detailed assessment of the differences in energy, labour and financing costs between potential biofuels-producing regions is beyond the scope of this study. Such an assessment would need to consider not only the components of processing cost but also external factors such as the availability of grants and subsidies.

Table 3.7: Contribution of processing costs to product costs (%)

Option & Fuel type	Feedstock	Feedstock Source	% of product cost due to processing cost
1/2. Biodiesel	Oil seeds	US	20%
3. Bioethanol	Wood - Acid hydrolysis	US	60%
4. Bioethanol	Straw - Acid hydrolysis	EU15	60%
5. Bioethanol	Wheat	EU15	50%
6. Bioethanol	Corn	US	50%
7/8. Bioethanol	Sugar cane	Brazil	20%
9. Bioethanol	Sugar beet	EU15	30%

Table 3.8: Regional differences in processing costs in 2020 (US=100)

Region	Cost index (US=100)
US/North America	100
EU15	110
South America	60
Eastern Europe	70

The figures in Table 3.8 reflect the assumption that South America and Eastern Europe will have much lower labour costs but that capital costs and energy costs may be only marginally lower than for the EU15 and US. EU15 costs are marginally higher than US costs due to the non-wage labour costs such as pension contributions and national insurance. These indices are applied to the proportion of product costs shown in Table 3.7, when estimating sensitivities to regional differences.

Co-product values or credits

There is very little information available from the literature on co-product values or credits, i.e. the sales value of electricity, glycerine, animal feeds etc produced by the different biofuels processing routes. These values will vary greatly over time, with scale of operation and between regions. For example, there may be a limited market for animal feedcake within a locality that would be saturated if biodiesel production rates were to increase. Such effects can only be fully assessed by site-specific studies of local co-product markets. The discussion in Appendix 3 gives some additional information on likely trends in co-product values for different processes, and some indicative data is provided in Table 3.9 for bioethanol from corn.

Table 3.9: Co-product values for bioethanol from corn (USDA, 2002)

	Co-product value £/GJ of ethanol	**Product cost £/GJ**	**Co-product value/ product cost**
Wet milling process	3.79	7.41	0.51
Dry milling process	2.37	7.51	0.32

The values in Table 3.9 show the extent to which the economics of bioethanol from corn rely on sales of co-products, with co-products worth over 50% of the total product cost for the wet-milling process.

For the purposes of this study we have assumed there is no change in co-product values between 2002 and 2020, although we note that this is subject to a high degree of uncertainty, particularly if biofuels production rates rise steeply over this period. Sensitivity analyses in Section 5 explore the likely impact of a change in co-product value for the bioethanol from corn process.

Distribution Costs

This section reviews and analyses information available from literature on the costs associated with the distribution of biodiesel and bioethanol for each of the fuel pathways described in Section 2. These costs comprise:

- **International distribution costs**: costs of transporting intermediate products (vegetable oils or raw sugar), bioethanol or biodiesel to the UK from their production site by a combination of road and sea transport. The sea transport cost will dominate for imports from North and South America while road transport costs will dominate for European imports.
- **Inland distribution costs**: costs of distributing biodiesel or bioethanol within the UK by road transport. These costs do not include any infrastructure costs, e.g. capital costs for storage tanks or fuel pumps at refuelling stations.

Table 4.1 shows international and inland distribution costs from different literature sources. The international costs for US and Brazil are based on distribution costs of crude oil of $3/barrel or 1.2p/litre (BP Amoco 2001). This figure is adjusted to reflect the lower energy density of bioethanol and biodiesel. The distances involved will be similar to importing crude oil from the Middle East to the US, and so costs are not adjusted for distance. As discussed in Section 2.2, the processes for distributing biofuels are likely to be almost identical to petroleum products, with some minimal modifications to the sea and road tankers.

Table 4.1: Distribution costs from literature sources

Product	Product imported	Source	International Distribution £/GJ biofuel	Internal UK Distribution £/GJ biofuel	Data Source
Biodiesel	Biodiesel	US	0.35	-	BP (2001)
Biodiesel	-	-	-	1.78	IEA (1994)
Biodiesel	-	-	-	0.60	ICCEPT (2002)
Biodiesel	Soybean oil	US	1.22	-	*
Bioethanol	Bioethanol	US	0.56	-	BP Amoco (2001)
Bioethanol	Bioethanol	Brazil	0.56	-	BP Amoco (2001)
Bioethanol	Raw sugar	Brazil	1.34	-	*
Bioethanol	-	-	-	2.51	IEA (1994)
Bioethanol	-	-	-	0.85	#

* Estimated from international biofuel distribution costs by scaling on relative weight of intermediate product.

Based on ICCEPT data for biodiesel.

There is considerable difference between the two values for UK internal distribution costs of biodiesel: £1.78/GJ from an IEA study and £0.60/GJ from a recent ICCEPT study. We have used the ICCEPT figure because the work is more recent and to retain consistency with other biofuels studies for UK Government. However, ICCEPT based their costs on internal distribution costs within the USA, so they may be underestimated for the UK.

For EU15 international distribution, where no literature values were available, costs were estimated by assuming:

- Road tankers travel an average roundtrip distance of 800 km to the port.
- Each tanker holds 35,000 litres.
- The fuel efficiency of road tankers is 10 MJ/km (estimated from HGV efficiencies).
- Fuel costs for road transport are £0.40/litre.
- Non-fuel costs for road transport are £0.32/km from the DTI low carbon study. These costs were based on Mercedes data for maintenance, driver salary, insurance and tax for a typical HGV travelling 103,000 km per year.

Sea transport costs are 10% of the costs of sea transport from the US or Brazil because of the much shorter distances involved.

International distribution costs for Eastern European sources can be estimated in the same way. The average roundtrip distance for Eastern Europe is estimated to be twice that of EU15 sources, i.e. 1,600 km.

Table 4.2 shows estimated costs of international distribution from EU15 and Eastern European sources, for biodiesel, bioethanol and soybean oil.

Table 4.2: Distribution costs estimated for European sources

Product	Product imported	Source	International Distribution £/GJ biofuel
Biodiesel	Biodiesel	EU15	0.30
Biodiesel	Biodiesel	Eastern Europe	0.59
Biodiesel	Soybean oil	EU15	1.05
Biodiesel	Soybean oil	Eastern Europe	2.04
Bioethanol	Bioethanol	EU15	0.48
Bioethanol	Bioethanol	Eastern Europe	0.95

It is somewhat surprising that international distribution costs are very similar for all imports, whether they come from North/South America or from Europe. This is due to the much lower costs of shipping by sea compared to road (on a per km basis) and the assumption that costs of shipping biofuel are equivalent to costs of shipping crude oil. In practice, the costs for biofuel distribution may be higher because of the smaller quantities involved, but we have been unable to find any data on this.

The costs in this section do not include any import tariffs, as resource costs exclude any taxation components. Import tariffs are discussed further in Section 6.

Comparison of Resource Costs

This section presents an analysis of likely resource costs for different fuel pathways and compares the resource costs for biodiesel and bioethanol with those of conventional petrol and diesel. Resource costs are estimated from the sum of product costs (which take account of co-product credits) and distribution costs. Further information on the component costs and the assumptions behind them is given in Sections 2-4 of this report.

Resource costs in 2002

Tables 5.1 and 5.2 give estimated resource costs in £/GJ and pence/litre respectively for 2002.

Table 5.1: Estimated resource costs for 2002 in £/GJ

Option & Fuel type	Feedstock	Source	Costs, £/GJ		
			Product	Distrib'n	Total
1. Biodiesel	Oil seeds	US	9.86	0.95	10.81
		EU15	12.22	0.90	13.12
2. Biodiesel	Oil seeds - UK production	US	9.86	1.82	11.68
		EU15	12.22	1.65	13.87
3. Bioethanol	Wood - Acid hydrolysis	US	10.18	1.41	11.59
4. Bioethanol	Straw - Acid hydrolysis	EU15	19.52	1.33	20.85
5. Bioethanol	Wheat	EU15	14.20	1.33	15.53
6. Bioethanol	Corn	US	7.41	1.41	8.82
7. Bioethanol	Sugar cane	Brazil	5.98	1.41	7.39
8. Bioethanol	Sugar cane - UK production	Brazil	20.75	2.19	22.94
9. Bioethanol	Sugar beet	EU15	16.16	1.33	17.49

Table 5.2: Estimated resource costs for 2002 in pence/litre

Option & Fuel type	Feedstock	Source	Costs, p/litre		
			Product	Distrib'n	Total
1. Biodiesel	Oil seeds	US	33.24	3.21	36.45
		EU15	41.19	3.03	44.22

2. Biodiesel	Oil seeds - UK production	US	33.24	6.12	39.36
		EU15	41.19	5.56	46.75
3. Bioethanol	Wood - Acid hydrolysis	US	21.45	2.98	24.42
4. Bioethanol	Straw - Acid hydrolysis	EU15	41.12	2.80	43.92
5. Bioethanol	Wheat	EU15	29.91	2.80	32.72
6. Bioethanol	Corn	US	15.61	2.98	18.59
7. Bioethanol	Sugar cane	Brazil	12.60	2.98	15.58
8. Bioethanol	Sugar cane - UK production	Brazil	43.71	4.62	48.33
9. Bioethanol	Sugar beet	EU15	34.04	2.80	36.84

Ethanol trade with Brazil is already established, with the Swedish company Alcotra having purchased ethanol from Brazil on a contract to 2007 at a cost of about £6/GJ. This agrees well with the figure for Option 7 in Table 5.1, as Alcotra's costs do not include inland distribution within Sweden.

Figures 5.1 and 5.2 show resource costs in £/GJ and p/litre respectively for each biofuel option. The lower (US) costs are shown for biodiesel options 1 and 2 in these figures. The comparative pre-tax costs for petrol and diesel are also shown in Figure 5.1. Petrol and diesel prices are pump prices excluding taxes but including profit margins made by fuel distributors. The biofuel prices do not include these distribution margins and so the real difference between biofuel and petrol/diesel costs is slightly underestimated.

Figure 5.1: Estimated resource costs for 2002 in £/GJ

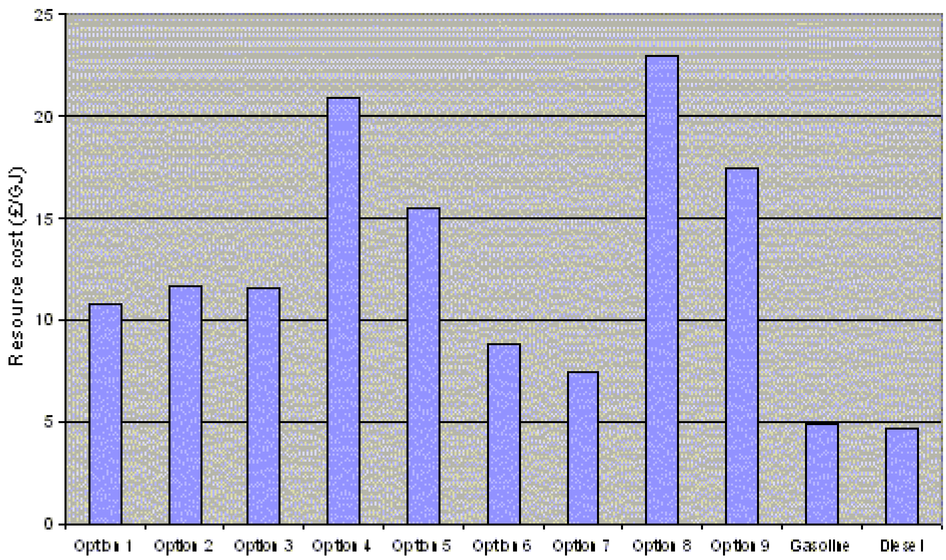
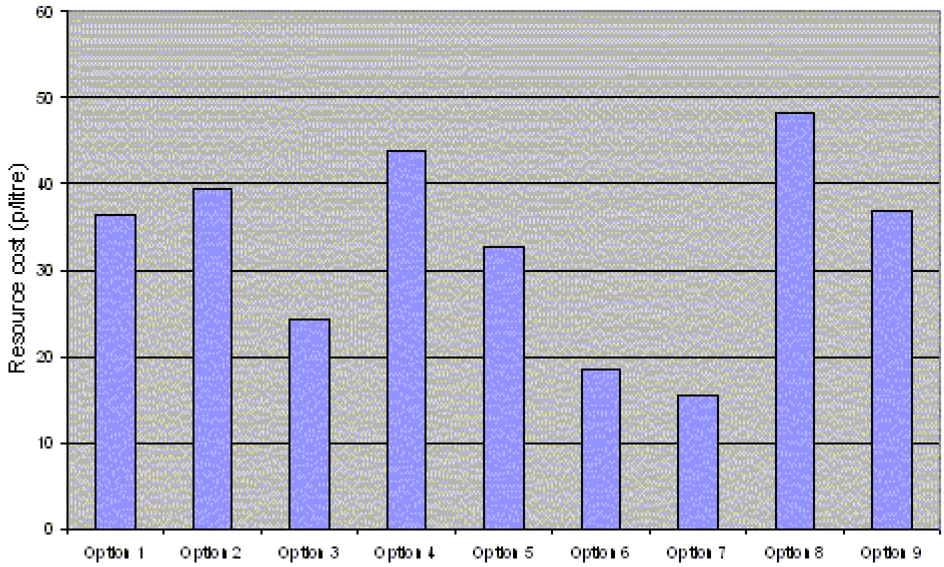


Figure 5.2: Estimated resource costs for 2002 in pence/litre



These results suggest that the lowest cost routes for bioethanol are to currently US corn and Brazilian sugar cane, which agrees with comments from stakeholders. None of the biofuel options are competitive with petrol and diesel on a pre-tax £/GJ basis.

Resource costs in 2020

Tables 5.3 and 5.4 give estimated resource costs in £/GJ and pence/litre respectively for 2020. Further information on these costs and the assumptions behind them is given in Sections 2-4 of this report.

Table 5.3: Estimated resource costs for 2020 in £/GJ

Option & Fuel type	Feedstock	Resource Cost £/GJ			
		US	EU15	Eastern Europe	South America
1. Biodiesel	Oil seeds	10.72	13.00	11.45	-
2. Biodiesel	Oil seeds - UK production	11.58	13.75	12.90	-
3. Bioethanol	Wood - Acid hydrolysis	11.49	12.01	11.63	-
4. Bioethanol	Straw - Acid hydrolysis	20.00	20.28	15.29	-
5. Bioethanol	Wheat	14.17	14.72	11.77	-
6. Bioethanol	Corn	8.15	8.40	7.07	-
7. Bioethanol	Sugar cane	7.88	-	-	6.65
8. Bioethanol	Sugar cane - UK production	27.82	-	-	22.94
9. Bioethanol	Sugar beet	16.95	17.33	14.81	-
10. Biodiesel	Wood - FT processing	6.49	6.55	5.40	-
11. Biodiesel	Straw - FT processing	6.49	6.55	5.40	-

12. Bioethanol	Wood - Enzymic hydrolysis	10.18	10.54	8.66	-
13. Bioethanol	Straw - Enzymic hydrolysis	10.18	10.54	8.66	-

Table 5.4: Estimated resource costs for 2020 in pence/litre

Option & Fuel type	Feedstock	Resource Cost p/litre			
		US	EU15	Eastern Europe	South America
1. Biodiesel	Oil seeds	36.12	43.81	38.59	-
2. Biodiesel	Oil seeds - UK production	39.03	46.34	43.47	-
3. Bioethanol	Wood - Acid hydrolysis	24.21	25.31	24.50	-
4. Bioethanol	Straw - Acid hydrolysis	42.12	42.73	32.21	-
5. Bioethanol	Wheat	29.85	31.02	24.81	-
6. Bioethanol	Corn	17.17	17.70	14.89	-
7. Bioethanol	Sugar cane	16.60	-	-	14.00
8. Bioethanol	Sugar cane - UK production	58.61	-	-	48.33
9. Bioethanol	Sugar beet	35.71	36.51	31.19	-
10. Biodiesel	Wood - FT processing	21.89	22.09	18.20	-
11. Biodiesel	Straw - FT processing	21.89	22.09	18.20	-
12. Bioethanol	Wood - Enzymic hydrolysis	21.45	22.19	18.24	-
13. Bioethanol	Straw - Enzymic hydrolysis	21.45	22.19	18.24	-

Discussion of Costs and Sensitivities

This section discusses the implications of the results presented in Section 4, explores their sensitivity to key parameters and considers the cost implications of blending biofuels with conventional fuels rather than distributing them separately.

Sensitivities to key parameters

Feedstock costs

As discussed in Section 3.2, it is very difficult to get accurate data on feedstock costs and equally difficult to relate feedstock costs to product costs. Based on the data in Table 3.5, a 10% increase in feedstock costs would generate a 3-27% increase in product cost, depending on the processing option. This in turn would increase resource costs by between 3% and 25%, or £0.57/GJ and £4.33/GJ.

Table 6.1: Sensitivity to feedstock costs

Option & Fuel type	Feedstock	% increase in product cost due to 10% increase in feedstock cost	% increase in resource cost due to 10% increase in feedstock cost	£/GJ increase in resource cost due to 10% increase in feedstock cost
1/2. Biodiesel	Oil seeds	23.0%	21.4%	2.27
3. Bioethanol	Wood acid hydrolysis	6.3%	5.7%	0.64
4. Bioethanol	Straw acid hydrolysis	2.9%	2.7%	0.57
5. Bioethanol	Wheat	7.5%	6.9%	1.07
6. Bioethanol	Corn	9.6%	8.4%	0.71
7/8. Bioethanol	Sugar cane	16.9%	14.3%	1.01
9. Bioethanol	Sugar beet	26.8%	24.8%	4.33

These results suggest that changes in feedstock cost would have a major effect on resource costs, particularly for biodiesel production from oil seeds and for bioethanol production from sugar beet.

Processing costs

Section 3.3 presented estimates of the proportion of product costs due to processing costs. Based on these estimates, we can explore sensitivities to a 10% increase in processing cost as shown in Table 6.2.

Table 6.2: Sensitivity to processing costs

Option & Fuel type	Feedstock	% increase in product cost due to 10% increase in processing cost	% increase in resource cost due to 10% increase in processing cost	£/GJ increase in resource cost due to 10% increase in processing cost	Option & Fuel type
1. Biodiesel	Oil seeds	2%	1.9%	0.20	1. Biodiesel
2. Biodiesel	Oil seeds - UK	2%	1.8%	0.20	2. Biodiesel
3. Bioethanol	Wood	6%	5.4%	0.61	3. Bioethanol

4. Bioethanol	Straw	6%	5.6%	1.17	4. Bioethanol
5. Bioethanol	Wheat	5%	4.6%	0.71	5. Bioethanol
6. Bioethanol	Corn	5%	4.4%	0.37	6. Bioethanol
7. Bioethanol	Sugar cane	2%	1.7%	0.12	7. Bioethanol
8. Bioethanol	Sugar cane UK	2%	1.9%	0.42	8. Bioethanol
9. Bioethanol	Sugar beet	3%	2.8%	0.48	9. Bioethanol

It is difficult to draw any firm conclusions from these results, except that biodiesel resource costs are generally less sensitive to processing costs than bioethanol resource costs.

Co-product values

As discussed in Section 3.4, there is very little information available from the literature on co-product values or credits, and these values will vary greatly over time, with scale of operation and between regions. Some information is available on co-product values for bioethanol from corn and from sugar cane, and this is used below to explore sensitivities.

Bioethanol from corn: Co-product values for this process are shown in Table 3.9. Based on these values, we can estimate the effect of a 10% increase in co-product as shown in Table 6.3. These results suggest that resource costs for this process are equally sensitive to processing costs and co-product values, and rather more sensitive to changes in feedstock costs.

Table 6.3: Sensitivity to co-product values for bioethanol from corn

	% reduction in product cost due to 10% increase in co-product value	**% reduction in resource cost due to 10% increase in co-product value**	**£/GJ reduction in product cost due to 10% increase in co-product value**
Wet milling process	5.1	4.4%	0.38
Dry milling process	3.2	2.8%	0.24

Bioethanol from sugar cane: About 1.2 kWh of electricity is generated per litre of ethanol produced from sugar cane, which equates to a co-product credit of about £2.28/GJ ethanol assuming a typical UK electricity price of 4 p/kWh. If this electricity price was to increase by 10% to 4.4 p/kWh then this would reduce the resource cost by £0.23/GJ or 2.7%. High volatility of electricity prices, particularly in regions such as South America, mean that fluctuations in co-product value could be very significant.

Import tariffs

The resource costs shown in Section 5 are pre-tax costs and so they do not include import tariffs. The applicable tariffs for biodiesel, bioethanol and intermediate products (oil seeds and raw sugar) are shown in Table 6.4. There are no import tariffs for products imported from EU countries. These tariffs were provided by the Customs & Excise telephone help line in early May 2003.

Table 6.4: Current import tariffs

Product imported	Country of origin	Tariff	Additional cost (£/GJ product)
Biodiesel	US	5.1%	0.53
Bioethanol	US	No tariff	0
Bioethanol	Brazil	No tariff	0
Rapeseed oil	US	3.2%	0.18 [1]
Soybean oil	US	3.2%	0.18 [1]
Raw sugar	Brazil	33.9 Euro/100kg	142.9

[1] Assuming feedstock price = 50% of total resource cost.

The tariff for biodiesel import from the US is not sufficiently high to tip the balance between US and EU supply options. The sum of resource costs and import tariffs would be £11.1/GJ and £13.9/GJ for the US and EU respectively, based on the tariff data in Table 6.4.

The figure for raw sugar is based on the import of sugar for foodstuffs as there is currently no import of raw sugar for bioethanol production and hence no agreed tariff. It is likely that a much lower tariff would be set for sugar for bioethanol production, but Customs & Excise were unable to speculate on this.

Regional processing and feedstock costs

Many of the resource costs for 2020 shown in Tables 5.3 and 5.4 were derived from assumed regional differences in processing costs and feedstock costs. For example, costs of producing bioethanol from wheat in Eastern Europe were estimated from EU costs assuming that feedstock costs were 20% lower and processing costs about 36% lower. The factors used to calculate these regional differences, shown in Section 3.2 and Table 3.8, were based on expert judgement and not on any authoritative economic forecasts. It is difficult to know how the economies of Eastern Europe will be affected by expansion of the European Union and to what extent their labour costs might increase as a result. As an indication of sensitivity to these assumptions, the cost of bioethanol from wheat produced in Eastern Europe would increase from £11.77/GJ to £13.98/GJ if we assumed instead that feedstock and processing costs were only 10% lower than EU costs.

Implications of blending

Biodiesel blending

Biodiesel may be used in blends with conventional diesel. This would reduce the cost associated with providing separate biodiesel storage and distribution facilities but it would not affect the resource costs shown in Section 5.

Bioethanol blending

Bioethanol may be used in blends with conventional gasoline. Bioethanol content of up to 5% can be introduced without any modification to vehicle engines or refuelling equipment. If bioethanol were to be introduced in this way, it may be possible to marginally reduce the cost of internal UK distribution of bioethanol, but the greater impact would be on the costs of supplying dedicated ethanol vehicles and refuelling infrastructure. These latter costs are not addressed in this study. Data provided by the

Department for Transport suggest that costs of transporting ethanol as part of an ethanol/gasoline blend may be between 0.5p/litre and 1.0p/litre cheaper than transporting the same ethanol separately. This would reduce the resource cost for ethanol by about 3.5-7% for bioethanol from sugar cane.

Wider Issues

This section briefly discusses some wider issues associated with biofuel production and use: resource constraints, agricultural subsidies and environmental impacts. The cost implications of such issues fall outside the scope of this study.

Resource constraints

The resource costs shown in Section 5 are based on the current availability of land for growing energy crops and current markets for co-products. If biofuel production is increased then this will put additional pressures on land availability, which could force prices up. In the short to medium term this is likely to be more of an issue for UK and EU grown crops where there is less available land and more competition from food production and urban development. It may also be more important for arable crops (wheat, corn, sugar) than woody crops as wood can be grown in less favourable soil and climatic conditions. Markets for co-products such as animal feeds could also become less valuable as a result of additional biofuel production.

Agricultural subsidies

Ongoing reform of the Common Agricultural Policy (CAP) is likely to affect the cost of biodiesel and bioethanol produced in the EU. Ten new regulations established in March 2000 after political agreement at the Council level and the conclusions of the Berlin Summit will reduce market support of prices for cereals in an attempt to bring farmers more into line with world prices. Cereals support was reduced from 119.19 Euro/tonne in 2000/2001 to 101.31 Euro/tonne in 2002/2003 but an accompanying increase in direct payments to farmers provided partial compensation for this reduction in support. Price reductions are likely to continue if market support is further reduced by CAP reform in connection with EU enlargement. It is not possible to predict the effects of future CAP reform as negotiations are ongoing.

Environmental impacts

Carbon dioxide and energy balance

An unpublished report by Imperial College for DTI (ICCEPT 2003) has suggested that some pathways to biodiesel and bioethanol have a negative or small positive energy ratio, as shown in Table 7.1. An energy ratio of less than 1.0 suggests that more energy is put into the process than is present in the biofuel product.

Table 7.1: Carbon balances for biofuel production (ICCEPT 2003)

Process	Energy ratio
Biodiesel from oil seeds	0.7 - 4.4
Biodiesel from FT processing of wood	18.1 - 44.3
Bioethanol from grain	0.9 - 2.6
Bioethanol from straw	0.8 - 2.4
Bioethanol from sugar beet	0.7 - 1.8

The ICCEPT report concludes that biodiesel and bioethanol routes are generally energy intensive and significantly favourable energy balances are only achieved when renewable fuels, mainly residues from the biomass resource used, are used to produce energy for the process, and when energy is allocated to co-products.

Another recent report for DTI by Sheffield Hallam University has examined carbon and energy balances for a range of alternative UK biofuel production routes. Their results for the process routes addressed in our report are summarised in Table 7.2.

Table 7.2: Carbon balances for biofuel production (Sheffield Hallam 2003)

Process	**Energy ratio**
Biodiesel from oil seeds	2.3
Bioethanol from acid hydrolysis of straw	5.6
Bioethanol from wheat	2.2
Bioethanol from sugar beet	2.0

The two sets of carbon balances in Tables 7.1 and 7.2 are quite different, reflecting differences in methodology and assumptions for the two studies.

Other environmental impacts

Biomass production is highly land-intensive and also requires nutrients and abundant water resources. The water requirements vary greatly but are typically between 300 and 1000 tonnes per tonne of dry biomass (IEA 1996).

A report from the European Environment Bureau (EEB 2002) has highlighted other environmental impacts associated with biofuel production such as N_2O emissions from fertiliser use, impacts on soil and groundwater quality, eutrophication or toxification of ecosystems through pesticide use, and reduction of biodiversity. These criticisms are mainly targeted at biofuels produced from agricultural products and there is likely to be less impact from wood-derived fuels.

Conclusions

The following conclusions can be drawn from this study.

1. 1. Currently, the lowest cost routes are to produce bioethanol from US corn or Brazilian sugar cane and to produce biodiesel from oil seeds in the US. These processes give resource costs of about £8.5/GJ and £7.0/GJ for bioethanol, respectively, and about £10.6/GJ for biodiesel. Process options which involve the importation of intermediate products (oil seeds or sugar concentrate) prior to processing in the UK are less cost-effective.
2. 2. None of the biofuel options addressed in this study are currently cost competitive with petrol or diesel on a pre-tax £/GJ basis. The lowest cost biofuel, bioethanol from Brazilian sugar cane, is about 40% more expensive than gasoline on an energy basis.
3. 3. By 2020, minimum costs of bioethanol are expected to fall by about 10% compared to 2002 values while biodiesel costs could fall by nearly 50% to about £6.3/GJ due to the development of a new process route based on Fischer-Tropsch technology.
4. 4. Resource costs are sensitive to changes in feedstock cost, processing cost and co-product value. For example, for bioethanol production from corn, a 10% change in each of these parameters is estimated to lead to changes of 8.4%, 4.4% and 4.4% respectively in the resource cost of ethanol produced.
5. 5. There are considerable uncertainties in the resource cost estimates and a more detailed, location-specific engineering study would be required to get a full understanding of the cost components for any particular process route.
6. 6. Import tariffs, which are not included in resource costs, would affect the cost of biodiesel imported from outside the EU, but only by about 5%. No import tariffs are applicable for bioethanol at present.
7. 7. Estimated resource costs inherently include subsidies for the production of agricultural crops, although they exclude subsidies on biofuel sales. The Common Agriculture Policy is currently being reviewed and agricultural subsidies are likely to reduce in future, thus increasing feedstock costs for many of the biofuel options considered in this report.
8. 8. Estimated resource costs are based on the current availability of land for growing energy crops and current markets for co-products. If biofuel production is increased then this will put additional pressures on land availability, which could force prices up. Markets for co-products such as animal feeds could also become less valuable as a result of additional biofuel production.

References

ACEA (2001). 2001 monitoring report of the ACEA Agreement on CO_2 reduction from new passenger cars.

Ahouissoussi, N & Wetzstein, M (2002) Life cycle cost of alternative fuels: Is Biodiesel cost competitive for Urban buses?

www.biodiesel.org/resources/reportsdatabase/reports/tra/19950901_tra-049.pdf

Australian Institute of energy (AIE) (2003) Typical Energy Content of Fossil and Biomass Fuels

http://www.aie.org.au/melb/material/resource/biofuel.htm

Bioenergy Chap.2 http://www.wws.princeton.edu/cgi-bin/byteserv.prl/~ota/disk1/1993/9337/933704.PDF

Biobase (2002) Economic Analysis of Production of the three most promising energy crops in Germany, University of Twente, http://btgs1.ct.utwente.nl.eeci/archive/biobase/B10568.html

BP Amoco (2001) Presentation on Crude Oil and Gas Transportation, available from http://reports.huginonline.com/797201/84587.pdf

Canadian Renewable Fuels Association, (2003) Energy Balance of Ethanol http://www.greenfuels.org/energybal.html

Carbon Trust (2002) Renewable Transport Fuels from Biomass, report by Future Energy Solutions

CEC (2000) European Commission Green Paper on the security of Energy Supply, CEC, Luxembourg

CEC (2001) European Commission Transport White Paper: "Transport for 2010: Time to decide" CEC, Luxembourg

CEC (2003) Biofuels - Market Barriers (Part of ATLAS website) http://europa.eu.int/comm/energy_transport/atlas/html/header_biodbarr.html

CEC (2003) Competitiveness of EU manufacturers (Part of ATLAS website) http://europa.eu.int/comm/energy_transport/atlas/html/header_biodcomp.html

CEC (2003) Current and Future deployment of Liquid Biofuels Worldwide http://europa.eu.int/comm/energy_transport/atlas/htmlu/lbpot2.html

Connemann, J & Fischer, J (1999) Biodiesel in Europe 2000, http://www.biodiesel.de/biodiesel2000.htm

CSIRO (2000) Life Cycle Emissions Analysis of Alternative Fuels for Heavy Vehicles, CSIRO Atmospheric Research Report C0411/1.1/F2 for the Australian Greenhouse Office, March 2000.

Dail Eireann (1955) Written Answers, Vol. 153 14/12/55 (Food product Energy Density)

DiPardo, J, (2000) Outlook for Biomass Ethanol Production and Demand http://www.eia.doe.gov/oiaf/analysispaper/biomass.html

DTI (2002) Digest of UK Energy Statistics 2002 (DUKES), DTI, London.

EBRD/FAO (1999) Agribusiness Handbooks Vol4. Sugar beets/White Sugar, http://www.fao.org/tc/tci/sectors/sugar.pdf

EEB (2002) European Environment Bureau position paper "Biofuels not as green as they sound", May 2002. Available from www.eeb.org.

EV World (2003) Biofuel may clean up as World Farm Prices flounder http://www.evworld.com/databases/shownews.cfm?pageid=news070502-01

Faaij, A, Hamelinck, C & Tijmensen M (2000) Long term perspectives for production of fuels from biomass: Integrated assessment and RD&D priorities - preliminary results, presented at the First World conference on Biomass for energy and industry Sevilla, Spain 5-9/6/2000

Faaij A et al (2001) The production of Fischer Tropsch liquids and power through Biomass gasification http://bioproducts-bioenergy.gov/pdfs/bcota/abstracts/28/z198.pdf

Fergusson M et al (2002) Fuelling Road Transport - Implications for Energy Policy Report for the Department for Transport
http://www.dft.gov.uk/stellent/groups/dft_roads/documents/page/dft_roads_507623.pdf

ICCEPT (2003). Technology Status Review and Carbon Abatement Potential of Renewable Transport Fuels (RTF) in the UK. Draft report to DTI Renewable Energy Programme. Imperial College, 2003.

IEA (1996) Automotive Fuels Survey - Raw Materials and Conversion. Report by INNAS for the IEA Alternative Motor Fuels Implementing Agreement, December 1996.

IEA (2002) Penetration of Alternative Fuels in the EU and Potential Impact on the Conventional Fuels Market, Fulton, L, IFQC European Automotive Fuels Briefing, Paris 21/11/2002

http://www.ifqc.org/

ITAPC (2002). Presentation by Edward Evans, International Trade and Policy Centre, University of Florida, May 2002.

Johanneson, R, (2002) Alcohol production from Biomass, Florida Energy Extension Service http://edis.ifas.ufl.edu/BODY_EH341

Luger E (1997) Energy crop species in Europe, BLT Weisenburg, Austria http://www.blt.bmlf.gv.at/vero/artikel/artik013/Energy_crop_species+.pdf

MCT (2003) Net Emissions for the Sugar Cane to Ethanol cycle, MCT, Brazil, http://www.mct.gov.br/clima/ingles/comunic_old/coperal2.htm

Minnesota Department of Agriculture (2002) Economic impact of Soy Diesel in Minnesota, www.mda.state.mn.us/AMS/ecoimpsoydiesel.html

NREL (1995) A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies NREL, Colorado

NREL (2000a) Bioethanol: Fuelling sustainable transportation http://www.eere.energy.gov/vehiclesandfuels/

NREL (2000b) Determining the Cost of Producing Ethanol from Corn

Starch and Lignocellulosic Feedstocks, Wooley et al NREL, Colorado http://www.afdc.doe.gov/pdfs/4898.pdf

NREL (2002) Presentation entitled "The Science and Technology of Turning Crops into Fuel-Current Programs, Status and Future Potential" by Ms. Cynthia Riley, Biofuels Technology Manager, National Renewable Energy Laboratory. Given at a CSIS conference on 20 June 2002. http://www.csis.org/tech/Biotech/other/Ebel.pdf

Oak Ridge National Laboratories (ORNL) (2003) Bioenergy Conversion Factors http://bioenergy.ornl.gov/papers/misc/energy_conv.html

Office for Technology Assessment (OTA), (1995) Renewing our energy future http://www.wws.princeton.edu/cgibin/byteserv.prl/~ota/disk1/1995/9552/955201.PDF

Ouwens C & Faaij A (2002) A comparison of production costs, and the market introduction of Fischer-Tropsch oil and Ethanol http://bioproducts-bioenergy.gov/pdfs/bcota/abstracts/28/z136.pdf

Reith et al (2002) Co-Production of Bio-ethanol, Electricity and Heat from Biomass Waste: Potential and R&D issues, ECN Biomass www.ecn.nl/library/reports/2001e/rx01011.html

Reith et al, (2002) Co-Production of Bio-ethanol, Electricity and Heat from Biomass Residues, ECN Biomass www.ecn.nl/library/reports/2002e/rx02030.html

*Ricardo (2002) "*Carbon to Hydrogen" Roadmaps for passenger cars: A study for the Department for Transport and The Department of Trade and Industry, December 2002.

Rickeard D & Thompson N (Esso Research Centre) (1993) A Review of the Potential for Bio-Fuel as Transportation Fuels, presented at SAE Exposition Philadelphia, October 1993

Ryan, B & Tiffany, D (1998) Energy Use in Minnesota Agriculture, Agricultural Economist 1998: Vol 2. http://www.extension.umn.edu/newsletters/ageconomist/components/ag237-693b.html

Sheffield Hallam (2003) Carbon and Energy Balances for a Range of Biofuels Options. Draft final report to the DTI, January 2003.

Sugartech (2003) Daily Sugar Prices (LIFFE and CSCE) http://www.sugartech.co.za/sugarprice/index.php

University of Leuven, (2002) Biotrans (EC Project Summary)

http://www.tmleuven.be/home.htm

USDA, (1998) USDA's 1998 Cost-of-Production survey Shapouri, H et al

Van Dyne D & Blasé M (1997) Estimated Volume and Energy Content of Biomass and Municipal Solid Waste Resources in Missouri, AEWP-1997-4 http://www.dnr.state.mo.us/energy/renewables/biomass.PDF

Verhoog, A (2002) Oilseed Production in the EU, Eurostat.

Wang, M, Saricks, C & Santini, D, (1999) Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions, Argonne National Laboratory,
WEC (2002a) Survey of Energy Resources - Wood http://www.worldenergy.org/wec-geis/publications/reports/ser/wood/wood.asp

WEC (2002b) Survey of Energy Resources - Wood http://www.worldenergy.org/wec-geis/publications/reports/ser/biomass/biomass.asp

Appendix 1: Stakeholders contacted

Discussions were carried out with the following stakeholders. Most discussions were conducted by telephone and ranged between 0.5 and 1.5 hours, but some interview questions were sent by e-mail where the respondent was unavailable for comment by telephone. Initial contact was also usually by e-mail, and so this method of contact is stated for most of the sources below, some sources also sent more detailed information after telephone interview by e-mail.

Name	Organisation	Type of contact
Jeremy Woods	Imperial College Centre for Energy Policy and Technology	Face to face, Telephone
Frank Rosillo-Calle	Imperial College Centre for Energy Policy and Technology	Telephone, E-mail
David Rickeard	Fuel Regulatory Affairs, ExxonMobil	Face to face, Telephone, E-mail, Fax
Björn Telenius	Swedish National Energy Administration, IEA Liquid Biofuels task Swedish representative	Telephone, E-mail
Anders Österman	Kemi information (Swedish Energy consultancy)	Telephone, E-mail
Don Stevens	Pacific Northwest National Laboratory, IEA Liquid Biofuels task leader	Telephone., E-mail, Mail
David Andress	US Department Of Energy	E-mail
Matthias Reichmuth	Institute for Energy and the Environment, Germany	E-mail
Huub Stassen	University of Twente, private biofuels involvement	Telephone, E-mail
Allan Bennett	Channel Tunnel Policy Director, Strategic Rail Authority	Telephone
Allen Marsden	Local government manager, English, Welsh and Scottish Railway	Telephone
John Bird	Petroleum Market Manager, English, Welsh and Scottish Railway	Telephone
Ausilio Bauen	Imperial College Centre for Energy Policy and Technology	Telephone, E-mail
Warren Mabee	University of British Columbia, linked to IEA Liquid Biofuels task	E-mail
Eric van Heuvel	IEA Liquid Biofuels Task, Dutch representative	E-mail, Telephone

Appendix 2: Potential for feedstock cost reduction

This Appendix presents further information on the potential for cost reduction for each feedstock: oil seeds, wood, straw, wheat, corn and sugar. This information was used in the development of the feedstock cost estimates shown in Section 3.2.

Oilseeds

Oilseeds are extensively produced in both the EU and the United States. In both cases, prices are distorted by subsidies and increases in oilseed production to supply biodiesel may threaten the economic sustainability of the current levels of subsidy. However, a number of factors may imply that the prices of these crops remain at or fall lower than present prices. Firstly, the EU common agricultural policy (CAP) allows the cultivation of energy crops on set aside land whilst still receiving set aside payments. This allows the use of land for which there is no competition with food production. Secondly, oilseed crops may be produced in Eastern European countries where labour costs are lower. The case of the accession countries to the European Union is particularly relevant here since there will be more of an open market between these countries and the U.K. once they are full EU members. At present it is very difficult to get cost data from these countries, it has been suggested that this is due to the fact that Eastern European production costs are much lower than for the rest of the EU but that this is not being revealed at the moment in order to avoid inflaming the sentiment of farmers in existing EU countries during accession negotiations. It should become clear in the next few years how competitive the Eastern European countries will be, and the extent to which CAP benefits are extended to these countries (the issue of subsidies is clearly crucial to crop prices in both the EU and the United States).

Genetically modified variants of oilseeds may produce further productivity increases; sources suggest around 10% increases, giving cost reductions of a similar order. However these gains maybe offset by cuts in producer subsidies.

Wood

Wood is extensively commercially produced, and the potential for cost reduction is centred on the use of short rotation woody crops grown specfically for use as biofuels (either to burn in CHP plants or to convert into liquid biofuels). Examples of such crops include willow short-rotation crop, for which present feedstock costs are given in Section 3. Another potential area for cost reduction relates to where the crop is grown. Firstly, as for oilseeds, the country source could be changed to Eastern Europe (instead of Scandinavia, for example) where labour costs are lower, and the market prce for wood is likely to be lower due to less demand for wood in CHP plant. Secondly, set aside land could be used as for oil seeds.

A further potential for costs reduction lies in the use of woody forestry wastes to produce liquid biofuels. The major source here, however, is the US and Canada, since in Scandinavia, the main wood-producing area in Europe, most forestry waste is already burnt in CHP plants. The market for woody residues is localised though (in some areas residues are already used) and so this is unlikely to be a raw material source that is available in sufficient quantity to give extensive economy of scale benefits, but it could provide some diversity of supply.

Straw

Straw is waste product from crop production, and therefore is availability is partly related to levels of crop productivity, which may indeed be increased by genetic modification. However, straw is subject to substantial regional price fluctuations - in some areas it is high demand due to use as animal feed and bedding (it is similar to woody residues in this respect). Therefore, large-scale straw to ethanol production is unlikely due to the localisation of straw markets. In addition, as a waste product, crops will not be grown simply in order to produce straw for ethanol, unless the crop is also used for producing ethanol. Some sources have suggested that such combined production, for example producing ethanol from wheat and straw on the same site, could be very efficient and offer a very competitive price. There would be a need for separate fermentation units for both the crop and straw, but there would only be a need for a single stream distillation unit in order to concentrate the dilute ethanol solution produced to a concentration suitable for transportation usage. Therefore reductions in the cost of production of straw feedstock may come about from changes in the approach to ethanol production, rather than improved process efficiencies. This is discussed further in Appendix 3, in relation to ethanol production from combined corn stover and corn cob processing plants.

Wheat

Stakeholders agreed that the cost of wheat was unlikely to decline significantly in the period to 2020 in Western Europe or the US. However, two source areas appear to be of interest in reducing the cost of this feedstock. A US stakeholder flagged the importance of Canadian production, but costs were not available for this. However, a Swedish stakeholder pointed also out the importance of the Eastern Europe market. At present Eastern European crop prices are difficult to obtain; this appears to be due to be partly due to the fact that costs were not available in the Soviet era and the agricultural sector is still experiencing the transition from this period to market capitalism. In addition, one source suggested that crop prices were being concealed by the accession countries to the European Union in order to prevent inflaming the sensitivities of western European farmers who fear being undercut by Eastern Europe. As for oilseeds, genetic modification may provide productivity gains of around 10% by 2020, but again a subsidy cut may offset these gains.

Corn

Corn is most extensively cultivated in the US where there is little potential for substantial cost production. Some genetic modification has already been implemented in this market so there is little potential in deriving cost reduction by GM-influenced productivity improvements. The Eastern European source may have some potential to reduce costs, but reduced labour costs in Eastern Europe may be offset by the advantages of a more favourable climate in the US. Therefore it would appear that substantial cost reductions for this source are only likely to derive from reductions in the cost of processing.

Sugar

Raw sugar is traded on the open market through the New York Coffee, Sugar and Cocoa exchange (CSCE), where it is known as the No11 contract and is traded in US cents per lb (Sugartech 2003). As it is an agricultural product and a traded commodity, sugar prices fluctuate from year to year due to market conditions and harvests. Figure A1 shows trends in raw sugar prices in the US and world markets over the last decade.

Enormous improvements have already been made in improving sugarcane productivity on a basis of tonne per hectare yields. The most efficient Brazilian plantations now achieve 80-100 tonnes per hectare per year, providing up to 8,000 litres of ethanol (stakeholder source). It is likely that further productivity gains for this crop will only be in small increments

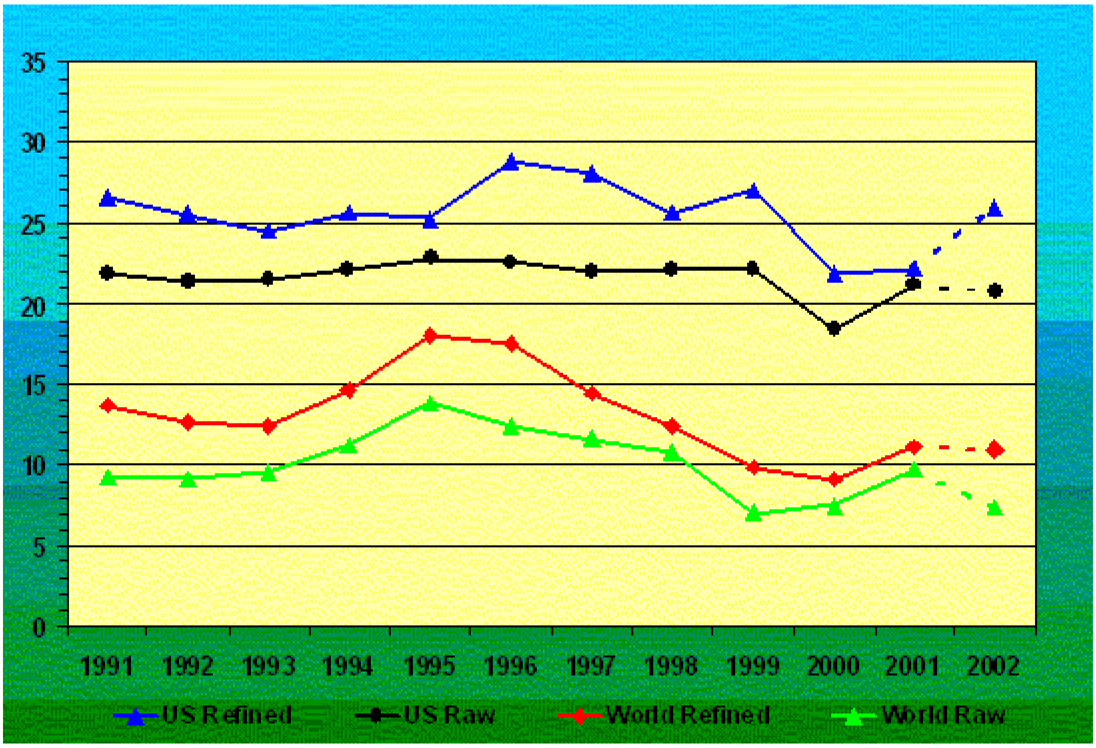


Figure A1: Trends in raw sugar prices, cents/lb, 1991-2001 [ITAPC 2002]

Sugar beet is also mature in terms of development, and further productivity gains would imply the use of more energy in growing the crop; it is already one of the most energy intensive crops to grow. Further productivity gains would therefore be countered by additional expense, which could rule out most, if not all benefits from productivity gains.

Appendix 3: Potential for production cost reduction

This Appendix presents further information on the potential for cost reduction for each biodiesel and bioethanol production route. This information was used in the development of the production cost estimates shown in Section 3.1.

Options 1 and 2: Biodiesel From Oilseeds

Producing biodiesel from oilseeds is the simplest of all the production chains, and the processing costs are therefore some of the cheapest (though specific figures are unavailable processing costs are assumed to be around 20% of overall product cost). The process is well established in several US states, particularly Minnesota, and there is substantial production in the EU, especially in Germany. The main cost is that of the methanol necessary for the esterification process. Filtering is necessary to remove the glycerine co-product, but this is a useful substance which can be sold to soap manufacturers. One stakeholder has suggested that the market for this glycerine co-product is fairly unlimited. Therefore, the problem common to some of the other production routes - that a co-product is produced for which there is only a limited market that would soon become saturated if production were increased - may note be true of the oilseed to biodiesel route. Given the simplicity of this process, capital expenditure on production plant is low compared to the other biofuel production routes. The maturity of the process implies little potential for further cost reduction.

Options 3 And 4: Bioethanol From Wood or Straw using Acid Hydrolysis

This process is under experimental testing in several countries, but only a few countries, including Sweden, are using it for the large-scale production of ethanol. In the case of Sweden, it is used for the production of ethanol to run buses for the Stockholm Transportation agency. The cost of the acid is a major consideration, but a greater issue is the equipment and reagents required to remove the acid before the fermentation process. A further cost is the cultures required for the conversion of the C5 and C6 sugars to alcohol. The process has relative low levels of productivity - partly due to the lack of efficiency in the fermentation of C5 sugars, and this further pushes up costs. Improving the efficiency of his fermentation process could bring about considerable increases in the efficiency of the process, but the problems and costs entailed by the use of acids for the hydrolysis process are inevitable, and therefore the enzymic hydrolysis route may be the only route to lower costs in the medium term for a lignocellulosic route to ethanol.

Option 5: Bioethanol From Wheat

This is a well-established process, not for the production of bioethanol for transport, but due to experience in the production of alcoholic beverages. However, it is an expensive and energy intense processes. The issue of C5 sugar fermentation, however, does not apply to this chain, but the costs of fermentation remains high and there is little chance of these costs being reduced. High-energy costs derive from the high temperatures used, including within the final distillation process to produce pure ethanol from the fermentation liquor. These energy costs could be reduced by the use of CHP plant, providing heat and electricity for the plant and additional electricity to export to the grid. CHP plants are already used at some breweries (CHPA 2001), but it is possible that further cost reductions could be derived by burning wheat residue (husks) in the CHP boiler, thereby making use of a low value by-product of the process. In summary, there is little potential for reduction in costs through improving process efficiency but some cost savings could be made in energy costs.

Option 6: Bioethanol From Corn

This is another well-established process with little apparent potential for cost reduction. With many of the other production chains, some of the potential to reduce costs may appear to possible by increasing scale, but the well-established corn to ethanol industry in the United States indicates a problem with this assumption. The cost of producing ethanol from corn in the US is in fact cheapest in medium size plants, and not large plants. This is due to lower feedstock costs for the medium sized plants, presumably because the sites of harvesting are closer and therefore feedstock distribution costs are higher. Although it must be considered that the distribution to retailers may be lower from a smaller number of larger scale plants, the lower energy density by weight of the feedstock compared to the ethanol output implies that more effort should be made to reduce feedstock distribution costs rather than the ethanol distribution cost.

Some figures were available on specific elements of operating costs for corn to ethanol plants (USDA 2002). These give an interesting comparison between the economics of wet and dry milling plants, indicating that while wet plants use less energy - £0.88/GJ product compared to £1.03/GJ, dry milling plants have lower labour costs at £0.86/GJ compared to £0.98GJ. Other costs to the two types of plant - management, administration, insurance and tax are fairly similar - at £0.30/GJ and £0.29/GJ for wet and dry mill plants respectively. Feedstock costs are also lower for wet mill plants. Capital recovery costs for each type of plant are the same, at £1.50/GJ ethanol produced. Although the labour costs are higher for wet mill plants, stakeholders suggested that this was due to a higher cost per unit of labour than for dry mill rather than the use of more units of labour. Therefore a reduction in the unit cost for wet mill plants could equate the costs for these two types of plant. There may be some potential for reduction in costs by using by-products to provide energy for the plants by CHP systems - some existing plants use inefficient coal-burning units to heat the plants. Processing cost reductions of the order of 20% may therefore be possible.

Options 7, 8 & 9: Bioethanol From Sugar Cane or Sugar Beet

The sugarcane to ethanol route is commercially mature in Brazil, and with the latest, most efficient plants, there is little potential for reductions in processing cost. The latest plants produce up to 80 litres of ethanol and 100kWh of electricity from the processing of 1 tonne of cane. The electricity is largely derived from the burning of the bagasse which also produces heat used for the fermentation and distillation processes in the plant (the heat can also be exported to district heating systems, though there is clearly much lower demand for heat in Brazil than in Europe and Northern America. Any fall in Brazilian costs may derive from an increase in the value of the electricity co-product - the value is higher in drought years when Brazil's hydroelectric capacity is constrained; this is, however, highly unpredictable (stakeholder comment).

Any UK processing plant would be unlikely to produce this heat output since it would only be fermenting raw sugar or cane juice and not burning bagasse (the economics associated with the importation of the whole cane, which has a low energy density, appear highly unfavourable). Indeed the feedstock costs table in Section 3.2 shows that ethanol produced from imported sugar would been much more costly than ethanol imported from Brazil, even excluding the higher distribution costs, as ethanol output would be less than half of the weight of the imported raw sugar. The figure in the table assumes the same production costs as in Brazil - but this is highly unlikely given higher labour costs, less experience in production and the lack of availability of a cheap co-product (bagasse) to provide heat to the plant and electricity to sell to the grid. In summary, the sugar importation route for UK conversion to ethanol does not appear to be economically viable.

Options 10 & 11: Biodiesel from Wood or Straw Using Gasification And Fischer-Tropsch (2020 only)

The processing costs of this route are highly unpredictable given that it is not been demonstrated as yet. The predictions provided for 2020 given by Faiij et al (2000) make many assumptions about volumes of production and do not appear to include capital recovery, and are therefore likely to be an underestimate of real cost. Production by this route is complex, and therefore initial capital costs are high. The process equipment includes a gasification module, a syngas filtering system (biofuel syngas would rapidly clog the system without filtering), the Fischer-Tropsch reactor itself and a final refinery stage. This final stage is a constraint to the use of the process as refineries are usually only constructed on a very large scale. The refinery process yields some high value co-product such as waxes. Indeed though the liquid product produced by the F-T reactor can be up to 80% biodiesel, one stakeholder commented that it would be preferred to give a lower yield of biodiesel in order to maximise the production of valuable co-products.

This necessary scale of operation does not integrate well with the wide distribution of the bulky feedstocks - indeed feedstock transport costs could be very significant. However, the biomass can be pyrolysed before transport to a tar with an energy density of around 20 GJ/tonne (compared to less than 10-15 GJ/tonne for wood), and which is also 2.5 times less bulky than wood for the equivalent energy content. This would reduce transport costs and allow the use of cheap, decentralised biomass from many sources, and central F-T plant benefiting from economies of scale (the tar would be the feedstock to this plant). It is very difficult to make cost predictions for this process and indeed Faaij (2000) study is one of the few that attempts to do so, although it does not assume the use of pyrolysis.

Options 12 & 13: Bioethanol from Wood or Straw by Enzymic Hydrolysis and Fermentation (2020 only)

This process is only established on an experimental basis implying that future processing costs are both unpredictable but also likely to be considerably lower than present provisional costs. The major component with potential forecast reductions is the enzymes used for the hydrolysis process. Some sources predict that this process will at least become competitive with the wood/ straw acid hydrolysis route - the enzymic route avoids the need for complex equipment to remove the acid. Indeed it may place acid hydrolysis. However, neither of these two routes are likely to become competitively in the short term due to the overall complexity of converting a lignocellulosic feedstock to sugars and the low ethanol yield achieved through the fermentation of C5 sugars. Genetically modified bacteria may provide potential for improving C5 sugar fermentation, but this is unpredictable.