THE IMPACTS OF CREATING A DOMESTIC UK BIOETHANOL INDUSTRY

A REPORT FOR
EAST OF ENGLAND DEVELOPMENT AGENCY

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EXECUTIVE SUMMARY

Introduction

The recent UK Energy White Paper[1] has highlighted the need for climate change objectives to be achieved through the energy system. Transport is a key sector, being responsible for around 25% of UK emissions of greenhouse gases. Transport is almost totally dependent on petroleum products, and whilst the White Paper envisages no immediate strategic risk for oil supplies to the UK, it recommends more focus on greater vehicle efficiency and alternative transport fuels as part of the move to a low carbon economy. At present, fuel diversity is constrained in the transport sector, and in the long-term resource depletion could pose a security of supply problem.

In the immediate future transport-induced CO_2 emissions may be cut from the adoption of technologically mature alternative fuels such as bio-diesel or bioethanol. Technologically immature innovations (such as fuel cells and hydrogen fuel) offer greater reductions in the future but are unable to contribute currently. The production of bioethanol consists of the fermentation of plant materials that are rich in sugar or starch with additional hydrolysis steps enabling fermentation of forestry and cellulose-based wastes. The potential long-term benefits of bioethanol in transport applications are:

- It is a proven technology, with opportunities to utilise crops, forestry and ligno-celullosic waste streams;
- it offers an alternative pathway to a low carbon economy, which could be developed in parallel with renewable electricity and could deliver low carbon road fuels more quickly;
- bioethanol is more easily distributed than hydrogen fuels, because it can readily be transported by road tanker. If required as a feedstock for hydrogen fuel cells, bioethanol can be reformed into hydrogen at the filling station or by reformers on-board the vehicles;
- bioethanol can also be used directly in internal combustion engines, and hence can be an insurance policy if fuel cells prove too expensive or technically difficult to develop into mass market applications;
- finally, bioethanol offers the potential of an energy-efficient and secure fuel supply system, which could make use of UK agricultural land.

However, production costs of bioethanol are greater than those of gasoline. The European Commission has proposed that Member States have indicative targets on the use of biofuels in transport, but in order to achieve a significant level of bioethanol uptake would require considerable fiscal or other incentives. There are various policy measures that could be adopted, including duty cuts in favour of bioethanol, specifying a minimum blend of bioethanol through legislation, and formalised voluntary agreements with fuel producers and suppliers. The benefits and policy costs of these measures need to be more fully understood. If these incentives are applied as an excise duty cut, how much of that excise duty is lost to from the National economy? How much is recycled into other sectors which are themselves then taxed? Since this report was commissioned, the Chancellor of the Exchequer, in his pre-budget statement in November 2002, announced a 20 pence/litre excise duty reduction for bio-ethanol (compared with the fuel duty rate for sulphur-free gasoline). The 2003 Budget

[1] "Our common future – creating a low carbon economy", Department of Trade and Industry, February 2003.

has confirmed this fuel duty reduction, with the plan to introduce it on 1 January 2005. Would such an incentive be sufficient to stimulate the development of a bio-ethanol industry in the UK?

Private sector interests are also involved in assessing the potential for developing a bioethanol industry. These private sector interests cover the fuel/vehicle supply chain, and comprise: fuel producers, fuel suppliers, vehicle manufacturers, transport service companies, research organisations, the agricultural industry, finance providers and end-users. Some of these organisations have proposed that a 25-30 pence/litre excise duty cut would be needed to maintain price parity at the fuel pump and render the production of bio-ethanol economic. Would any duty cut promote a UK industry or simply open up the marketplace to imported, less expensive bioethanol from overseas? How might market support be structured to prevent that?

The key issues that have been assessed in this study are:

- What are the most attractive technical routes and crops for bioethanol production in the UK?

- What are the characteristics of the bioethanol supply chain?

- How does the production, processing and distribution costs of bioethanol compare with conventional transport fuels?

- What are the macro-economic impact, the impact on employment and the impact on the Treasury of bioethanol as compared with conventional transport fuels?

- What are the economic development benefits for the agricultural sector and rural communities?

- What are the environmental impacts in terms of climate change mitigation, air quality, landscape changes and biodiversity?

- What are the effects on North Sea oil depletion and gasoline prices?

- What are the impacts on specific sectors of the economy?

- What are the risks of imports of fuel or feedstock to a UK bioethanol industry?

- What are the regional impacts in the East of England?

It is assumed throughout this study that bioethanol will be blended into gasoline at a 5% wt concentration, and that the blended fuel will be sold via conventional retail distributors into the transport fuels market. This level of blending should pose no performance or technical problems to modern car engines, and is taken to be within the warranty conditions of the car manufacturers. Higher concentrations levels, certainly those above 15-20%, could give problems unless the engine is specially modified or designed to operate on such bioethanol/gasoline mixtures.

<u>Immediate prospects</u>

Sugar beet and starch crops such as wheat are available as feedstocks for use in proven mature technology routes to bioethanol production, and facilities using these routes could be built within a 1-2 year time frame. The retail costs of bioethanol from these feedstocks are in the range between 38-42 p/litre, dependent on feedstock and the conversion plant capacity. In order to make bioethanol competitive with current retail gasoline prices, a fuel duty reduction of around 24 p/litre would be needed for wheat feedstock produced in a 100,000 t/year production facility[2]. This level of fuel duty reduction would need to be guaranteed for the 15-year lifetime of the plant. If later plant were of larger capacity, the fuel duty rebate could be less, at around 20 p/litre, but it would still be necessary for the rebate to be guaranteed for the 15-year lifetime.

A UK bioethanol industry using currently available conversion technology and sugar and starch crops as feedstocks can offer economic development benefits for the agricultural sector and rural communities. However, the industry will require active financial stimulation and encouragement by central and regional government, with RDAs working in partnership with other public and private sector interests. There should also be sufficient government incentives, perhaps in the form of fuel duty reductions and/or capital grants, for commercial investments to go ahead.

The development of a UK bioethanol industry would also require process plant suppliers to gear up to design and build the required conversion facilities, and hence there might need to be involvement by RDAs in helping to stimulate the supply chain for this process industry.

Longer-term prospects

A variety of ligno-cellulosic feedstocks require demonstration of conversion technologies at the pilot and commercial scales, and it is unlikely that a facility could be built to compete on an economic basis with sugar beet or starch crops commercially for several years to come. In addition to fuel excise duty cuts of greater than 24 p/litre, ligno-cellulose processing would require significantly more support, perhaps in the form of capital subsidies, to enable it to compete with fossil derived gasoline. Nevertheless in the medium term – perhaps within 4-5 years - the first generation of ligno-cellulosic conversion facilities using wheat straw feedstocks could be in operation on a demonstration scale in the UK, and the technology routes involved offer the prospect of economic competitiveness with conventional sugar and starch conversion. In the longer term, of 10-12 years, other ligno-cellulosic feedstocks could be introduced into second generation conversion facilities, assuming that the capital and operating costs can be reduced through R&D and technology development.

Using Monte-Carlo based probability analysis the comparative potential economic returns were investigated for starch/sugar versus ligno-cellulose processing. The assumption was that both processing technologies would be able to produce 1.2 million tonnes annually by 2015. For ligno-cellulose there would be a significant lag period whilst R&D and demonstration was carried out, during which time the cost of production would be higher. The work indicated that the significant investment in R&D is warranted, since lower production costs/ litre of bioethanol could be achieved in the longer term, but that significant risks of failure do exist. Demonstration projects and R&D should be supported in order to help the industry develop the necessary technologies and processes.

Climate change mitigation

Bioethanol has the potential to reduce net emissions of greenhouse gases from the transport sector. The actual climate change benefits depend on the feedstock used, and the resulting

[2] Using capital and operating costs for production plant of capacities between 100kt/year and 300kt/year and with a 15 year life.

costs also vary over a wide range. The public costs of climate change mitigation (calculated as the net costs to the Treasury of reduced fuel duty revenues, offset by lower job seekers' allowances and increased company taxes) are around £140-160/t CO_2-equivalent for sugar beet and wheat, and between £190-360/t CO_2-equivalent for wheat straw and short rotation coppice/forestry. Relatively modest greenhouse gas reductions have been indicated for the sugar and starch crop feedstocks, but there are much more significant reductions available for ligno-cellulosic feedstocks. Hence a UK bioethanol industry that makes use of ligno-cellulosic feedstocks could represent a viable low carbon option that provides a renewable transport fuel. However, the cost-effectiveness of this option is crucial in determining whether it is in the national interest to develop and deploy the relevant technologies.

Other environmental benefits

As a gasoline fuel extender, bioethanol provides few air quality benefits, other than a reduction in carbon monoxide levels from older car engines. Nitrogen oxide emissions are not significantly influenced, but some tests have indicated that fuel consumption can be improved. For the purposes of this assessment, it was assumed that bioethanol would not have any major positive or negative effects on air quality, compared with conventional and forthcoming internal combustion engine technologies using gasoline fuels.

Methods of support

Support for bioethanol production could come in the following forms:

- Purely from excise duty cut for the duration of the processing plant's life (set in this study at 15 years)
- Excise duty cut capped at 20pence per litre with additional support in the form of capital grants in order to offset (some of) the initial expenditure on bioethanol processing infrastructure. The level of capital grant would be varied in order to accommodate different technologies;
- A Transport Fuels Obligation applied to all UK fuel suppliers under which they are required to supply a minimum percentage of bioethanol fuel ;
- A combination of capital grant and staged excise duty cuts which decline through time, to zero after fifteen years, (whilst still maintaining a 15 year guarantee for each successive reduction) thus minimising the overall cost to the exchequer.

The study compared the relative costs (to the Treasury) of enabling price parity at the petrol pump for bioethanol and unleaded gasoline by either excise duty cut or capital grant, or by a combination of the two. A capital subsidy of £300 million would save the Treasury £50 million annually in excise duty cuts.

A multi-criteria assessment of various implementation strategies for stimulating the market for bioethanol was also undertaken. One implementation strategy is a combination of fuel duty reductions in favour of bioethanol blends and Government subsidies for the capital investment required for the feedstock conversion plant. From the Government point of view, however, a Transport Fuels Obligation would be the optimum strategy, since although this would require administrative effort in setting up and verification, there is a high level of certainty that the targets would be met.

Feedstock supply

England and Wales have sufficient sugar starch and ligno-cellulose resources in which to meet the EUs Transport Fuel Directive (5.75% renewable transport fuels by 2010). Under the current cropping regime this would most likely come from a mixture of industrial cropping on set-aside and diversion of grain from export markets to indigenous bio-ethanol production. The Mid Term Review of the Common Agricultural Policy will remove area –based payments and may expose cereal growers to greater market volatility. Decoupled aid payments and the need for environmental cross compliance may favour the development of longer-term supply contracts. Sugar beet quotas are set to fall, with again indications of a long-term policy aim of lower prices and more exposure to world markets. Sugar beet grown for bioethanol production is likely to be processed to sugar rich juice and as such circumvent the culinary sugar quota system. Indications are that a price per tonne of £18-20 will be paid. In the most favourable location in the East of England a 100,000 t ethanol processing plant would require 38,000 hectares of land. (A proportion of this land would be set-aside).

To meet 5.75% of our projected unleaded demand by 2010 would require approximately 13 such processing plants if all were to be met by sugar and starch crops.

Ligno-cellulose waste streams offer longer term low cost feedstocks, but their cost must not be underestimated. Currently, collection, separation, screening and shredding render waste paper feedstocks relatively expensive. UK waste directives will be essential to promoting such waste materials as a viable alternative once conversion technologies for ligno-cellulose are mature.

North Sea oil depletion

The effects on North Sea oil depletion and gasoline prices are likely to be relatively minor, since and reduction in UK demand will mean that crude oil or refined petroleum products will be diverted from UK markets to international trade. Moreover, oil prices are determined largely by international markets, so that any bioethanol production in the UK would not markedly affect these prices.

Economic, institutional and technical Barriers

The main economic, institutional and technical barriers to the market development and up-take of bioethanol as a transport fuel are:

- The overall production costs for all feedstocks are higher than the production costs of gasoline. The least expensive conversion process, namely for sugar beet and starch crops, are commercially available now, but investors and project developers need to be assured that the retail prices for the consumer will be competitive with gasoline. This will require Government action, in the form of fuel duty reductions in favour of bioethanol and/or in the form of other support such as investment subsidies;

- Ligno-cellulosic feedstocks are still at an early stage of development, and capital and operating costs need to be reduced through R&D and technology development before they can compete with sugar and starch crops. This might also require Government support, perhaps through funding specific R&D and demonstration projects;

- Production of most feedstocks is heavily influenced by area aid and other EU mechanisms. The Mid-Term Review of the Common Agriculture Policy, the GATT and WTO trade agreements and national mechanisms such as landfill tax will all exert a significant effect on feedstock production costs, and type of feedstock utilised;

- The agricultural sector and project developers are keen to see the potential for bioethanol taken up, but the major UK oil companies will also need to be convinced that the product is worth developing for the road fuels market;

- The Government also needs to be convinced that encouragement of a bioethanol industry is a viable and long term option for the UK transport fuels market, and that bioethanol has a role to play in the Climate Change Programme.

- The Treasury has a key role to play by ensuring that any fiscal incentives are provided on a guaranteed timescale of fifteen years or more to enable investor confidence.

Multi-criteria presentation

The national impacts of a UK bioethanol industry can be summarised in a multi-criteria presentation. There are several competing policy issues involved in developing such an industry, each of which has economic, environmental and social features. The main policy issues are:

- the overall cost of bioethanol;
- the level of added value for the national economy (i.e. the contribution to national GDP);
- the extent of the net financial costs to the Treasury.
- the extent to which rural economic development can be enhanced by a bioethanol industry;
- the additional employment in the main sectors of agriculture, feedstock conversion, fuel supply and distribution and in the manufacturing sector;
- the levels of greenhouse gas avoidance available by substituting bioethanol for gasoline, and the cost-effectiveness of public support within the Climate Change programme objectives;

The Table below provides a summary of these impacts in a qualified manner for selected bioethanol production routes in comparison with gasoline.

MULTI-CRITERIA PRESENTATION OF IMPACTS FOR UK SOURCED FEEDSTOCKS

	Bioethanol			Gasoline
	Set aside crops		Existing crops*	
	Wheat/sugar beet	Ligno-cell		
Fuel cost	Expensive	Very Expensive	Expensive	Cheap
Value added to UK economy	High	Moderate - Low	Low	Moderate
Additional employment	Good	Good	Moderate	Low
Impact on the Treasury	Moderate	Poor	Moderate	Good
Greenhouse gas avoidance	Good	Very good	Good	No
Cost of greenhouse gas avoidance	Moderate	Moderate	Moderate	N/a

* There may also be additional costs due to changes in land-use and land values.

Bioethanol imports

At present, there is little or no international trade in bioethanol. However, the increased production and utilisation of bioethanol could encourage the development of international trade. One benefit of international trade would be that it could act as a market stabilisation mechanism in the event of regional production shortfalls. If liquid biofuels in general become more acceptable in the transport markets, it can be expected that international trade, at least in the form of trade between EU partners, might grow in importance.

A competitive assessment of bioethanol imports-v-UK production was carried out, using the potential imports of bioethanol from the sugar cane conversion industry in Brazil. Brazil was chosen because it is the largest producer of bioethanol, and has a well-established industry, although there is little export of bioethanol from Brazil at the present time. Furthermore it should be noted that the Brazilian bioethanol industry has received considerable subsidies and government funds over the last 15-20 years, so that the true economic costs of Brazilian bioethanol production are difficult to identify.

Brazilian production costs were calculated as 18-22 p/litre, and total transport costs around 3.5-6 p/litre. These calculations indicated that the landed cost of bioethanol produced in Brazil and transported to the UK would be between 22-28 p/litre at the port of delivery. To these costs would need to be added the UK blending and retail distribution costs. Hence the imported bioethanol costs are around as much as 10 p/litre lower than the costs for bioethanol produced from UK sugar beet and wheat. However, if the current EU import duty of 6-7 p/litre on denatured ethanol were to be imposed on the Brazilian bioethanol, then the cost of the imported product would be broadly similar to, or slightly cheaper than, the UK production.

Imports would have a low impact on the value added to the UK economy, and on UK employment. There would be an overall net impact to the Treasury, since there would be revenues from the import duty, as well as fuel duty, although there would be no reduction in job seekers' allowance and revenues from other taxes.

<u>Regional Issues</u>

The location of the most suitable catchment positions for starch/sugar and ligno-cellulose processing facilities were identified using a GIS-based model written specifically for this report. Position of processing facility was seen to be very sensitive to a) tonnage required and b) catchment density of product secured. At a national level, 100kt bioethanol/year facilities producing equal quantities of bioethanol from sugar beet and wheat grain (enabling seasonality of supply) are feasible. Based on current cropping, and with the initial assumption that 10% of crops are diverted into the bioethanol facility, the optimally located facility would require a catchment of 24,344 km^2. This would secure 15,578 ha and 22,718 ha of sugar beet and wheat, respectively. The location of this processing plant would be in Norfolk. Successive processing facilities would require greater catchments and would move into areas of more sparse crop coverage. These crop availability figures are based on current non-set-aside cropping. Clearly, the advent of a processing plant would increase set-aside utilisation and the proportion of cropped area in the immediate vicinity that is diverted to the bioethanol plant. However, in terms of identifying the most appropriate location and the regional economic impacts, the scenario is robust. At an inclusion rate of 10% there is insufficient sugar beet grown to provide half of the feedstock needed for a 250kt/yr bioethanol facility. The national Input-Output tables were scaled to provide a regional equivalent, based in the East of England catchment, in order to study regionalised effects. A regionally-based 100kt bioethanol facility was determined to provide an additional £17.8 million into the regional 'GDP', one third of which was in the agriculture sector (compared to 40% at a national level). Regional processing facilities were determined to, potentially, provide significant sources of additional labour, particularly in the agriculture sector. The absolute number of jobs created will depend on the proportion of long-term set-aside land that is put into industrial crop production as a result of the creation of the market demand.

The scenarios presented in this work represent the full range of future options, i.e.

A succession of systems based upon crops, or
A succession of systems based on the gradual development of ligno-cellulose based systems following an initial crop-based industry.

In the former case the 1.2 million tonnes of bioethanol produced annually could be delivered either from the current export surplus or wheat grain, or by cropping approximately 500,000 hectares for bioethanol.

For the latter scenario, the work also considered the most appropriate location for mixed crop/forestry/waste and waste only facilities. The wastes considered in detail were cereal straw and cellulose-based refuse. Mixed systems are best located in the south east, since domestic waste arisings are linked closely to population density and straw arisings are highest in Cambs/Lincs and the south east. A 100kt bioethanol/yr plant processing waste streams would require a catchment area of only 1,200 km^2 if based near London.

CREATING A BIOETHANOL INDUSTRY

The production of bioethanol for transport offers a challenging opportunity to the UK. It would require the agricultural sector to engage with the transport fuels market in a manner that has not been undertaken in the past. It would address several of the Government's environmental, economic and social objectives, by helping to tackle climate change, stimulating the development of a new UK industry, and supporting rural communities in diversifying from traditional crop production. Technically mature routes to production using wheat and sugar-based crops are currently available, with the prospect of more advanced processes using ligno-cellulosic feedstocks becoming available in the next 5-10 years.

One wheat/sugar beet bioethanol plant of 100kt/year capacity would:-

- require a capital investment of around £50-£60M and produce 127M litres per year;
- to be competitive with gasoline, require a fuel duty cut of 24p/litre, or a combination of a fuel duty cut of 20p/litre plus other support in the form of capital grants;
- represent a cost to the Treasury of 18p/litre, after taking into account the savings in job seekers' allowances and additional company taxation gained as a result of the industry employing more people and generating company revenues;
- increase the total value added of transport fuels that remains in the UK economy from 82% (for imported gasoline) to 91%;
- create 970 jobs, and contribute to rural regeneration and greenhouse gas abatement.

Twelve of these plants would be needed to achieve a 5% bioethanol blend in all gasoline.

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GLOSSARY

GLOSSARY OF TERMS

Bioethanol	Ethyl alcohol produced from biomass feedstocks
CO_2	Carbon dioxide
DEFRA	Department of the Environment, Food and Rural Affairs
DfT	Department for Transport
DTI	Department of Trade and Industry
ETBE	Ethyl tertiary butyl ether
GHG	Greenhouse gas
MTR	Mid Term Review of the Common Agricultural Policy of the EU
NO_x	Oxides of nitrogen
N_2O	Nitrous oxide
NREL	National Renewable Energy Laboratory (US)
SRC	Short rotation coppice

PHYSICAL PROPERTIES

	Ethanol	Gasoline
Carbon composition (% by weight)	52	85-88
Density (kg/litre)	0.785	0.72-0.78
Heat of combustion (MJ/kg)	29.7	47.0
Research octane number	107	93

1. INTRODUCTION

Bioethanol can be produced from fermentation of sugar rich plants, or from starch or cellulosic materials, which can be converted to sugar by hydrolysis, and then fermented. The potential of ethanol as a fuel for transport and/or centralised energy can be seen in the Brazilian bioethanol programme, where 2.3 million hectares of sugar cane cultivated for the bioethanol programme produce 13 billion litres of ethanol annually (1998 figures). In the USA, approximately 5 billion litres of ethanol are produced annually from corn[3]. Sugarcane and sugar beet yield 70-95 litres of ethanol per tonne of cane processed. The ethanol yield from 1 tonne of wood is 280-330 litres, although the energy input to convert wood to ethanol is higher. Ligno-cellulosic hydrolysis, whilst offering greater potential for conversion of wood residues, is a less well proven technology. Thus, there are a number of technology routes to bioethanol production.

The recent UK Energy White Paper[4] has highlighted the need for climate change objectives to be achieved through the energy system. Transport is a key sector, being responsible for around 25% of UK emissions of greenhouse gases. Transport is almost totally dependent on petroleum products, and whilst the White Paper envisages no immediate strategic risk for oil supplies to the UK, it recommends more focus on greater vehicle efficiency and alternative transport fuels as part of the move to a low carbon economy. At present, fuel diversity is constrained in the transport sector, and in the long-term resource depletion could pose a security of supply problem.

Bioethanol is one possible alternative transport fuel. The potential long-term benefits of bioethanol in transport applications are:

- it offers an alternative pathway to a low carbon economy, which could be developed in parallel with renewable electricity and could deliver low carbon road fuels more quickly;

- bioethanol is more easily distributed than hydrogen fuels, because it can readily be transported by road tanker. If required as a feedstock for hydrogen fuel cells, bioethanol can be reformed into hydrogen at the filling station or by reformers on-board the vehicles;

- bioethanol can also be used directly in internal combustion engines, and hence can be an insurance policy if fuel cells prove too expensive or technically difficult to develop into mass market applications;

- finally, bioethanol offers the potential of an energy-efficient and secure fuel supply system, which could make use of UK agricultural land.

Bioethanol production facilities, where they exist, are typically subsidised in order to enable them to compete with fossil fuel equivalents. The rationale behind these subsidies is either, to promote less environmentally damaging products or to reduce reliance of fossil fuel imports, or both. Over-reliance on subsidies can itself present problems, and in recent years the Brazilian ProAlcool programme has become stagnant due to a combination of poorly directed energy policy, high sugar prices in the international market and low oil prices[5]. The fact that

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[3] Kheshgi HS, Prince RC & Marland G (2000). The potential of biomass fuels in the context of global climate change: Focus on Transport Fuels. Annual Review of Energy and the Environment **25**, 199-244.

[4] "Our common future – creating a low carbon economy", Department of Trade and Industry, February 2003.

[5] Rosillo-Calle F & Cortez AB (1998). Towards Proalcool II – A review of the Brazilian bioethanol programme. *Biomass & Bioenergy* **14**, 115-124.

producing and using bio-ethanol rather than fossil unleaded fuel provides reduced CO^2 emissions over the lifecycle of the respective products is now acknowledged by all authorities although the magnitude of the benefit is still debated. Given the range of mitigation potentialities reported in the literature, is the support of a

bio-ethanol industry 'good value for money'? Having considered speed of uptake and cost, would other technologies be more effective in delivering a carbon benefit?

Both public and private sector interests are involved in the prospects for developing a UK bioethanol industry. The UK has signed up to the Kyoto protocol for the reduction of greenhouse gas emissions (GHGs) and aims to produce 10% of its electrical requirements from renewable resources by 2010, and to reduce CO_2 emissions by 20% from 1990 levels in that time (and GHG emissions by 12.5% overall). Even though UK strategies for climate change mitigation are mainly focussed on electricity generation from renewables, bio-ethanol used as a substitute to fossil fuel could contribute to achievement of emissions reductions targets, particularly in the short to medium term whilst the hydrogen economy is developed. The EU Transport Directive proposes a non-binding target of 5.75% of transport fuels derived from renewable resources by 2010. Currently, the UK consumes approximately 24 Mt of unleaded gasoline and 21 Mt of diesel fuel annually (Figure 1). To meet the EU target would require an annual production of 1.4 Mt bio-ethanol plus 1.2 Mt of bio-diesel, or 2.7 Mt of bio-ethanol alone.

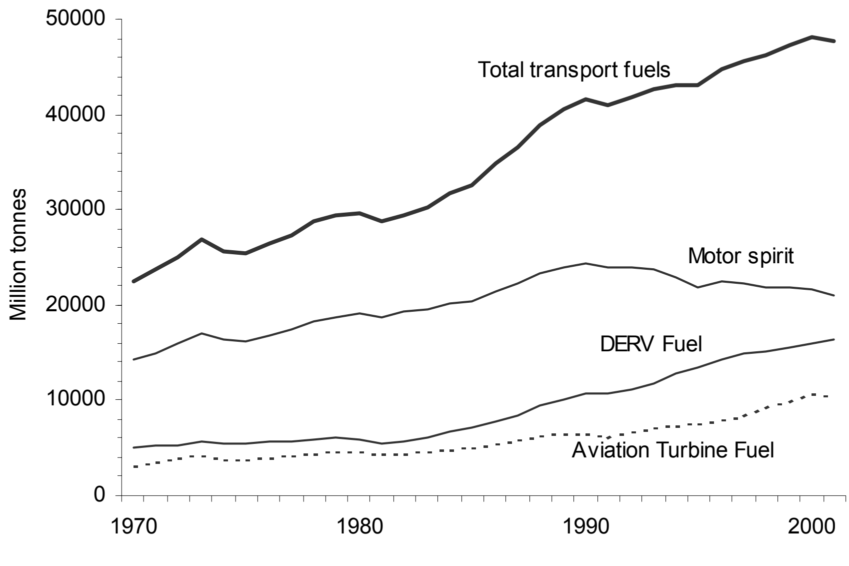

Figure 1.1 Domestic transport fuel consumption

To achieve this level of uptake would require considerable fiscal incentives. There are various fiscal measures that could be adopted, including duty cuts in favour of bioethanol, specifying a minimum blend of bioethanol through legislation, and formalised voluntary agreements with fuel producers and suppliers. The benefits and policy costs of these measures need to be more fully understood, and this study for the East of England Development Agency aims to examine a number of issues at a national level. If these incentives are applied as an excise duty cut, how much of that excise duty is lost to from the National economy? How much is recycled into other sectors which themselves are then taxed? Since this report was commissioned, the Chancellor of the Exchequer, in his pre-budget statement in November 2002, announced a 20 pence/litre excise duty reduction for bio-ethanol (compared with the fuel duty rate for sulphur-free gasoline). The 2003 Budget has confirmed this fuel duty reduction, with the plan to introduce it on 1 January 2005. Would such an incentive be sufficient to stimulate the development of a bio-ethanol industry in the UK? Many interested parties (BABFO, British Sugar) propose that a 25-30 pence/litre excise duty cut would be needed to maintain price parity at the fuel pump and render the production of bio-ethanol economic. Would any duty cut promote a UK industry or simply open up the marketplace to imported, less expensive bioethanol from overseas? How might market support be structured to prevent that?

There is much current interest in the development of fuel cell vehicles, which would use hydrogen as an energy carrier. If the hydrogen were to be produced from renewable energy sources in the UK, then this would be a low carbon option, which also provides a degree of supply security. Another low carbon option is the development of biofuels using UK sources. Bioethanol used in advanced hybrid engines is one of the few configurations that could challenge the hydrogen/fuel cell option for vehicles. A recent review of future transport energy options[6] (ref.) has indicated that developing hydrogen from renewable fuel sources such as biomass, rather than using electricity to hydrolyse water, is the preferred environmental and sustainable option.

Bioethanol from sugars could provide niche markets in blends with gasoline, and in the longer-term from woody crops and vegetable waste could widen the market if the costs are acceptable. However, bioethanol production is constrained by land availability, crop yield and the demand for biomass for other uses. The raw materials for bioethanol are priced on markets that not are directly related to the oil market – sugar prices are mainly determined by foodstuff markets, and woody crop prices are mainly determined by pulp and paper markets.

Both public and private sector interests are involved in the potential for developing a bioethanol industry. The EU has proposed a directive and a series of targets on the use of biofuels in transport. There are various fiscal measures that could be adopted, including duty cuts in favour of bioethanol, specifying a minimum blend of bioethanol through legislation, and formalised voluntary agreements with fuel producers and suppliers. The benefits and policy costs of these measures need to be more fully understood, and this study will provide an input into Government thinking on the consumer impacts and taxation policy. The private sector interests cover the fuel/vehicle supply chain, and comprise: fuel producers, fuel suppliers, vehicle manufacturers, transport service companies, research organisations, the agricultural industry, finance providers and end-users.

The key issues that have been assessed in this study are:

- What are the most attractive technical routes and crops for bioethanol production in the UK?
- What are the characteristics of the bioethanol supply chain?
- How does the production, processing and distribution costs of bioethanol compare with conventional transport fuels?
- What are the macro-economic impact, the impact on employment and the impact on the Treasury of bioethanol as compared with conventional transport fuels?

[6] "Fuelling road transport – implications for energy policy", Eyre, Fergusson and Mills, Energy Saving Trust, Institute for European Environmental Policy, and National Society for Clean Air, November 2002.

- What are the economic development benefits for the agricultural sector and rural communities?

- What are the environmental impacts in terms of climate change mitigation, air quality, landscape changes and biodiversity?

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It is assumed throughout this study that bioethanol will be blended into gasoline at a 5% wt concentration, and that the blended fuel will be sold via conventional retail distributors into the transport fuels market. This level of blending should pose no performance or technical problems to modern car engines, and is taken to be within the warranty conditions of the car manufacturers. Higher concentrations levels, certainly those above 15-20%, could give problems unless the engine is specially modified or designed to operate on such bioethanol/gasoline mixtures.

2 NATIONAL IMPACTS OF A UK BIOETHANOL INDUSTRY

2.1 GENERIC UK BIOETHANOL PRODUCTION PLANT FOR CONVERSION OF SUGAR CROPS AND STARCH MATERIALS

The first step in the analysis requires capital and operating costs data for bioethanol production plant. A generic model of a production plant was devised in order to represent the most likely configuration for UK conditions for starch and sugar feedstocks.

The key assumptions in devising this model are:

- Wheat or sugar beet feedstock would be used;

- The production plant would be located on a green field site, and would require full site services, including a combined heat and power plant for electricity and heat production;

- Three capacity sizes could be used at 100,000, 200,000, and 300,000 t/year of bioethanol. Biomass processing plant of these sizes are larger than current designs of plant for electricity production from biomass. The 100,000 t plant requires about 200 MWth input of biomass. However, in the sugar industry such sizes are quite common;

- The animal feed, produced as a by-product of fermentation, will find a viable market and sales of animal feed will generate a credit for the process;

- Other by-products include carbon dioxide, but no sales credits have been assumed since it is not clear that an effective market for such products could be developed.

Capital Costs

The estimates of capital costs inevitably have to be based on a combination of different information sources. These have included published data from the European and North American studies[7], some of which are outlined in Annex 2, together with several private communications from UK bioethanol project developers. Hence there is a range of possible values for each of the component items. For the purposes of the cost analysis, judgements of the most representative values from these ranges were taken for the main process plant, ancillary plant, design/planning and construction services. The remaining components are the land costs and roads and infrastructure on the bioethanol plant site, and the costs of these are very dependent on the actual site selected for the plant.

Table 2.1 lists the capital costs (for a generic bioethanol plant of 100,000 t/year), which have been used in this study. This size of plant was chosen because several of the project developers examining investment opportunities in the UK are basing their plans on a 100,000 t/year conversion facility.

[7] Annex 2 contains references to the published sources on bioethanol production used in this study.

TABLE 2.1: CAPITAL COSTS: GENERIC BIOETHANOL PLANT OF 100,000 T/YEAR CAPACITY USING WHEAT OR SUGAR BEET FEEDSTOCK.

Item	Costs (£M)	Comments
Main process plant	18.5	Includes feedstock preparation, fermentation, distillation, drying and associated process equipment
Ancillary plant	14.0	Includes feedstock handling, effluent treatment, chemical handling and storage, cooling towers, on-site utilities (CHP plant), and warehousing
Design/planning	7.5	Includes engineering design, plant specification, procurement and QA
Construction services	16.5	Includes site labour costs, head office costs, insurance during construction, temporary buildings, small tools, consumables and field construction supervision
Roads and infrastructure	1.5 to 4.0	Includes land clearance, site services, fencing, parking, roads, workshops and laboratories
Land	1.0 to 7.0	Acquisition costs for green field site area approximately 6 ha, dependent on alternative uses.
Total	**59.0 to 67.5**	

Crop production costs for wheat grain and sugar beet

The costs of feedstock production and transport from the field to the bioethanol plant have been calculated as described in Annex 6 of this report. In Summary, they are presented in Table 2.2. Component costs for each crop are presented in Table 2.3.

TABLE 2.2: CROP PRODUCTION COSTS: GENERIC BIOETHANOL PLANT OF 100,000 T/YEAR CAPACITY USING WHEAT OR SUGAR BEET FEEDSTOCK, ASSUMING 50% SUPPLIED FROM EACH CROP.

Item	Costs (£M/yr)	Comments
Wheat grain production	11.08	Includes variable costs of seed, sprays, fertiliser and fixed costs of machinery operations associated with drilling, chemical application and harvesting plus labour, running costs and capital depreciation.
Sugar beet production	9.19	Includes variable costs of seed, sprays, fertiliser and fixed costs of machinery operations associated with drilling, chemical application and harvesting plus labour, running costs and capital depreciation.
Wheat grain transport	0.96	Assumes 50km transport to processing facility
Sugar beet transport	2.65	Assumes 50km transport to processing facility
Total	**23.88**	

TABLE 2.3. COMPONENT PRODUCTION COSTS (PENCE/LITRE) FOR WHEAT GRAIN AND SUGAR BEET USED TO GENERATE MACROECONOMIC SCENARIOS

Category	Wheat	Sugar beet
Seed	1.31	2.85
Cultivations	5.34	2.93
Fertiliser	2.72	2.22
Herbicides and fungicides	3.71	2.46
Harvesting and storage	3.53	3.18
In-field transport	0.41	0.87
Haulage	1.51	4.18
TOTAL	**18.54**	**18.70**

Other costs include the blending of bioethanol into gasoline, and the retail distribution and sales activities. Annex 3 contains a description of the fuel distribution, storage, blending and end-use stages, together with costs estimates.

Component costs of fuel production

The overall conversion yields for the raw materials are assumed to be:

- 355 litres/t of wheat feedstock (fresh);
- 95 litres/t of sugar beet feedstock (fresh).

The biomass conversion costs assumed in this study for the conversion of sugar and starch materials in a generic production facility are listed in Table 2.4. Costs estimates for larger capacity plant of 200,000 t/year and 300,000 t/year are also shown. It is assumed that the capital costs are written off after 15 years, at a discount rate of 15%. This is a slightly higher value than may currently be used for energy investments, but it reflects the greater commercial risks associated with bioethanol production, and is based on discussions with prospective bioethanol developers.

TABLE 2.4: BIOMASS CONVERSION COSTS: GENERIC BIOETHANOL PLANT USING WHEAT OR SUGAR BEET FEEDSTOCK (PENCE/LITRE).

Feedstock	**Sugar beet**			**Wheat**		
Capacity (kt/year)	**100**	**200**	**300**	**100**	**200**	**300**
Production	14.52	14.52	14.52	17.03	17.03	17.03
Transport	4.18	4.18	4.18	1.51	1.51	1.51
Conversion (capital)	8.50	6.38	5.44	8.50	6.38	5.44
Conversion (O&M)	10.80	9.95	9.65	10.80	9.95	9.65
Blending	5.00	5.00	5.00	5.00	5.0	5.00
Distribution	5.00	5.00	5.00	5.00	5.0	5.00
By-products credit	-5.90	-5.90	-5.90	-5.90	-5.9	-5.90
Total	**42.14**	**39.17**	**37.84**	**41.98**	**39.00**	**37.67**

There are relatively small differences in the overall costs of bioethanol production for sugar beet and wheat feedstocks. The effect of economies of scale in operating with larger capacity conversion plant indicates that there is about a 10% reduction in overall costs in moving from 100,000 t/year capacity to 300,000 t/year capacity.

The employment opportunities involved in the conversion plant, blending and distribution stages are estimated to be as follows for a 100,000 t/year conversion plant:

- 50-55 direct employees in the conversion plant;
- 12-18 HGV drivers for the road haulage movement of bioethanol to the oil depots and/or retail outlets;
- 4-10 supervisors and quality control staff for the blending operation at the oil depots.

For the 200,000 t/year conversion plant, 55-65 direct employees would be needed, together with 20-30 HGV drivers and 6-12 supervisors and quality control staff. For the 300,000 t/year conversion plant, 65-70 direct employees would be needed, together with 30-40 HGV drivers and 8-14 supervisors and quality control staff.

2.2 GENERIC UK BIOETHANOL PRODUCTION PLANT FOR CONVERSION OF LIGNO-CELLULOSIC MATERIALS

In the medium to longer tem, ligno-cellulosic materials could also be considered as feedstocks for bioethanol production. Annex 2 includes a description of the conversion technologies involved in ligno-cellulosic processing. Agricultural residues (e.g. cereal straw), forest products, energy crops (miscanthus and short rotation coppice – SRC) or waste (wood and paper/cardboard) are all potential sources of ligno-cellulosic feedstock. Each products stream has been considered in this report. More detail of the availability and price derivation of these feedstcks is presented in Annex 6 and the regional studies.

For the purposes of this study, the generic bioethanol production facility for ligno-cellulosic feedstocks was taken to have a capacity of 156,000 t/year. This size of plant was chosen because some of the US data are based on a theoretical conversion facility of this size. As before, for the purposes of the cost analysis, judgements of the most representative values from the literature were taken for the capital costs of the main process plant, ancillary plant, design/planning and construction services. The remaining components are the land costs and roads and infrastructure on the bioethanol plant site. The costs of these are very dependent on the actual site selected for the plant.

Capital Costs

Table 2.5 lists the capital costs (for a generic bioethanol plant of 156,000 t/year), which have been used in this study for the current technology status. It should be recognised that these data are much less certain than the equivalent data for sugar and starch conversion plant, due to the relative immaturity of development of the ligno-cellulosic processes. Data have been obtained from a variety of sources; in particular the bioethanol yield data have been obtained from the most recent estimates of yields from North American and EU studies and adapted, where necessary, to account for UK conditions of moisture content of the feedstock material[8].

Other assumptions used in the analysis are:

[8] Annex 2 contains references to the published sources used in this study.

- The production plant would be located on a green field site, and would be a stand-alone facility, requiring full site services, including a combined heat and power plant for electricity and heat production;

- The potential feedstocks for UK ligno-cellulosic processing are wheat straw, miscanthus, short rotation coppice (SRC) and forestry residues. In addition, waste paper material could be considered as a feedstock. (waste paper is included as an option in the sensitivity analysis in Section 2);

- The conversion processes for wheat straw and miscanthus are similar. The yields are assumed to be 280 litres/t for wheat straw (at 15% moisture content) and 230 litre/t for miscanthus (at 30% moisture content);

- The conversion processes for SRC and forestry residues are similar. The conversion yields are assumed to be 280 litres/t of feedstock material for SRC and forestry residues (both at 30% moisture content) and 309 litre/t for waste paper. However, the capital and operating costs of the conversion processes are higher than for wheat straw and miscanthus, since there are additional costs associated with feedstock treatment, enzyme production and application, and waste water treatment;

- Use of a high throughput conversion plant and a lower throughput conversion plant, arising from uncertainties in the reliability and performance of the operating systems;

- A co-product of the ligno-cellulosic conversion process is lignin, which can be used as a fuel in a combined heat and power plant within the process. The economics are assumed to include a credit for the use of lignin in this way;

- Other by-products include acetic acid, but no sales credits have been assumed since it is not clear that an effective market for such products could be developed.

TABLE 2.5: CAPITAL COSTS: 156,000 T/YEAR CAPACITY USING LIGNO-CELLULOSIC FEEDSTOCK FOR THE CURRENT TECHNOLOGY STATUS

Item	Cost (£M)	Comments
Main process plant	43.0	Includes feedstock preparation, fermentation, distillation, drying and associated process equipment
Ancillary plant	45.5	Includes feedstock handling, effluent treatment, enzyme and other chemicals handling and storage, cooling towers, on-site utilities (CHP plant) and warehousing
Design/planning	18.0	Includes engineering design, plant specification, procurement and QA
Roads and infrastructure	6.0	Includes land clearance, site services, fencing, parking, roads, workshops and laboratories
Construction services	21.0	Includes site labour costs, head office costs, insurance during construction, temporary buildings, small tools, consumables and field construction supervision
Land	1.0-10.0	Acquisition costs for a green field site: site area approximately 10 ha, dependent on alternative uses
Total	**134.0-143.0**	

Production costs of feedstock for the various ligno-cellulosic crop and waste streams

The costs of feedstock production and transport from the field to the bioethanol plant have been presented in detail in Annex 6. They are summarised in Table 2.6, and more detailed breakdowns of component costs are presented in Tables 2.7 and 2.8.

TABLE 2.6: CROP FEEDSTOCK COSTS (£M/YR): GENERIC BIOETHANOL PLANT OF 156,000 T/YEAR CAPACITY USING LIGO-CELLULOSE FEEDSTCOK.

	Wheat straw	Miscanthus	SRC	forestry	Paper waste
Production	9.40	21.19	27.61	21.43	52.41*
Transport	4.94	4.19	3.48	2.49	2.25
Total	14.34	25.38	31.09	23.92	54.66

*Assumes that all collection costs are borne by the bioethanol processor

TABLE 2.7. COMPONENT PRODUCTION COSTS (PENCE/LITRE) FOR SRC AND MISCANTHUS USED TO GENERATE MACROECONOMIC SCENARIOS

Category	SRC[9]	Miscanthus[10]
Planting Year		
Propagules & planting	7.55	8.3
Cultivations & cut-back	4.72	0.74
Fertiliser	0.27	0.21
Herbicides and fungicides	0.09	0.29
Production phase costs (annualised where appropriate)		
Fertiliser	0	0
Herbicides and fungicides	0.82	0.65
Harvesting and storage	2.93	3.8
In-field transport	1.25	0.79
Haulage	1.76	2.12
Planting grant	-5.39	-4.02
TOTAL	**15.74**	**12.85**

TABLE 2.8. COMPONENT PRODUCTION COSTS (PENCE/LITRE) FOR WHEAT STRAW, FORESTRY RESIDUES AND PAPER WASTE USED TO GENERATE MACROECONOMIC SCENARIOS

Category	Wheat straw	Forestry	Paper waste
Production/collection	0	5.74	19.42
Screening	-	-	6.47
Shredding & Baling	-	-	3.24
Baling/chipping	2.98	3.04	-
On-site transport	1.79	1.81	1.62
Haulage	2.5	1.26	1.14

[9] Costs for perennial crops have been amortised across the 15 year assumed lifetime of the crop.
[10] Costs for perennial crops have been amortised across the 15 year assumed lifetime of the crop.

Landfill tax foregone	-	-	-4.21
TOTAL	**7.26**	**11.85**	**27.68**

Other costs include the blending of bioethanol into gasoline, and the retail distribution and sales activities. Annex 3 contains a description of the fuel distribution, storage, blending and end-use stages and estimates of costs.

Component costs of fuel production

The ethanol yield of the ligno-cellulosic feedstocks assumed in this study is presented in Table 2.9.

TABLE 2.9: BIOETHANOL YIELDS FROM VARIOUS LIGNO-CELLULOSE FEEDSTOCKS

Product	Ethanol yield (litres/tonne)	Moisture content
Wheat straw	280	15%
Miscanthus	230	30%
SRC	280	30%
Forestry residues	280	30%
Waste paper	309	-

These ethanol yield figures provide component costs of production, expressed per litre of fuel produced as follows (Table 2.10 and 2.11).

The conversion costs assumed in this study for the conversion of ligno-cellulosic materials in a generic production facility are listed in Table 2.10. It is assumed that the capital costs are written off after 15 years, at a discount rate of 15%. As with the capital costs, the operating and maintenance costs are broad estimates due to the relative immaturity of the ligno-cellulosic processes. In order to account for the inherent uncertainties in the efficiency and operation of the conversion technology at a commercial scale, Table 2.11 includes estimates of production costs using a lower throughput of 75% of the design rate. This lower throughput illustrates the sensitivity of conversion costs to any shortfall in production efficiency.

TABLE 2.10 BIOMASS CONVERSION COSTS: GENERIC PLANT USING LIGNO-CELLULOSIC FEEDSTOCKS (PENCE/LITRE) AT DESIGN THROUGHPUT

Feedstock	Wheat straw	SRC	Forestry residues	Miscanthus
Design capacity (kt/year)	**156**	**156**	**156**	**156**
Production	4.76	13.96	10.62	10.72
Transport	2.50	1.76	1.26	2.12
Conversion (capital)	15.52	18.62	18.62	20.18
Conversion (O&M)	21.55	33.86	33.86	36.93
Blending	5.00	5.00	5.00	5.00
Distribution	5.00	5.00	5.00	5.00
Total	**54.33**	**78.31**	**74.36**	**79.95**

TABLE 2.11 BIOMASS CONVERSION COSTS: GENERIC PLANT USING LIGNO-CELLULOSIC FEEDSTOCKS (PENCE/LITRE) AT 75% OF DESIGN THROUGHPUT

Feedstock	Wheat straw	SRC	Forestry residues	Miscanthus
Design capacity (kt/year)	**156**	**156**	**156**	**156**
Production	4.76	13.96	10.62	10.72
Transport	2.50	1.76	1.26	2.12
Conversion (capital)	20.69	24.83	24.83	26.90
Conversion (O&M)	31.39	48.33	48.33	52.15
Blending	5.00	5.00	5.00	5.00
Distribution	5.00	5.00	5.00	5.00
Total	**69.34**	**98.89**	**95.04**	**101.90**

There are many different harvesting methods depending on the scale of woodland, type of forest, and machinery available (see Annex 6). For example in upland areas using costly sky lining equipment can be the only option, but a farmer with a small area of woodland may use a tractor and skidder, and a large harvesting company a harvester head and clam bunk. A large bioethanol processing plant will need to take feedstock derived from a whole range of forest and woodland types and scales, therefore we cannot be too prescriptive about supply costs. In the study we have produced a generic scenario based on pole top cutting and extraction. It is based on the predominant UK conditions of felling with chainsaw, extraction with skidder or forwarder, chipping at ride side and the loading chips and hauling them to the plant.

There are other options available such as whole tree harvesting , but this is not suitable for most parts of the UK, where the brash mat is needed for supporting the machinery.

Another option is to transport logs and chip at the site. This may be appropriate in some cases, but discussions with UK biomass power companies, and experiences abroad indicate that the plant will wish to receive a chipped product at gate, and may have little room for storage.

It can be seen that the overall costs for ligno-cellulosic feedstocks are currently much higher than the costs for sugar beet and wheat feedstocks, ranging between about 35% and 100% greater when comparing throughputs at the design capacity. The costs are dominated by the costs of the feedstock conversion stages, due to the high capital and operating costs involved. Because different ligno-cellulosic feedstocks require different production processes, and in particular use different enzymes, there is also a wide variation between the conversion costs of the various feedstocks. If the design capacity is not achieved, then the conversion costs will be even greater, due to the inefficient use of plant and materials in the processing facilities. There is around a 27% increase in costs for a 33% shortfall in output, which indicates the sensitivity of the overall economics to achieving the design capacity.

R&D and technology development are expected to reduce the capital and operating costs of the ligno-cellulosic conversion processes, as outlined in Annex 2.

The employment opportunities involved in the conversion plant, blending and distribution stages are estimated to be as follows for a 156,000 t/year conversion plant:

- 60-70 direct employees in the conversion plant;
- 15-20 HGV drivers for the road haulage movement of bioethanol to the oil depots and/or retail outlets;
- 6-12 supervisors and quality control staff for the blending operation at the oil depots.

2.3 MACRO-ECONOMIC ANALYSIS

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The macro-economic methodology in this study aims to examine the national economic impacts of establishing a UK bioethanol industry on the GDP (i.e. the value added created), employment, North Sea oil depletion and the net cost for the Treasury of CO_2 reductions from the transport sector. Annex 4 provides a fuller description of the macro-economic modelling and the modified Input-Output analysis that has been used in this study.

In order to estimate the effect on the national economy (GDP) and employment due to the production of bioethanol (to replace gasoline) the economic methodology of a national input/output analysis has been used. The advantages of using the input/output (IO) analysis are that the method is:

- Time and cost efficient;
- Relatively accurate, because of the modification to the IO analysis that will be applied;
- Usable to make comparisons between the macro versus the micro-economic impact.

The impact of an individual project (or product) on the Gross Domestic Product (GDP) and employment

The total cost (c) of a product can be split into three segments:

(1) value added,
(2) intermediate expenditures in the productive sector of the economy and
(3) imports (see “round 0" in Figure 2.1).

Value added consists of all types of income for the various economic actors in society, such as salaries (income from labour), interest (income from capital), land rent, profit (income from entrepreneurship) and taxes minus subsidies (government income). The total gross value added in an economy (which includes depreciation) adds up to the GDP. Therefore a project's contribution to the GDP can be represented by the amount of value added in its cost. In turn, the intermediate expenditures can be subdivided into the same three components, and so on (see “round 1" and further in Figure 2.1). Finally, the cost can be divided into imports (direct and indirect) and value added (direct and indirect).

The split into segments in round 0 in Figure 2.1 can be derived directly from the calculation of the cost. Using the standard input-output method it is possible to come directly from the cost breakdown of round 0 to that of round n. This method is discussed in more detail in Annex 4.

Figure 2.1 shows the division of the cost into the segments of import, intermediate expenditures and value added. (In the figure Int. exp. means intermediate expenditure, v.a. means value added and imp. means import).

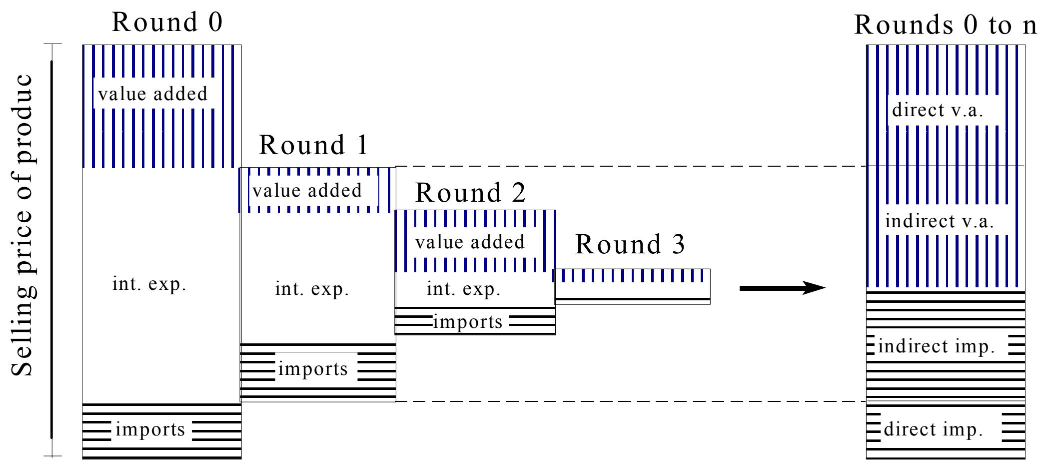

FIGURE 2.1: PRODUCT COST SEGMENTATION

The standard input-output table

The starting point for the standard input-output method is the input-output transaction table, which is available as standard statistical information for most countries in the world.[11] For this study, the UK Input-Output table was readily available from the Office of National Statistics[12].

The Input-Output analysis requires the use of input costs for all stages of bioethanol production, for each of the feedstocks and conversion processes to be considered. The data presented in Tables 2.4 and 2.10 have been used for the bioethanol production cases. These costs have also to be allocated to each of the relevant sectors of the national economy, as described in Annex 4. In addition, the input costs for the petroleum-to-gasoline reference case have to be allocated in a similar fashion

Employment creation can be included as a non-monetary variable that is important in view of the macro-economic objectives that EEDA have as part of their Regional Economic Strategy.

Gasoline reference case

Data on production costs have been obtained from previous studies on alternative transport fuels[13] and the UK Petroleum Industries Association[14]. Table 2.12 lists the production costs data for gasoline derived from petroleum.

The range of costs for the final gasoline product reflects the possible range of production costs at different UK refineries. However, there are other possible variations in overall costs,

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[11]In this description, capital letters represent matrices (including vectors) and lower case letters are scalars.

[12] "UK Input-Output Analytical Tables, 1995 – 2002 Edition", HMSO, London , 2002, available from www.statistics.gov.uk

[13] "Alternative road transport fuels – a preliminary life-cycle study for the UK", ETSU, Harwell, 1996 (study co-funded by DTI and DoT).
[14] Briefing: Understanding pump prices", UK Petroleum Industries Association, September 2002, London.

especially in respect of crude oil prices, due to market fluctuations in the price of oil on the world markets. The price of US$26/bbl is the current 12-months average price quoted on the oil market, but spot prices in Rotterdam may be lower than this, dependent on market conditions. The range of US$10-20/bbl is used by the Department of Trade and Industry as the most likely range for policy analysis purposes[15].

TABLE 2.12: PETROLEUM-TO-GASOLINE FUEL CYCLE COSTS

Fuel	**Gasoline produced from petroleum refining**	
Feedstock	Crude oil (80% Brent; 20% Middle East). Long-run price range US$10-20/bbl.	
Cost of final product		
Fuel cycle stage		p/litre
Crude oil	Quoted price at US$26/bbl	10.5
Refining	Fluid Catalytic Cracker capital costs	1.5-2.0
	Fluid Catalytic Cracker operating costs	1.1-1.4
Distribution	Including dealers' margin	4.0-5.0
	Total cost (excluding fuel duty and VAT)	**17.1-18.9**

The final price to the consumer is determined by taxation policy. Fuel duty is currently charged at the fixed rate of 45.8 p/litre on ultra low sulphur gasoline, and VAT at 17.5 % is then charged on the total. Using the price of crude oil at US$26/bbl, the resulting retail pump prices in the UK are around 74-76 p/litre for ultra low sulphur gasoline. A rough rule-of-thumb is that for every US$2/bbl increase or decrease in oil price above or below US$26/bbl, the retail pump price should rise or fall by 1 p/litre[16].

Table 2.13 lists the input costs for the production, conversion, distribution and supply of gasoline from petroleum that have been used in the Input-Output analysis in this study.

TABLE 2.13 INPUT COSTS FOR PETROLEUM-TO-GASOLINE

Feedstock	**Petroleum**
Capacity (kt/year)	3000
Production	10.50
Conversion (capital)	1.50
Conversion (O&M)	1.10
Blending	-
Distribution	5.00
Total	**18.10**

Analysis cases

Based on the Input-Output analysis, this section describes the effects of bioethanol production using different feedstocks and conversion routes on the following:

Impact on the Treasury: costs and income for the Treasury which are relevant for the bioethanol chains under consideration.

[15] See for example, Energy paper 68, DTI, London, 2000.

[16] At the time of writing this report (late March 2003), the UK retail pump price was about 80p/litre, and crude oil prices were varying between around US$33/bbl and US$25/bbl due to considerable political and market uncertainties caused by the Iraq war.

Analysis of the impact on the GDP of the UK economy (i.e. the total direct and indirect value added created) and the direct and indirect employment: *for both the bioethanol and the reference case.*

Analysis of North Sea oil depletion: for the case that less North Sea oil consumption will lead to more export of oil or to more net reserve of oil.

An assessment of the net CO_2 emission reduction: examining the various chains in comparison with the reference chain. This can be combined with the net cost for the Treasury in order to calculate the cost per net tonne of CO_2 avoided for the various bioethanol feedstocks.

The Input-Output model was used to calculate these parameters for each of several cases, which are listed in Table 2.14.

TABLE 2.14: INPUT-OUTPUT ANALYSIS CASES

Feedstock	Process	Source	Production capacity (kt/year)
Wheat	Fermentation/distillation	UK	100, 200, 300
Wheat	Fermentation/distillation	Imported	100, 200, 300
Sugar beet	Fermentation/distillation	UK	100, 200, 300
Wheat straw	Enzyme hydrolysis	UK	156
Short Rotation Coppice	Enzyme hydrolysis	UK	156
Short Rotation Coppice	Enzyme hydrolysis	Imported	156
Forestry residues	Enzyme hydrolysis	UK	156
Miscanthus	Enzyme hydrolysis	UK	156
Petroleum	Refining	UK	UK generic refinery
Petroleum	Refining	Imported	UK generic refinery

The main results of the Input-Output analysis are best presented in graphical form, in terms of pence/litre of bioethanol (or gasoline). The results shown below are aimed at illustrating the key findings of the macro-economic analysis.

Figure 2.2 shows the input data (as set out above) for the allocation of costs for each stage of the production, conversion, distribution process for bioethanol and gasoline. The feedstocks shown in the figure are wheat, sugar beet, imported wheat, wheat straw, short rotation coppice and forestry residues. By-product credits are included for the cases of wheat and sugar beet, where the costs are calculated for a conversion plant capacity of 100,000 t/year[17]. For the ligno-cellulosic feedstocks, the conversion plant capacity is 156,000 t/year, using the design throughput of the process. Gasoline is shown as using both imported and UK sourced petroleum, with the refinery operations being carried out in the UK. It should be noted that the most appropriate basis for macro-economic comparison of bioethanol costs with gasoline costs is the case of 100% imported petroleum. This case represents not only the long-term substitution opportunity, but also the situation where the fuel crop is grown on set-aside land and the bioethanol replaces fuel imports[18].

[17] The total net cost of bioethanol in each case is found by subtracting the by-product credit from the sum of the production, capital, blending, transport, O&M and retail distribution costs.
[18] For a diagrammatic illustration of this point, see Figures 2.11 and 2.12.

The gasoline and wheat import cases are assigned the same respective costs structure as the UK sourced cases of these feedstocks. This is because, from a macro-economic point of view, there is no differential in costs between these cases since the international commodity trade in petroleum or wheat would ensure that the price of imported feedstock was equalled to the price of the UK sourced feedstock.

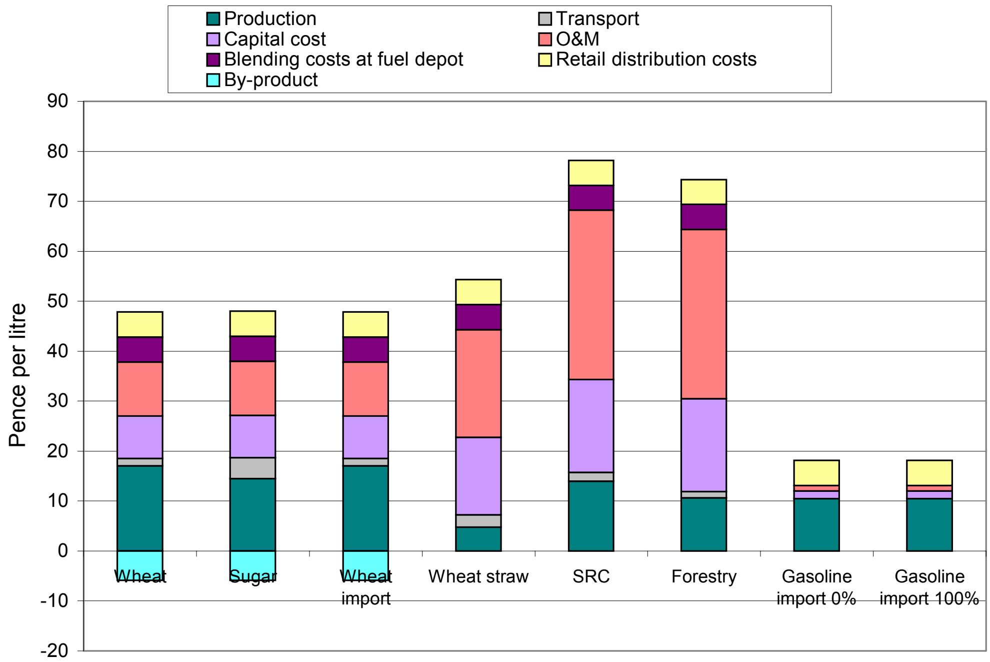


FIGURE 2.2: DISTRIBUTION OF COSTS FOR BIOETHANOL AND GASOLINE

Figure 2.3 shows the direct and indirect value added to the UK economy and the expenditure on direct and indirect imports for bioethanol from these feedstocks and plant capacities, together with the imported and UK sourced gasoline cases. It can be seen that the value added for all the bioethanol cases exceeds the value added for both gasoline cases, but there are also indirect imports for bioethanol due to the use of imported goods and services. Hence a UK bioethanol industry would still require imports, whilst also contributing to the national economy through the direct and indirect value added. The figure also shows the difference between imported and UK sourced feedstocks, in that the direct import component of the total cost is much higher and the value added in the UK is much lower for the import cases.

Bioethanol production costs are more expensive than gasoline, but the retail price for the consumer is also determined by the amount of fuel duty imposed by the Treasury[19]. For a full and fair comparison of bioethanol with conventional transport fuels the price at the pump including fuel duty should be the basis. Figure 2.4 shows the amount of fuel duty required to equalize the bioethanol retail price with the gasoline retail price (using the current fuel duty of 45.82 p/litre for gasoline). To achieve this equalisation, fuel duty for bioethanol from wheat and sugar beet feedstocks needs to be reduced to around 21 p/litre (i.e. a reduction of about 25 p/litre from the current gasoline fuel duty).

For short rotation coppice and forestry, the pre-tax costs of bioethanol are greater than the retail price of gasoline including fuel duty. Hence in order to equalize retail prices, an

[19] VAT is added in addition to the fuel duty, but its effect is not included in this analysis.

additional subsidy would need to be paid to the bioethanol producers, amounting to around 11 to 14 p/litre.

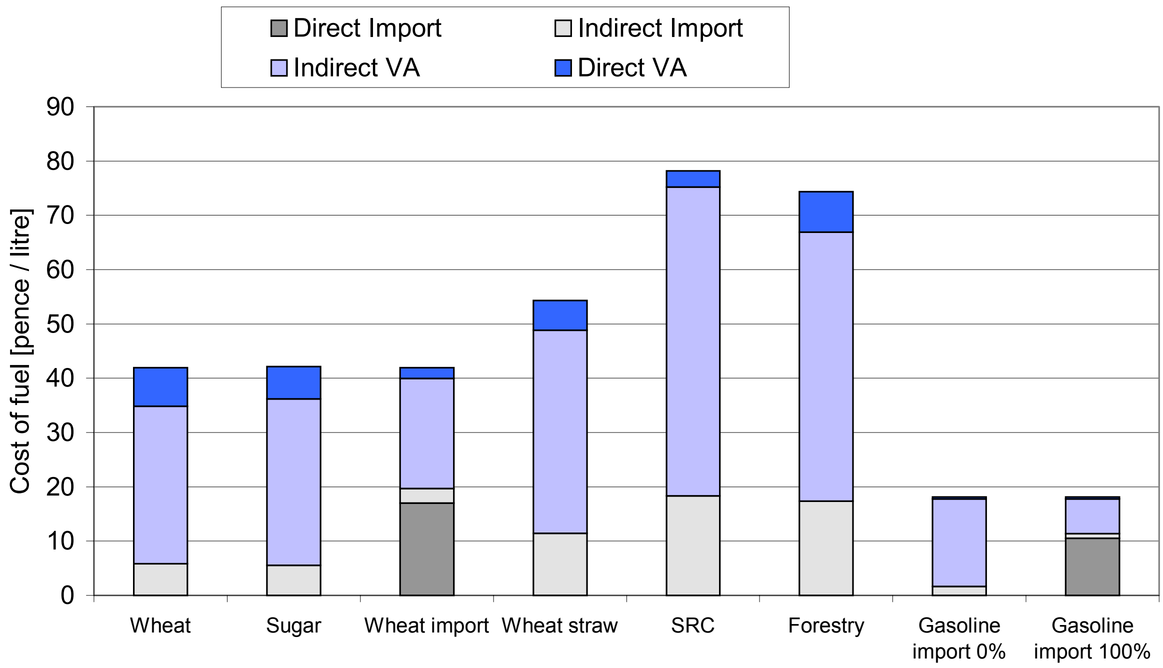


FIGURE 2.3: DIRECT AND INDIRECT VALUE ADDED AND DIRECT AND INDIRECT IMPORTS FOR BIOETHANOL AND GASOLINE

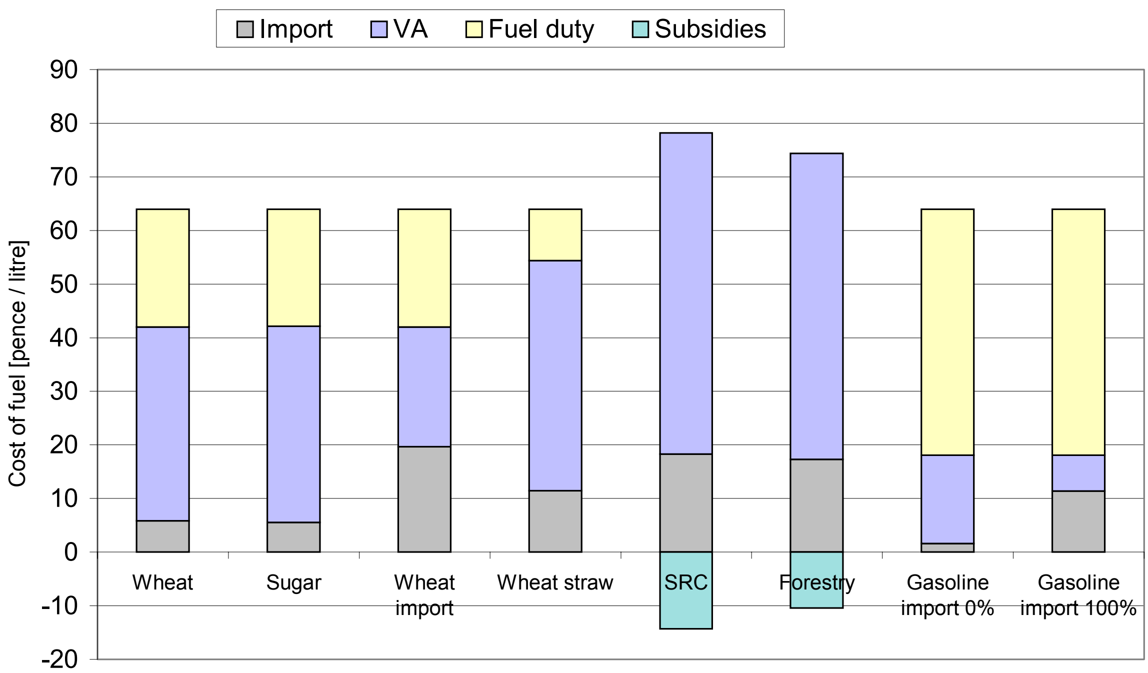


FIGURE 2.4: FUEL DUTY REQUIRED TO EQUALIZE BIOETHANOL AND GASOLINE PRICES

The cases presented in Figure 2.4 can now be compared on the basis of their total amount of import required and the total value added created. Since the fuel duty is income for the government and thus value added, the total value added to the national economy in Figure 2.4 is the sum of "VA" and "fuel duty". Table 2.15 shows for each case the percentage of overall costs represented by imports and the percentage of overall costs represented by total value added (being the sum of VA and fuel duty). This allows for a direct comparison of the economic impacts of bioethanol compared with gasoline.

TABLE 2.15 SHARE OF OVERALL COSTS BY IMPORTS AND TOTAL VALUE ADDED

Feedstock	Imports as % of overall costs	Value added as % of overall costs
Wheat	9.1	90.9
Sugar	8.7	91.3
Wheat import	30.8	69.2
Wheat straw	17.9	82.1
SRC	28.7	71.3
Forestry	27.0	73.0
Gasoline import 100%	17.8	82.2

For SRC and forestry, the value added to the national economy takes account of the financial subsidy that is needed to equalise the retail prices (i.e. the subsidy is subtracted from the value added).

The data in Table 2.15 show that the difference in value added created between the several fuel chains is much less pronounced now, once the effects of fuel duty are included. In the case of UK sourced wheat and sugar beet, the value added is the largest, about 91% of the total cost of the fuel. In the case of imported gasoline this is about 82%. Thus a switch from gasoline to bioethanol has as an impact that the part of the amount spent on fuel that remains within the national economy, rises by about 10%. In the case of wheat straw, the value added is very similar to imported gasoline, and in the case of imported wheat (and therefore the crop replacement case) the value added creation is lower than with gasoline. Similar results are obtained with bioethanol from SRC and forestry residues.

Figure 2.5 shows the total impacts on the Treasury. The Treasury would receive fuel duty, together with an amount of indirect taxes (less subsidies on production) that are imposed on the sectors of the economy involved in bioethanol production. In addition, the Treasury would save payments of job seekers allowances. This is because a UK bioethanol industry would create direct employment within the agricultural sector and in the bioethanol conversion, distribution and supply chains, together with indirect employment in other sectors of the economy. It is clear that the net receipts to the Treasury would be reduced, if the fuel duty were to be reduced as suggested above, since the savings in job seekers allowances would not compensate for the loss of some fuel duty. Furthermore, for the cases of short rotation coppice and forestry, if subsidies were paid, then there would be a net outflow of funds from the Treasury. However, much of the duty foregone will generate revenue, and thus taxes, in other sectors of the economy. The overall loss of revenue to the Treasury is about 18p/litre in the case of wheat and sugar beet feedstocks.

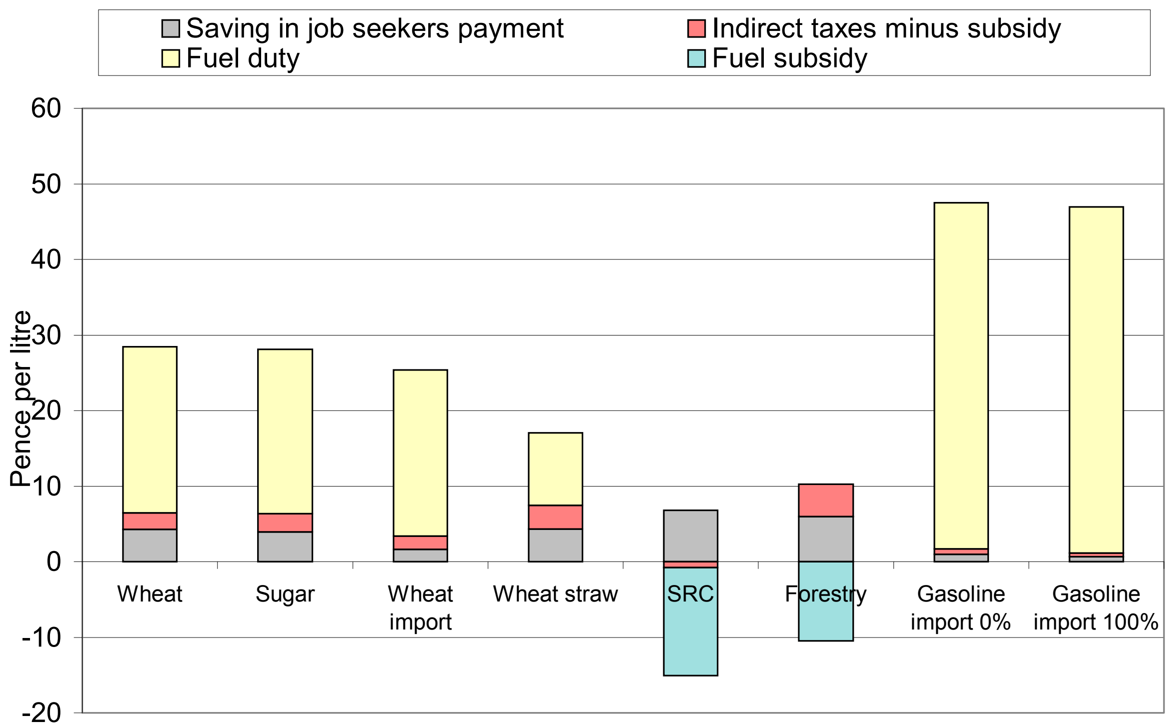


FIGURE 2.5: TREASURY IMPACTS

Figure 2.6 illustrates the value added in the main economic sectors involved in the supply of bioethanol from the case of wheat feedstock. Not surprisingly, agriculture receives the most value added, accounting for about 40% of the total value added. The manufacturing sector, along with the wholesale and retail trade and transport (in the form of road haulage), also has significant value added. Further considerations of the various sectoral impacts are given in Chapter 6.

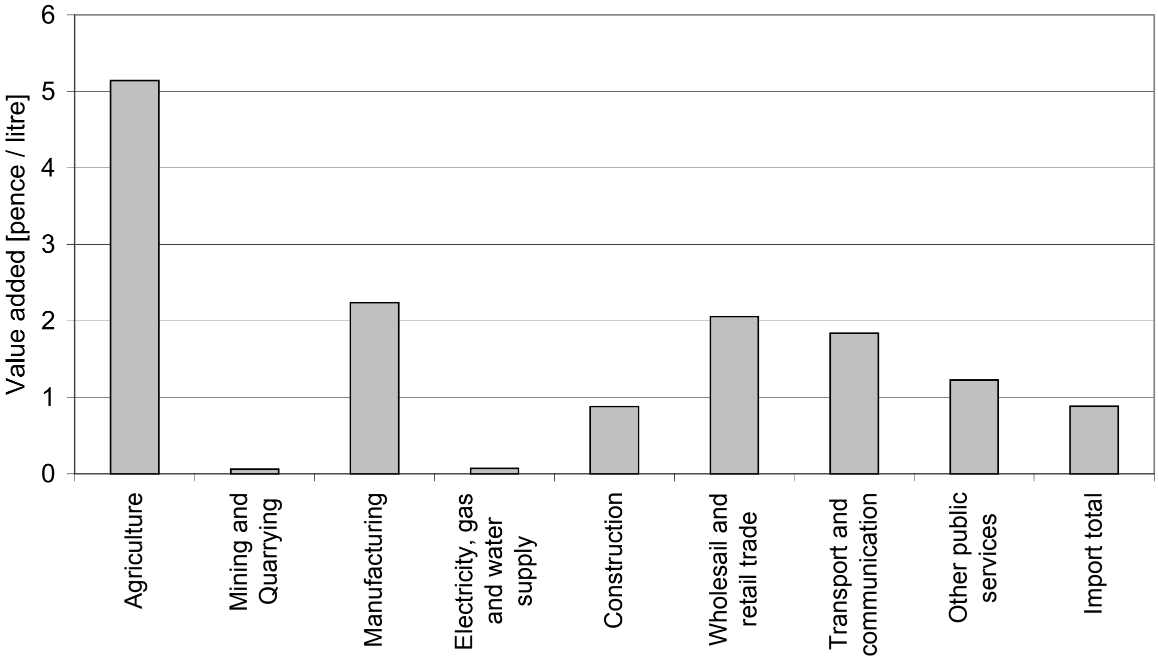


FIGURE 2.6: VALUE ADDED IN MAIN ECONOMIC SECTORS FOR BIOETHANOL FROM WHEAT FEEDSTOCK

Using the estimates of employment for each stage of the production and feedstock conversion routes, it is possible to calculate the overall effects on employment generation. Figure 2.7 shows the effects on total employment generation (expressed as man-years/litre of bioethanol or gasoline) for the various feedstocks. The data are shown for one indirect and seven direct employment categories, corresponding to the main steps in the production and conversion processes. It can be seen that the gasoline and imported wheat cases generate the least employment impact, whereas SRC, forestry and miscanthus feedstocks are responsible for the highest levels of employment generated. These high levels are mainly due to the indirect labour effects. Employment generation for wheat, sugar beet and wheat straw feedstocks are also influenced by indirect labour and by the direct labour generated in the feedstock production stages.

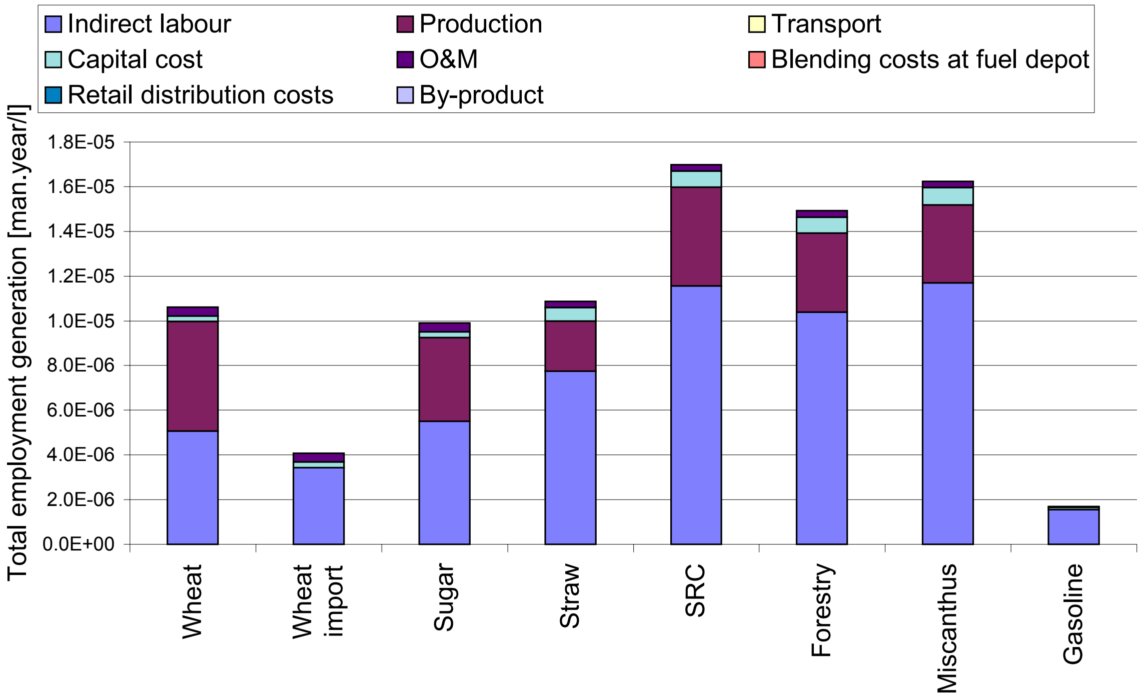


FIGURE 2.7: EMPLOYMENT IMPACTS

Mechanisms of subsidy delivery

Capital grants versus Excise Duty cuts

We present here some preliminary results of ongoing analysis which examine the manner in which support for the bioethanol industry might be achieved. In particular a) what level of capital grant would be needed at 20 p/litre excise duty rates and b) what is the most efficient (for the Treasury) way of supporting the industry?

In Figure 2.8 the impact on the excise duty decrease needed (to get bioethanol at the same price level of gasoline) of an investment subsidy that rises from 0% to 100% (just to see the full impact; in practice more than 40% will not be allowed by the EC) is calculated. Even if one subsidises the investment completely, one would still need some excise duty decrease for bioethanol since the difference in cost with gasoline is higher than the capital cost per litre of bioethanol (between 8.5 and 5.4 pence/l). This figure is for the six most likely cases in the short term.

In Figure 2.9 the approach above is then examined for the most likely scenario for the short term. The y axis here shows the total amount of investment subsidy given (i.e. that is a payment that has to be made once) versus the impact on the total excise duty that should be paid (in order to get bioethanol at gasoline prices) and on the saving in excise duty payment, because of the investment subsidy. Again, the maximum means the theoretical case of the government paying the full subsidy (which will never be allowed by the European Commission), but this at least shows the mechanism well. The saving is an annual amount of money. An interesting observation here is that an investment subsidy can be attractive for the government as long as the rate of return on investments (which a subsidy basically is for the government) of the government is lower than the rate of investment of the investor. In other words: a payment of an investment subsidy of £300 M, would save the government roughly £50M annually. It is up to them to decide whether this "payback period" of 6 years is attractive or not.

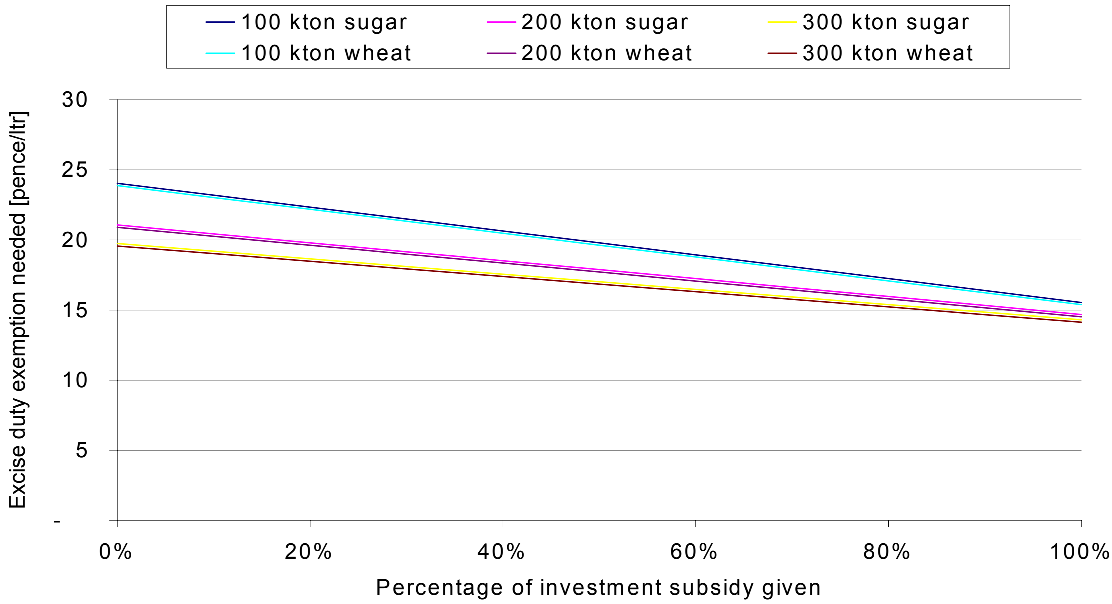


FIGURE 2.8: THE IMPACT OF INCREASING CAPITAL GRANT ON THE LEVEL OF EXCISE DUTY CUT REQUIRED TO ACHIEVE PUMP PRICE PARITY BETWEEN BIOETHANOL AND UNLEADED GASOLINE

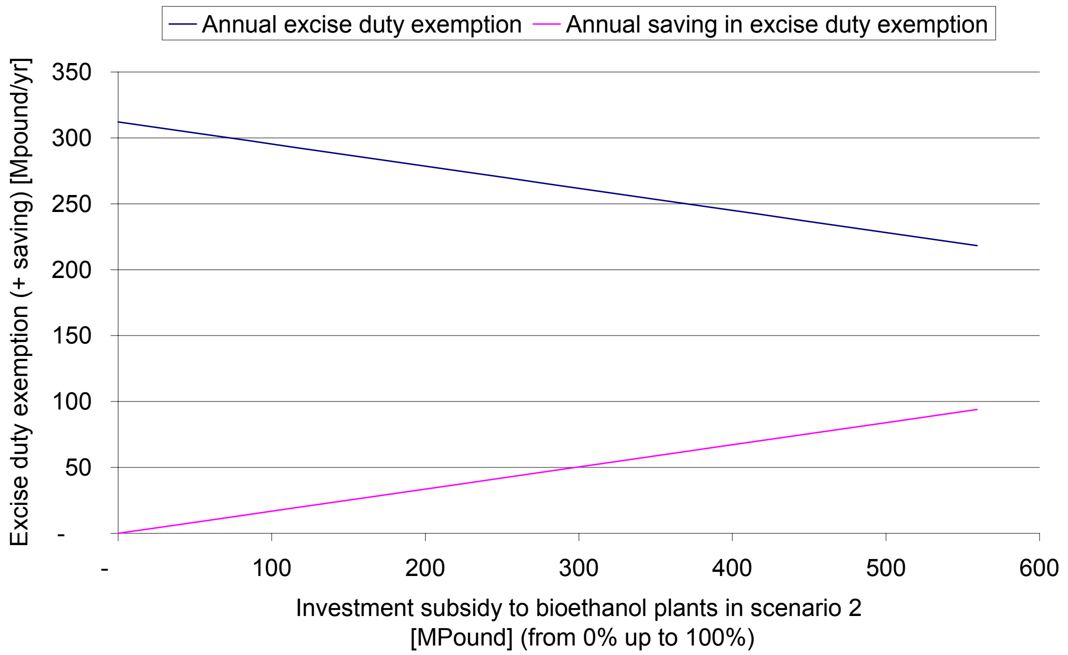


FIGURE 2.9: FOR SCENARIO TWO, TOTAL EXCISE DUTY CUT REQUIRED, AS A RESULT OF TOTAL CAPITAL GRANT EXPENDITURE.

North Sea oil depletion

The issues of oil depletion and the security of oil supply for energy markets in the UK are complex. They are influenced by factors such as the technology of reservoir engineering and oil extraction, extraction and production costs, geo-political considerations, and the availability and costs of effective substitutes for oil products.

The UK has enjoyed the benefits of oil and gas production from the UK Continental Shelf (UKCS) for over 20 years. The UK currently both imports and exports crude oil. The UK produces more than enough crude oil to meet its own needs, but imports still take place. This is because, as UK crude oil generally contains lower levels of contaminants such as sulphur, exports can command a higher price than other crude oils in the international market. It is, therefore, financially attractive for the oil companies to export some crude oil rather than use it in the UK, with imports being brought in to make up the difference.

An assessment of the oil security situation for the UK was undertaken by the Cabinet Office's Performance and Innovation Unit (PIU) in the Energy Review published in 2002[20]. The PIU report showed that at present, the UK is a net total exporter of oil, and this is expected to remain the case until at least 2010. Table 2.16 lists UK oil production and trade for 1973, 1990, and 1998 and also presents one set of forecasts for 2005 and 2010. It can be seen that the UK will continue to have a positive balance in its oil trade for the immediate future.

TABLE 2.16: UK OIL PRODUCTION AND TRADE 1990 – 2010 (MTOE[21])

	1973	1990	1998	2005	2010
Production	0.6	95.3	138.9	150.0	126.0
Exports	20.9	76.5	113.1	123.3	95.5
Imports	136.9	65.4	61.3	70.0	70.0
Bunker use	5.4	2.5	3.1	2.0	2.0
Net imports	110.6	-13.6	-54.9	-55.3	-27.5

Nevertheless, the analysis undertaken by the PIU indicated that total net exports are projected to fall rapidly after 2010, so that the UK becomes a net importer of oil shortly after 2010. For the longer term, the PIU report recognised that the UK will almost certainly become a significant energy importer by 2020. The analysis went on to suggest that the future world resources of oil are unlikely to be a major concern in the period to 2020, and probably for some time beyond. It argued that there is no immediate risk envisaged for oil suppliers to the UK, but if it became a more serious concern over the next 20 years, further ways of mitigating the risks should be considered. The PIU also suggested that one of these ways is the introduction of alternative fuels, as part of the move to a low carbon economy. A further factor is the prospect that, as oil supplies become less and prices increase, the use of crude oil as a petro-chemical feedstock may become its primary market, as there are few alternatives sources of raw materials for this industry.

The UK Petroleum Industries Association (UKPIA), in their responses to the consultation on the Energy Review[22], agreed that despite the predicted decline in the production of crude oil from the North Sea, there is unlikely to be a physical world-wide shortage of oil for a large number of years. UKPIA also noted that when conventional crude oil declines there are large reserves of heavy oil and natural gas, which can be used to provide transport fuels. Improvements in the technology used to exploit these resources will reduce the cost over time, including techniques to extract unconventional sources of oil, and to convert natural gas to liquid fuel products. The processing of coal-to-liquid fuels is also an option, for example by means of gasification and Fisher Tropsch synthesis.

The UK's current position of being a net exporter of crude oil does not insulate our economy from any upset in world energy markets, and this will remain the case even when the UK is a

[20] Source: "The Energy Review", Cabinet Office Performance and Innovation Unit, London, February 2002.
[21] Million tonnes of oil equivalent.
[22] "UKPIA's Response to HMG consultation on the Energy Review", London, September 2002.

net importer of oil. The Energy Review pointed out that while supplies of crude oil could be disrupted, for example, during periods of international conflict, the main impact of producer pressure has been on prices rather than on quantities. Recent experience suggests that when there is a major upheaval in world oil markets, oil remains available on international markets, although at a high price. This reflects a world where supplies come from a range of different suppliers.

Clearly, bioethanol used as a blend in gasoline does offer the prospect of substituting a proportion of the gasoline demand in the UK with an alternative fuel. In principle, the effects of this substitution would be:

- A lower demand for petroleum products from UK refineries, whether for imported or UK-sourced crude oil;

- A downward pressure on prices for UK refinery products.

However, the quantities of bioethanol that are likely to be produced, even with the most positive scenario used in the analysis in this study, will be relatively small compared with the total demand for gasoline in the UK. The impact of a UK bioethanol industry on UKCS oil depletion would seem to be marginal. Moreover, crude oil prices will be determined more by events outside the UK in terms of price movements on international markets than by UK domestic supply and demand considerations.

Greenhouse gas emissions

Greenhouse gas emissions for the biomass-to-ethanol and petroleum-to-gasoline fuel cycles are normally calculated by adding the energy use and emissions for each stage in the production and processing chain. Annex 5 provides a review of some of the most recent published data on these fuel cycles.

The review indicates that there is a wide variety of estimates of the greenhouse gas emissions associated with bioethanol production. This reflects the numbers of technologies available for each segment of the production chain, the uncertainties surrounding some of these technologies in terms of production efficiencies and energy requirements, and the assumptions used in calculating the resulting emissions. For example, the application of fertilisers, the production and use of co-products and the boundary used to define the fuel cycle involved will all have an important influence on the end-result. It was considered important to use where possible a single source of data for this part of the analysis, so that consistent assumptions and calculation methods could be expected.

For the purposes of the present analysis, two studies[23] provide the most authoritative data set for greenhouse gas emissions of different fuel pathways – these are from General Motors and Sheffield Hallam University. The petroleum pathway, and the production of bioethanol from a range of different sugar beet options, together with various ligno-cellulosic materials are included in the GM study. However, the GM study does not present any calculations for the use of wheat as the feedstock for bioethanol production. The Sheffield Hallam study includes extensive data sets for wheat, sugar beet and wheat straw materials. Hence a combination of these two sets of study results is used as the greenhouse gas emissions characteristics for this present study, as shown in Table 2.17:

[23] "GM Well-to-wheels analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems – a European study", LB Systemtechnik GmbH, Ottobrunn, Germany, September 2002, and "Carbon and energy balances for a range of biofuels options", draft report by N Mortimer et al, Sheffield Hallam University, March 2003.

TABLE 2.17 GREENHOUSE GAS EMISSIONS FOR DIFFERENT FUEL PATHWAYS

Feedstock	CO_2 equivalent/MJ bioethanol
Sugar beet	37
Wheat	30
Wheat straw	18
Short rotation coppice	21
Forestry residues	28

Based on these greenhouse gas emissions data, Figure 2.10 shows the public costs of greenhouse gas emissions avoidance for various bioethanol feedstocks. The calculation is based on the difference in greenhouse has emissions between each bioethanol feedstock and gasoline. The public costs are the net costs to the Treasury, namely the costs of the fuel duty reduction, less the saving in job seekers payments and less any additional indirect taxes minus subsidies. The assumption is made that fuel duty reductions (and subsidies where needed) are applied to bioethanol such that the retail price for consumers is equalized with gasoline. It can be seen that wheat, sugar beet and imported wheat offer the lowest cost/t of CO_2 equivalent avoided, whilst the ligno-cellulosic feedstocks have generally much high costs.

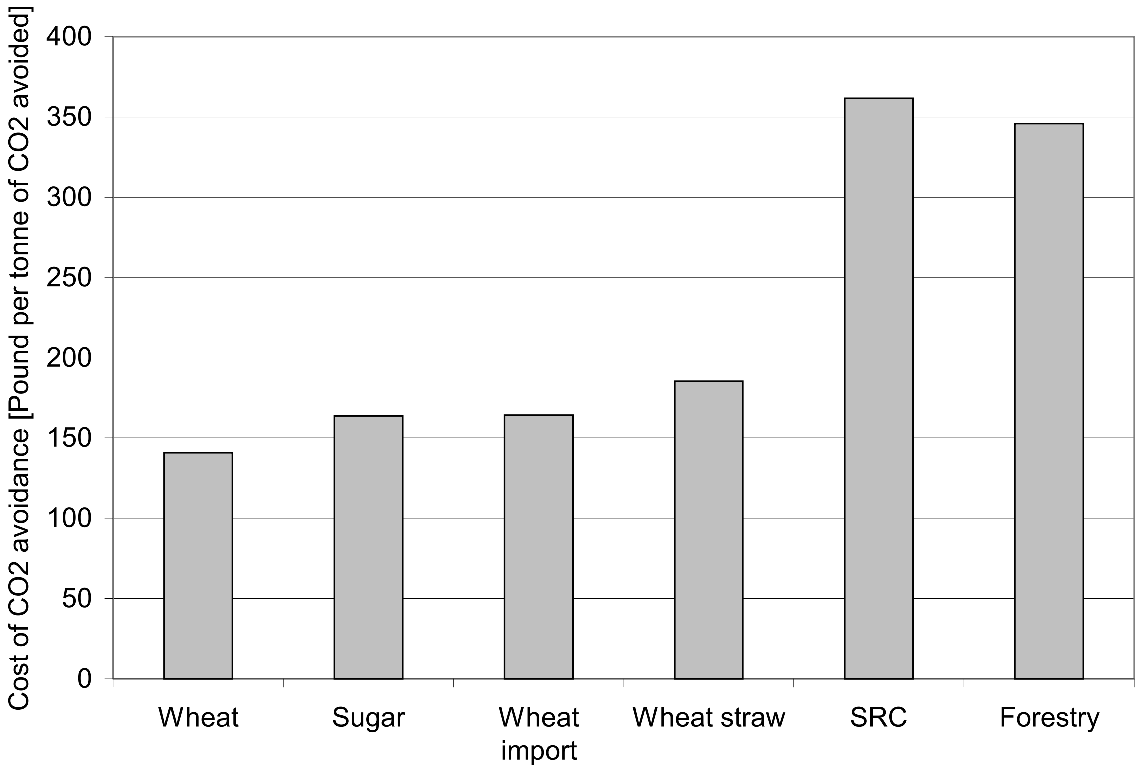


FIGURE 2.10: PUBLIC COSTS OF GREENHOUSE GAS EMISSIONS AVOIDANCE

Summary

The macro-economic analysis shows that there are considerable value added benefits to be obtained from the development of a UK bioethanol industry. The key points are:

- the demand for petroleum products would be reduced;
- there would be additional employment, and several different sectors of the economy would generate additional business;
- the share of the money that is spent on fuel that stays within the UK economy increases by about 10% with a switch from gasoline (from imported oil) to bioethanol produced from wheat or sugar beet cultivated on set-aside land. In the case of bioethanol from wheat straw this share stays about the same, and in all other bioethanol cases, the amount of the money that flows abroad (for imports) increases as compared with gasoline (from imported oil);
-
- if the retail prices were to be equalised with gasoline, however, the Treasury would incur a net reduction in revenues since the fuel duty on bioethanol would need to be about half the fuel duty on gasoline;
- in terms of greenhouse gas emission avoidance, bioethanol offers a relatively expensive means of achieving the UK's climate change objectives using biomass. For example, energy crops are estimated to have a carbon abatement cost of between £70 and £200/t carbon.[24].

Nevertheless, the analysis has enabled the quantification of the overall national impacts of a UK bioethanol industry, and, together with other analysis elsewhere in this report of the regional and environmental aspects of bioethanol, judgements can then be made regarding the importance of stimulating the development of a bioethanol sector.

Set-aside crops

A key point is whether or not the crop is grown on set aside land, or whether it replaces other crops that are used for food production. The latter is basically the same as import of sugar beet or wheat, as illustrated in the following diagrams. In Figure 2.11, where set-aside land is used for fuel feedstock production, the system comparison shows that there is a lower demand on the UK oil imports due to the substitution of oil products with UK sourced set-aside crops. In Figure 2.12, where land used for the current UK food crop is switched to fuel feedstock production, additional food crops are required in the form of imports, which effectively replace imports of crude oil.

Further examination of the set-aside issue is contained in Chapter 6.

[24] See for example, "The Energy Review", Performance and Innovation Unit, Cabinet Office, February 2002.

Figure 2.11 System comparison: "set aside"

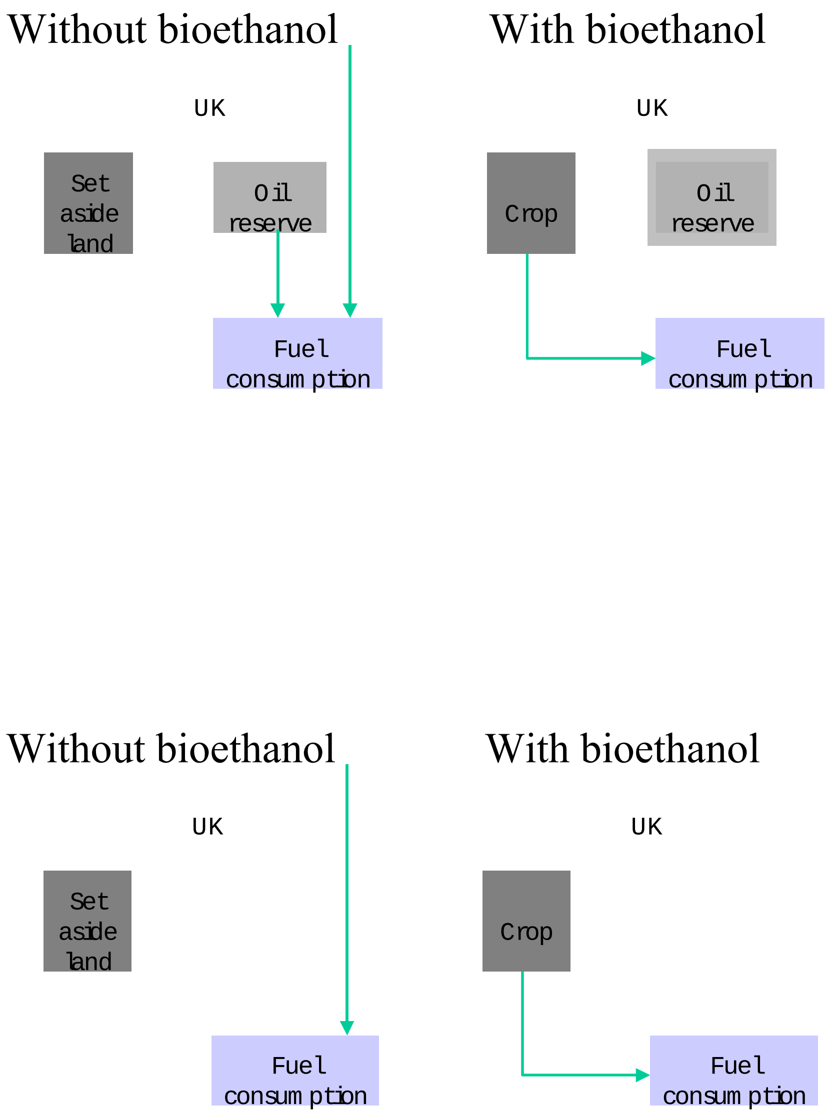
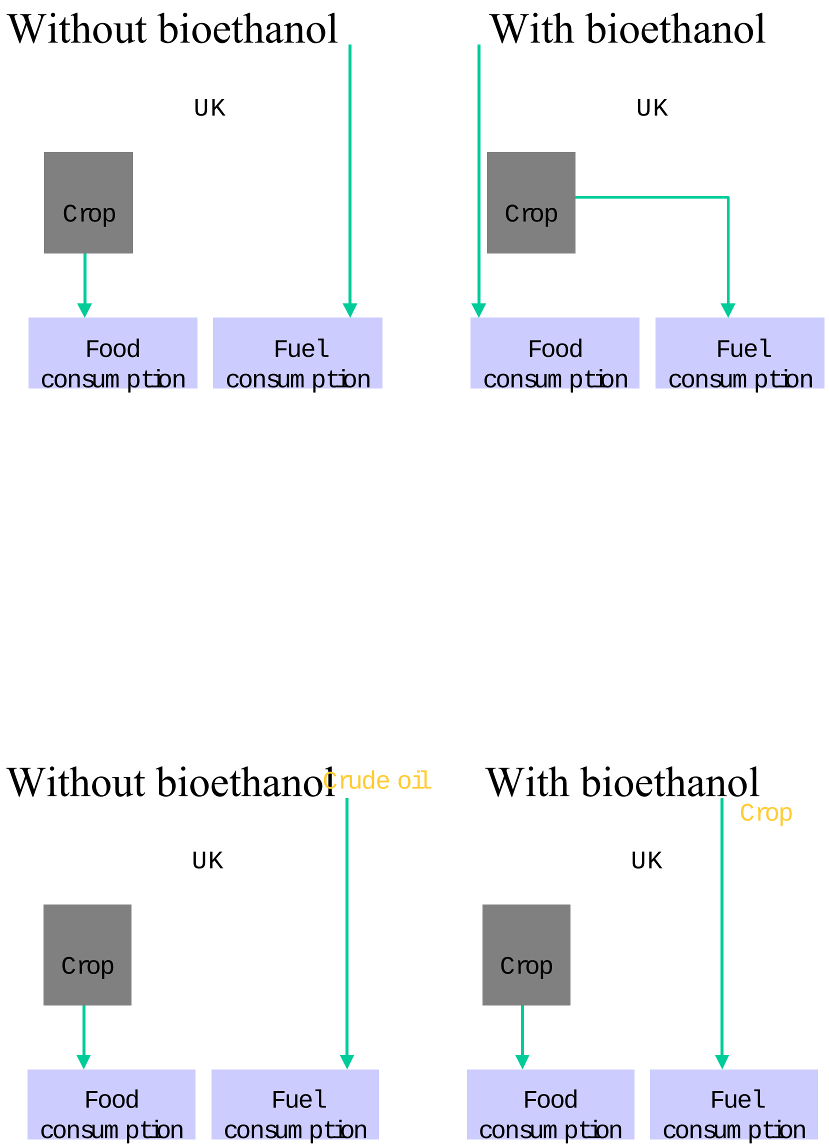


Figure 2.12 System comparison:"current crop"



3 SCENARIO AND SENSITIVITY ANALYSIS

3.1 DEFINITION OF SCENARIOS

In order to examine the potential structure of a UK bioethanol industry in more detail, a scenario analysis has been carried out using different assumptions on the size, feedstocks and capacities of bioethanol production facilities. The time horizon for the scenarios is taken to be the period up to 2015. Four main scenarios have been used, including one without any bioethanol use - the "without" scenario - and including one with import of bioethanol, each of which are characterised by:

- Definition of the type of biomass resources to be used
- Definition of the type of conversion technologies to be used
- Characterisation of the logistics system
- Assumptions on any government incentives for bioethanol
- Market penetration of each of the selected biomass chains

The current status of the principal conversion technologies is:

- *Sugar beet and starch crops feedstocks:* These are proven mature technologies, with large-scale commercial operations existing in several EU countries and elsewhere. There is still scope for some improvements in energy efficiency, enzyme production and feedstock varieties, which would have an impact on production costs;

- *Ligno-cellulosic feedstocks:* Feedstock supply for wheat straw, short rotation coppice and forestry residues for energy markets are at early commercial stages. For miscanthus and municipal wastes such as waste paper, the potential supply chain for a bioethanol industry is immature and undeveloped. The ligno-cellulosic conversion technologies still require demonstration at pilot and commercial scales in the UK. Continued improvements in enzyme production and reductions in capital and operating costs need to be implemented before these feedstocks can compete successfully with sugar beet and starch crops.

Sugar beet and starch crops conversion processes are available now, and production facilities could be built in the UK, given the right market signals, investment conditions and sufficient developer confidence. On the other hand, for ligno-cellulosic feedstocks, it may be some years before the technologies can be brought into commercial operation. A suggested timeline for implementation of the different conversion technologies is shown in Figure 3.1. The timeline assumes that the first commercial facility using sugar beet or starch crops could receive the go-ahead before the end of 2003, and the facility would require a construction period of 18-24 months. Hence it could be in operation by mid-2005. A ligno-cellulosic demonstration facility using wheat straw as feedstock material could be in operation by 2007/2008, and, assuming that the production costs are competitive with the then costs of the sugar beet/starch crop conversion process, a commercial plant could be in operation by 2012/2013. Further developments of the ligno-cellulosic processes might result in a second-generation technology, which could be brought on stream by 2015/2016 using other feedstocks such as short rotation coppice, miscanthus, forestry residues and waste paper.

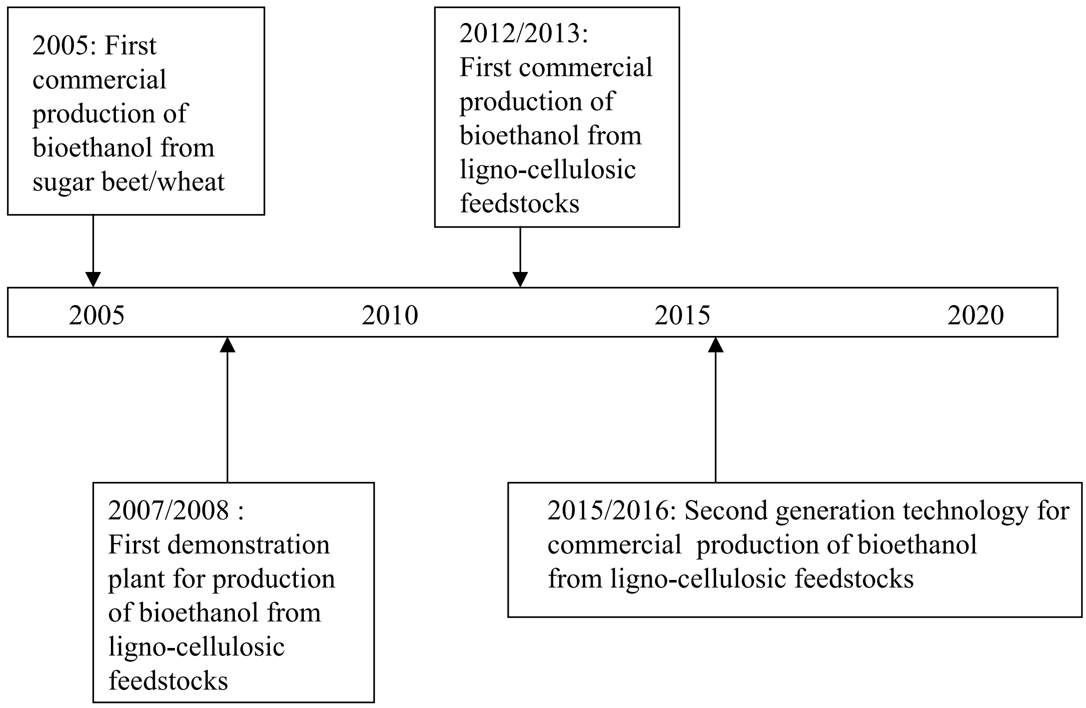


FIGURE 3.1: TIMELINE FOR IMPLEMENTATION OF CONVERSION TECHNOLOGIES

3.2 THE POTENTIAL UK MARKET FOR BIOETHANOL

Cars and light goods vehicles are the main users of gasoline (motor spirit), and are the main potential market for bioethanol blended with gasoline. The most recent UK National Road Traffic Forecasts[25], which were produced in 1998, indicated that, for example, car traffic levels could increase by between 22% and 39% over the period from 2001 to 2021. The central forecast for car traffic was an increase of 31%, after considering the effects of congestion and nominal capacity constraints.

The most recent projections of UK energy demand were published by the DTI in the Energy Paper 68 in 2000[26]. These projections included forecasts of final energy demand by road traffic over the period up to 2010. Energy demand is expected to increase due to the increased levels of road traffic, and including the effects of increased congestion. Energy demand is offset to some extent by improvements in the energy efficiency of vehicles, with the potential for large changes in fuel consumption as set out by the EU voluntary agreement with car manufacturers[27]. An additional factor is the increased demand for diesel fuel, caused by car purchasers switching to diesel fuelled vehicles. Energy Paper 68 indicated that demand for motor spirit under the DTI's central forecast would increase as shown in Table 3.1.

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[25] "National Road Traffic Forecasts (Great Britain) 1997", Department of the Environment, Transport and the Regions, London, 1998.
[26] "Energy projections for the UK", Energy Paper 68, Department of Trade and Industry, London, November 2000
[27] This agreement sets out a proposal for car manufacturers to reduce the average in-use CO_2 emissions from new cars sold in the EU from 2008 onwards by around 25% from a 1995 datum (viz from around 189 to 140 g/km).

TABLE 3.1: FORECASTS FOR GASOLINE DEMAND

Year	2000	2005	2010
Index of gasoline demand	100	100.4	106.8

The actual gasoline demand in Great Britain in 2000 was 21.6 Mt. Assuming a proportional share for Northern Ireland, the total UK gasoline demand in 2000 would have been about 22.4 Mt. For the purposes of this scenario analysis, the UK gasoline demand over the time period to 2020 is assumed to be fairly constant at around 24 Mt/year. Assuming that a 5% wt bioethanol blend would be used, then the overall market for bioethanol in the UK would be around 1.2 Mt/year.

However, it should be noted that diesel demand in the transport fuels market both in the UK and across the EU is growing rapidly, and that the increase in demand for gasoline is not keeping pace with the increase in diesel demand. This has implications for the oil supply companies, since refinery operations have to be modified to take account of the imbalance between diesel and gasoline demand. Indeed, if bioethanol were to substitute some of the gasoline supply, this would further unbalance the oil refinery operations, since one effect of this is that there would be excess gasoline available in the market[28].

3.3 SCENARIOS

The scenarios that have been selected break down into basic categories, dependent upon market penetration (expressed in terms of the proportion of gasoline substituted) and generic feedstock type. The descriptions of these scenarios are as follows:

<u>Scenario 1 – Business as usual, which is a baseline case with a gasoline supply chain but without any UK production of bioethanol.</u>

Gasoline is manufactured from petroleum products, which can be sourced either from the UK Continental Shelf or from imported petroleum.

<u>Scenario 2 – Supply of 1.2 Mt/year of bioethanol from manufacturing plant using a combination of sugar beet and cereal crops as feedstock materials, grown on set-aside land.</u>

Construction of the first bioethanol production facility would start in 2004 and the facility would be in operation by 2005. Further facilities would be built in succeeding years, each with a construction period of 18-24 months. Manufacturing would be by a simple fermentation process, with the sugar beet and cereal crops sourced from within the UK. Bioethanol would be blended into normal gasoline at up to a 5% blend. There would be a government tax incentive to reduce fuel duty sufficiently to make the price of blended gasoline equal to the price of normal gasoline. Consumers would not notice any difference from normal gasoline, so the product would not be need to be specially marketed. The area needed for cropping and collateral impacts on other agricultural sectors are key issues here. The total production needed would be 1.2 Mt/year, and would be delivered via a series of biomass conversion facilities, comprising:

- 2 facilities with 100,000 t/year capacity
- 2 facilities with 200,000 t/year capacity

[28] This situation might imply that gasoline prices would be reduced, but an analysis of this effect is beyond the scope of this study.

- 2 facilities with 300,000 t/year capacity.

Scenario 3 – Supply of 1.2 Mt/year of bioethanol using a combination of sugar beet and cereal crops and first generation ligno-cellulosic feedstocks, grown on set-aside land.

The build rate would be one facility in operation from 2005 onwards, and a series of further facilities constructed in succeeding years, each with a construction period of 18-24 months. Feedstock materials for the first four facilities would be sugar beet and cereal crops. The second set of four plant would use ligno-cellulose materials with advanced hydrolysis and fermentation. The capital and operating costs of the ligno-cellulosic conversion plant would need to be much lower than the data presented in Section 1. The assumption is made that R&D and technology development occurs sufficiently quickly for the costs to become competitive with sugar and starch based conversion.

Bioethanol would be blended into normal gasoline as before. To make this scale of capital investment attractive, there would need to be a government tax incentive to reduce fuel duty so that the selling price is equal to the normal gasoline price. Once all facilities were in operation, bioethanol would be supplying up to 5% of total UK demand for gasoline fuels. The total production would be delivered via a series of conversion facilities comprising:

- 2 facilities with 100,000 t/year capacity using sugar beet and cereal crops
- 2 facilities with 200,000 t/year capacity using sugar beet and cereal crops
- 4 facilities with 156,000 t/year capacity using first generation ligno-cellulosic conversion with wheat straw as the feedstock material.

Scenario 4 - Using wheat as the feedstock, with supply from both UK and imported sources, and a total production of 1.2 Mt/year.

The total production would be delivered by the same set of production facilities as for Scenario 2. 50% of the wheat feedstock would be imported. It should be noted that this case is basically similar to 50% of the wheat being cultivated on land that is currently used for other crops, as illustrated in Figure 2.11.

The scenario analysis makes use of the results from the Input-Output analysis, by aggregating the effects of the selected bioethanol production routes within each scenario, and making assumptions about reductions in capital and operating costs.

The results are summarised graphically in monetary terms, as £M/year once all the production facilities are in full operation. Figure 3.2 compares the total value added and cost of imports for each of the scenarios. In Figure 3.2, 1 – UK indicates the Scenario 1 results for UK sourced petroleum, and 1 – Imports indicates the Scenario 1 results for imported petroleum. Figure 3.3 compares the impact on the Treasury for each scenario. The overall impact in terms of value added includes the reduction in job seekers payments, the fuel duty receipts and the indirect taxes received.

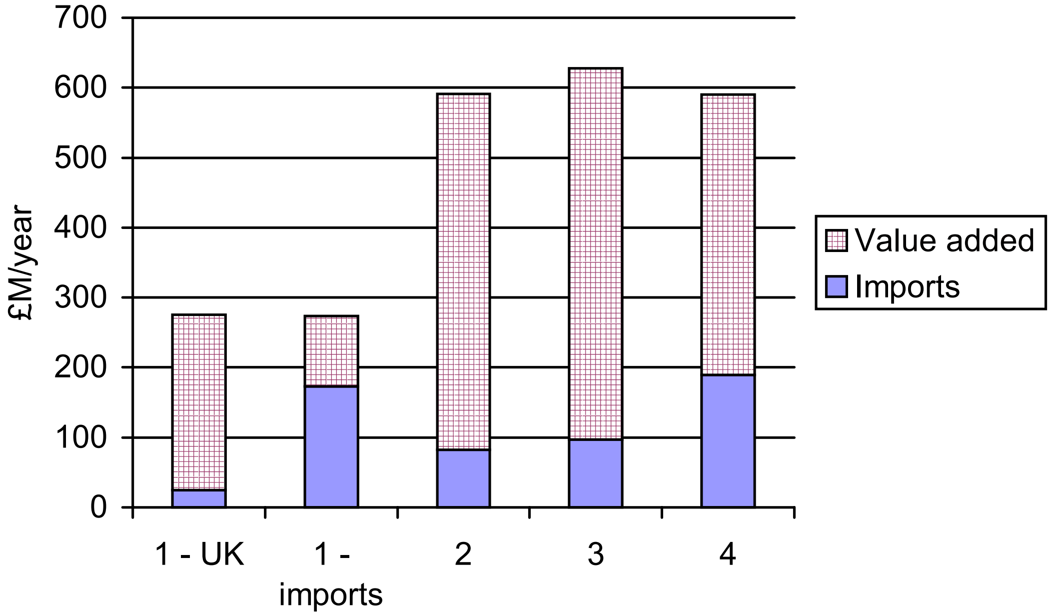

FIGURE 3.2 VALUE ADDED AND IMPORTS

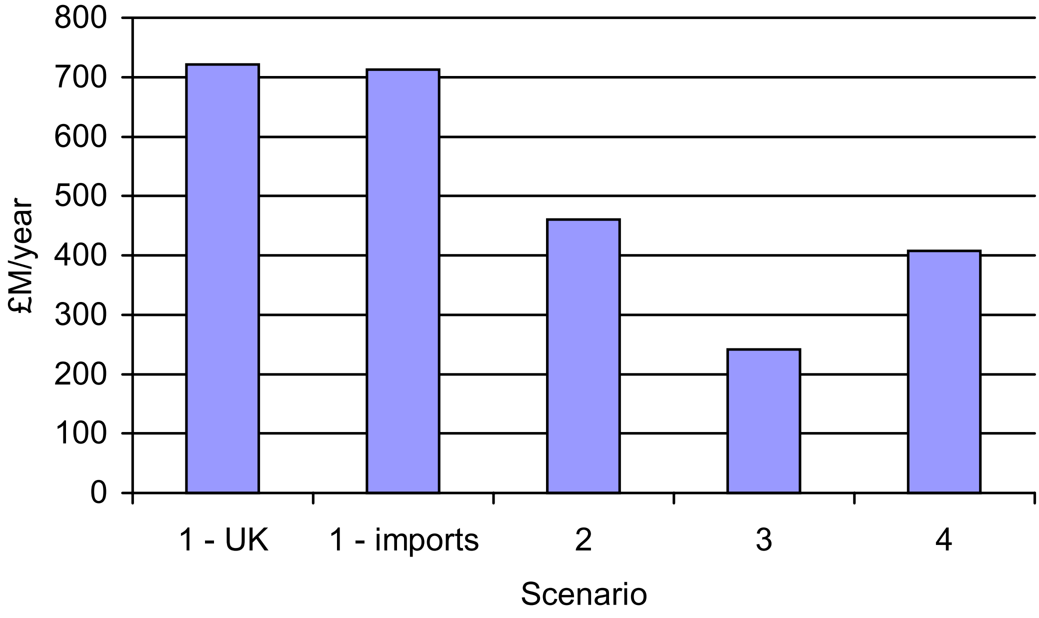

FIGURE 3.3 TREASURY IMPACT

As can be seen in Figure 3.2, the value added is larger than the reference gasoline cases for all the scenarios involving bioethanol production. A UK bioethanol industry of the size considered in this analysis would require a total expenditure of around £600 M/year, of which about £500 M /year would be value added (thus contributing to the GDP of the UK) for Scenarios 2 and 3, and around £400 M/year in Scenario 4 which includes imported feedstocks. These values compare with about £275 M/year economic value for the gasoline reference cases in Scenario 1.

As shown in Figure 3.3, the gasoline reference cases provide the largest revenues for the Treasury, totalling around £700 M/year, and made up principally of fuel duty revenues. Treasury receipts for Scenarios 2 and 4 are around £460 M/year, whilst the least attractive bioethanol case from the Treasury point of view is Scenario 3, which yields only £250 M/year.

3.4 FUTURE DEVELOPMENT WITH LIGNO-CELLULOSIC FEEDSTOCKS

As described in Section 1, ligno-cellulosic conversion facilities could use a wide variety of feedstocks such as wheat straw, short rotation coppice, miscanthus, forestry residues and waste paper. Once the ligno-cellulosic conversion technologies are commercially developed, then the range of opportunities for bioethanol production would be considerably enlarged. However, the capital and operating costs of the ligno-cellulosic conversion plant would need to be much lower than the data presented in Section 2.

The assumption is made that R&D and technology development occurs sufficiently quickly for the overall costs to become competitive with sugar and starch based conversion during the next 8-10 years. As outlined in Annex 2, NREL[29] have estimated the potential improvements in the process economics, and a summary of these estimates is shown in Table 3.2.

TABLE 3.2: FUTURE IMPROVEMENTS IN LIGNO-CELLULOSIC CONVERSION ECONOMICS COMPARED WITH YEAR 2000 TECHNOLOGY STATUS

	2005	2010	2015
Increased yield	+20%	+38%	+65%
Increased throughput	+16%	+35%	+64%
Reduced capital costs	-8%	-15%	-14%
Reduced production costs	-24%	-44%	-48%

It should be emphasised that realising these improvements in conversion processes still requires demonstration at pilot and commercial scales. Nevertheless, there is the potential for ligno-cellulosic conversion technologies to deliver bioethanol at overall costs that are lower than the costs of sugar or starch-based processes. Assuming that a 48% reduction in production costs is achievable by 2015, the conversion costs for wheat straw would come down from 37 to 19 p/litre, and for short rotation coppice from 52 to 27 p/litre. Other UK estimates indicate that, if these future developments are successful, the conversion costs for wheat straw and short rotation coppice could be as little as 18 p/litre[30]. At this level of cost, the overall costs for bioethanol from these feedstocks would be very competitive with sugar beet and wheat feedstocks.

Municipal wastes are also a potential feedstock and work in California has examined the potential for waste paper[31]. Various waste streams are available in the UK, but there are costs involved in partitioning certain waste streams and delivering them to the bioethanol production facility. For bioethanol the most pertinent route would be composting via kerbside collection, which has a cost of between £70 and £120/t. This is higher than the costs of producing other ligno-cellulosic feedstocks, but use of wastes for bioethanol production enables landfill tax to be offset. If this tax rises over the next few years, to a level

[29] "Ligno-cellulose biomass-to-ethanol process design and economics utilising co-current dilute acid pre-hydrolysis and enzymatic hydrolysis current and futuristic scenarios", National Renewable Energy Laboratory, Golden, Colorado, July 1999 (NREL/TP 580-26157).
[30] Woods, Imperial College, London, private communications, 2003.
[31] "Costs and benefits of a biomass to ethanol production industry in California", California Energy Commission, March 2001.

of around £35/t, the opportunity cost of waste paper feedstock comes into the range of £35-85/t. The lower end of this range would result in a feedstock cost of around 12 p/litre for bioethanol from waste paper, and this is comparable with the current feedstock cost for short rotation coppice. Hence waste paper might also become a viable feedstock material to produce bioethanol at an overall cost which is competitive with current sugar beet and wheat feedstocks. Detailed analysis of UK waste stream availabilities and costs is presented in Annex 6.

The future development prospects for ligno-cellulosic feedstocks are, therefore, promising, in that overall costs, either in feedstock production, or in conversion, could reduce to such an extent that these technology routes become competitive with the current fermentation and distillation of sugar or starch based materials. A significant advantage of the ligno-cellulosic feedstocks is that they extent the availability of the biomass resource that could be utilised in bioethanol manufacture, and thereby open the way to wider applications in the UK transport sector beyond the niche market level of 5% wt blends.

3.5 CONCLUSIONS

This part of the study has undertaken the following tasks:

- Characterisation of various technology options for bioethanol production, including suitable feedstocks such as sugar and starch crops, ligno-cellulosic materials, forestry residues and wastes;
- Examination of a range of feasible scenarios and technology routes for the production of bioethanol;
- Assessment of the direct and indirect economic, social and environmental impacts at the UK national level of these scenarios and technology routes;
- Evaluation of the entire production chain of each scenario, highlighting bottlenecks, sensitivities and risks for each component, at a national level;
- Quantification of the capital expenditures needed and the impact of fiscal measures that might be implemented to achieve a competitive position in relation to gasoline fuel.

The study has examined the various technical routes and crops for bioethanol production in the UK, and compared the production, processing and distribution costs of bioethanol with conventional transport fuels. The scope and nature of a bioethanol fuel supply chain and distribution infrastructure has been examined, and the interactions between the various links in the supply chain have been quantified as far as possible in terms of costs and efficiencies.

Sugar beet and starch crops are available as feedstocks for use in proven mature technology routes to bioethanol production, and facilities using these routes could be built within a 1-2 year time frame. A variety of ligno-cellulosic feedstocks require demonstration at conversion technologies at the pilot and commercial scales, and it is unlikely that a facility could be built to compete on a economic basis with sugar beet or starch crops commercially for several years to come. Nevertheless in the medium term – perhaps within 4-5 years - the first generation of ligno-cellulosic conversion facilities using wheat straw feedstocks could be in operation on a demonstration scale in the UK, and the technology routes involved offer the prospect of economic competitiveness with conventional sugar and starch conversion. In the longer term, of 10-12 years, other ligno-cellulosic feedstocks could be introduced into second generation conversion facilities, assuming that capital and operating costs can be reduced through R&D and technology development.

The public costs (i.e. the costs to the Treasury) of climate change mitigation, by blending bioethanol with gasoline up to a 5% level, are around £140-160/t CO_2 equivalent for sugar beet and wheat, and between £190-360/t CO_2 equivalent for wheat straw and short rotation coppice/forestry. These estimates refer to current technology and costs, and could reduce in future if technology improvements take place via R&D. Relatively modest greenhouse gas reductions have been indicated for the sugar and starch crop feedstocks, and there are much more significant reductions available for ligno-cellulosic feedstocks. Hence a UK bioethanol industry that makes use of ligno-cellulosic feedstocks could represent a viable low carbon option that provides a renewable transport fuel. However, the cost-effectiveness of this option as compared to alternative greenhouse gas reduction options is crucial in determining whether it is in the national interest to develop and deploy the relevant technologies.

The effects on North Sea oil depletion and gasoline prices are likely to be relatively minor, since and reduction in UK demand will mean that crude oil or refined petroleum products will be diverted from UK markets to international trade. Moreover, oil prices are determined largely by international markets so that any bioethanol production in the UK would not markedly affect these prices.

The main institutional and technical barriers to the market development and up-take of bioethanol as a transport fuel are:

- the overall production costs for all feedstocks are higher than the production costs of gasoline. The least expensive conversion process, namely for sugar beet and starch crops, are commercially available now, but investors and project developers need to be assured that for the whole depreciation period of their bioethanol facility the retail prices for the consumer will be competitive with gasoline. This will require Government action, perhaps in the form of fuel duty reductions in favour of bioethanol together with other capital support such as investment subsidies;

- ligno-cellulosic feedstocks are still at an early stage of development, and capital and operating costs need to be reduced through R&D and technology development before they can compete with sugar and starch crops. This might also require Government support, perhaps through funding specific R&D and demonstration projects;

- the agricultural sector and project developers are keen to see the potential for bioethanol taken up, but the major UK oil companies will also need to be convinced that the product is worth developing for the road fuels market;

- the Government also needs to be convinced that encouragement of a bioethanol industry is a viable and long term option for the UK transport fuels market, and that bioethanol has a role to play in the Climate Change Programme.

The means by which these barriers can be overcome will comprise the preparation of technical and economic arguments, setting out the advantages and disadvantages of bioethanol, both at a UK national level and in a regional context.

3.6 CONCLUSIONS FOR GOVERNMENT

This part of the study indicates that a UK bioethanol industry using currently available conversion technology and sugar and starch crops as feedstocks can offer economic development benefits for the agricultural sector and rural communities. However, the industry will require active stimulation and encouragement by government and agencies , working in partnership with other public and private sector interests.

The development of a UK bioethanol industry would also require process plant suppliers to gear up to design and build the required conversion facilities, and hence there might need to

be some involvement by government and agencies in helping to stimulate the supply chain for this process industry.
This assessment of the national impacts of a UK bioethanol industry can be summarised in a multi-criteria presentation. There are several competing policy issues involved in developing such an industry, each of which has economic, environmental and social features. The main policy issues are:

- the overall cost of bioethanol;
- the additional employment in the main sectors of agriculture, feedstock conversion, fuel supply and distribution and in the manufacturing sector;
- the levels of greenhouse gas avoidance available by substituting bioethanol for gasoline, and the cost-effectiveness of public support within the Climate Change programme objectives;
- the level of added value for the national economy;
- the extent of the net financial costs to the Treasury.

Table 3.3 provides a summary of these impacts in a qualified manner for selected UK bioethanol production routes in comparison with gasoline. This presentation is intended to act as a tool for assisting decision making on the next steps for Government.

TABLE 3.3: MULTI-CRITERIA PRESENTATION OF IMPACTS FOR UK BIOETHANOL PRODUCTION

	Bioethanol			**Gasoline**
	Set aside crops		**Existing crops***	
	Wheat/sugar beet	**Ligno-cell**		
Fuel cost	Expensive	Very Expensive	Expensive	Cheap
Value added to UK economy	High	Moderate	Moderate	Moderate
Additional employment	Good	Good	Moderate	Low
Impact on the Treasury	Moderate	Poor	Moderate	Good
Greenhouse gas avoidance	Good	Very good	Good	No
Cost of greenhouse gas avoidance	Moderate	Moderate	Moderate	N/a

* There may also be additional costs due to changes in land-use and land values.

The means by which stimulation of the industry and the development of a UK market could be pursued are dependent on government policies, and on the public and private costs involved. Various implementation strategies could be devised, such as:

- a reduction in excise duty in favour of bioethanol (as currently proposed by the Treasury);
- subsidies for the capital investment for the bioethanol conversion facilities, possibly combined with a voluntary agreement with fuel producers and suppliers to meet agreed targets for bioethanol content in conventional fuels;
- specifying through UK legislation a minimum bioethanol blend in gasoline, so that fuel suppliers would have to meet a Transport Fuels Obligation to supply a certain percentage of bioethanol (similar to the Renewable Obligation used for electricity supply, with a system of national certificates to prove origin and compliance);
- an EU or international system of certification of bioethanol blends;
- other fiscal incentives for users of bioethanol fuels, such as rebates on the annual road fund licence, exemption from congestion charging in cities and reduced fees for parking.

Although it is not possible within the scope of this project to calculate the degree of market penetration due to these different strategies, some quantification of the costs and impacts can be made. In general, using Scenario 2 as the starting point, qualitative and quantitative assessments of these different implementation strategies are shown in Table 3.4. (Note that in the case of other fiscal incentives, a variety of relatively small-scale measures could be used, and no quantitative calculation was undertaken).

TABLE 3.4: MULTI-CRITERIA ASSESSMENT OF IMPLEMENTATION STRATEGIES

Qualification	**Excise duty**	**Investment subsidy**	**UK Obligation**	**EU Obligation**	**Other fiscal incentives for users**
Cost limitation for Government	Low	High	High	High	Reasonable
Effectiveness	Reasonable	Very low	High	High	Low
Value for money for Government	Low	Reasonable	Very high	High	Low
Simple to administer	High	Reasonable	Low	Very low	Low
Stimulates new technology	Low	High	Low	Low	Low
Generates employment	Reasonable	Low	High	Low	Low
Generates UK value added	High	Low	High	Low	Low
Visibility for users	Good	Good	Reasonable	Low	Very good
Cost limitation for users	Low	High	Low	Very high	Reasonable
Market signal	Reasonable	Low	Good	Very good	Low
International competitiveness	No problem	No problem	No problem	No problem	No problem
Quantification					
Direct costs to Government[32] (£M/year)	240	231	0	0	Not calculated
Additional value added (£M/year)	503	503	503	133-503	"
Additional employment generated	11,900	11,900	11,900	0-11,900	"
Direct cost for user (p/litre)	0	0	1.2	0-1.2	"

In Table 3.4, the market penetration is assumed to be 5% for both the quantitative and qualitative assessments, and for each of the implementation strategies. This may not be truly representative of the way in which the market does respond – for example, in the case of an obligation, the market up-take can normally be expected to be close to the obligation level, whereas in the case of excise duty reduction, there may be a lower rate of up-take due to consumer inertia.

It should also be noted that in the qualitative assessment, the investment subsidy is assumed to be implemented as a single measure. As outlined earlier in this report, it is unlikely that the EC would allow more than about 40% subsidy, and a combination of subsidy, fuel duty reduction and perhaps voluntary agreements would be needed. In order to make the quantification closer to reality, the Government may wish to use a lower discount rate in order

[32] Excluding policy costs, and any costs of technical and economic studies to develop the strategies examined here.

to compare the subsidy with a fuel duty reduction, than the 15% used in the private sector investment calculation. In order to achieve a similar effect, a subsidy may be less expensive than a fuel duty reduction. With an arbitrary discount rate of 10%, the costs of the combined subsidy and fuel duty reduction are as shown in Table 3.4.

For the international obligation strategy, a range of cost outcomes are given, since these will depend on whether the UK industry will be able to compete with foreign industry. If all the bioethanol is imported, then the low end of the cost ranges apply, if all the bioethanol is UK produced the high end applies.

From this assessment, the optimal implementation strategy would appear to be a combination of fuel duty reductions in favour of bioethanol blends and Government subsidies in the form of grants for the capital investment required for the feedstock conversion plant.

4 MARKET SENSITIVITIES

4.1 WORLD ETHANOL MARKETS

In 2002, the worldwide production of bioethanol was estimated to be around 16.5 Mt/year, with world biodiesel production around 2.3 Mt/year[33]. These figures represent significant increases in production over the last 10 years. In comparison, bioethanol production was 13 Mt/year in 1992, whilst biodiesel production was 0.3 Mt/year. The current world bioethanol production is dominated by Brazil with an output of around 11 Mt/year, derived from sugar cane, and the US with an output of around 2 Mt/year, mostly derived from corn. The EU has a much smaller share of world bioethanol production, with France, Spain and Sweden being the main producing countries. The total EU production was around 0.2 Mt/year in 2001, and France produced almost 50% of the EU total.

Forecasts for future production indicate that there will be continued growth, with some estimates showing total bioethanol production reaching around 24 Mt/year by 2006[34]. These forecasts are based partly on the numbers of new bioethanol production projects that have been announced over the last 1-2 years. These include large-scale new investments in the US, Canada, China and Thailand, and continuing production from existing plant which are currently concentrated in countries such as the US and Brazil. Many of these developments are dependent on national government support programmes, other fiscal measures and other economic, political and legislative requirements.

At present, there is little or no international trade in bioethanol. However, the increased production and utilisation of bioethanol could encourage the development of international trade. One benefit of international trade would be that it could act as a market stabilisation mechanism in the event of regional production shortfalls. If liquid biofuels in general become more acceptable in the transport markets, it can be expected that international trade, at least in the form of trade between EU partners, might grow in importance.

Bioethanol production is often supported by government fiscal measures, and as such is used as an instrument to support the agricultural sector. The EU currently imposes an import duty of 10.2 euro cents/litre on denatured ethanol. In the context of World Trade Organisation negotiations, a higher tariff would only be permitted if bioethanol production were to be put in the so-called "green box". In order to qualify for this designation, a subsidy must not distort trade, or at most cause minimal disruption. Such subsidies have to be government-funded (not by charging consumers higher prices) and must not involve direct price support[35].

Bioethanol imports

A brief competitive assessment of bioethanol imports-v-UK production has been carried out, using the potential imports of bioethanol from the sugar cane conversion industry in Brazil. Brazil was chosen because it is the largest producer of bioethanol, and has a well-established industry, although there is little export of bioethanol from Brazil at the present time. Furthermore it should be noted that the Brazilian bioethanol industry has received considerable subsidies and government funds over the last 15-20 years, so that the true economic costs of Brazilian bioethanol production are difficult to identify.

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[33] "World of Biofuels 2002", World Ethanol and Biofuels Report, F O Licht, December 2002, http://www.fo-licht.com

[34] "Review of World Ethanol Production, 2001", F O Licht, July, 2001, http://www.fo-licht.com

[35] "Fuel ethanol production in the USA and Germany – a cost comparison", F O Licht, World Ethanol and Biofuels Report, February, 2003.

Nevertheless, data on the bioethanol production costs, and the costs of local Brazilian road transport, together with sea transport to the UK and loading and unloading costs were obtained from recent sources[36]. Brazilian production costs are calculated as being around 18-22 p/litre, and total transport costs are around 3.5-6 p/litre. These calculations indicate that the landed cost of bioethanol produced in Brazil and transported to the UK would be between 22-28 p/litre at the port of delivery. To these costs would need to be added the UK blending and retail distribution costs. Hence the imported bioethanol costs are around as much as 10 p/litre lower than the costs calculated in Section 2 for bioethanol produced from UK sugar beet and wheat. However, if the current EU import duty of 6-7 p/litre on denatured ethanol were to be imposed on the Brazilian bioethanol, then the cost of the imported product would be broadly similar to, or slightly cheaper than, the UK production.

Imports would have a low impact on the value added to the UK economy, and on UK employment. There would be an overall net impact to the Treasury, since there would be revenues from the import duty, as well as fuel duty, although there would be no reduction in job seekers' allowance and revenues from other taxes.

Energy consumption and greenhouse gas emissions from bioethanol production from sugar cane indicate a more favourable energy balance and lower emissions than for UK sugar beet or wheat. This is due to the higher yields per hectare from sugar cane, and the use of the sugar cane bagasse co-product for energy production at the bioethanol plant. The level of greenhouse gas avoidance would be greater with imports, and the costs of avoidance would be less. There is a question, however, as to which country the greenhouse gas avoidance credits are assigned. For the purposes of this assessment, it is assumed that the credits are assigned to the end-user of the bioethanol, i.e. the credits are assigned to the UK economy.

To compare the Brazil import case with the UK analysis cases presented in Section 3, Table 4.1 provides the same multi-criteria assessment, with the addition of Brazilian imports.

[36] "Bioenergy primer: modern biomass energy for sustainable development", Kartha and Larson, UN Development Programme, New York, 2000; and "Long distance bioenergy logistics: an assessment of costs and energy consumption for various biomass energy transport chains", Suurs, Utrecht University, Utrecht, 2002.

TABLE 4.1: MULTI-CRITERIA PRESENTATION OF IMPACTS INCLUDING IMPORTS FROM BRAZIL

	Bioethanol				Gasoline
	Set aside crops		Existing crops	**Import Brazil**	
	Wheat/sugar beet	Ligno-cell			
Fuel cost	Expensive	Very Expensive	Expensive	**Expensive**	Cheap
Value added to UK economy	High	Moderate	Moderate	**Low**	Moderate
Additional employment	Good	Good	Moderate	**Low**	Low
Impact on the Treasury	Moderate	Poor	Moderate	**Good**	Good
Greenhouse gas avoidance	Good	Very good	Good	**Very good**	No
Cost of greenhouse gas avoidance	Moderate	Moderate	Moderate	**Moderate - good**	N/a

4.2 GOVERNMENT POLICY ON FUEL DUTY AND ENVIRONMENTAL TAXATION

The Government has used the tax system to encourage the use of less-polluting fuels, both through fuel duty differentials and through reforms to the Vehicle Excise Duty and company car taxation systems. These actions are in line with the 1997 Statement of Intent on Environmental Taxation, which is reproduced in Figure 4.1

FIGURE 4.1: GOVERNMENT POLICY ON ENVIRONMENTAL TAXATION (JULY 1997)

"The Government's central economic objectives are the promotion of high and sustainable levels of growth and high levels of employment. By that we mean that growth must be both stable and environmentally sustainable. Quality of growth matters; not just quantity.

Delivering sustainable growth is a task that falls across government. It will be a core feature of economic policy under this administration. The Treasury is committed to that goal. How and what governments tax sends clear signals about the economic activities that they believe should be encouraged or discouraged, and the values they wish to entrench in society. Just as work should be encouraged through the tax system, environmental pollution should be discouraged. To that end, the Government will explore the scope for using the tax system to deliver environmental objectives – as one instrument, in combination with others like regulation and voluntary action. Over time the Government will aim to reform the tax system to increase incentives to reduce environmental damage. That will shift the burden of tax from "goods" to "bads"; encourage innovation in meetings higher environmental standards; and deliver a more dynamic economy and a cleaner environment, to the benefit of everyone.

But environmental taxation must meet the general tests of good taxation. It must be well designed, to meet objectives without undesirable side effects; it must keep deadweight compliance costs to a minimum; distributional impact must be acceptable; and care must be had to the implications for international competitiveness. Where environmental taxes meet these tests, the Government will use them."

One of the earliest instances of this approach was in encouraging the uptake of ultra-low sulphur diesel fuel. Ultra-low sulphur diesel (ULSD) offers significant reductions of particulate and nitrogen oxide emissions, and enables the introduction of new pollution-reducing engine and exhaust technology. Its maximum sulphur content of 50 ppm meets the EU diesel specifications for the year 2005. Between 1997 and 1999, the Government encouraged the uptake of ULSD through fuel duty incentives. An increase of the duty differential over conventional diesel in favour of ULSD from 1p to 3p/litre persuaded oil companies to produce and supply ULSD and achieved an almost complete conversion of the diesel market over a two-year time period. The differential helped offset the additional production and development costs associated with the tightened specification. This differential was increased in successive years to reach a level of 6p/litre by March 2001. ULSD now has virtually 100% penetration of the diesel market.

The success of this approach has encouraged the Government to use it as a model to create market-based incentives for other environmentally-friendly road fuels, such as road fuel gases and ultra-low sulphur gasoline[37]. These duty incentives introduced by the Government have already encouraged industry to convert unleaded and diesel sales for road vehicles to ultra-low sulphur gasoline and ULSD fuels, leading to local air quality benefits through reductions in emissions of regulated pollutants.

Road fuels gases can offer reductions in particulates and nitrogen oxide emissions compared with conventional fuels. The current rate of fuel duty on road fuel gases (CNG: compressed natural gas and LPG: liquefied petroleum gases) is 9 p/kg – approximately equivalent to 4.5 p/litre. LPG is now supplied at over 1,200 fuel forecourts and a wide range of cars and light vans are capable of using this fuel as an alternative to gasoline. CNG is used by a number of haulage operators as an alternative to ULSD. The Government has made a commitment to freeze fuel duty (in real terms) on road fuel gases until 2004 in order to provide the stability needed to encourage growth in the road fuel gas market.

A new fuel duty rate for biodiesel, set at 20 p/litre below the rate for ultra-low sulphur diesel was introduced in July 2002. The aim of this reduction was to support the production of the biodiesel fuel and to allow the UK to benefit from any reductions in greenhouse gas emissions it can offer. The Chancellor announced in his 2003 Budget that the Government intends to introduce a new duty rate for bioethanol set at 20p/litre below the prevailing duty rate for sulphur-free gasoline, with an implementation date of 1 January 2005. The current duty rate for ultra-low sulphur gasoline is 45.82p/litre[38], and sulphur-free gasoline will benefit from a 0.5 p/litre reduction in duty relative to ultra-low sulphur gasoline[39].

4.3 IMPLICATIONS FOR THE PROCESS PLANT INDUSTRY

The UK engineering construction industry is large and very diversified. It employs over 14,000 people on engineering design and project management, not including the much larger numbers of staff required for site construction and equipment manufacture. The main industries served by the engineering construction sector are: oil and gas extraction; oil refining; power generation; petrochemicals; heavy and fine chemicals; polymers; fibres:

[37] "Using the tax system to encourage cleaner fuels: The experience of ultra-low sulphur diesel", HM Customs and Excise, November 2000, London.
[38] This will be increased in line with inflation on 1 October 2003.
[39] VAT at 17.5% of the total of fuel price + duty is then applied in addition.

pharmaceuticals; pulp and paper; industrial gases; food and beverages; fertilisers; agrochemicals; and biotechnology. Services provided by the sector include any or all of the wide range of activities needed for the successful realisation of process plant projects, i.e. consultancy, (seeking project financing) feasibility studies, basic designs and detailed engineering, procurement, construction, project management, planning and cost control, commissioning, maintenance and training.

Although there is no reference basis in the UK for experience with designing and building bioethanol production plant, the wide range of skills and knowledge available in the chemical plant contracting sector should be able to cope with the requirements for designing and building suitable plant in the UK. The key processes involved are mashing (for starch conversion), fermentation, distillation and dehydration. These processes and plant would be derived directly from the alcoholic beverage production industry, which is well established in the UK. Furthermore, these processes are well understood and would impose few technological constraints in being incorporated into a suitable plant system for bioethanol production. Sourcing of components and equipment from UK suppliers should also not be difficult. Ligno-cellulosic processing for bioethanol production would, however, require additional or new types of plant and equipment and hence is not readily amenable to technology transfer from the alcoholic beverage industry.

Table 4.2 gives a list of the leading companies operating in the sector together with the location of their main offices in the UK. Several of these companies are owned by US corporations, but have a strong UK presence[40].

TABLE 4.2: UK CHEMICAL ENGINEERING CONSTRUCTION COMPANIES

Company	UK main office location
ABB	London
AMEC	Crawley
Bechtel	London
CEL International	Coventry
Fluor	Camberley
Foster Wheeler	Reading
KBR	Leatherhead
Jacobs Engineering	Croydon
Kvaerner	Solent
M W Kellogg	Greenford
Parsons Energy and Chemicals Europe	Brentford
Simon Carves	Cheadle
Stone and Webster	Milton Keynes
Washington E&C	Warrington

Outside the UK, there is direct experience in bioethanol production plant. For example some of the companies that have recently been involved in the engineering and construction of bioethanol production plant in Europe include:

- Abener, Spain – currently involved in three developments using grain and sugar beet feedstocks in Spain with a total bioethanol production capacity of over 300,000 t/year;
- Vogelbusch, Austria – with several years' experience of bio-alcohol plant in the US, Canada and Europe;

[40] The British Chemical Engineering Contractors Association website gives more information about this industry sector, see http://www.bceca.org.uk

- Jaako Poyry, Finland – recently responsible as turn-key contractor for a 40,000 t/year bioethanol plant using grain feedstock which has just been completed in Finland.

It can also be expected that project developers from North America, such as the Iogen Corporation of Canada and Arkenol of the US, would be able to bring their ligno-cellulosic conversion technologies to the UK.

4.4 CEREAL PRODUCTION FOR BIOETHANOL: The impact of policy change

Cereal production in the UK and EU is currently controlled by the Area Aid Payment Scheme originally introduced in the 1992 MacSharry reforms as compensation for the adoption of set-aside. Since then the area payments[41] have been revised. The Commission's Agenda 2000 reforms simplified the scheme with set-aside and all eligible crops, with the exception of protein crops, getting the same area payment support. Protein crops receive a small additional payment (currently € 56.02) designed to increase EU domestic protein production. Additionally the levels of intervention support payment have been reduced.

The above policy changes have coincided with changes in the world supply and demand situation, but as UK feed wheat does not generally meet EU Intervention standards the decline in prices has been more a reflection of world price trends, and reduced tariff protection following the ratification of the GATT Uruguay round. Additionally feed wheat prices are kept under pressure to some extent by competition from maize, which in the US is the prime feedstock for bioethanol projects. In future it would appear the price of feed grains globally may be firmed as bioethanol projects develop.

The decline in UK feed wheat prices since the highs of the mid 1990's is shown in Figure 4.2.

[41] Area payments are based on a price per tonne of generic 'cereals' produced at the regional base yield. Currently the UK base yield is 5.89 t/ha for England, and the payment per tonne is €63 . The payments for England for the 2002 harvest year are £238.94, based on an average June 2002 £/€ conversion rate of €1 =£0.64394, and before any deductions for base area overshoot or modulation.

FIGURE 4.2: UK FEED WHEAT PRICES JAN 1996-JAN 2003 (£/T)

The high price at the start of the period shown is a combination of the effects of world supply and demand shortages, and the protection of internal EU prices before the GATT Uruguay round tariff reductions were fully implemented. The chart therefore shows market responses to a better supply and demand balance and reduced tariff protection. In addition a strengthening pound against the euro has helped reduce grain prices in stirling (Figure 4.3). The decline in grain prices over the last 12 month period is due in part to further removals of tariff protection as the producers in Eastern Europe and the FSU states were give access to the EU markets. Since the start of 2003 tariff protection has been reintroduced to try and prevent too great a loss of confidence in the EU cereal sector.

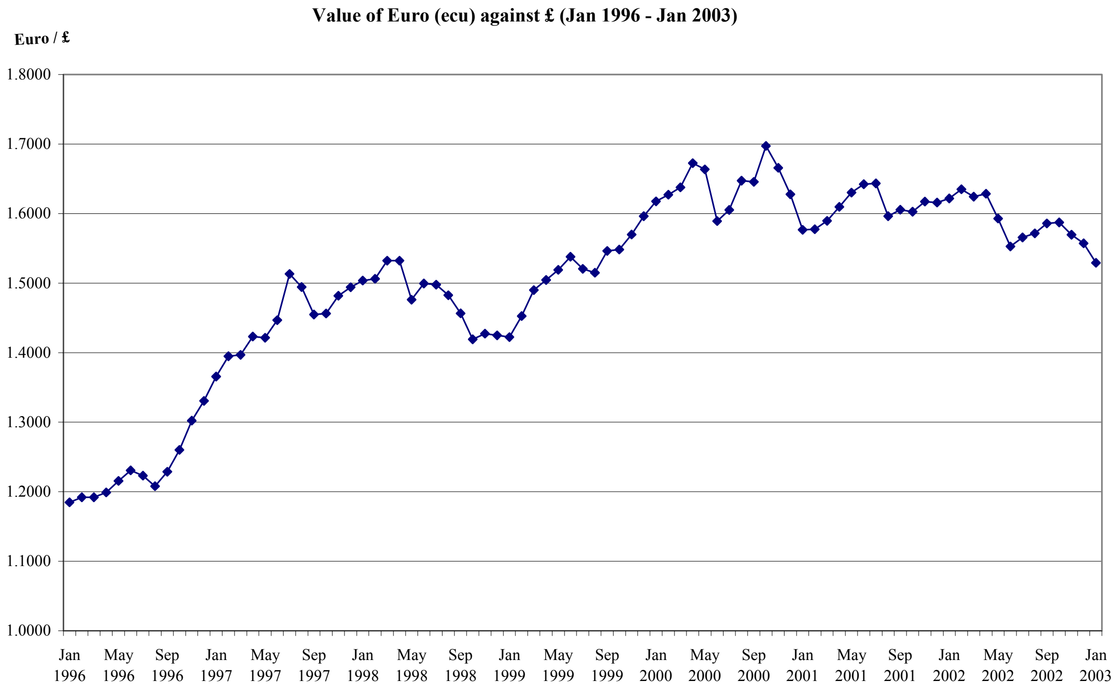

FIGURE 4.3: VALUE OF EURO AGAINST THE POUND (JAN 1996 TO JAN 2003)

Low grain prices appear to be here to stay, although exposure to world supply and demand will increase the volatility. The Uruguay round reduced protection levels, freer trade with FSU states has kept them down, and the Doha round of the WTO talks has freer trade as a corner stone of its ultimate aims. The so-called Mid Term Review (MTR) being put forward as the structure for the Common Agriculture Policy to around 2012/13 also lowers grain prices; the Commission are proposing a 5% cut in the intervention price from July 2004, compensated for by a €3/t increase in the rate of decoupled direct aid.

Perhaps the most significant feature of the MTR proposals is that aid will be decoupled from production, and will be paid, linked to land ownership, on the basis of previous aid entitlement levels. Various issues like the level of capping for payments, and the rate of reduction due to modulation are still being discussed, but there are two significant features of the proposal which add to the attraction of growing cereals for bioethanol. Firstly the payments will be cross compliant with good environmental management, and although the most profitable way to produce cheap cereals for bioethanol will undoubtedly be to farm crops well and relatively intensively, because of the end use some aspects may allow environmental benefits and cost reduction. Plant requirement and contract drafting will give this point clearer focus. Secondly their will be no requirements to produce crops to get the payments. Clearly producers will want maximise their incomes, but with greater exposure to more volatile markets the longer term security of price that could be built into contracts would provide a useful secure income stream.

Conclusions

- Lower grain (world market) prices are likely to be the norm for UK and EU cereal markets. Market volatility will lead to periodic higher prices, although some analyses have suggested the removal of trade distorting tariffs and liberalisation of world markets will reduce the levels of volatility we have seen over recent decades.

- EU reforms, including decoupled aid payments and the need for environmental cross compliance may favour the development of longer term supply contracts for grain destined bioethanol production.

4.5 SUGAR BEET PRODUCTION FOR BIOETHANOL: The impact of policy change

Unlike cereals, Sugar Beet and sugar production were outside the MacSharry, Agenda 2000 and MTR reforms, save for reductions in the total quantity of subsidised exports. Indeed since the start of the CAP sugar has had its own support regime. Like the combinable commodity crops it had minimum support prices, import duties and export refunds to protect the internal market and an intervention system to guarantee the minimum support price. In addition sugar production was limited by a production quota system to limit the total quantity eligible for price support. The quotas refer to the amount of sugar eligible for support (Intervention purchase). Surplus production has to be sold outside the EU. Thus quotas:

- limit the total quantity of sugar that can be brought on the EU sugar market
- limit the cost of intervention purchases
- guarantee each Member State a share of the EU sugar market.

The relatively small changes in the sugar regime to date are likely to change this year. Already the Commission has reduced A and B sugar production quotas by 663,976 t and 163,011 t respectively, and later this year the Commission will come forward with proposals that are likely to result in big price cuts. These in turn will require significant investment in compensatory direct aid, and already 'degressive' aid cuts are planned in the MTR proposed payments to cover the reforms in the sugar (and dairy) sector.

The sugar regime reforms have to take into account the wide range of supplies of imports from sugar producers around the world. To date the amounts imported have been governed by trade agreements and well over 1 million tonnes of the preferential sugar has been imported annually into the EU. The accession of the UK allowing into the EU supplies from its former colonies. Much of this sugar imported is produced more cheaply than EU sugar, and in trade terms more open access of the EU markets for this material is a feature of both WTO aims and the EU's 'Everything But Arms' import concession to Less Developed Countries (LDCs). As the latter implies this allows free access to EU markets for all products originating in LDC countries with the exception of arms and ammunition. Although the EBA agreement has been in force since March 2001, full liberalisation bananas, rice and sugar are being phased in. Sugar liberalisation will be phased in between 1 July 2006 and 1 July 2009, by gradually reducing the tariff to zero. During this period LDC raw sugar can come into the EU duty free within the limits of tariff quota, which will grow from 74,185 tonnes white sugar equivalent to 197,355 tonnes in 2008/2009. The ACP- EC Sugar Protocol is excluded from these calculations.

Clearly the outcome of the sugar regime reforms cannot be judged accurately at this time, but with UK A and B quota beet selling at £28 per tonne and C at around £8 per tonne, it seems feasible that beet prices could fall say, in the £12 - £20 range, with the difference initially being made up by compensatory aid. The level of the beet price 'post-reform' will have a significant impact on the viability of any bioethanol project using sugar beet as a feed stock.

In producing ethanol from beet it is likely that beet may be processed to lower grade (c 60%) syrups for storage and subsequent use after the main harvest and processing campaign. Such material would not be deemed to be sugar for quota purposes, but for the grower the production and margins for the crop would be judged alongside the commercial sugar crop. Thus the reform of the EU sugar regime will impact on beet production for bioethanol, although the produce of the crop may be deemed 'industrial' and outside the legislative influence of the sugar regime *per se*.

QUOTAS, EU SUGAR REGIME AND EXPANSION

Within the EU, Member States allocate A and B quota to each undertaking producing sugar, and companies producing isoglucose and inulin syrup. The amounts of white sugar allocated under A and B quotas under Council Regulation 1260/2001 for each Member State are shown below and were set for the 2001/2 to 2005/6 marketing years..

Regions	A quota (*t white sugar*)	B quota (*t white sugar*)	Total
Denmark	325000.0	95745.5	420745.5
Germany	2612913.3	803982.2	3416895.5
Greece	288638.0	28863.8	317501.8
Spain	957082.4	39878.5	996960.9
France (mainland)	2506487.4	752259.5	3258746.9
France (overseas departments)	463872.0	46372.5	510244.5
Ireland	181145.2	18114.5	199259.7
Italy	1310903.9	246539.3	1557443.2
Netherlands	684112.4	180447.1	864559.5
Austria	314028.9	73297.5	387326.4
Portugal (mainland)	63380.2	6338.0	69718.2
Azores	9048.2	904.8	9953
Finland	132806.3	13280.4	146086.7
Sweden	334784.2	33478.0	368262.2
Belgium/Luxembourg	674905.5	144906.1	819811.6
United Kingdom	1035115.4	103511.5	1138626.9
Total EU A&B quota of white sugar			14482142.5

The above quota guarantees may be reduced for one or more marketing years in order to comply with the EU's commitments to the GATT Uruguay Round.

For the purposes of the guaranteed quantities, quotas are be fixed before 1 October for each marketing year on the basis of forecasts relating to production, imports, consumption, storage, carryovers, the exportable balance and the average loss likely to be borne by the self-financing scheme. If these forecasts show that the exportable balance for the marketing year in question is greater than the maximum laid down under GATT rules, then the guaranteed quantities are reduced. This reduction is split between sugar, and *isoglucose* and inulin syrup (*tonnages not shown here*) according to the percentage represented by the sum of each product's A and B quotas for the entire Community. It is then broken down by Member State and by product by applying coefficients set out in Council Regulation 1260/2001.

Sugar produced above these tonnages is C quota sugar and cannot be disposed of on the Communities internal market, and must be exported without further processing before 1 January following the end of the marketing year. C quota sugar can be carried over into the next marketing year, but will be treated as part of that years production. Material not processed to white sugar but kept as syrup is not deemed to be sugar, and so falls outside this regulation. Thus surplus production if fully processed to sugar needs positive action to remove it from the EU market, either by carrying it over or export.

The diagram below shows schematically the relationship of A, B and C quota, carryover, exports and bioethanol production.

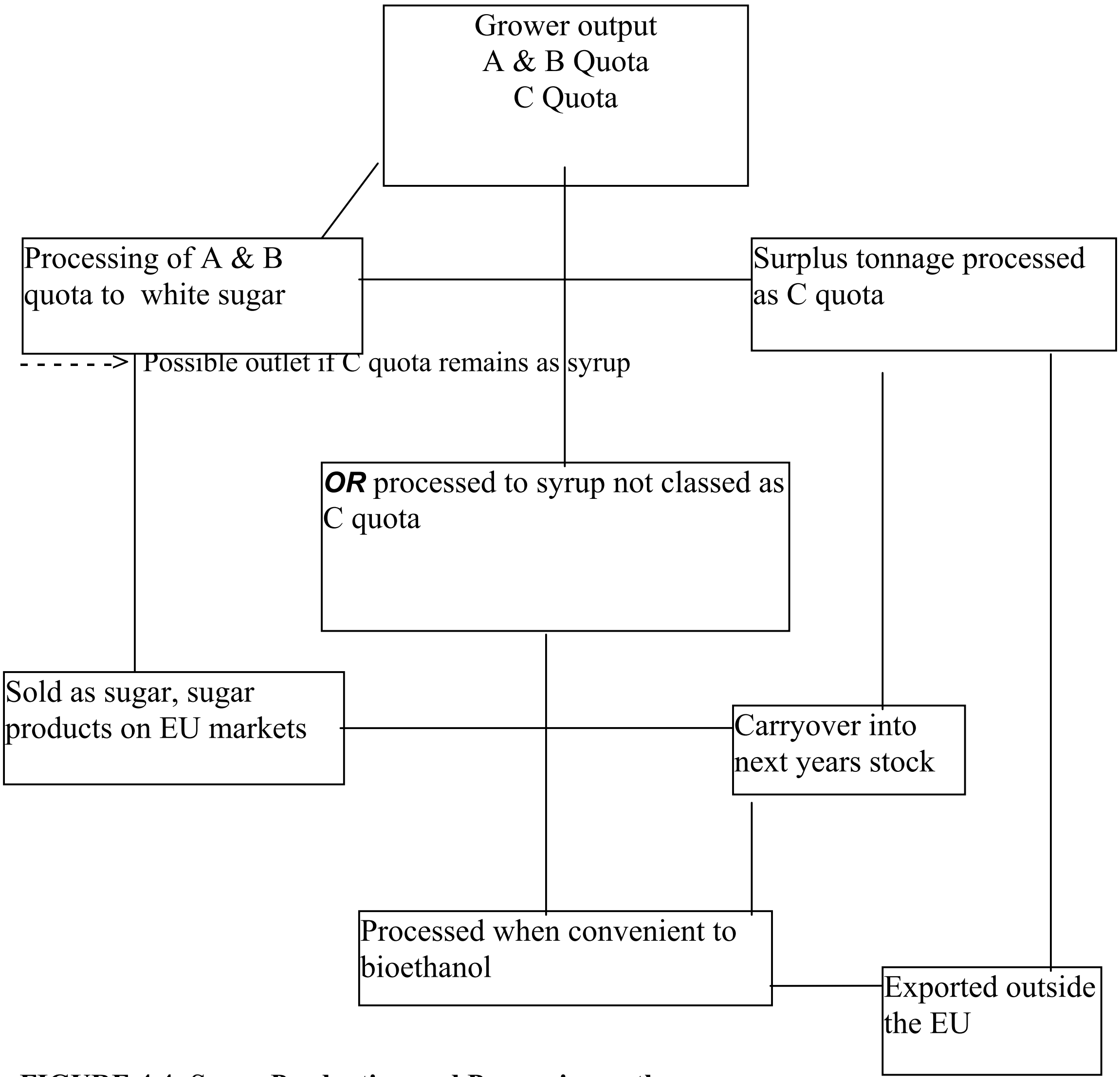

FIGURE 4.4: Sugar Production and Processing pathways

As mentioned above the sugar regime is facing reform later this year. The Community is facing enlargement and is taking on significant producers of sugar beet. Sugar production from new accession counties (Table 4.3).

TABLE 4.3: PROPOSED SUGAR QUOTA FOR EU ACCESSION COUNTRIES

Country	Proposed sugar quota[42] (*tonnes*)
Poland	1665017
Czech Republic	445237
Hungary	380021
Slovakia	208736
Lithuania	96241
Slovenia	52977
Latvia	52482
	2900711

The above sugar production represents an increase of about 20% in the current EU quota tonnage, and represents just over 18 million tonnes of beet production at the standard quality sugar content of 16%.

Conclusions

- The detailed way forward for the inclusion of sugar beet in this project cannot be clearly predicted until the reforms to the EU sugar regime, and thereby the UK quota arrangements and prices, are announced later this year.

- Such changes will need to take into account the impact of accession countries and their sugar production.

- As with cereals, all indications are of a long term policy aim of lower prices and more exposure to world markets, with freer access of imported sugar. This will result in lower price feedstocks, with producers receiving some form of compensation as part of the market reforms.

Carbon credits

The MTR reforms contain proposals for a €45/ha carbon credit payment to farmers growing non-food crops. The 1.5 million hectare cap on these payments will roughly equates to the current level of support for industrial crops on set aside. Taking Community policy forward under the MTR and WTO regimes will involve crops production for bioethanol and the like, being able to justify their production along side other commodity crops in the open market.

To date planners of some projects in the UK have bemoaned the lack of support for projects over say a 10 – 20 year period. The restructuring of support to agriculture, in allowing crops to be produced on the open market should, in theory given long term security of supply. The caveat being that some contractual / option mechanisms will be needed to buffer supplies against the volatility of market.

The free market model reduces the administration costs of carbon credit policing, which could be high given the possible scale of production. The future for both bioethanol and biodiesel looks more comfortable in a free market situation along side the normal commodity trade.

[42] Enlargement and Agriculture: Successfully integrating the new Member States into the CAP. EC SEC(2002) 95 final.

4.6 ENERGY CROPS AND FORESTRY

Energy crops
Growing either short rotation coppice or miscanthus presents long term benefits to the farmer in terms of reduced fixed costs and labour requirements as well as reduced input variables. A comprehensive discussion of cropping issues is presented in Annex 6. However, there are inherent risks with perennial cropping, in particular:

- Very high up-front costs. Even once the Defra planting grants[43] is taken into consideration the outlay is £500-1,000/ha.
- Long-term risk. The viability of these crops from an economic perspective is reliant upon secured contracts for 15-20 years. Loss of contract before then would render the entire activity uneconomic.
- Uncertainties within the Common Agricultural Policy are likely to reduce the amount of energy crop grown, at least in the short term. Under current MTR proposals, perennial crops would not be eligible to be grown on set-aside. As a consequence existing crop could not be taken as a contributor to the 10% set-aside requirement. To partly offset this the proposal suggest a modest carbon credit payment.
- The specifics of growing energy crops for bioethanol are unproven – the ethanol yield from miscanthus, in particular, has yet to be quantified.

Forest Products sensitivities

Generally timber prices have been in decline for the last decade or so (source:Forestry Commission). The year September 2000-2001 saw a slight rise, but coniferous standing sales prices in Great Britain were 28.6 % lower in real terms in the year to September 2002, compared with the previous year.

The main decline is in the market for small roundwood and sawmill residues due to the traditional users for these products looking to other sources, for example, Shotton paper mill in Wales will run on 100% recycled fibre as of 2004, and Nexfor board mill in the south west is using a high proportion of waste wood. The problem of oversupply is increasing, with the some private owners bringing forward harvesting prior to Shotton moving to recycled fibre in 2004.

Some of the excess small roundwood is exported for pulpwood to Finland, from ports in north east Scotland and Ayrshire. It is expected that exports will commence from Wales. These are only small short term solutions and the main requirement is for a major new user of small roundwood or expansion of existing capacity.

The major competitor for the UK markets are the Baltic states. The continued strength of sterling against the Euro is a major factor, resulting in strong import competition for the UK mills. In the short term little change is expected in timber prices (Tilhill and FPDSavills Market Report, 2002).

[43] A planting grant of £920/ha is offered for miscanthus. A grant of wither £1000/ha or £1,600/ha is available for coppice.

4.7 WASTE STREAMS

England and Wales produce over 100 million tonnes of waste a year from households, commerce and industry. Some of which could be a useful source of starch and cellulose for the production of ethanol. The diversion of some of this waste could go along way to helping the Government meets its target for waste reduction, under EU Landfill Directive (99/31/EC), which require the amount of biodegradable municipal waste sent to landfill to be reduced to 75% of that produced in 1995 by 2010, 50% by 2013 and 35% by2020. As well as solving the problem of the lack of available sites in the future. England and Wales has only 1,530 site (46,000 ha) with around 635m m3 of remaining landfill void-space left, the equivalent to just 6.1 years of landfilling at the current levels. The East of England has one of the largest remaining void-spaces left in England and Wales, but only 4.8 years of landfill left, because of the considerable amount of waste from London and the South East region which is landfilled in this region.

There were around 28 million tonnes of municipal waste (household waste, street litter, waste delivered to council recycling points, municipal parks and gardens, council office waste, civic amenity site waste and some commercial waste from shops and small trading estates where local authority waste collection agreements are in place) produced in England and Wales in 2000/01 (Table 1). The amount of municipal waste being produced in England is growing at a rate of 3-4% per year. Household waste accounts for over 25 million tonnes of the municipal waste produced, household waste includes waste from household collection rounds, bulky waste collection, hazardous household waste collection and separate garden waste collection, plus waste from services such as street sweeping, litter and civic amenity sites and school waste. These vast quantities of waste are made-up of a number of different types of waste: garden waste (5.6m tonnes), paper and board (5.1m tonnes), kitchen waste (4.8m tonnes), sweepings (2.5m tonnes), glass (2m tonnes), wood (1.4m tonnes), miscellaneous non-combustible (1.4m tonnes), dense plastics (1.1m tonnes), plastic film (1.1m tonnes), textiles (0.8m tonnes), metal packaging (0.8m tonnes), Soil (0.8m tonnes) and nappies (0.6m tonnes), some of which could be recycled and others which could be used to produce energy. Currently over 80% of the wasted produced is landfilled [3] (Table 2).

There were around 78 million tonnes of industrial and commercial waste produced in England and Wales in 2000/01, of which 48 m tonnes was industrial waste (factories and industrial plants) and 30 m tonnes was commercial waste (wholesalers, catering establishments, shops and offices). This waste is made-up of a number of different waste stream: construction (2m tonnes), paper and card (7m tonnes), food (3m tonnes), biodegradable (9m tonnes), metal (6m tonnes), contaminated (5m tonnes), mineral (6m tonnes), general commercial (23m tonnes) and industrial (13m tonnes), some of which could be recycled and others which could be used to produce energy (Table 3 and 4), but most of which is currently landfilled [1].

The Government is committed to reducing our reliance on landfill through the use of Landfill Tax. This tax on the disposal of waste to landfill was introduced in October 1996 at a rate of £7 per tonne for active wastes and a lower rate of £2 per tonne for inactive wastes. The tax was designed to promote the *polluter pays* principle by increasing the cost of landfill to reflect its environmental costs, and to promote a more sustainable approach to waste management in which less waste is produced and more is recovered or recycled. From April 1999, the Government increased the rate for active wastes to £10 per tonne, and is committed to continuing to increase it by £1 per tonne per year; the current landfill tax is £13/tonne (2002) [3]. The current cost of the waste management options are; collecting and landfilling waste (£45 - 65/t excluding tax), collection and incineration (£45 - 100/t); composting via kerbside collection (£70 - 120/t) and recycling via collection (£55 - 145/t). The reason for the large differences in the cost of the waste management options are the considerable capital cost required for the non landfilling option and the number of process that are require to sort the waste into useful product streams. This processing can be done at the kerb side or in material recovery facilities. These facilities can either take sorted mixed recyclables or dirty MRF which accept mixed solid waste (Figure 1) from residential, commercial and industrial sources. This scenario is likely to change in the future, the Strategy Unit believes a rise to 35/t is required in the medium term to reduce the amount of waste going to landfill. If this happens then the alternative methods of waste disposal will look more attractive. Especially, when you consider that the raw products will be available all the year round, in large quantities, reasonably uniformed and that a supply chain system already exists. The calorific value of these products depends on how and if they have been sorted, unsorted waste has a value of around 9 Gj/t compared to 20 Gj/t for pre-sorted waste [2].

Therefore, the diversion of some of the 27 million tonnes of waste which contains sources of starch and cellulose from both municipal, industrial and commercial into ethanol production could help meet both the EU Landfill Directive targets as well UK's Government commitment to renewable energy. This approach would also help the Eastern Region meet some of its regional environmental goals and objective; to increase waste minimisation, recycling and reuse and to increase the use of renewable energy.

4.8 WIDER ENVIRONMENTAL IMPACTS OF CROPS GROWN FOR BIOETHANOL

The carbon and energy impacts of substituting fossil gasoline with bioethanol have already been addressed and are not repeated here. The purpose of this section is to briefly review the wider environmental impacts of substituting one form of cropping with another, with particular focus on the role of set-aside. This section is written assuming that current industrial cropping on set-aside continues following revision of CAP. As discussed previously this may not be the case. Increasing the proportion of wheat or sugarbeet in an arable rotation is unlikely to have any significant impact. If wheat or sugar beet are grown on non-set aside land then it is unlikely that any appreciable environmental benefits will accrue. Possibly, if the crops are grown on contract to a bioethanol processor, then fewer late fungicides and late nitrogen applications (in the case of wheat) will be needed, resulting in slightly lower energy inputs into growing the crop and reduced risks of pesticide and nutrient leaching. However, the fundamental cropping regimes would remain unchanged. Relative to natural vegetation regeneration (i.e. leaving set-aside alone and allowing weeds to grow) in terms of potential to reduce pesticide contamination of water, increase or sustain wildlife value and improve or maintain soil stability, wheat and sugar beet are poor alternative land uses. Table 4.4 (taken from Britt & Spink, 1998[44]) ranks the performance of all of the crops considered in the bioethanol report for these key criteria, where a score of 3 is similar to natural vegetation regeneration. The major limitations from wheat and sugar beet arise from their annual cropping (and thus soil disturbance) and high agrochemical input requirements. Some perennial crops for ligno-cellulose production score more favourably. Here, the benefits accrue, primarily, from the lack of soil disturbance, lower input requirements and diversified habitat creation. If technological and economic arguments allowed, ligno-cellulosic crop production would be a favoured cropping option from an environmental perspective.

[44] C Britt & J Spink (1998). Crops for set-aside land:an economic and environmental appraisal. MAFF report.

TABLE 4.4. RELATIVE IMPACT OF VARIOUS ANNUAL AND PERENNIAL CROPS GROWN ON SET-ASIDE, RELATIVE TO NATURAL VEGETATION REGENERATION.

a) Pesticide contamination of water

Ranking	Definition	Crops
1	High rates of highly mobile chemicals used in autumn	Wheat, Barley, Rye, Winter evening primrose, SRC,
2	Chemicals used in autumn but not particularly mobile or low rates	Oats, Winter HEAR, Winter OSR,
3	High rates of mobile chemicals used in spring/summer	Spring HEAR, Spring OSR, Sugar beet, Potatoes
4	low rates of mobile or Immobile chemicals used in spring/summer	Linseed, Dual purpose linseed, Flax, Spring evening primrose, Miscanthus, Natural regeneration
5	Chemicals not used or only infrequently	Hemp, Broad leaved farm forestry, Conifer farm forestry, Grass leys

b)Soil Protection

Ranking	Definition	Crops
1	High risk of erosion and damage to soil structure	Potatoes, Sugar beet,
2	Increased risk of erosion and soil structural damage compared to natural regeneration with reasonable ground cover	Linseed, Dual purpose linseed, Flax, SRC, Wheat, Hemp
3	Risk of erosion and soil damage similar to natural regeneration with reasonable ground cover	Natural regeneration, Conifer farm forestry, Spring HEAR, Spring OSR, Oats, Winter HEAR, Winter OSR, Barley, Rye, Winter evening primrose,
4	Reduced risk of erosion and soil structural damage compared to natural regeneration with reasonable ground cover	Miscanthus,
5	Little or no risk of erosion or soil structural damage	Broadleaf farm forestry, Grass leys

c) Flora and Fauna

Ranking	Definition	Crops
1	Significant benefits to both flora and fauna compared to natural regeneration.	Broadleaved farm forestry,
2	Significant benefits to either flora or fauna compared to natural regeneration	Conifer farm forestry
3	Equal to Natural regeneration	SRC, Grass leys
4	Providing over winter feeding for birds but no nesting sites, or possible increases in floral diversity	Spring HEAR, Spring OSR, Linseed, Flax, Dual purpose linseed, Hemp, Spring evening primrose, Miscanthus
5	Providing neither winter feeding or nest sites	Winter HEAR, Winter OSR, Wheat, Barley, Oats, Rye, Triticale, Winter evening primrose, Sugar beet, Potatoes,

5 GIS-BASED SCENARIO DEVELOPMENT

5.1 INTRODUCTION

On the basis of the information generated under the national economic evaluation of the different bioethanol production options, and the development of the scenarios as detailed in section 3, a Geographical Information System (GIS) approach was undertaken in order to

a) identify the most suitable locations, in terms of feedstock availability, for the development of a processing facility
b) identify the catchment areas for different options, and thus the transport distances and vehicle emissions generated as a result of the haulage of crop and refined bioethanol
c) provide a focal point for the detailed analysis of regional socio-economic impacts of different options
d) investigate the effect of scale and catchment intensity on the location of the hypothetical processing facility

The GIS-based scenarios examined on a regional level (East of England) are presented in Table 5.1 and scenarios for the National level (England & Wales) are presented in Table 5.2.

TABLE 5.1 REGIONAL BIOETHANOL PRODUCTION SCENARIOS

Scenario	Ethanol tonnage ('000) from each feedstock type				
	Wheat	Wheat straw	Sugar beet	Forestry	Waste paper
Wheat grain only	100				
Wheat grain plus sugar beet	12.5		12.5		
Wheat grain plus sugar beet	50		50		
Wheat grain plus sugar beet[1]	125		125		
Wheat grain plus straw	50	50			
Wheat grain plus forestry	50			50	
Straw and forestry		50		50	
Straw, waste and forestry		33.3		33.3	33.3
Waste only					100

TABLE 5.2 NATIONAL BIOETHANOL PRODUCTION SCENARIOS

Scenario	Ethanol tonnage ('000) from each feedstock type				
	Wheat	Wheat straw	Sugar beet	Forestry	Waste paper
Wheat grain only	100				
Wheat grain only[1]	250				
Wheat grain plus sugar beet	50		50		
Wheat grain plus straw	50	50			
Wheat grain plus forestry	50			50	
Straw and forestry		50		50	
Straw, waste and forestry		33.3		33.3	33.3
Waste only					100

Notes:

1. The original scenario of a 250,000 tonne plant being fed by a 50:50 blend of wheat and sugar beet in the East of England could not be considered as it was found that there is not enough current cropping of sugar beet to feed this plant. To gauge the impact of a very large plant, a further scenario of a 250,000 tonne plant being fed by wheat only was added, and this scenario has been run at the England and Wales scale.

5.2 DATA COLATION AND FORMATTING

5.2.1 Waste

Domestic Waste

Household waste statistics for Wales are available from the National Assembly for Wales website and for England from the Department of the Environment, Food and Rural Affairs website. These originate from the Municipal Waste Management Surveys from 1999/2000 and 2000/2001 and the values used in this analysis are tabled in Tables 5.3, 5.4 and 5.5.

It was necessary to convert the amount of waste generated at Regional and County level to the predicted amount available for supply to a Bioethanol plant on a 2 x 2km grid. The first step was to convert the amount of waste produced per Region or County to an estimated amount of waste produced per person. The Population Census 1991 data at postcode boundary level (Sector Level) was assigned to a 2 x 2km grid for the East of England analysis by ADAS using the ADAS Landcover Map 1995 proportion of urban area data, and assuming the same population density throughout the postcode sector.

The Population Census 1991 was used to estimate the population per Region or County, and then this figure used to estimate the amount of waste produced per person, by Region or County. The Population Census 1991 is provided at a 1km grid resolution, and so by using the estimated waste produced per person by Region or County, and the actual population aggregated up to 2 x 2km resolution, an estimate of the amount of waste per 4km^2 grid cell was produced. Quite understandably, this methodology results in the highest concentrations of waste occurring in the most populated cells.

The same methodology was used for estimating waste on a 5 x 5km grid for use in the England and Wales analysis.

TABLE 5.3. MUNICIPAL WASTE ARISINGS IN WALES, 1999/2000 AND 2000/2001 (NATIONAL ASSEMBLY FOR WALES, 2003)

Source of Waste	1999/2000	2000/2001	Change (%)
Regular household collection	972,558	994,932	2.3
Other household sources	104,705	83,018	-20.1
Civic amenity sites	249,146	269,641	8.2
Household recycling	83,727	89,736	7.2
Non household sources (excl. recycling)	188,622	179,640	-4.7
Non household recycling	25,100	25,220	0.5

TABLE 5.4. MUNICIPAL WASTE ARISINGS IN THE REGIONS OF ENGLAND, 2000/2001.

Region	Regular household collection	Other household sources	Civic amenity sites	H'hold	Non h'hold sources	Non h'hold recycling	Total
North East	887,794	110,428	201,227	51,593	158,274	43,159	1,452,475
North West	2,560,933	121,446	737,189	289,074	349,012	97,001	4,154,655
Yorkshire and Humber	1,707,895	97,132	514,250	180,144	355,861	104,049	2,959,331
East Midlands	1,489,030	49,182	304,496	276,915	92,660	77,331	2,289,614
West Midlands	1,741,696	128,305	515,028	237,252	219,889	52,900	2,895,070
Eastern	1,864,141	93,513	367,383	414,558	128,283	50,592	2,918,470
London	2,377,392	299,663	524,384	304,853	923,844	33,157	4,463,293
South East	2,539,653	177,767	756,713	683,161	108,258	78,330	4,343,883
South West	1,623,020	109,790	397,380	374,940	79,435	93,564	2,678,129

TABLE 5.5 LOCAL AUTHORITY MUNICIPAL WASTE ARISINGS IN WALES, 2000/01

Region	Regular h'hold collection	Other h'hold sources	Civic amenity sites	H'hold recycling	Non h'hold sources	Non h'hold recycling	Total
Blanaeu Gwent	24,709	3,778	7,414	1,582	9,293	0	46,775
Bridgend	43,958	1,630	12,594	4,056	4,546	0	66,785
Caerphilly	59,776	7,321	16,807	4,212	15,289	0	103,405
Cardiff	122,192	6,122	16,699	7,296	7,428	0	159,736
Camarthenshire	53,378	0	15,997	3,818	4,978	365	78,537
Ceredigion	25,204	654	5,350	3,959	10,816	0	45,983
Swansea	63,925	3,985	28,426	6,664	39,614	9,580	152,194
Conwy	42,008	14,598	4,265	7,963	5,718	12,061	86,613
Gwynedd	41,866	6,867	4,727	3,498	6,295	0	63,253
Denbighshire	24,381	0	15,489	1,728	5,597	709	47,904
Flintshire	40,798	11,295	26,389	5,708	5,606	0	89,797
Anglesey	28,027	6,235	4,406	1,101	2,912	0	42,681
Merthyr Tydfil	22,170	528	4,291	833	953	21	28,797
Monmouthshire	27,571	659	13,049	4,113	4,169	0	49,562
Neath Port Talbot	51,005	2,286	12,768	2,080	15,846	0	83,983
Newport	47,200	0	10,316	4,244	0	0	61,760
Pembrokeshire	35,246	1,695	17,575	6,891	4,590	0	65,997
Powys	41,516	40	1,398	4,886	9,669	0	57,510
Rhondda Cynon Taff	84,067	7,220	10,007	3,681	5,572	497	111,045
Torfaen	31,138	2,952	11,501	2,849	8,987	0	57,427
Glamorgan	38,160	3,049	12,922	6,433	0	1,992	62,556
Wrexham C.B.	46,629	2,745	17,185	2,158	11,880	0	80,598

Industrial Waste

The most up-to-date waste statistics available for Industrial and Commercial waste are produced by the Environment Agency and are accessible via their website. The Regional data used in this analysis are documented in Table 5.6. These figures were distributed to the 2 x 2km grid and the 5 x 5km grid using the same methodology as for the Domestic Waste figures, detailed in the section above.

TABLE 5.6. INDUSTRIAL AND COMMERCIAL WASTE ARISINGS BY REGION, 1998-99. (ENVIRONMENT AGENCY).

Region	Industrial	Commercial	Total
East of England	3,652	2,487	6,139
East Midlands	5,919	1,787	7,707
London	2,740	4,350	7,090
North East	3,761	996	4,756
North West	6,475	3,104	9,578
South East	4,958	4,043	9,001
South West	2,914	2,322	5,236
Wales	4,989	1,141	6,130
West Midlands	5,219	2,340	7,558
Yorkshire & the Humber	9,465	2,231	11,696
National total	**50,090**	**24,801**	**74,892**

Paper and Cardboard

The estimates for the amount of domestic, commercial and industrial waste that is paper or cardboard come from the Waste Management Strategy 2000 (DTLR, 2000). The breakdown of these wastes are given in Table 5.7 and Table 5.8. The same proportions of paper and cardboard were used at the Regional or County level as at the National level, i.e. 18% of domestic waste and 9% of industrial and commercial waste.

TABLE 5.7. BREAKDOWN OF MUNICIPAL WASTE. SOURCE: DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGIONS, 2000

Type of Waste	Quantity (million tonnes)
Garden waste	5.6
Paper and Cardboard	5.1
Kitchen Waste	4.8
Sweepings	2.5
Glass	2.0
Wood	1.4
Miscellaneous non-combustible	1.4
Dense plastics	1.1
Plastic film	1.1
Textiles	0.8
Metal packaging	0.8
Soil	0.8
Nappies	0.6
TOTAL	28.0

TABLE 5.8. BREAKDOWN OF INDUSTRIAL AND COMMERCIAL WASTE. SOURCE: DEPARTMENT OF THE ENVIRONMENT, TRANSPORT AND THE REGION, 2000

Type of Waste	Quantity (million tonnes)
Construction	2.0
Paper and Cardboard	7.0
Food	3.0
Biodegradable	9.0
Metal	6.0
Contaminated	5.0
Mineral	6.0
General Commercial	23.0
General Industrial	13.0
TOTAL	74.0

5.3 Agricultural Crops

The Agricultural Census 2000 has been gridded to 1 x 1km cells by ADAS. These data provide estimates of the area of land under each crop. These data have been aggregated up to 2 x 2km cells for use in the East of England regional analysis. As the Agricultural Census 2000 is only available as a 1 x 1km grid for England, the ADAS Landcover Map 1995 has been used for the England and Wales analysis. These data provide estimates from the Agricultural Census 1995 for England and Wales on a 1 x 1km grid and have been aggregated up to 5 x 5km cells for use in the England and Wales analysis (Table 5.9). For Sugarbeet a yield of 53t/ha was assumed. For cereals the following Table presents the data set used. Straw yields were assumed to be 5/ha from an 8 t/ha grain crop. Table 5.9 shows the areas of wheat and sugar beet used in the England and Wales analysis. Regional yields of straw were adjusted relative to their grain yield (Table 5.10).

TABLE 5.9. AREA OF WHEAT AND SUGAR BEET IN ENGLAND AND WALES. SOURCE: AGRICULTURAL CENSUS 1995

Region	Area (ha)	
	Wheat	Sugar Beet
East Midlands	357949	43295
Eastern	483631	107859
North East	66502	0
North West	23832	652
South East and London	239562	158
South West	130883	567
Wales	10496	86
West Midlands	173567	17360
Yorkshire and Humber	235262	24069
Total	**1721683**	**194046**

TABLE 5.10: REGIONAL WHEAT YIELDS (SOURCE:DEFRA, 2002)

Region	Wheat Yield (t/ha)	Straw Yield (t/ha)
East Midlands	8.0	5.0
Eastern	8.0	5.0
North East	7.5	4.7
North West	6.4	4.0
South East & London	7.7	4.8
South West	7.3	4.6
Wales	6.8	4.3
West Midlands	7.3	4.6
Yorkshire & Humberside	8.2	5.1

Forestry Crops

The Forestry Commission produce the National Inventory of Woodland and Trees for the UK. These data are polygon-based vector shapes of the areas of woodland or trees and a script was written in the Avenue language for ArcView 3.2 in order to convert the polygon areas to the estimated areas in each grid cell. A grid of 2 x 2km cells were used across England and Wales for use in the East of England analysis, and a 5 x 5km grid across England and Wales was used in the England and Wales analysis. Table 5.11 shows the total area of forestry in England and Wales.

TABLE 5.11. TOTAL AREA OF FORESTRY IN ENGLAND AND WALES (CONIFEROUS, BROADLEAVED AND MIXED WOODLAND). SOURCE: NATIONAL INVENTORY OF WOODLAND AND TREES, 2001

Region	Area (ha)			
	Conifer	Broadleaved	Mixed Woodland	Total
East Midlands	16729	37618	10688	65034
Eastern	34143	48522	18648	101312
London	72	4346	1229	5647
North East	64636	18320	6405	89361
North West	35684	35524	10233	81441
South East	37590	137793	50185	225568
South West	43303	103064	15076	161443
Wales	139101	78922	16332	234356
West Midlands	34734	59128	14955	108817
Yorkshire and Humber	33760	38145	13313	85218
Total	**439752**	**561382**	**157062**	**1158196**

5.4 MODEL DEVELOPMENT

The model was written in the Avenue language for the GIS software ArcView 3.2. Figures 5.1(a), (b) and (c) show a schematic of the derivation of estimates for ethanol yield per 2 x 2km or 5 x 5km cell. Figure 5.2 shows how the potential area for cropping is derived. Figure 5.3 shows the model expanding the catchment until the required ethanol source has been reached. Figure 5.4 indicates how the emissions have been calculated for each scenario.

Each cell in the search region (East of England, or the whole of England and Wales) is treated as a possible location for the Bioethanol plant. Taken in turn, the amount of crop(s) in that cell is calculated and converted to the estimated ethanol yield of that cell. The search catchment is expanded around that cell until the required bioethanol yield has been obtained.

The key assumptions for the model runs are detailed in Table 5.12.

Once the 10 locations with the minimum catchment size for each scenario has been determined, the crop is transported from the field/forest to the plant via the quickest route along the road network and the emissions for each scenario estimated. Different vehicle properties can be defined for each crop and each vehicle type travels at a different speeds along roads of different class, as indicated in Table 5.13. The vehicles return from the plant to the field/forest until the entire available crop has been harvested from that cell. Emissions are calculated using the emission rates provided by the National Atmospheric Emissions Inventory (see Table 5.14 for details). The transportation assumptions are that wheat, straw and forestry are transported in 22 tonne articulated HGV's, sugar beet is transported in 25 tonne rigid HGV's and waste is transported in 17 tonne rigid HGV's. The scenarios for which the emissions have been calculated are detailed in Table 5.15. The cost per km of transport assumptions for each crop are detailed in Table 5.16.

The model includes the crops of: wheat, winter barley, spring barley, oats, rye, mixed corn, triticale, maize, sugar beet, miscanthus, conifers, broadleaved trees, mixed trees, short rotation coppice, coppice with standards, and paper and cardboard waste. There is the option of assessing the potential for most of the crops to be grown either on set-aside land or to use the current cropping patterns. The potential is assessed via criteria of agricultural land grade, rainfall and elevation parameters, distance from SSSI's and from rivers. The England and Wales scenario has the addition of the wheat yield varying by region.

Although the model itself is relatively simple, the processing time is quite significant and each scenario will take a number of days to run.

TABLE 5.12. KEY ASSUMPTIONS IN THE GIS MODELLING

Crop	Crop Yield (tonnes/ha)	Percentage of crop available to plant (%)	Ethanol yield from crop (litres / tonne)	Vehicle Type and Size
Wheat	8[1]	10-50	355	Articulated, 22 tonnes
Straw	5[1]	10	280	Articulated, 22 tonnes
Sugar Beet	53	10	95	Rigid, 25 tonnes
Waste	N/A[2]	50	309	Rigid, 17 tonnes
Conifers	0.67	50-100	280	Articulated, 22 tonnes
Broadleaved Trees	0.88	50-100	280	Articulated, 22 tonnes
Mixed Woodland	0.95	50-100	280	Articulated, 22 tonnes

Notes: 1. For the England and Wales assessment the wheat and straw yields vary by region as detailed in Table 5.10.
2. Waste figures per 2 x 2 km cell are given as weight and not as area.

TABLE 5.13. VEHICLE SPEEDS BY ROAD CLASS. (ALLEN ET AL, 1996)

Road Surface	Vehicle Speed (kph) Agricultural tractors / forestry vehicles	High speed agricultural tractors	HGV's
Field	8	10	N/A
Farm track / forest road	12	14	14
Unclassified public road	16	24	24
Single land 'A' and 'B' roads	20	48	48
Dual land 'A' roads	25	64	64
Motorways	N/A	N/A	80
Urban roads	16	24	24

TABLE 5.14. EMISSIONS RATES BY VEHICLE SPEEDS. SOURCE: NAEI EMISSION FACTOR DATABASE, 2002

Pollutant	HGV Type	Speed (kph) 10	14	24	48	64	80
CO (g/km)	rigid	2.0020	1.4158	0.8660	0.5671	0.5078	0.4757
	artic	5.3790	3.8042	2.3273	1.5245	1.3655	1.2793
Benzene (g/km)	rigid	0.0005	0.0004	0.0003	0.0002	0.0001	0.0001
	artic	0.0014	0.0010	0.0007	0.0004	0.0004	0.0003
1, 3-Butadiene (g/km)	rigid	0.0251	0.0190	0.0121	0.0075	0.0066	0.0063
	artic	0.0649	0.0490	0.0311	0.0193	0.0171	0.0163
Hydrocarbons (g/km)	rigid	0.7930	0.5986	0.3803	0.2360	0.2091	0.1991
	artic	2.1470	1.6206	1.0293	0.6383	0.5653	0.5383
Fuel (g/km)	rigid	400.28	323.04	249.36	205.84	198.99	204.59
	artic	933.98	753.77	581.80	480.39	464.66	478.12
Carbon (g/km)	rigid	343.04	276.846	213.700	176.41	170.53	175.33
	artic	800.42	645.986	498.60	411.70	398.21	409.75
CO^2 (g/km)	rigid	1258.03	1015.27	783.70	646.94	625.39	643.00
	artic	2935.35	2369.01	1828.50	1509.81	1460.35	1502.66
Nox (g/km)	rigid	3.7000	3.0713	2.3087	1.7239	1.6217	1.6272
	artic	7.9280	6.5825	4.9489	3.6958	3.4767	3.4887
PM (g/km)	rigid	0.0650	0.0522	0.0361	0.0228	0.0197	0.0188
	artic	0.1710	0.1364	0.0941	0.0593	0.0513	0.0489

TABLE 5.15 TRANSPORTATION EMISSIONS SCENARIOS FOR EAST OF ENGLAND REGION ANALYSES

Scenario	Ethanol Tonnage Wheat	Wheat Straw	Sugar Beet	Forestry	Waste
Cereals + Beet	12500		12500		
Cereals + Beet	50000		50000		
Ligno (from waste, straw and forestry)		33333		33333	33333

TABLE 5.16 TRANSPORTATION COSTS FOR RIGID AND ARTICULATED VEHICLES

	Rigid HGV	**Articulated HGV**
General		
licence etc.	£1,200	£1,900
labour	£19,000	£20,000
Insurance	£6,000	£6,000
rent	£0	£0
mpg	7.4	8
fuel cost (pence per gallon)	350	350
service interval (miles)	6,000	6,000
lubricant cost (pence)	5,000	5,000
maintenance	0.07	0.07
vehicle life (miles)	250,000	250,000
vehicle value	75,000	90,000
tyres	4,000	6,000
tyre life	60,000	60,000
interest (loan @ 6%)	86.54	103.85
Weekly cost		
licences	23.08	36.54
wages	365.38	384.62
rent and rates	0.00	0.00
insurance	115.38	115.38
interest	86.54	103.85
Total/week	590.38	640.38
Mileage cost		
Fuel pence /mile	47.30	43.75
lubricants	0.83	0.83
tyres	6.67	10
maintenance	17.5	21
depreciation	30	36
Total	102.30	111.58
Weekly costs		
1000 weekly miles	£590.38	£1,058.82
Cost per mile	£1.61	£1.76
Cost per km	**£1.00**	**£1.09**

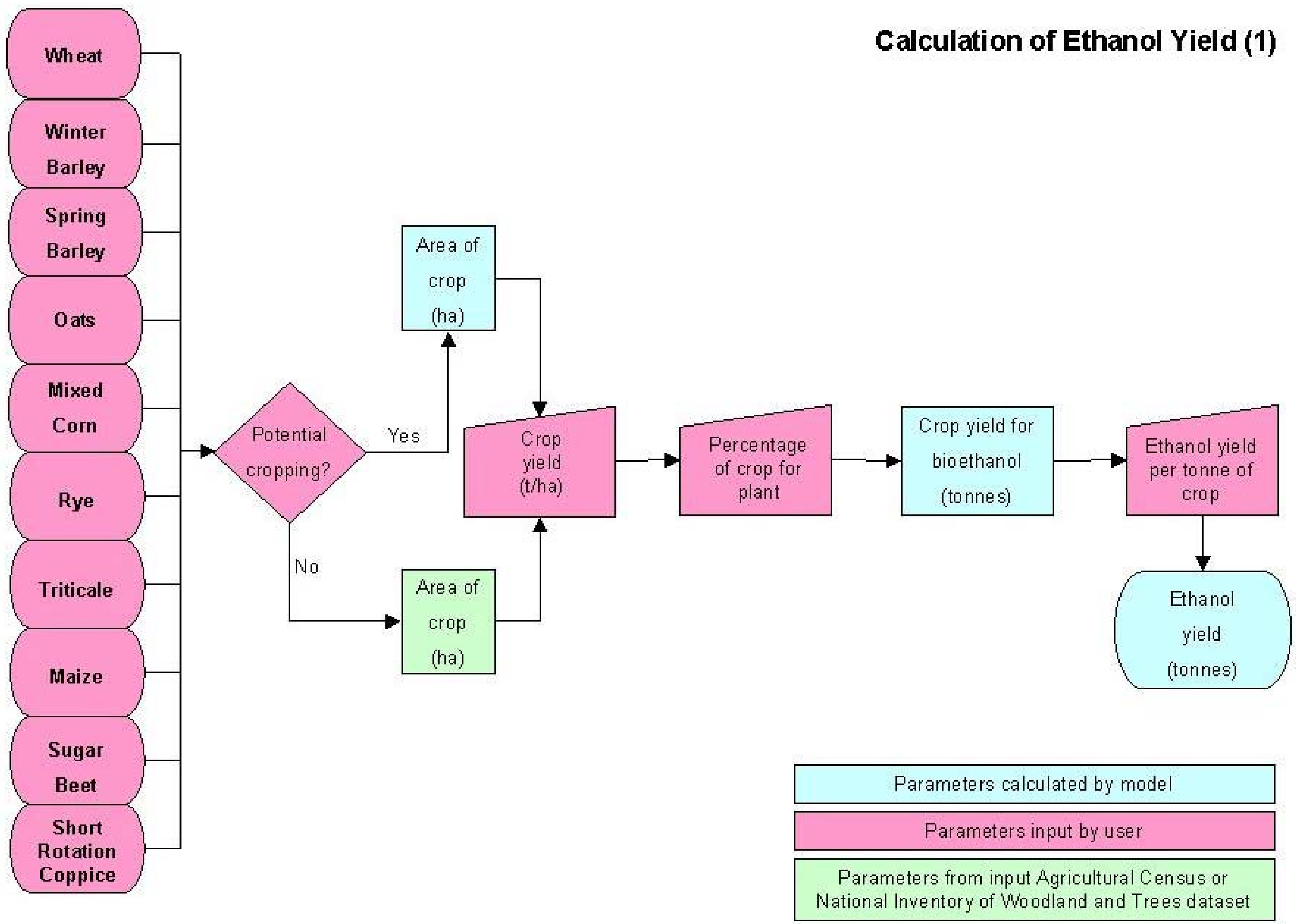

FIGURE 5.1(a). SCHEMATIC REPRESENTATIONS OF GIS-BASED METHODOLOGIES – ETHANOL YIELD CALCULATION

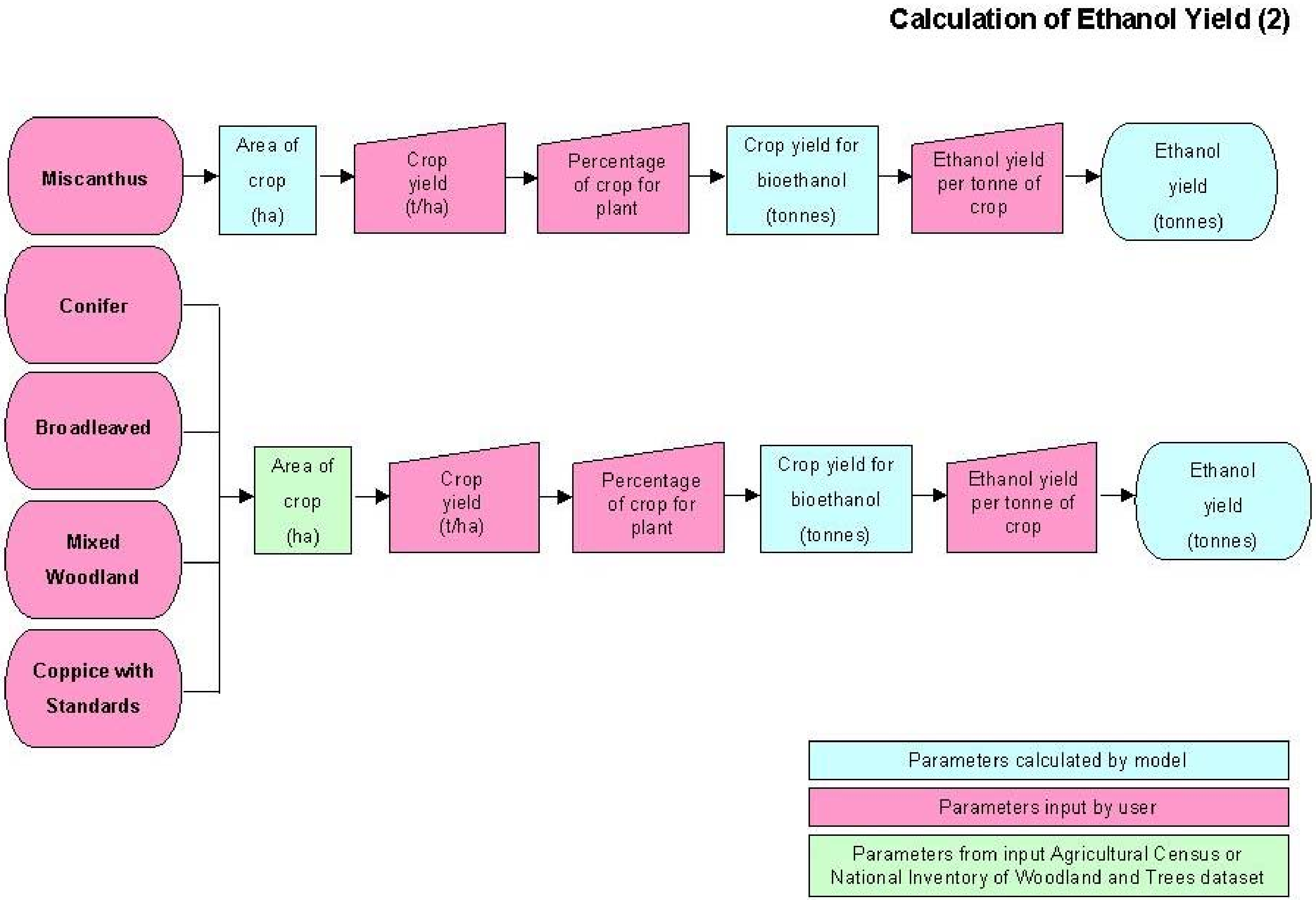

FIGURE 5.1(b). SCHEMATIC REPRESENTATIONS OF GIS-BASED METHODOLOGIES – ETHANOL YIELD CALCULATION

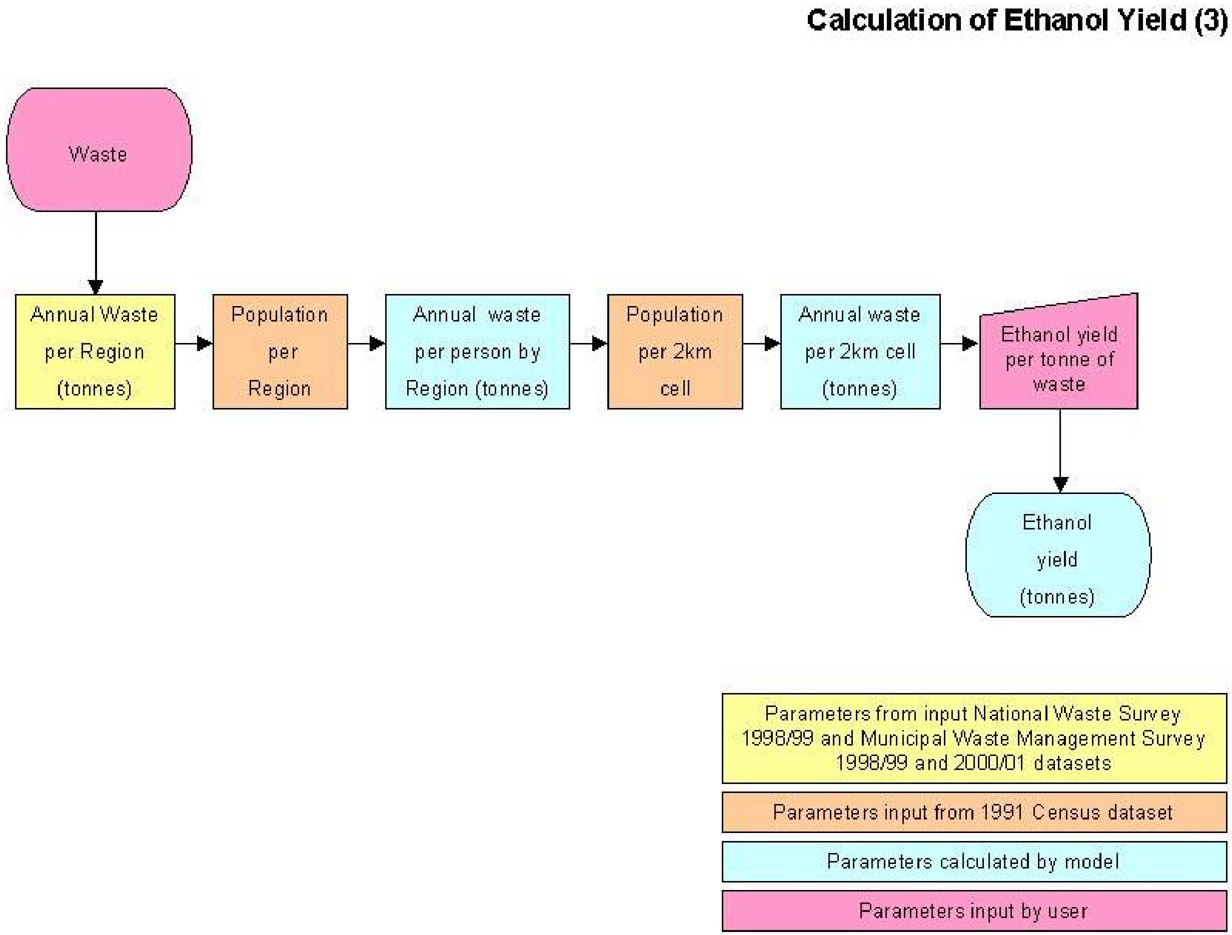

FIGURE 5.1(c). SCHEMATIC REPRESENTATIONS OF GIS-BASED METHODOLOGIES – ETHANOL YIELD CALCULATION

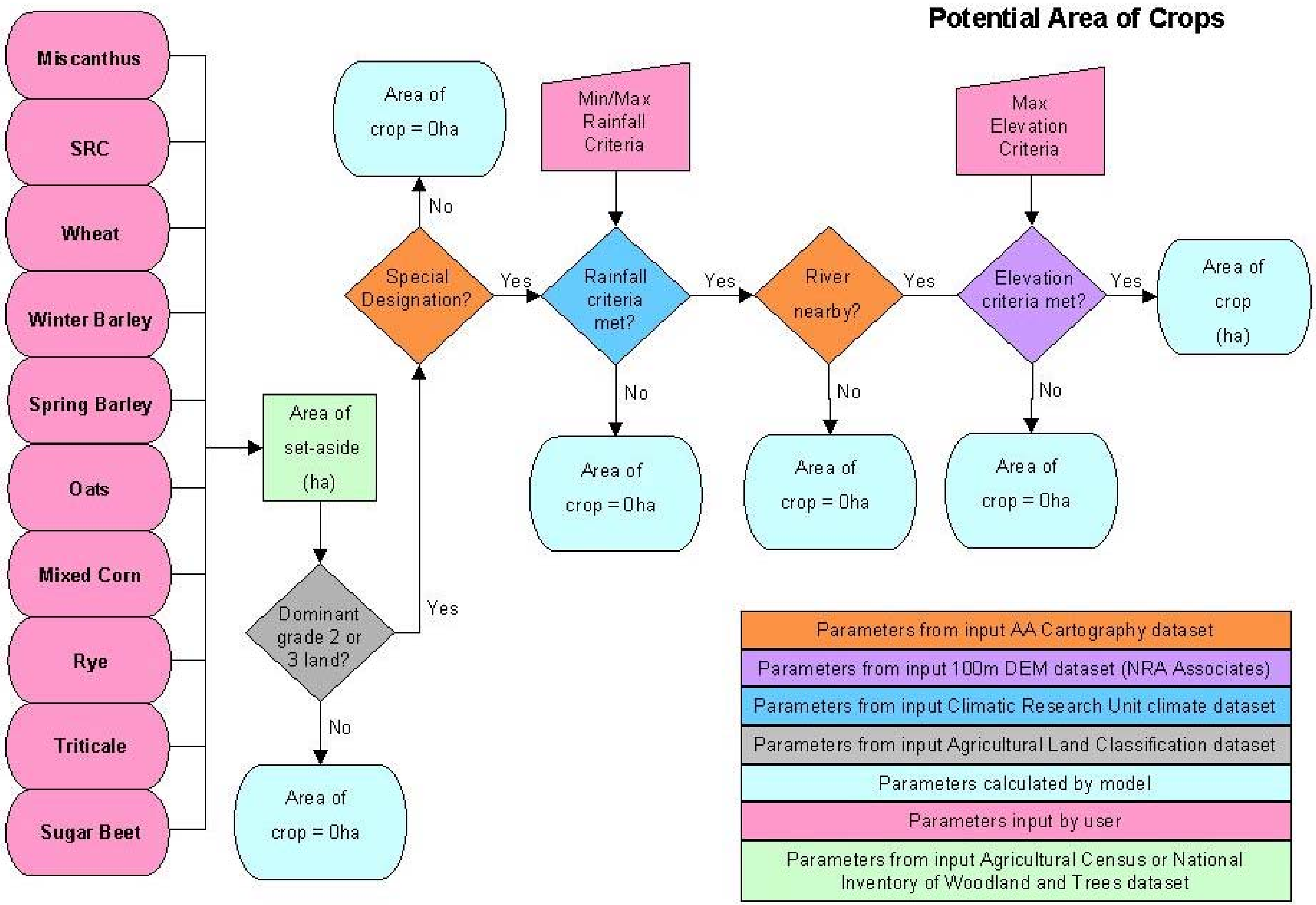

FIGURE 5.2. SCHEMATIC REPRESENTATIONS OF GIS-BASED METHODOLOGIES – POTENTIAL AREA OF CROPS

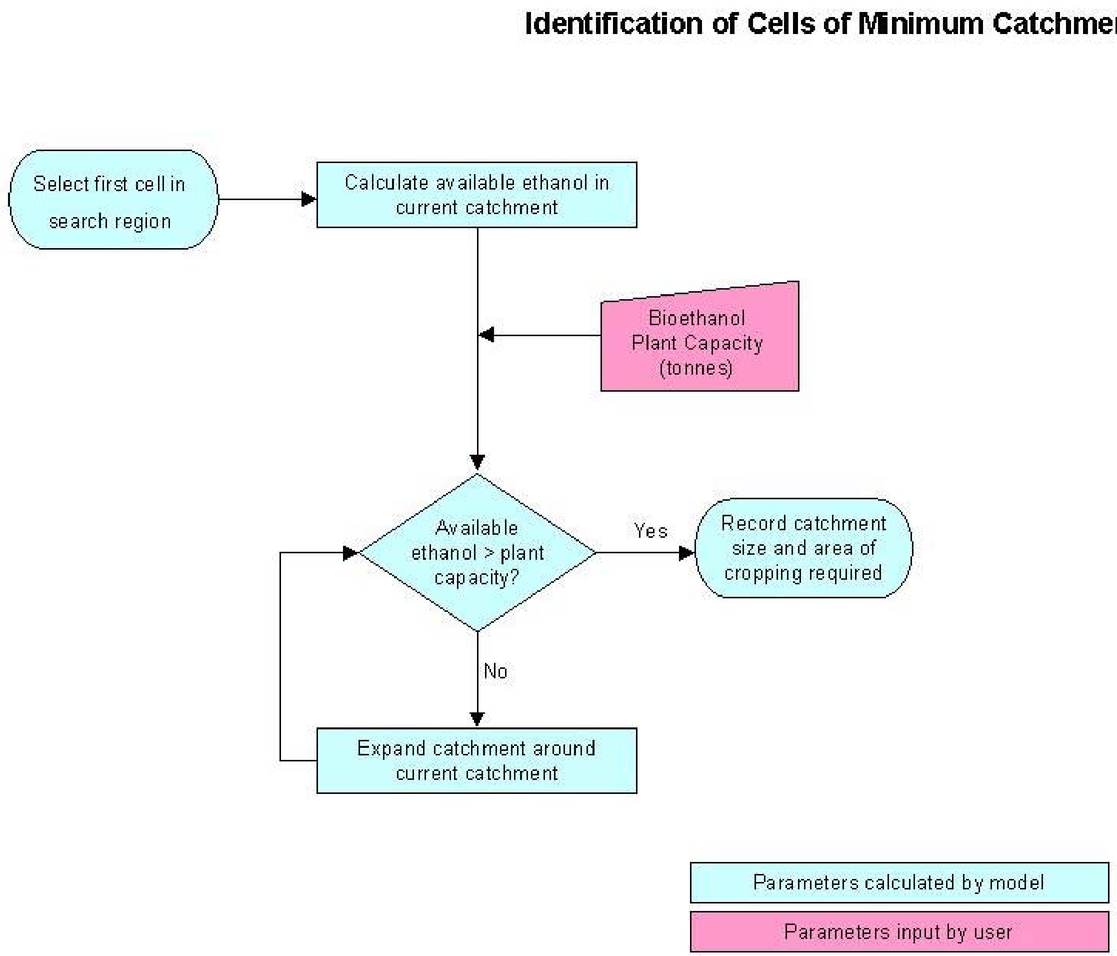

FIGURE 5.3. SCHEMATIC REPRESENTATIONS OF GIS-BASED METHODOLOGIES – CALCULATION OF CATCHMENT SIZE

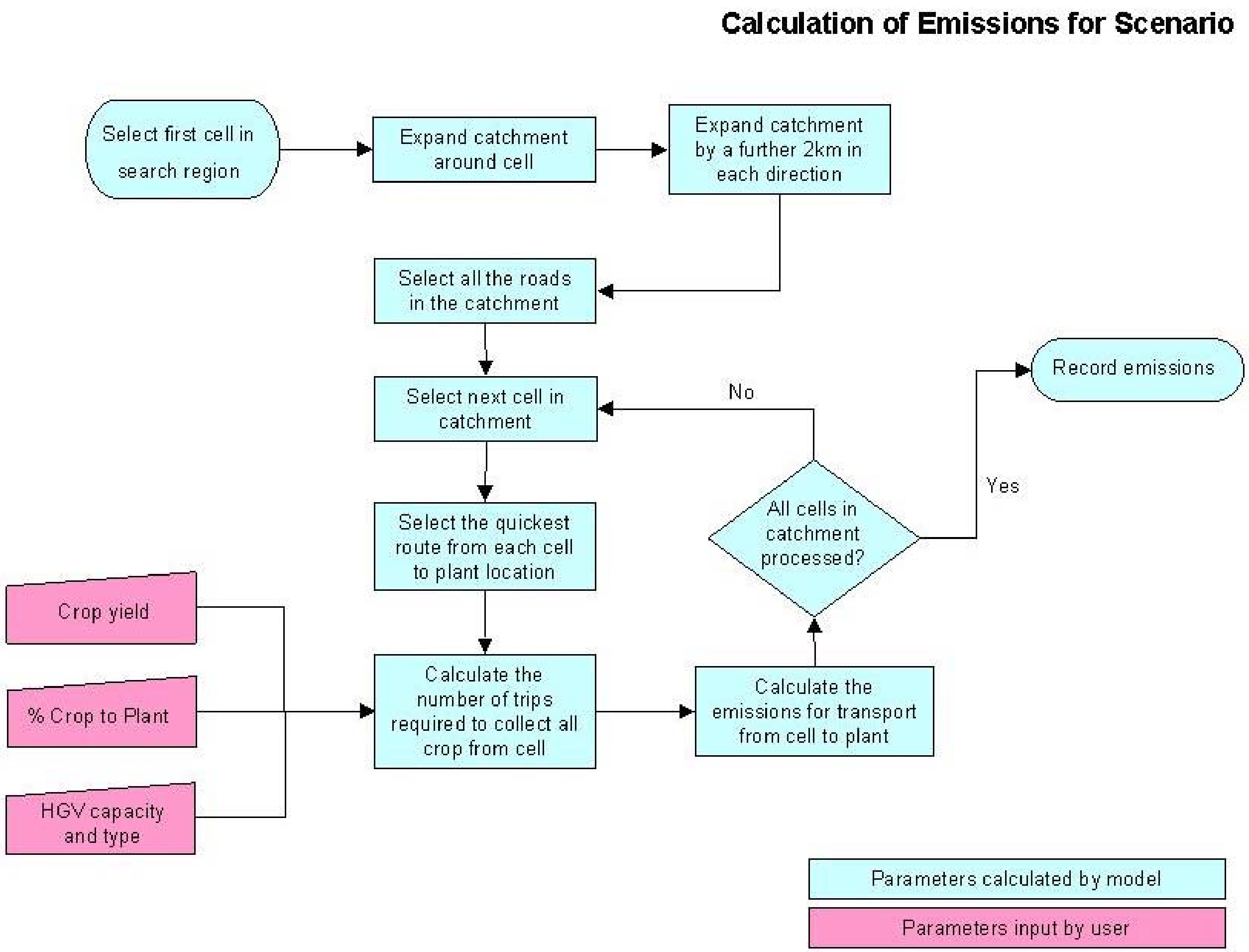

FIGURE 5.4. SCHEMATIC REPRESENTATIONS OF GIS-BASED METHODOLOGIES – CALCULATION OF EMISSIONS

5.5 RESULTS

The catchment sizes of the scenarios are given in Table 5.17, together with the cropping areas for the East of England analyses, and in Table 5.18 for the England and Wales analyses.

For the scenario of wheat only feeding a 100,000 tonne plant, the minimum catchment size for the East of England analyses is about 14,000km^2 and increases to about 16,000km^2 for the England and Wales analyses, but there is little difference in the area of cropping required. This is because of the changes in wheat yield across different regions under the England and Wales analyses. The optimum location for the analyses constrained by the East of England border is to the north-east of Cambridge as shown in Figures 5.5a and 5.5b. When accounting for differences in wheat yield, and not constraining the location to the East of England region border, the optimum location shifts to the north of Cambridgeshire and into Lincolnshire, as shown in Figures 5.6a and 5.6b. The minimum catchment increases to 50,800km^2 for the very large plant with a 250,000 tonne capacity, for an England and Wales scenario, but the optimum location is still in the north of Cambridgeshire / south of Lincolnshire, as shown in Figures 5.7a and 5.7b.

Table 5.19 and Figures 5.8a, 5.8b, 5.8c and 5.8d show the effect of increasing the proportion of the current cropping available to the plant for wheat only feeding a 100,000 tonne bioethanol plant. The minimum catchment size reduces from 13,830km^2 to 2,374km^2 as the percentage increases from 10% to 50% availability and the cropping area required reduces from 44,439ha to 9,204ha. All of these scenarios result in the optimum location for the plant in Cambridgeshire, and for most of the scenarios, the optimum location is to the far north of the county. The scenario with only 10% of the crop being made available to feed the plant results in the optimum location towards the mid-east of the county.

TABLE 5.17. MINIMUM CATCHMENT SIZE OF EAST OF ENGLAND SCENARIOS AND CROPPING AREAS

Scenario	Minimum Catchment Size (km^2)	Area of Cropping for Minimum Catchment Size (ha)
Cereals only (100,000)	13,830	44,439
Cereals (12,500) + Beet (12,500)	3,110	5,920 (wheat), 3,167 (sugar beet)
Cereals (50,000) + Beet (50,000)	24,344	22,718 (wheat), 12,578 (sugar beet)
Cereals (50,000) + ligno from straw (50,000)	14,306	22,956 (wheat), 45,919 (straw)
Cereals (50,000) + ligno from forestry (50,000)	44,583	23,093 (wheat), 54,352 (conifer), 156,755 (broadleaved), 54,556 (mixed woodland)
Ligno from straw (50,000) and forestry (50,000)	44,583	46,283 (straw), 54,352 (conifer), 156,755 (broadleaved), 54,556 (mixed woodland)
Ligno from waste (33,333), straw (33,333) and forestry(33,333)	26,662	31,373 (straw), 43,975 (conifer), 56,138 (broadleaved), 15,706 (mixed woodland) [1]
Ligno from waste only (100,000)	1,444	N/A[1]

Notes:
1. The tonnage of waste per grid cell is used directly in the analyses and therefore the area of cropping for the minimum catchment is equal to the minimum catchment size.

TABLE 5.18. MINIMUM CATCHMENT SIZE OF ENGLAND AND WALES SCENARIOS AND CROPPING AREAS

Scenario	Minimum Catchment Size (km^2)	Area of Cropping for Minimum Catchment Size (ha)
Cereals only (100,000)	15,989	44,690
Cereals only (250,000)	50,836	110,981
Cereals (50,000) + Beet (50,000)	17,298	23,542 (wheat), 12,532 (sugar beet)
Cereals (50,000) + ligno from straw (50,000)	16,133	23,117 (wheat), 45,385 (straw)
Cereals (50,000) + ligno from forestry (50,000)	36,643	24,656 (wheat), 68,090 (conifer), 155,978 (broadleaved), 45,645 (mixed woodland)
Ligno from straw (50,000) and forestry (50,000)	39,175	49,477 (straw), 53,329 (conifer), 162,848 (broadleaved), 49,748 (mixed woodland)
Ligno from waste (33,333), straw (33,333) and forestry (33,333)	24,357	31,673 (straw), 28,960 (conifer), 109,866 (broadleaved), 39,064 (mixed woodland) [1]
Ligno from waste only (100,000)	224	N/A[1]

Notes:

1. The tonnage of waste per grid cell is used directly in the analyses and therefore the area of cropping for the minimum catchment is equal to the minimum catchment size.

TABLE 5.19. MINIMUM CATCHMENT SIZE FOR EAST OF ENGLAND CEREALS ONLY SCENARIOS WITH A 100,000 TONNE BIOETHANOL PLANT.

Percentage of Crop Available to Plant	Minimum Catchment Size (km^2)
10%	13,830
20%	6,331
30%	4,059
40%	2,880
50%	2,374

Figures 5.9a and 5.9b, and 5.10a and 5.10b show the effect of a variation in the plant scale for scenarios of a 25,000 tonne and 100,000 tonne plant fed by a 50:50 blend of wheat and sugar beet for the East of England. These figures show that for both scenarios the optimum location is in Norfolk, but for the larger plant the optimum location moves nearer the Wash whereas the smaller plant locates more inland. When the 100,000 tonne plant is not constrained to the East of England region border for the England and Wales analyses, the optimum location is still in Norfolk, despite the variation in crop yields for different regions under this scenario (see Figures 5.11a and 5.11b).

The 50:50 blend of wheat and straw feeding a 100,000 tonne bioethanol plant has an optimum location in the north of Cambridgeshire when constrained by the border of the East of England region as shown in Figures 5.12a and 5.12b. When that constraint is removed for the England and Wales analyses, the optimum location is still in the north of Cambridgeshire, but also moves into Lincolnshire as shown in Figures 5.13a and 5.13b. The catchment size and the area of cropping required increases for the England and Wales analyses because of the regional variation in crop yields.

The scenario of a 100,000 tonne plant fed by wheat and forestry reveals that the optimal location for this plant is Hertfordshire in the East of England region analyses, as shown in Figure 5.14a and 5.14b. for the England and Wales analyses, the pull of the location is towards the south and west of England, as shown in Figure 5.15a. Figure 5.15b indicates that the optimal locations for this scenario are in the central south of England, close to Poole and Bournemouth. The same patterns arise for the scenario of a 100,000 tonne plant fed by straw and forestry. Again the optimal location is in Hertfordshire in the East of England region (Figures 5.16a and 5.16b), and in the central south when considering the whole of England and Wales (Figure 5.17a), except that the optimal location is a little more to the east, near to Southampton and Portsmouth (Figure 5.17b).

Perhaps not surprisingly, the optimum location for a waste-fed bioethanol plant (100,000 tonnes capacity) is in the south of the East of England region, nearest to the areas of highest population – refer to Figures 5.18a and 5.18b with the assumption of 50% of all the paper and cardboard produced being made available to the plant, the actual catchment size required to meet the plant capacity is much smaller than the crop-fed plants. Just under 1500km^2 for the waste scenario rather than the 14,000 to 24,000km^2 for the wheat, straw and sugar beet scenarios. When this scenario is run for England and Wales, the results clearly show that any large city would be able to support a 100,000 tonne bioethanol plant fed by paper and cardboard (see Figure 5.19).

The impact of the large resource of waste in Greater London and the forestry resource in the central south of England mean that a 100,000 tonne plant fed by waste, straw and forestry would be optimally located in the south-west of the East of England region, in Hertfordshire (Figures 5.20a and 5.20b). The England and Wales picture shows that the optimum location is around Greater London, having the waste from the capital, the forestry from the central south and the straw from East Anglia (Figures 5.21a and 5.21b).

The initial methodology to calculate the transportation emissions for the three scenarios detailed in Table 5.15 was to use existing functionality within commercial software as the cheapest/quickest option. However, the first attempt using ESRI's ArcGIS software was unsuccessful as there where significant problems with memory usage by this package. The second attempt was to use the older version of the ESRI software, ArcView 3.2. Unfortunately this software also had memory problems when running some of the scenarios with the larger catchment sizes. Therefore, in order to obtain some results for this work, an as-the-crow-flies analysis was undertaken, effectively representing the best case scenario. The transportation emissions scenario results as-the-crow-flies for the East of England region analyses are detailed in Table 5.20 and Table 5.21. These emissions do not include those from transportation of the ethanol to an oil refinery.

Table 5.20 shows that the there is a 12-fold increase in the cost of transportation of wheat and sugar beet when the plant capacity increases 4-fold from 25,000 tonnes to 100,000 tonnes. Table 5.20 also shows that the scenario of a 100,000 tonne plant fed by straw, waste and forestry is about 14% cheaper than a plant of the same capacity fed by wheat and sugar beet, with the majority of the cost being borne by the sugar beet component.

Table 5.21 details the estimated annual emissions for the transportation of crops to the plant. The emissions depend on the speed of travel. These speeds have been estimated by distributing the total distance travelled by the proportion of roads of different types in the catchment for each scenario. Table 5.21 shows that the total annual amount of CO_2 for the 25,000 tonne plant fed by wheat and sugar beet is just under 600 tonnes. This amount increases to just over 9,000 tonnes when the plant capacity is increased to 100,000 tonnes.

The scenario of a 100,000 tonnes plant fed by waste, straw and forestry indicates an annual CO2 emission of 35,000 tonnes. This is because although the distance travelled under this scenario is less than that for the plant of the same capacity but fed by wheat and sugar beet, two of the crops are transported by articulated HGV's, which are responsible for greater emissions rates (refer to Table 5. 14).

TABLE 5.20. ANNUAL COSTS OF TRANSPORTING CROPS TO A BIOETHANOL PLANT FOR EAST OF ENGLAND REGION ANALYSES

25,000 Plant fed by Wheat and Sugar Beet (50:50 ratio)		
Wheat		**Sugar Beet**
£129,581		£123,043
	Total £252,624	
100,000 Plant fed by Wheat and Sugar Beet (50:50 ratio)		
Wheat		**Sugar Beet**
£966,771		£2,275,185
	Total £3,241,956	
100,000 Plant fed by Straw, Waste and Forestry (33:33:33 ratio)		
Straw	**Waste**	**Forestry**
£1,970,309	£393,540	£485,099
	Total £2,848,948	

TABLE 5.21. ANNUAL EMISSIONS OF TRANSPORTING WHEAT AND SUGAR BEET CROP TO A 25,000 TONNE CAPACITY BIOETHANOL PLANT (TOP 10 LOCATIONS) FOR EAST OF ENGLAND REGION ANALYSES

Scenario	Total Distance (km)	Annual Emissions of Transportation of Crops to Plant (tonnes)								
		CO	BZ[1]	BT[1]	HC[1]	Fuel	Carbon	CO_2	NO_X	PM[1]
100,000t (waste, straw, forestry)	2,625,729	40.32	0.01102	0.52	17.11	11,396	9,766	35,817	91.52	1.54
25,000t (wheat, sugar beet)	240,844	0.65	0.00018	0.01	0.27	188	161	593	1.55	0.02
100,000t (wheat, sugar beet)	3,154,068	9.75	0.00272	0.13	4.12	2,957	2,534	9,294	24.82	0.38

Notes:
1. PM = Particulate Matter, HC = Hydrocarbons, BT = 1,3-Butadiene, BZ = Benzene

Towards the end of the project, a piece of bespoke software was written in Visual Basic using ESRI's MapObjects' Pathfinder library in order to provide a proof of concept. As a great deal of resource had already been used on this work, only the waste component of the 100,000 tonne bioethanol plant fed by waste, straw and forestry was investigated. The total distance travelled for this crop scenario as-the-crow-flies has been calculated as 393,540km. The along-the-roads calculation using MapObjects increases that distance to 490,957km. This is an increase of 25%, and although perhaps not indicative of the road efficiency in the whole country, provides an indication as to how the figures in Tables 5.20 and 5.21 might increase under the along-the-roads calculations.

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National Atmospheric Emissions Inventory, 2003, "Emission Factors Database", http://www.naei.org.uk/other/vehicle_emissions_v8.xls

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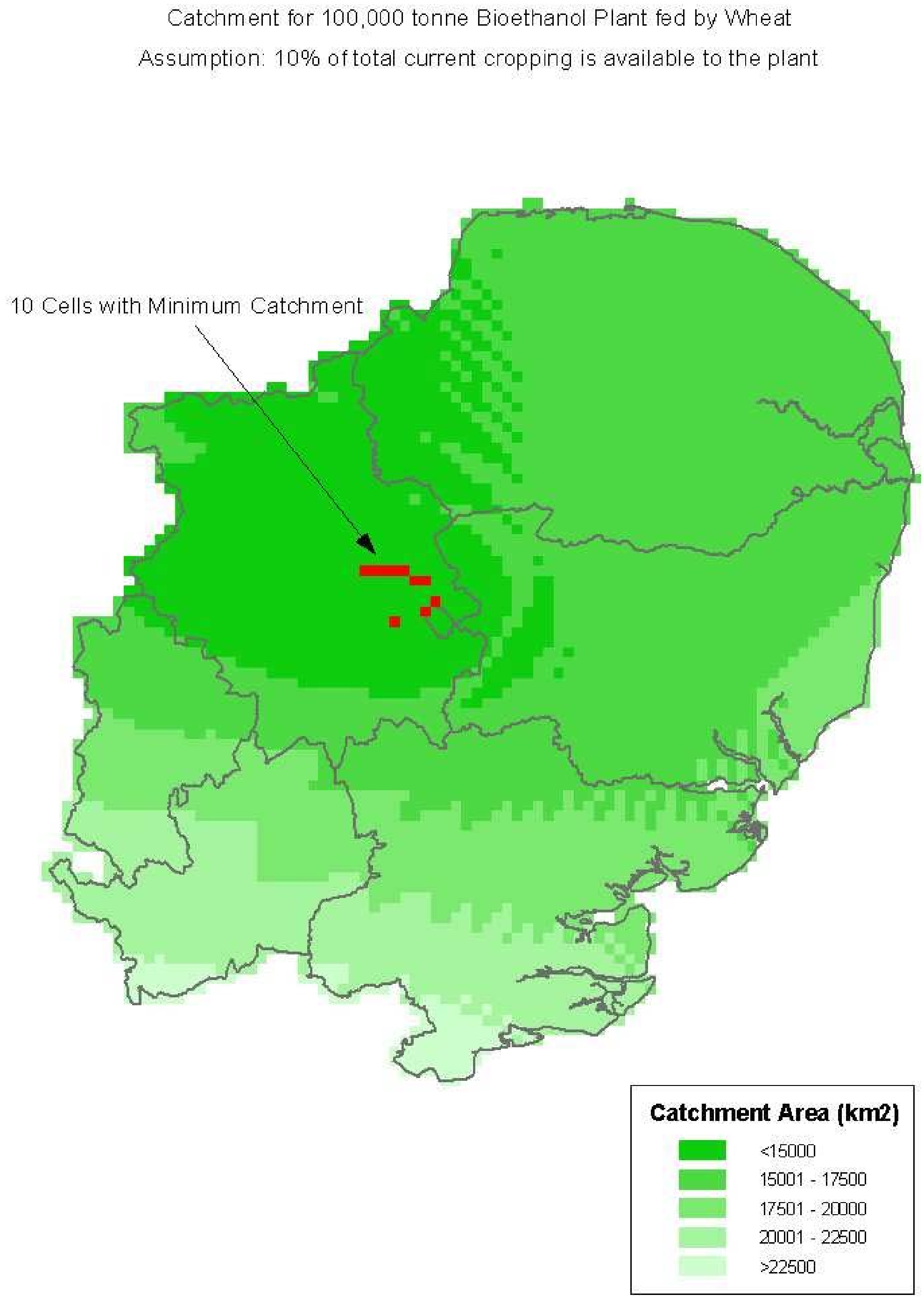
FIGURE 5.5(a).


Catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 10% of total current cropping is available to the plant
10 Cells with Minimum Catchment
Catchment Area (km2)
<15000
15001 - 17500
17501 - 20000
20001 - 22500
>22500

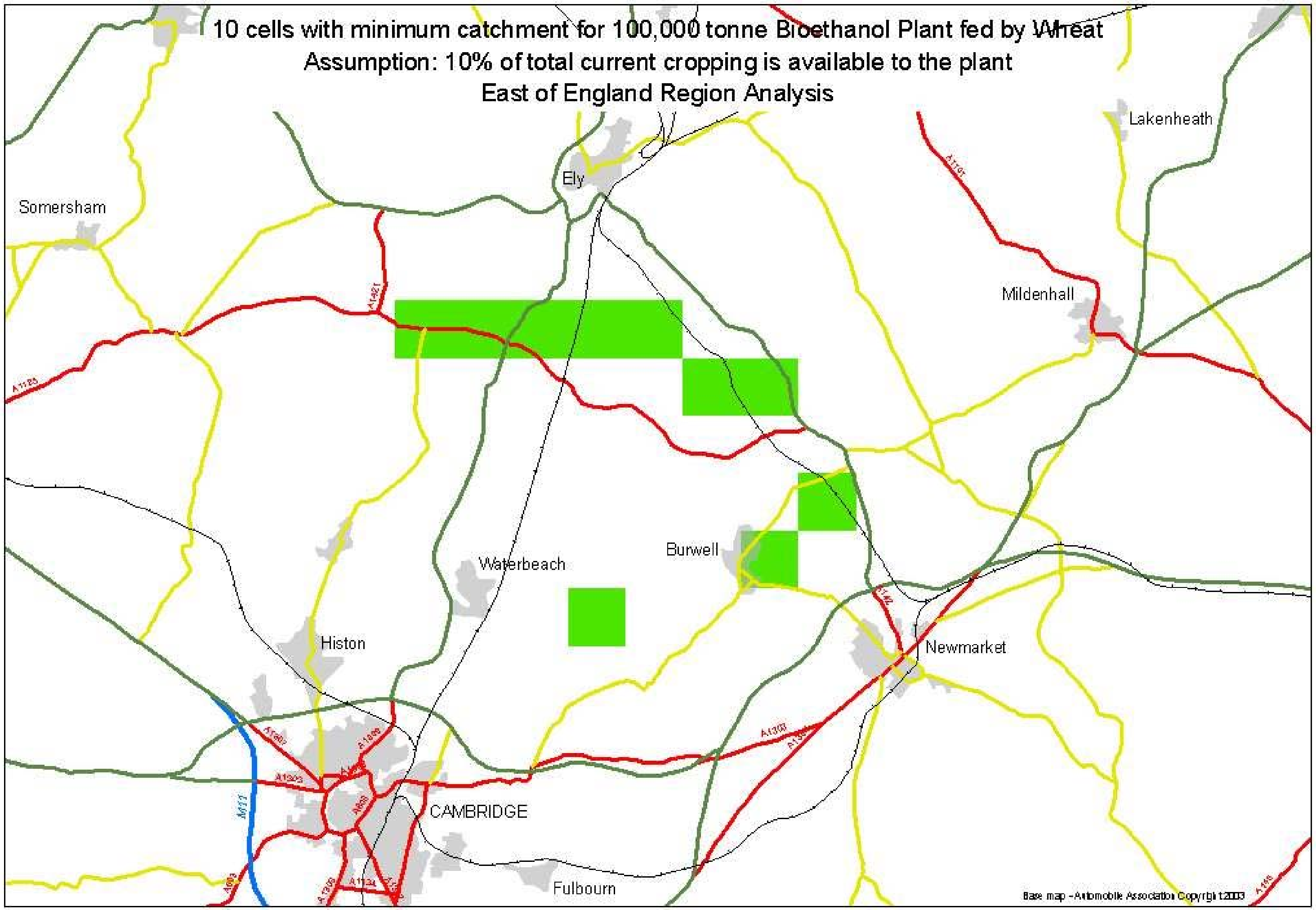
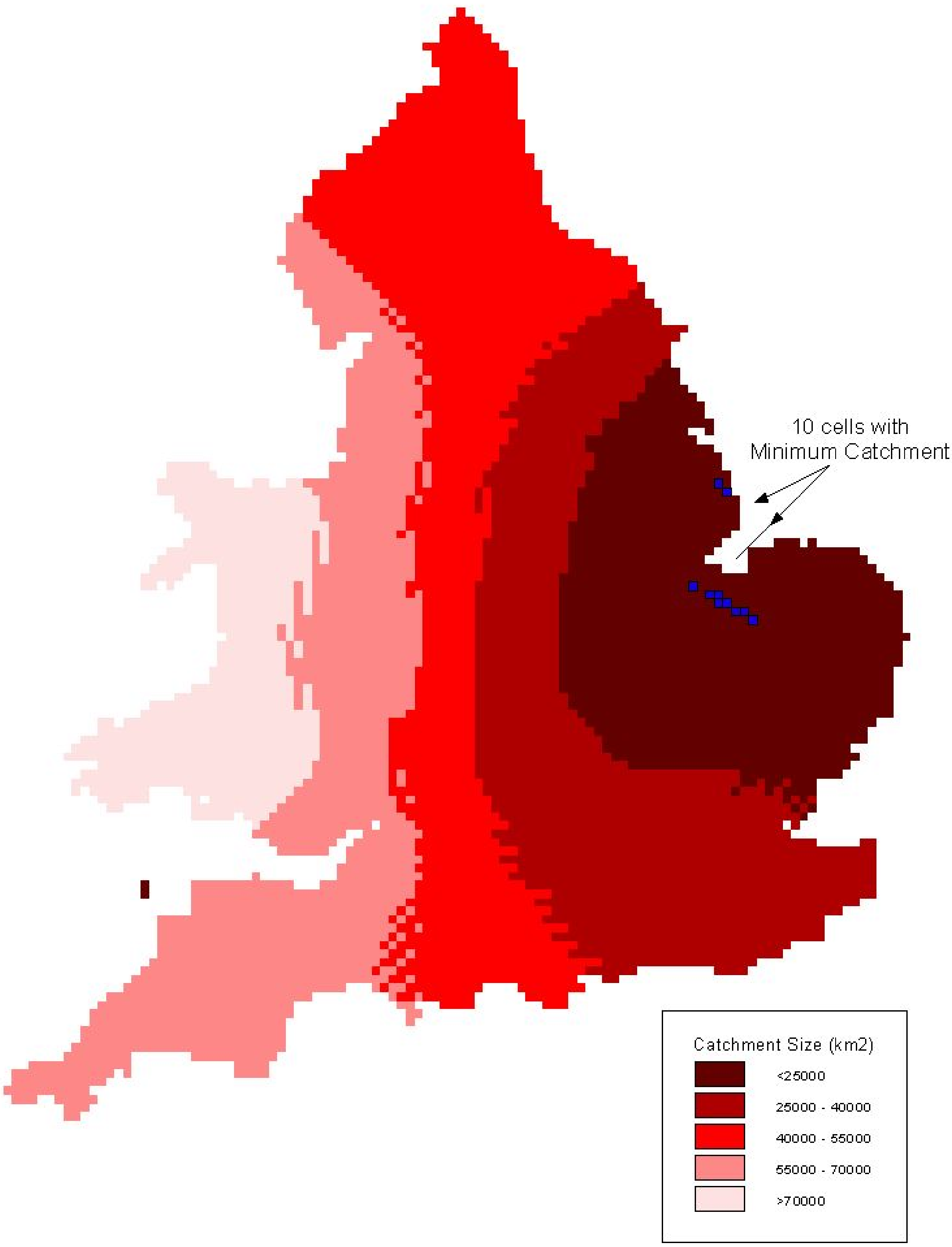

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 10% of total current cropping is available to the plant
East of England Region Analysis
Lakenheath
Ely
Somersham
Mildenhall
Burwell
Waterbeach
Histon
Newmarket
CAMBRIDGE
Fulbourn
M11
Base map - Automobile Association Copyright 2003

FIGURE 5.5(b).

FIGURE 5.6(a).

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 10% of total crop is available to the plant



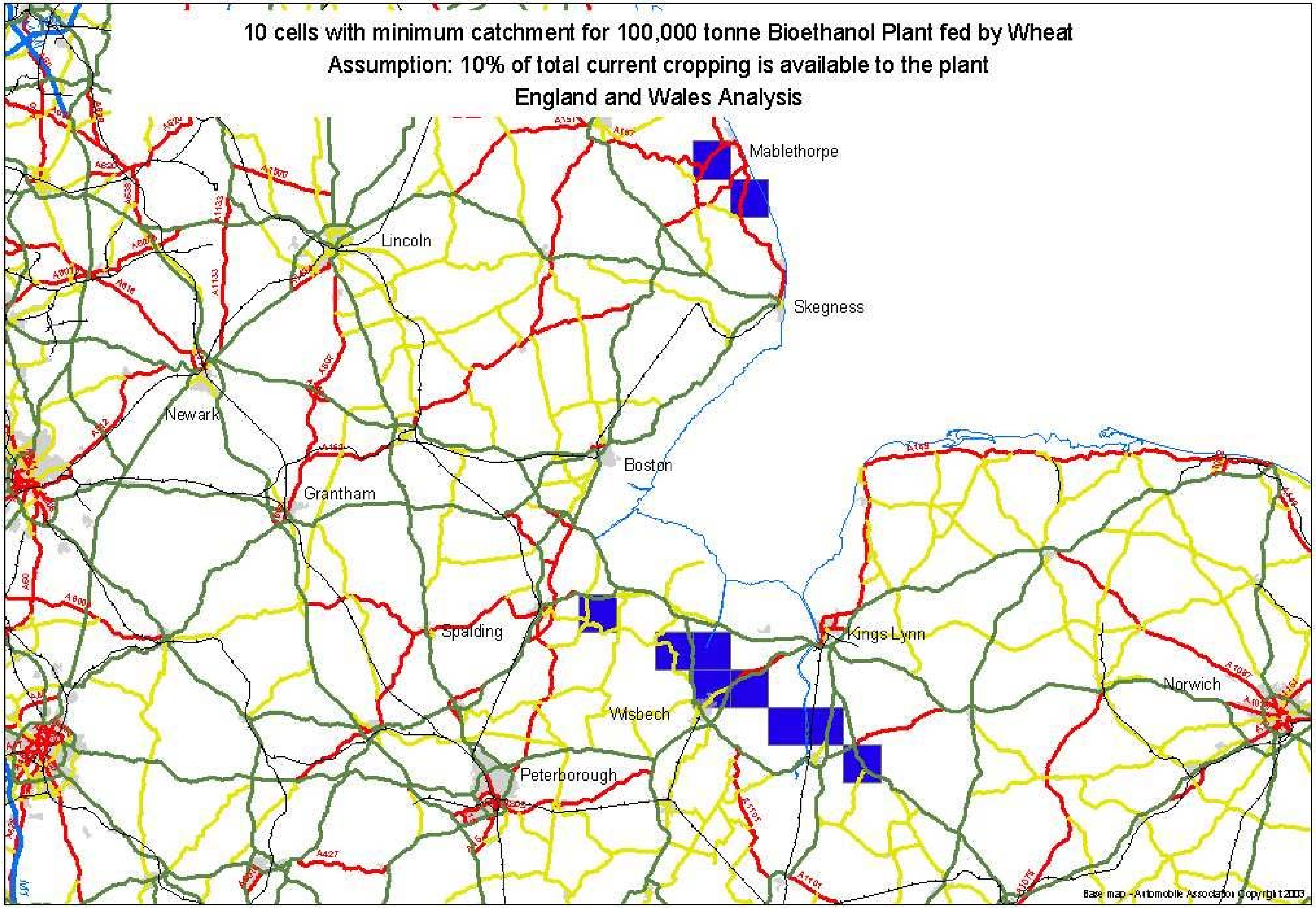
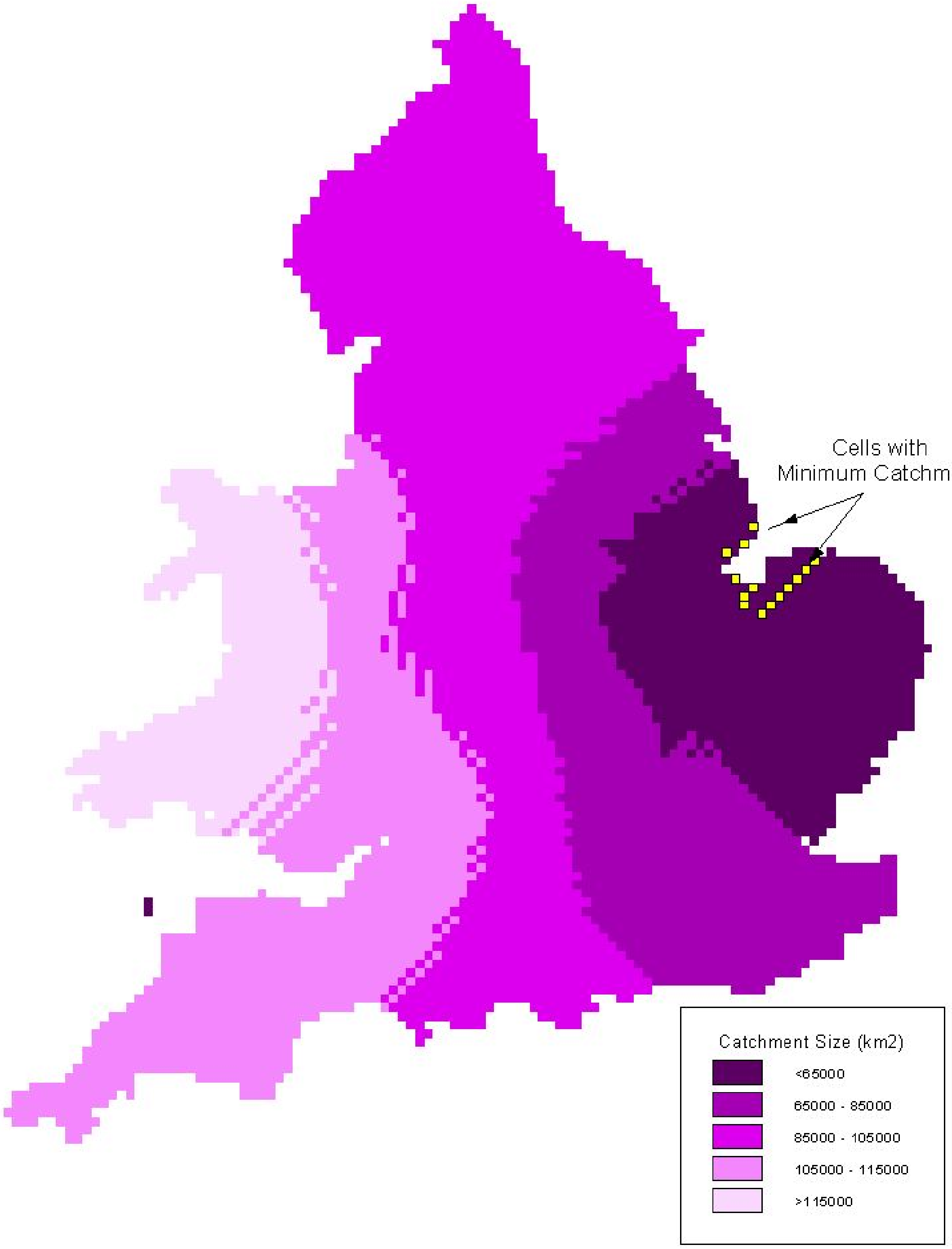

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 10% of total current cropping is available to the plant
England and Wales Analysis
Mablethorpe
Lincoln
Skegness
Newark
Boston
Grantham
Spalding
Kings Lynn
Norwich
Wisbech
Peterborough
Base map - Automobile Association Copyright 2003

FIGURE 5.6(b).

FIGURE 5.7(a).

Catchment for 250,000 tonne Bioethanol Plant fed by Wheat
Assumption: 10% of total wheat crop is available to the plant



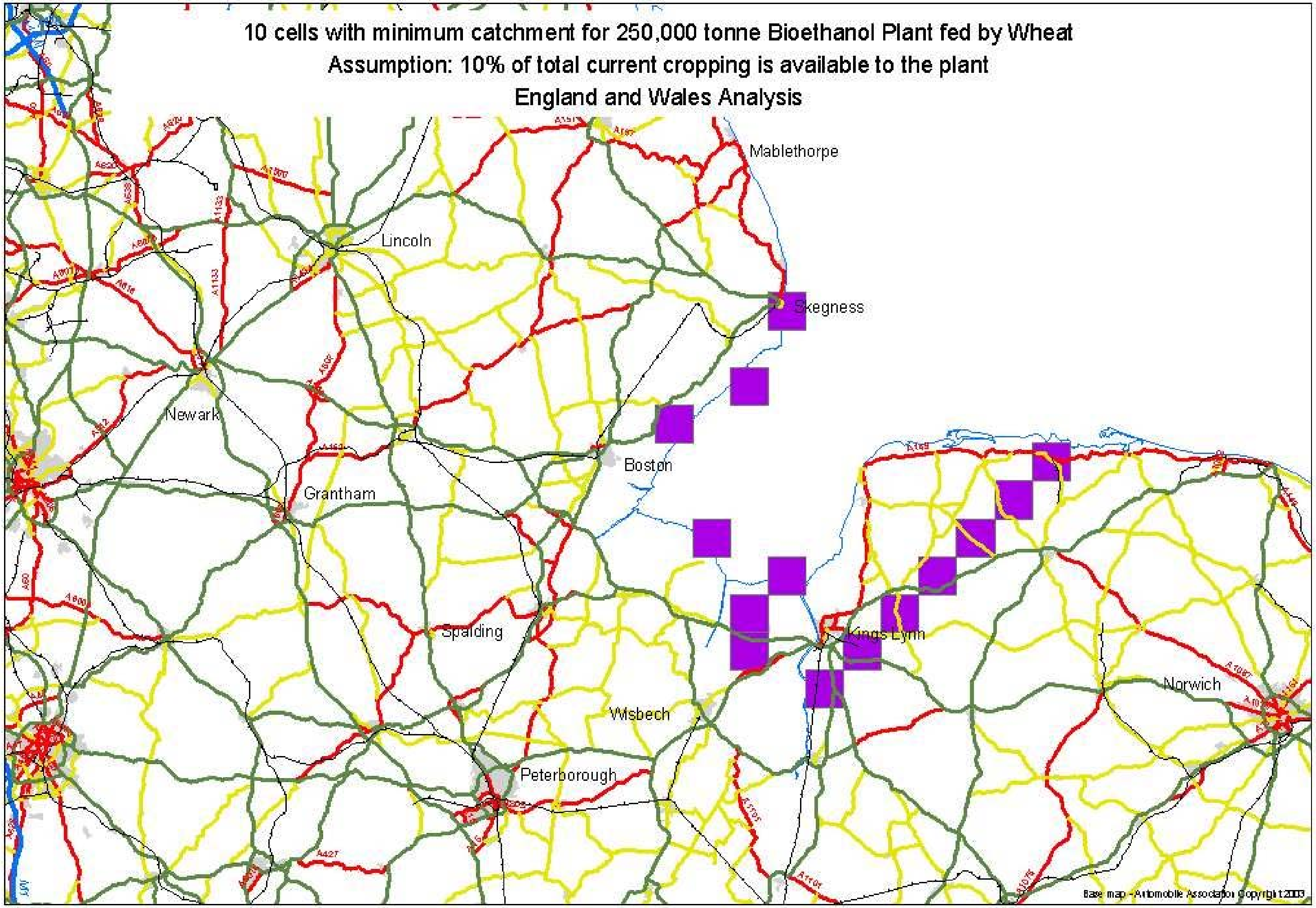

10 cells with minimum catchment for 250,000 tonne Bioethanol Plant fed by Wheat
Assumption: 10% of total current cropping is available to the plant
England and Wales Analysis
Mablethorpe
Lincoln
Skegness
Newark
Boston
Grantham
Spalding
Kings Lynn
Norwich
Wisbech
Peterborough
Base map - Automobile Association Copyright 2003

FIGURE 5.7(b).

FIGURE 5.8(a).

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 20% of crop is available to the plant

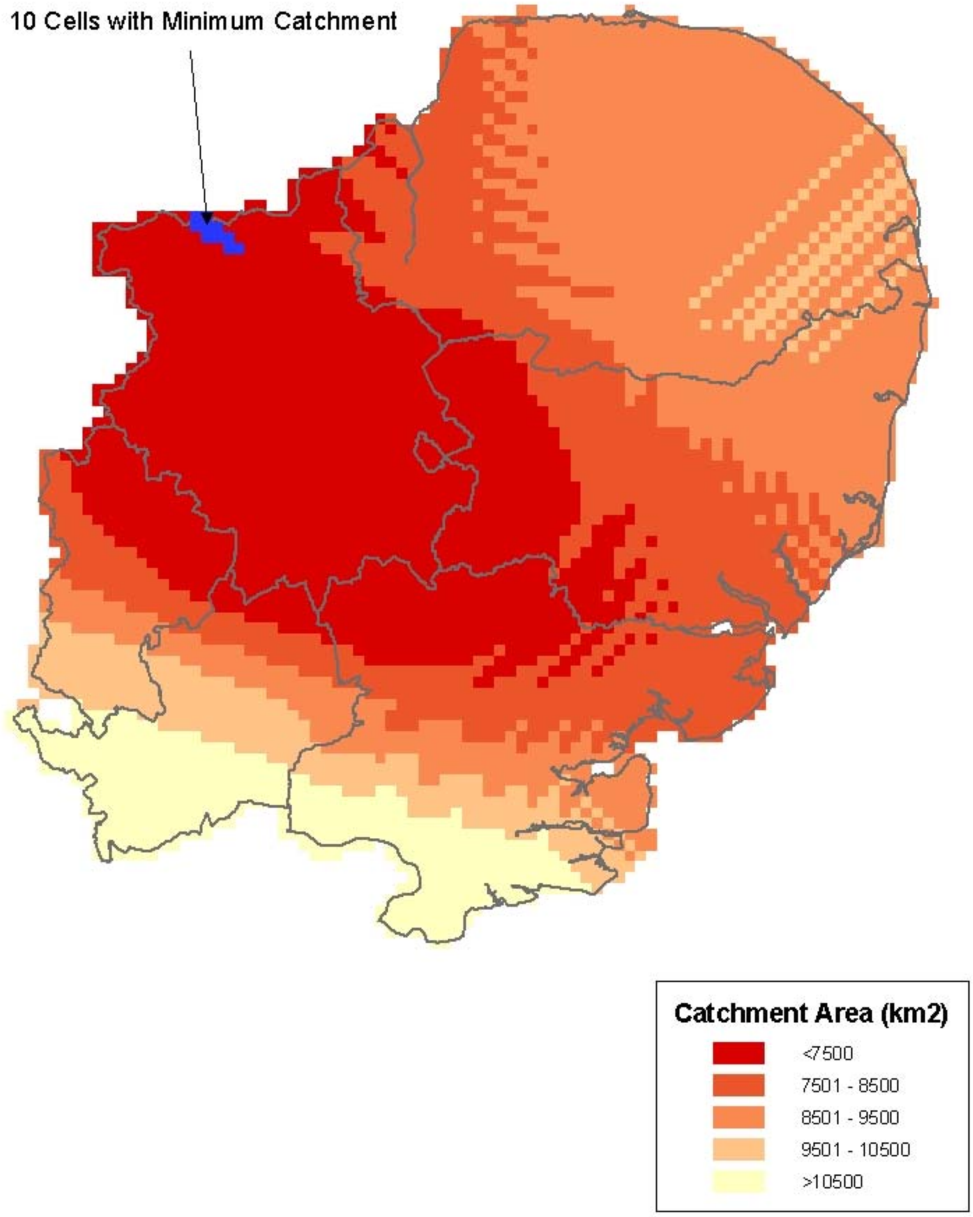
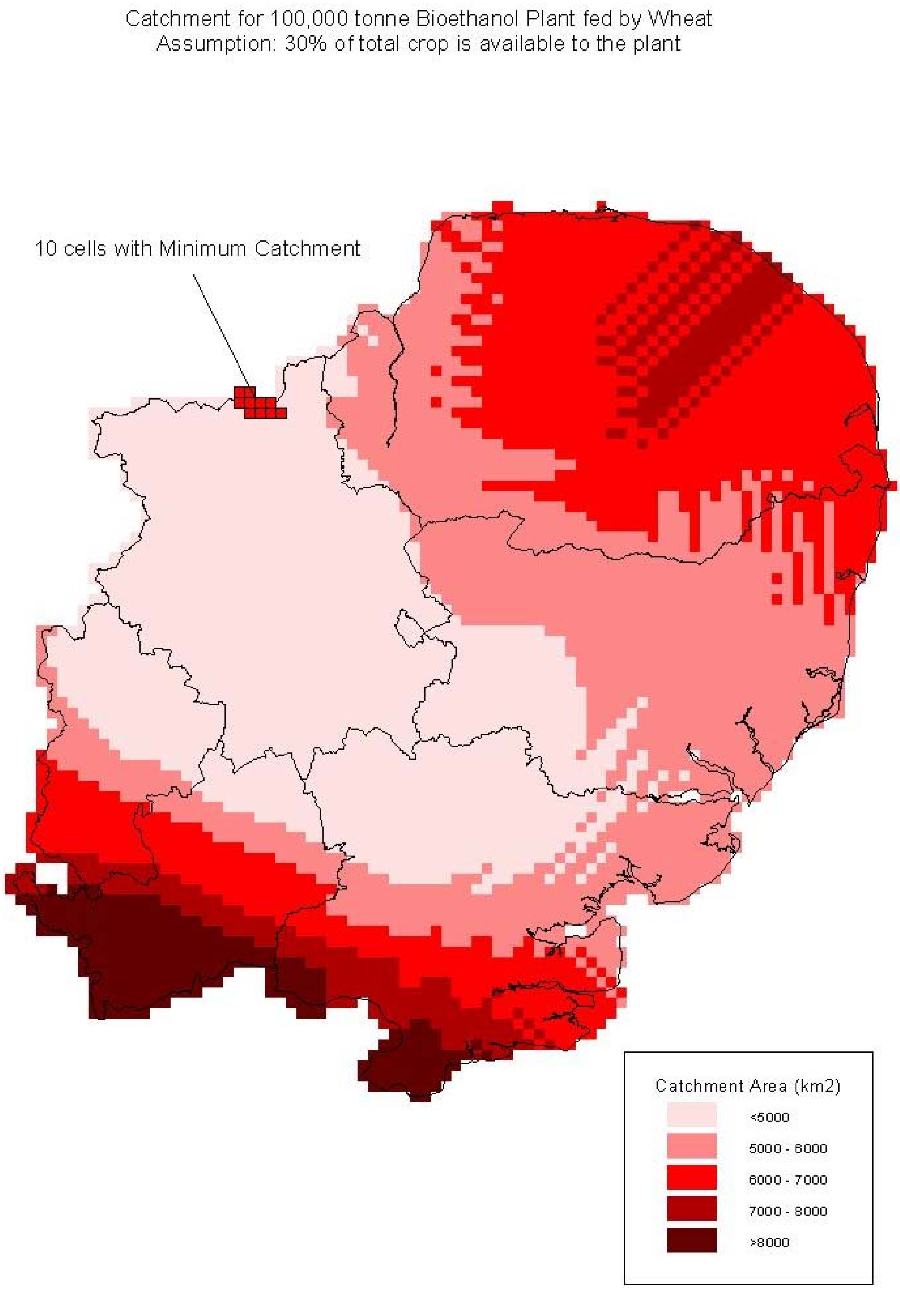
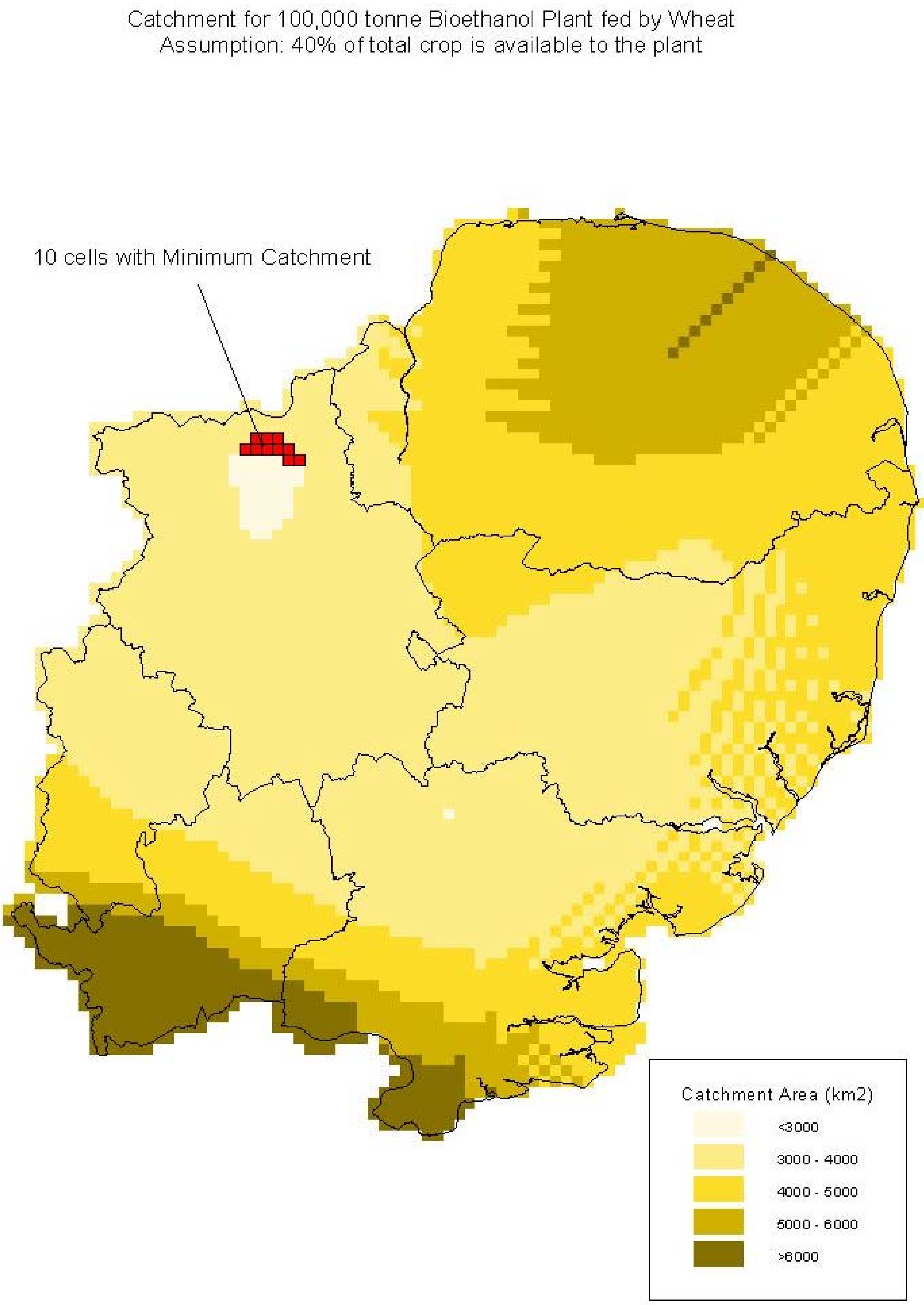


FIGURE 5.8(b).



Catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 30% of total crop is available to the plant
10 cells with Minimum Catchment
Catchment Area (km2)
<5000
5000 - 6000
6000 - 7000
7000 - 8000
>8000

FIGURE 5.8(c).



Catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 40% of total crop is available to the plant
10 cells with Minimum Catchment
Catchment Area (km2)
<3000
3000 - 4000
4000 - 5000
5000 - 6000
>6000

FIGURE 5.8(d).

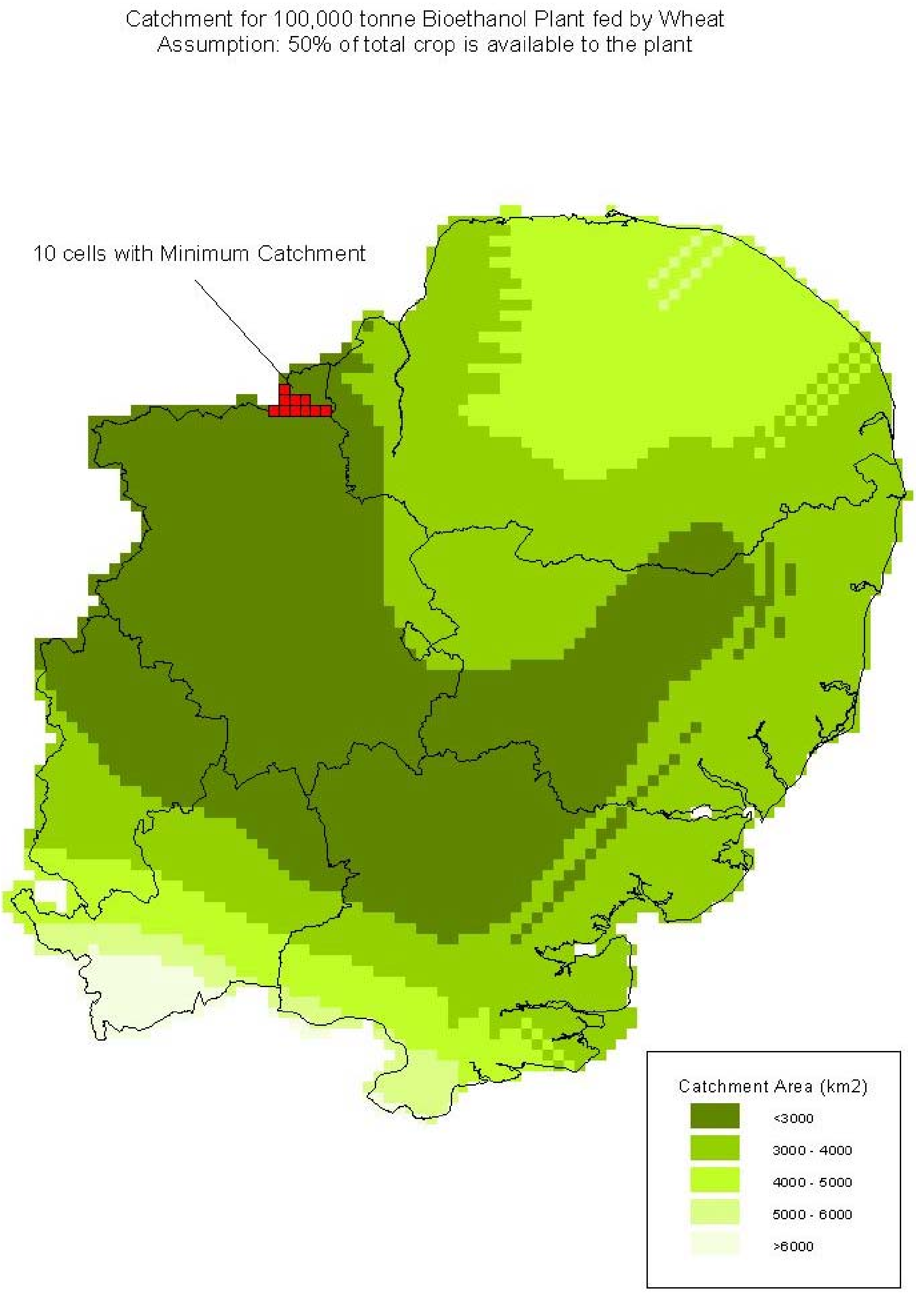
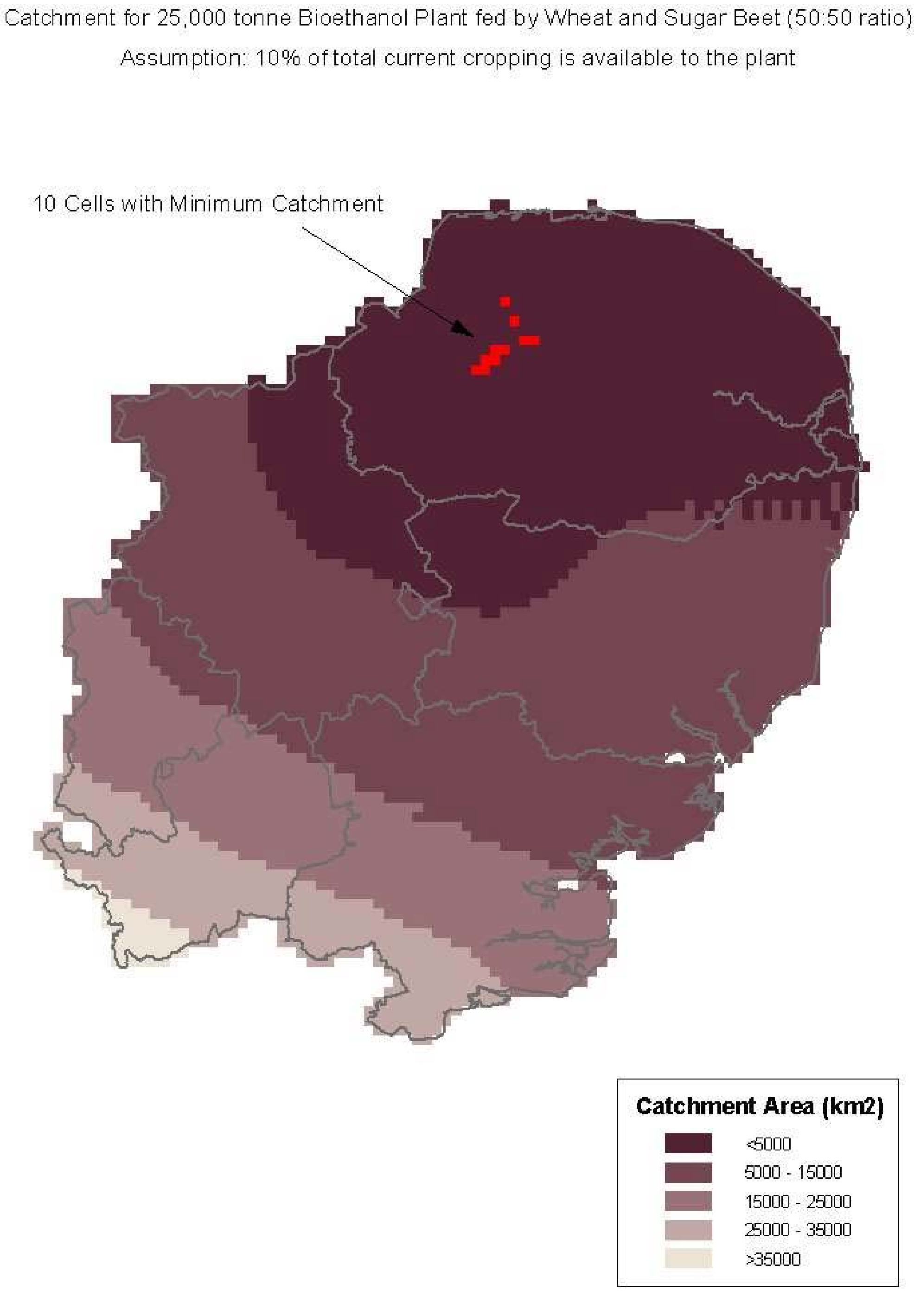

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat
Assumption: 50% of total crop is available to the plant
10 cells with Minimum Catchment
Catchment Area (km2)
<3000
3000 - 4000
4000 - 5000
5000 - 6000
>6000

FIGURE 5.9(a).


Catchment for 25,000 tonne Bioethanol Plant fed by Wheat and Sugar Beet (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
10 Cells with Minimum Catchment
Catchment Area (km2)
<5000
5000 - 15000
15000 - 25000
25000 - 35000
>35000

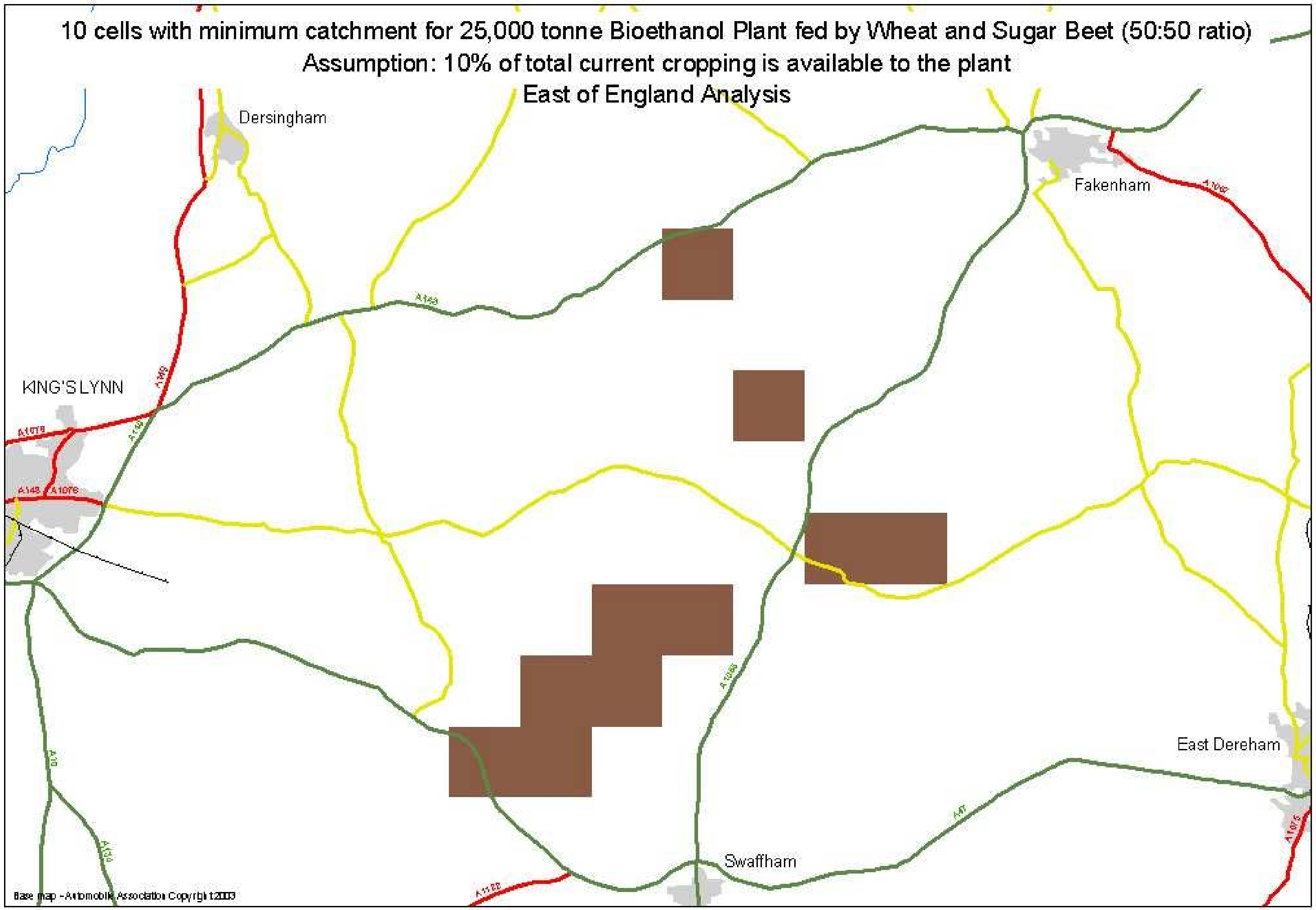
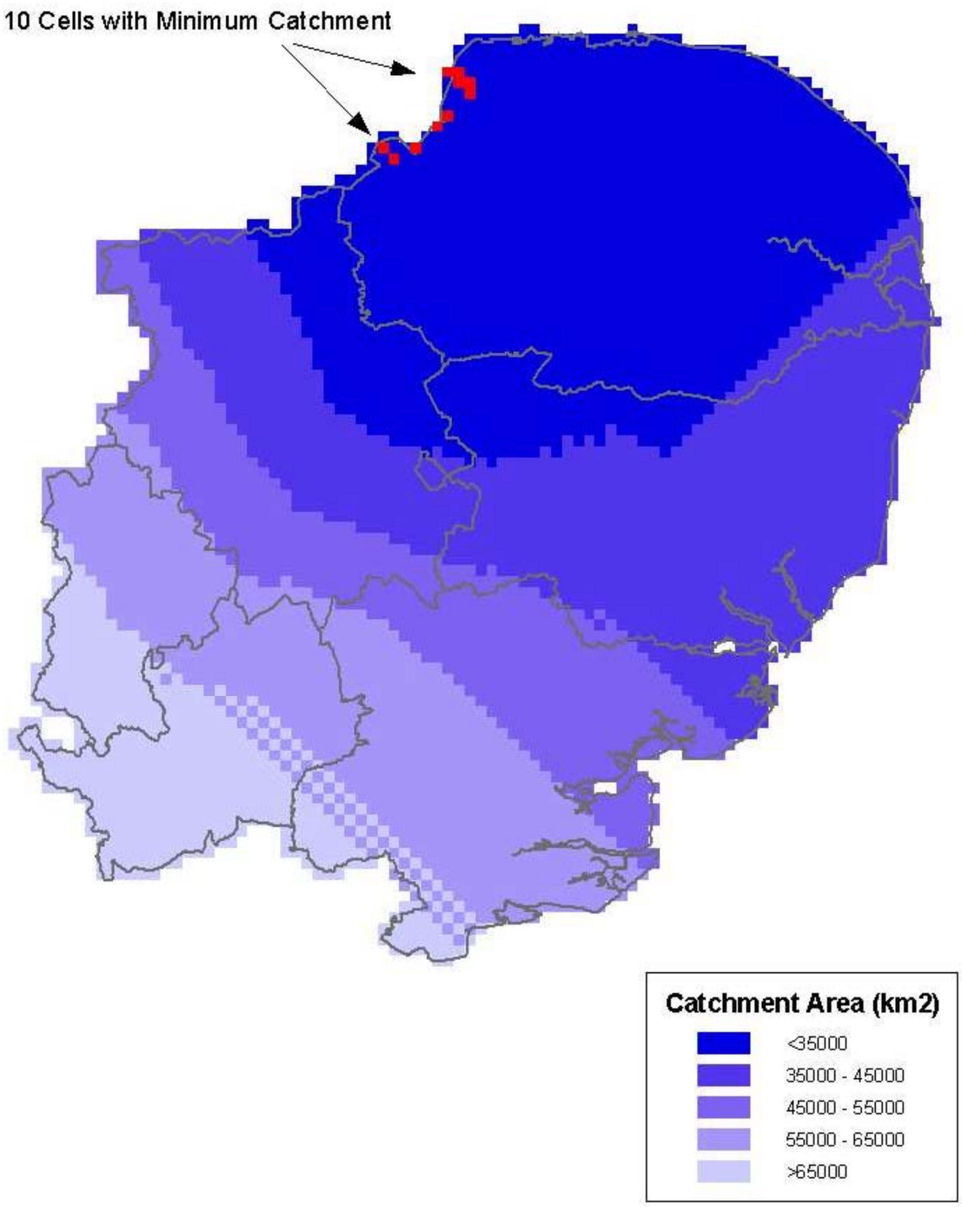

10 cells with minimum catchment for 25,000 tonne Bioethanol Plant fed by Wheat and Sugar Beet (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
East of England Analysis
Dersingham
Fakenham
KING'S LYNN
East Dereham
Swaffham
A148
A47

FIGURE 5.9(b).

FIGURE 5.10(a).

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Sugar Beet (50:50 ratio)

Assumption: 10% of total current cropping is available to the plant



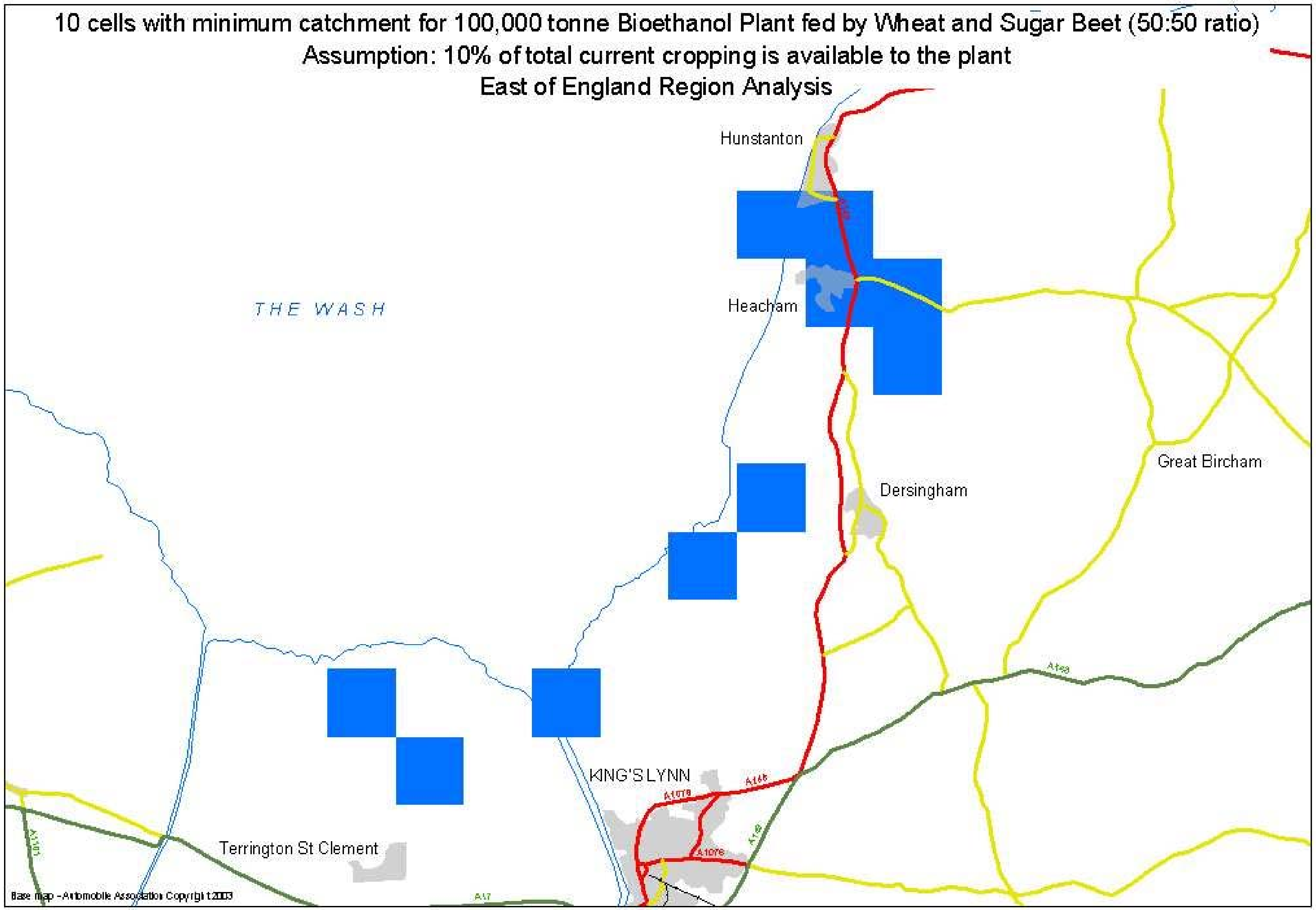
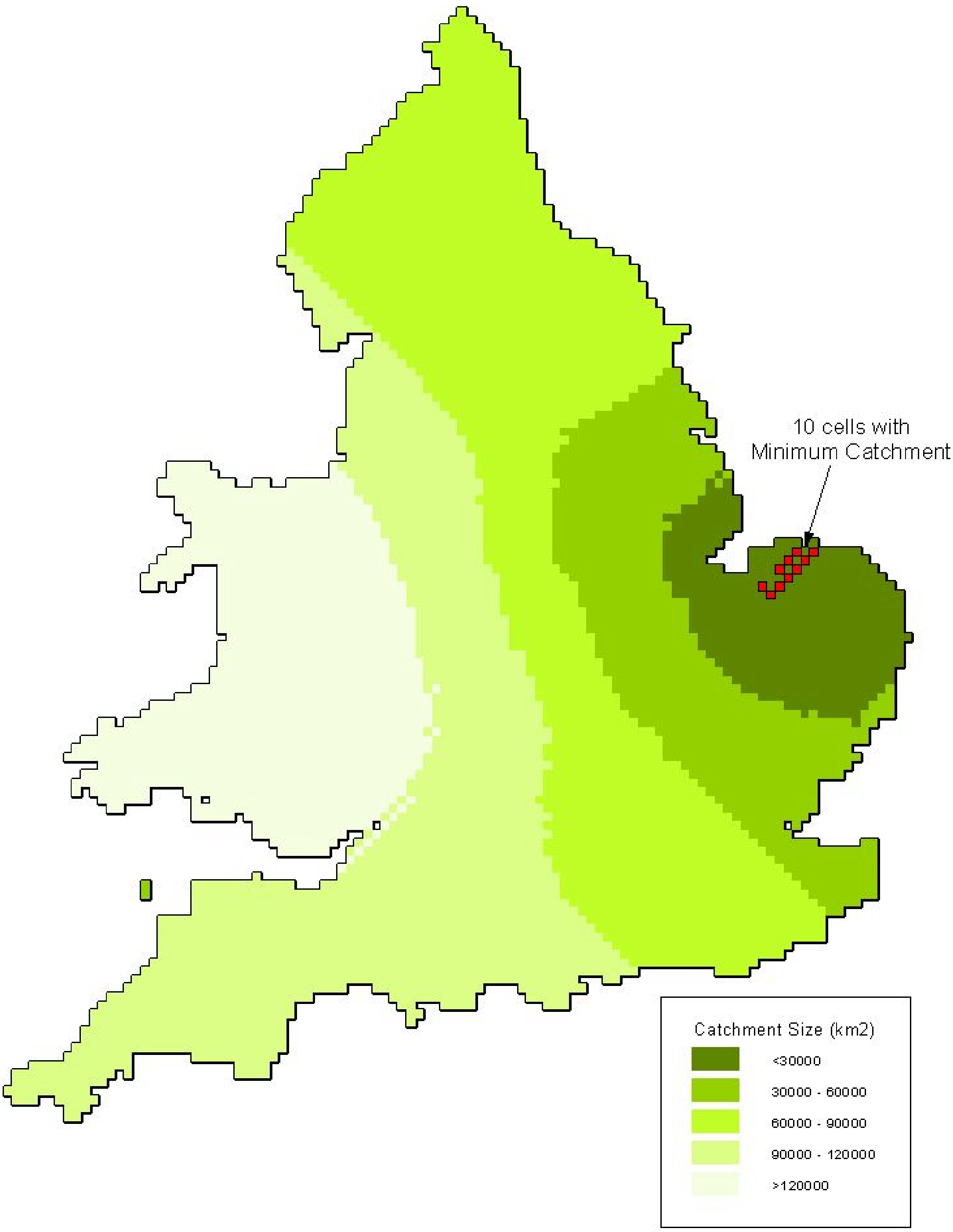

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Sugar Beet (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
East of England Region Analysis
Hunstanton
THE WASH
Heacham
Great Bircham
Dersingham
KING'S LYNN
Terrington St Clement

FIGURE 5.10(b).

FIGURE 5.11(a).

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Sugar Beet (50:50 ratio)
Assumption: 10% of total crop is available to the plant



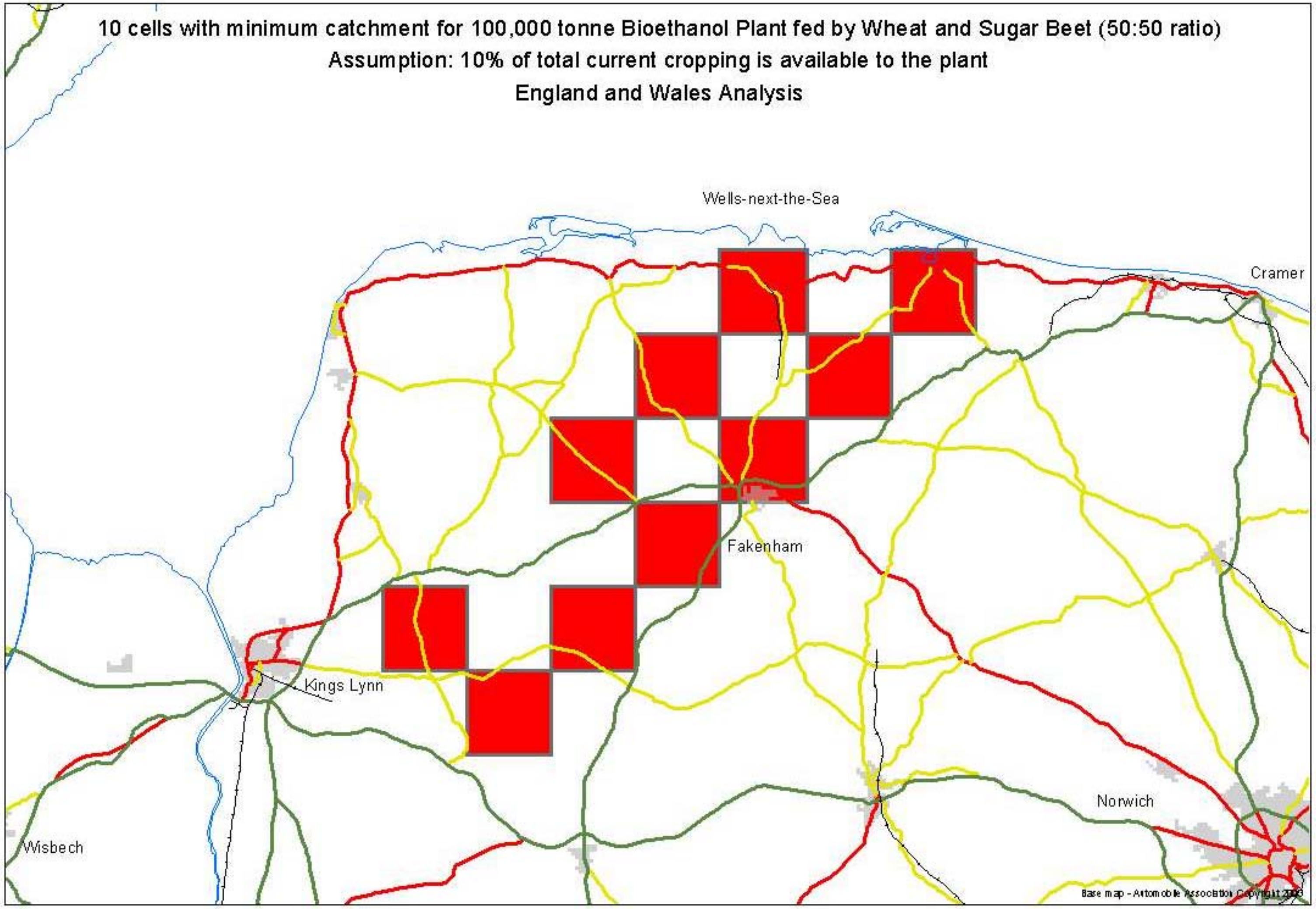
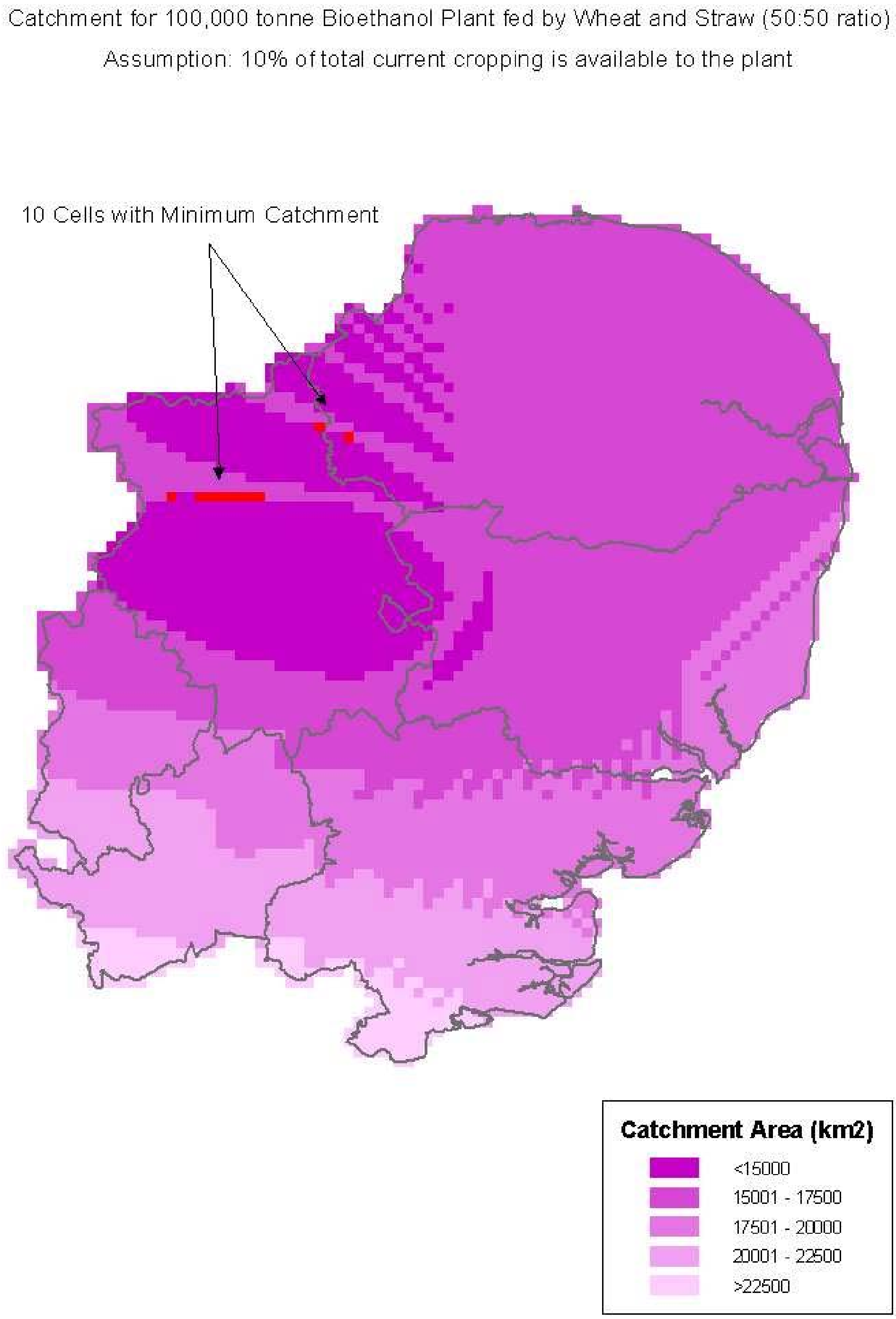

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Sugar Beet (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
England and Wales Analysis
Wells-next-the-Sea
Cramer
Fakenham
Kings Lynn
Norwich
Wisbech

FIGURE 5.11(b).

FIGURE 5.12(a).


Catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Straw (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
10 Cells with Minimum Catchment
Catchment Area (km2)
<15000
15001 - 17500
17501 - 20000
20001 - 22500
>22500

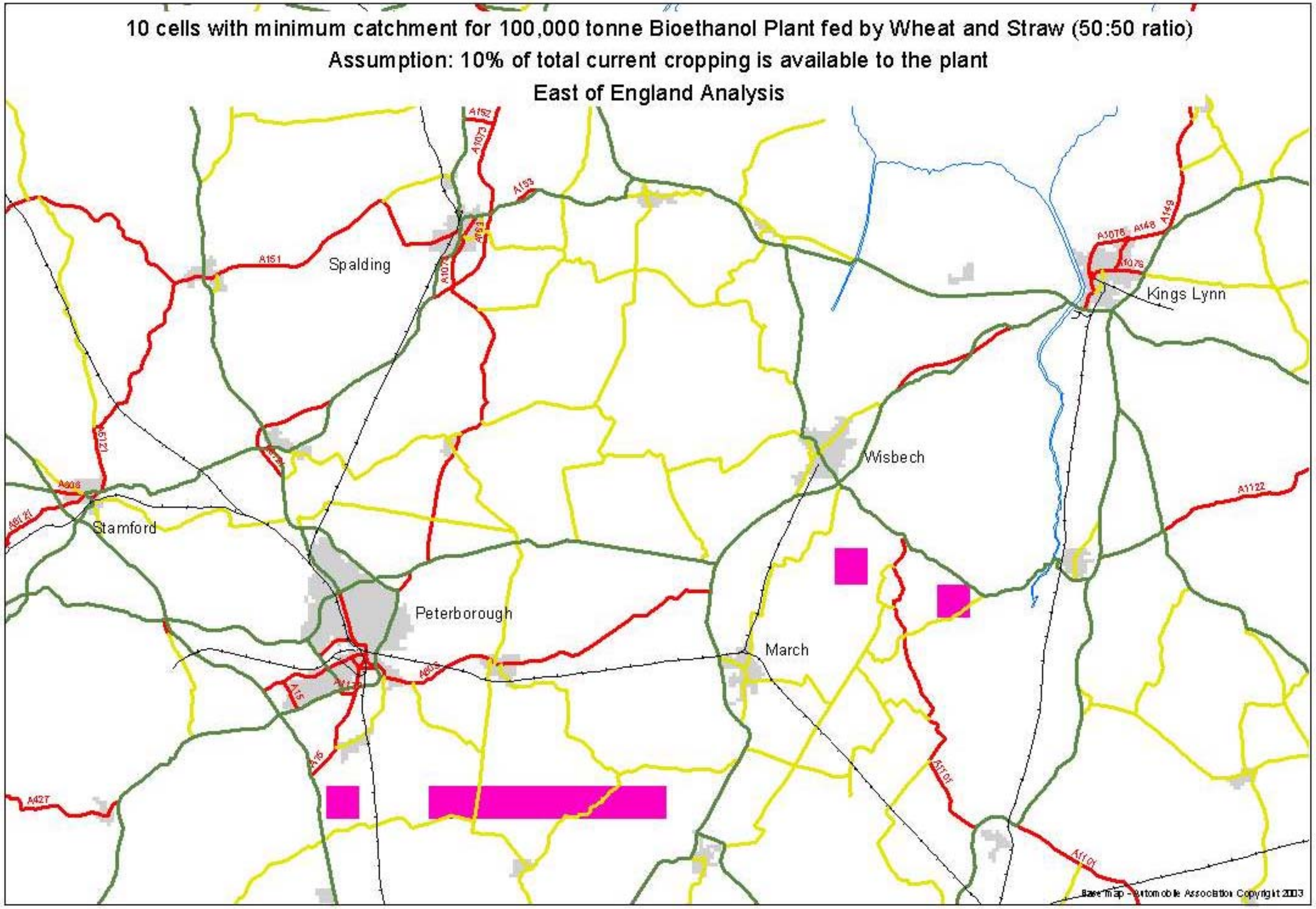
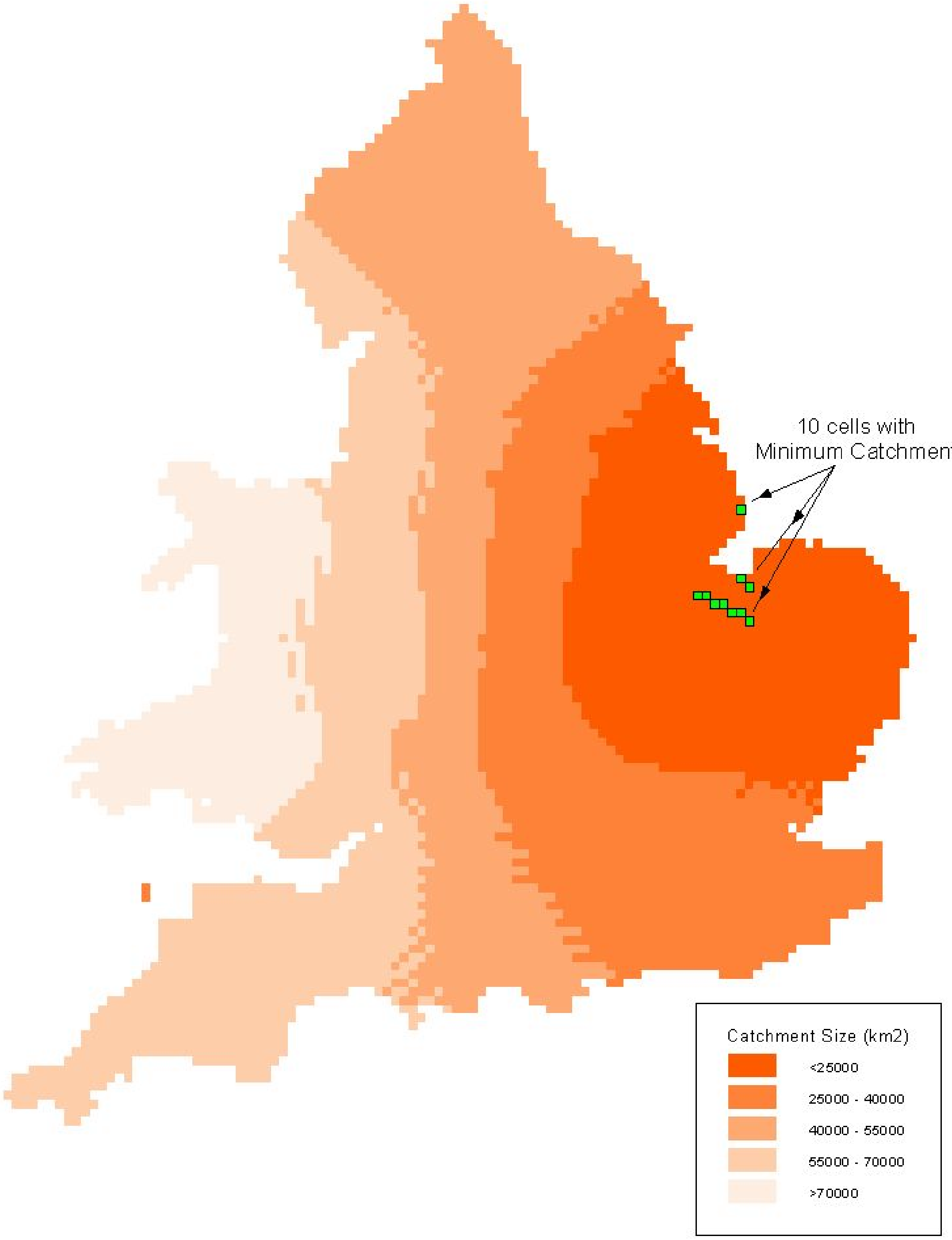

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Straw (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
East of England Analysis
Spalding
Kings Lynn
Wisbech
Stamford
Peterborough
March
Base map - Automobile Association Copyright 2003

FIGURE 5.12(b).

FIGURE 5.13(a).

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Straw (50:50 ratio)
Assumption: 10% of total crop is available to the plant

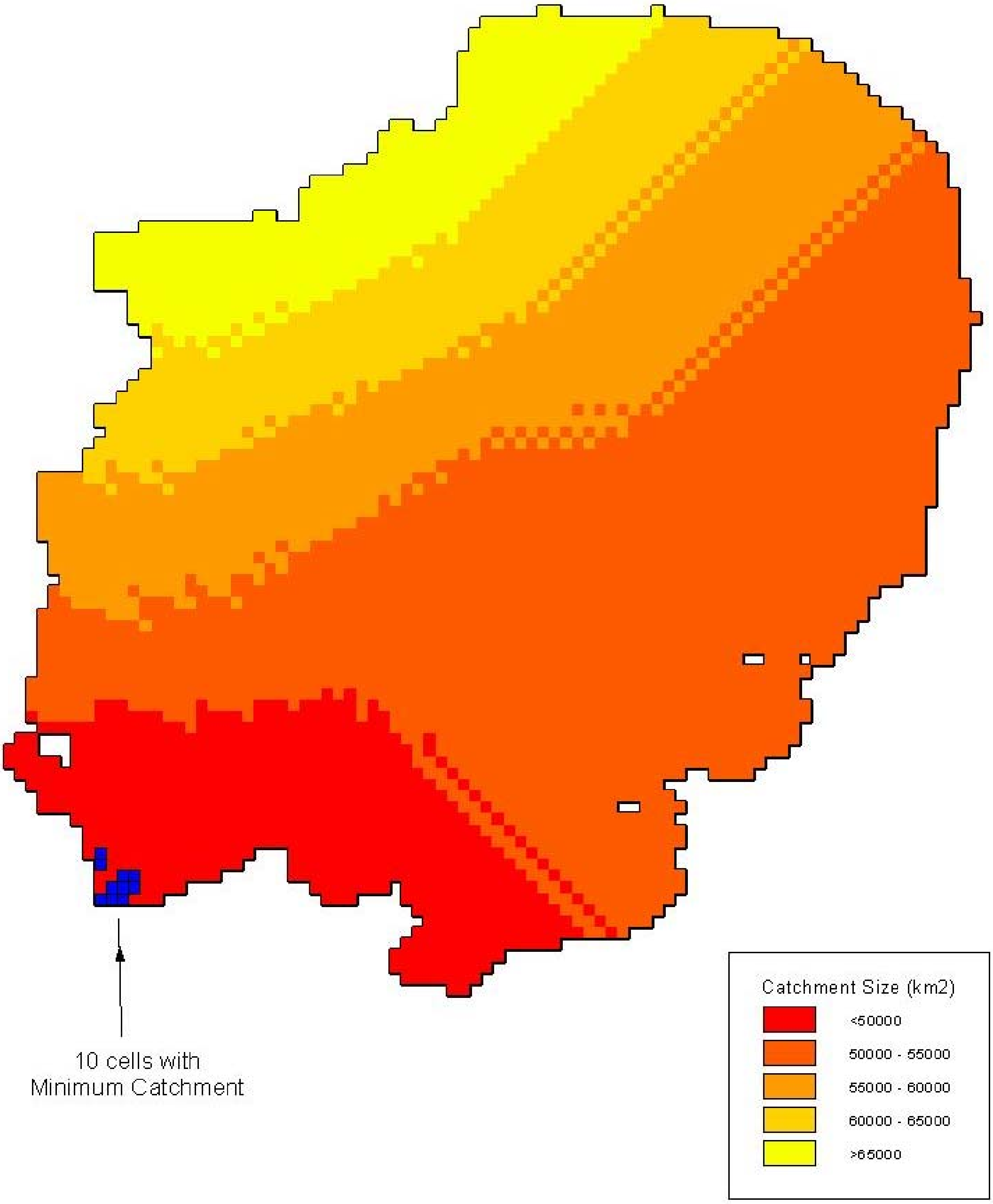



10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Straw (50:50 ratio)
Assumption: 10% of total current cropping is available to the plant
England and Wales Analysis
Lincoln
Skegness
Newark
Wells-next-the-Sea
Cramer
Boston
Grantham
Fakenham
Spalding
Kings Lynn
Norwich
Stamford
Wisbech
Peterborough
March
Base map - Automobile Association Copyright 2003

FIGURE 5.13(b).

FIGURE 5.14(a)

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Forestry (50:50 ratio)
Assumption: 10% of total wheat crop and 75% of total forestry crop is available to the plant



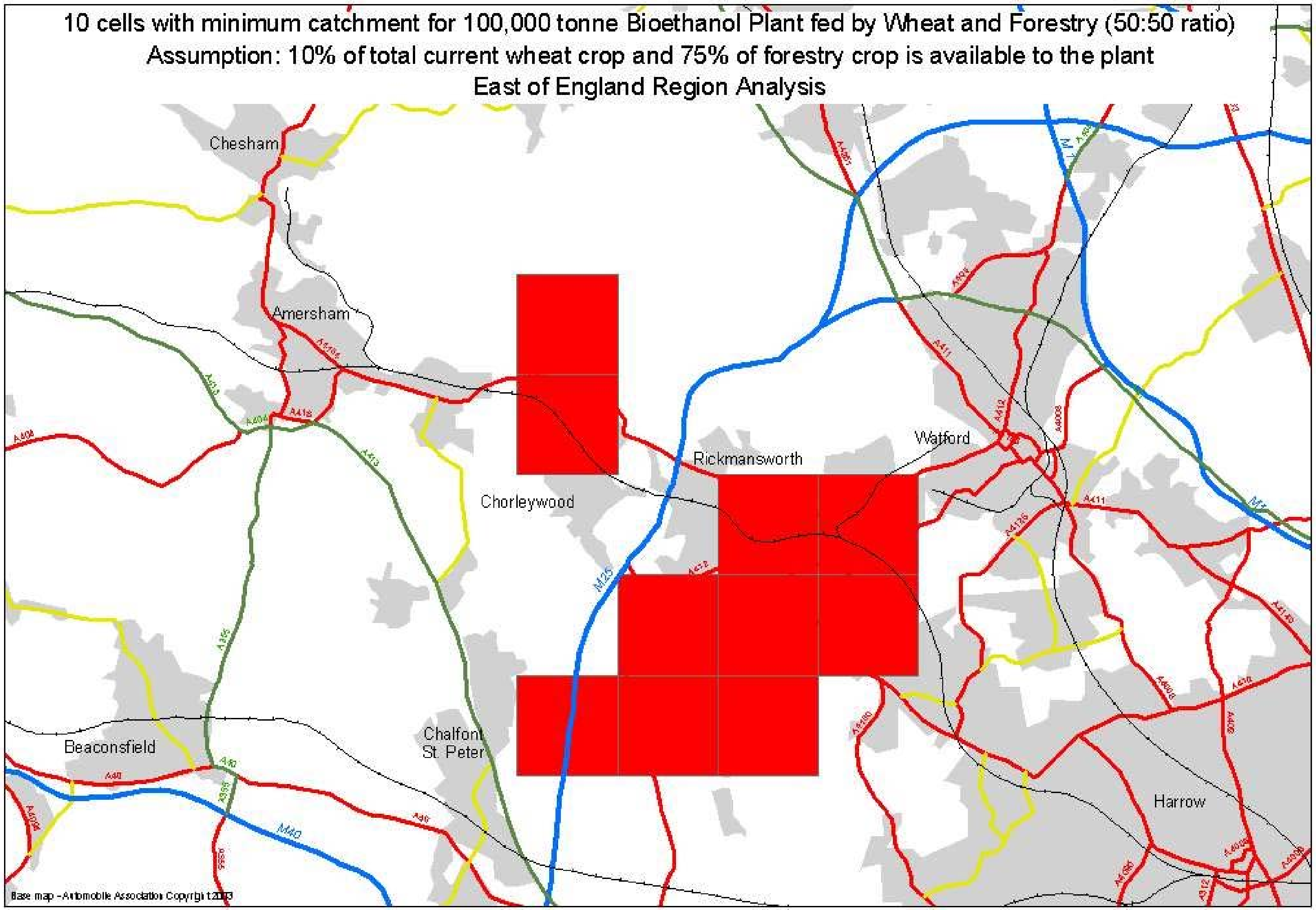
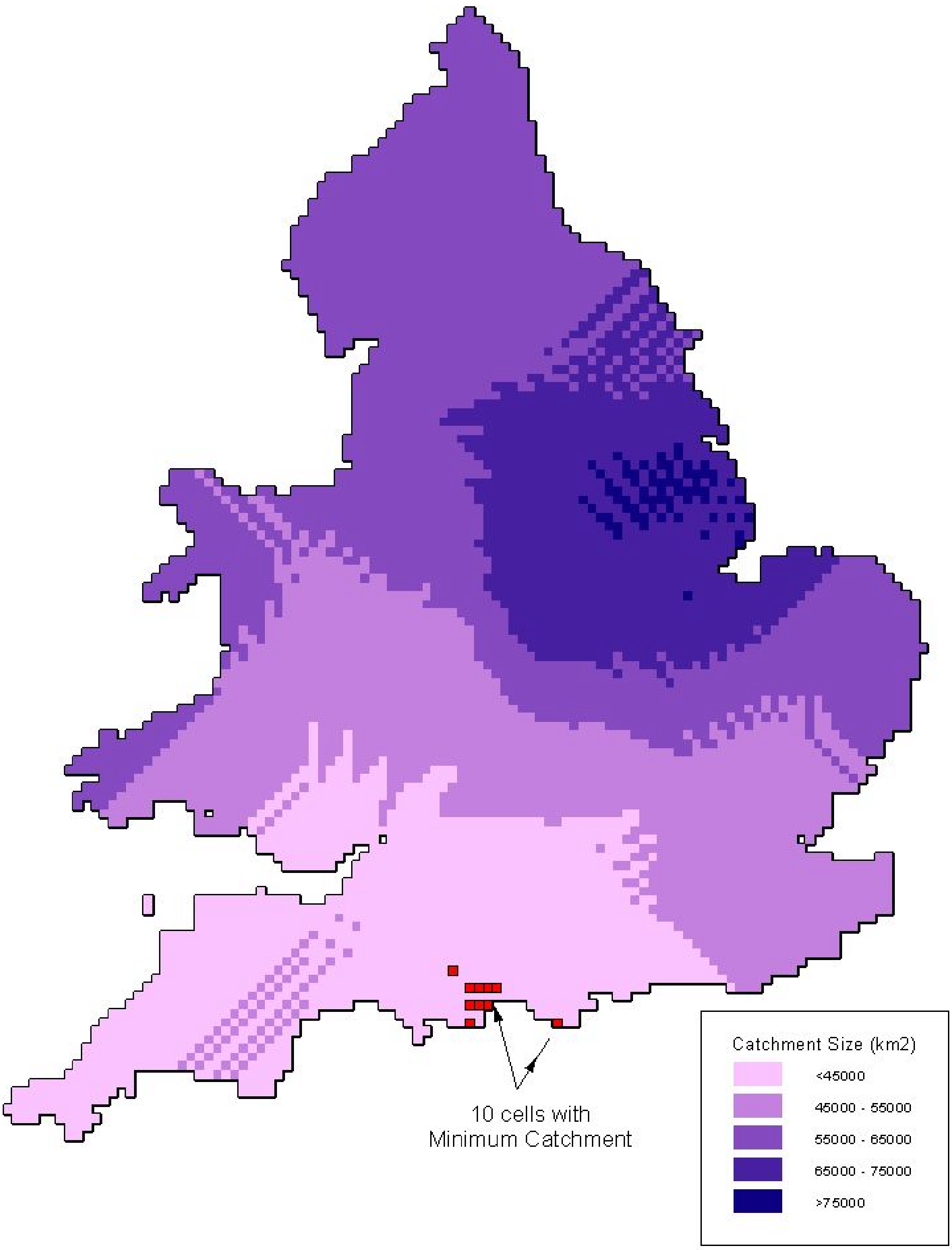

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Forestry (50:50 ratio)
Assumption: 10% of total current wheat crop and 75% of forestry crop is available to the plant
East of England Region Analysis
Chesham
Amersham
Watford
Rickmansworth
Chorleywood
M25
Beaconsfield
Chalfont
St. Peter
M40
Harrow
M1

FIGURE 5.14(b)

FIGURE 5.15(a)

Catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Forestry (50:50 ratio)
Assumption: 10% of total wheat crop and 75% of total forestry crop is available to the plant



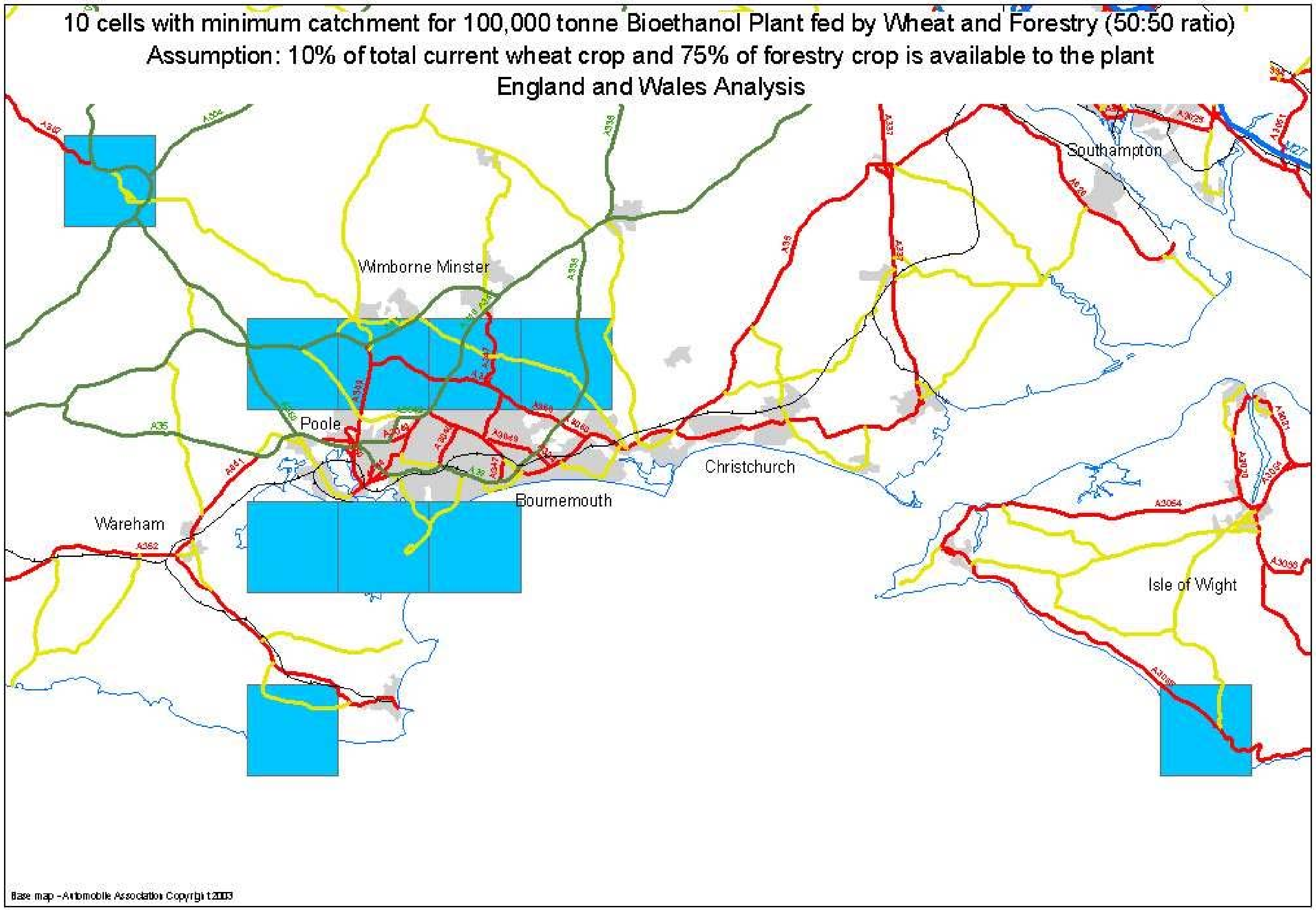
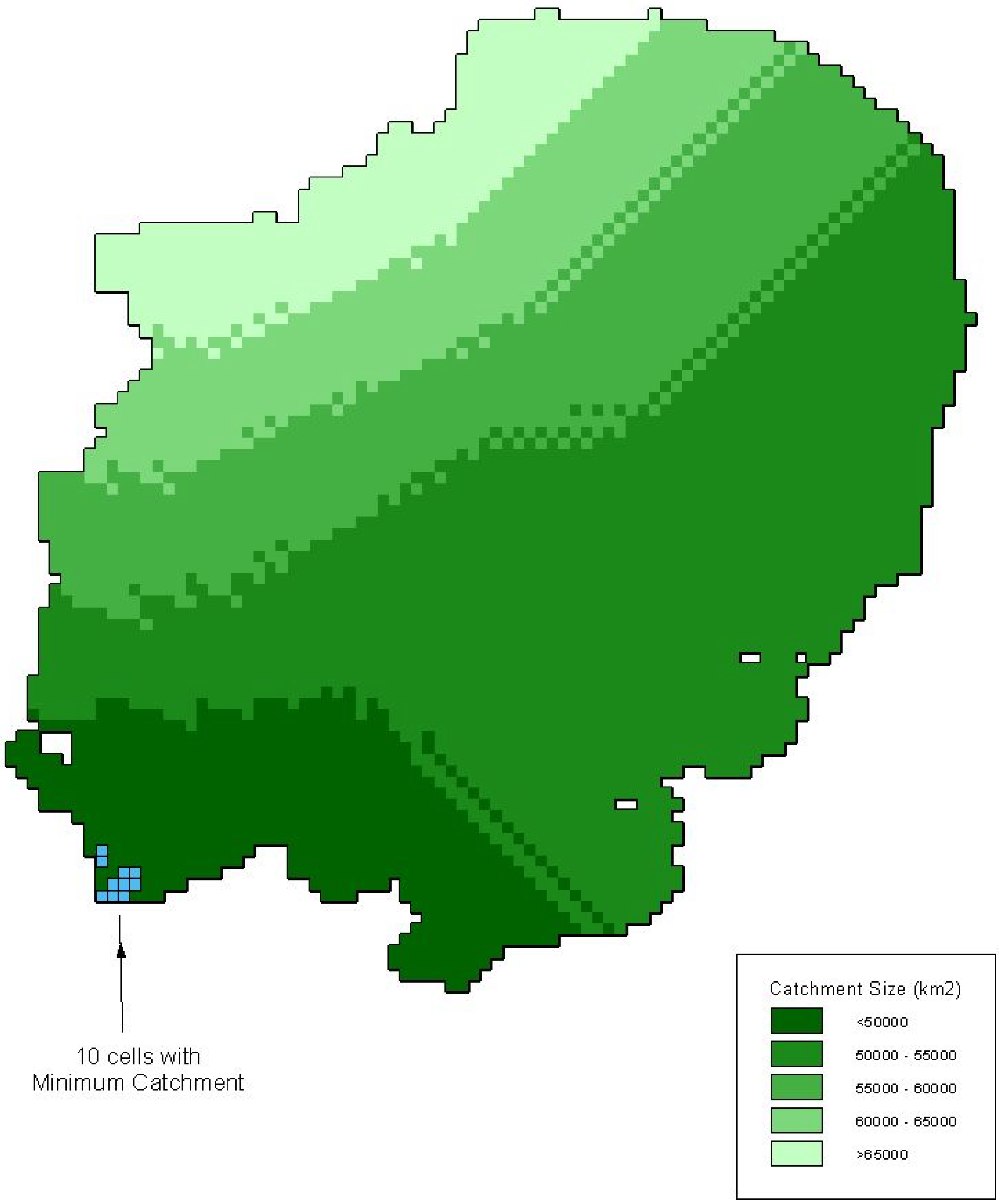

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Wheat and Forestry (50:50 ratio)
Assumption: 10% of total current wheat crop and 75% of forestry crop is available to the plant
England and Wales Analysis
Southampton
Wimborne Minster
Poole
Christchurch
Bournemouth
Wareham
Isle of Wight

FIGURE 5.15(b)

FIGURE 5.16(a)

Catchment for 100,000 tonne Bioethanol Plant fed by Straw and Forestry (50:50 ratio)
Assumption: 10% of total straw crop and 75% of total forestry crop is available to the plant



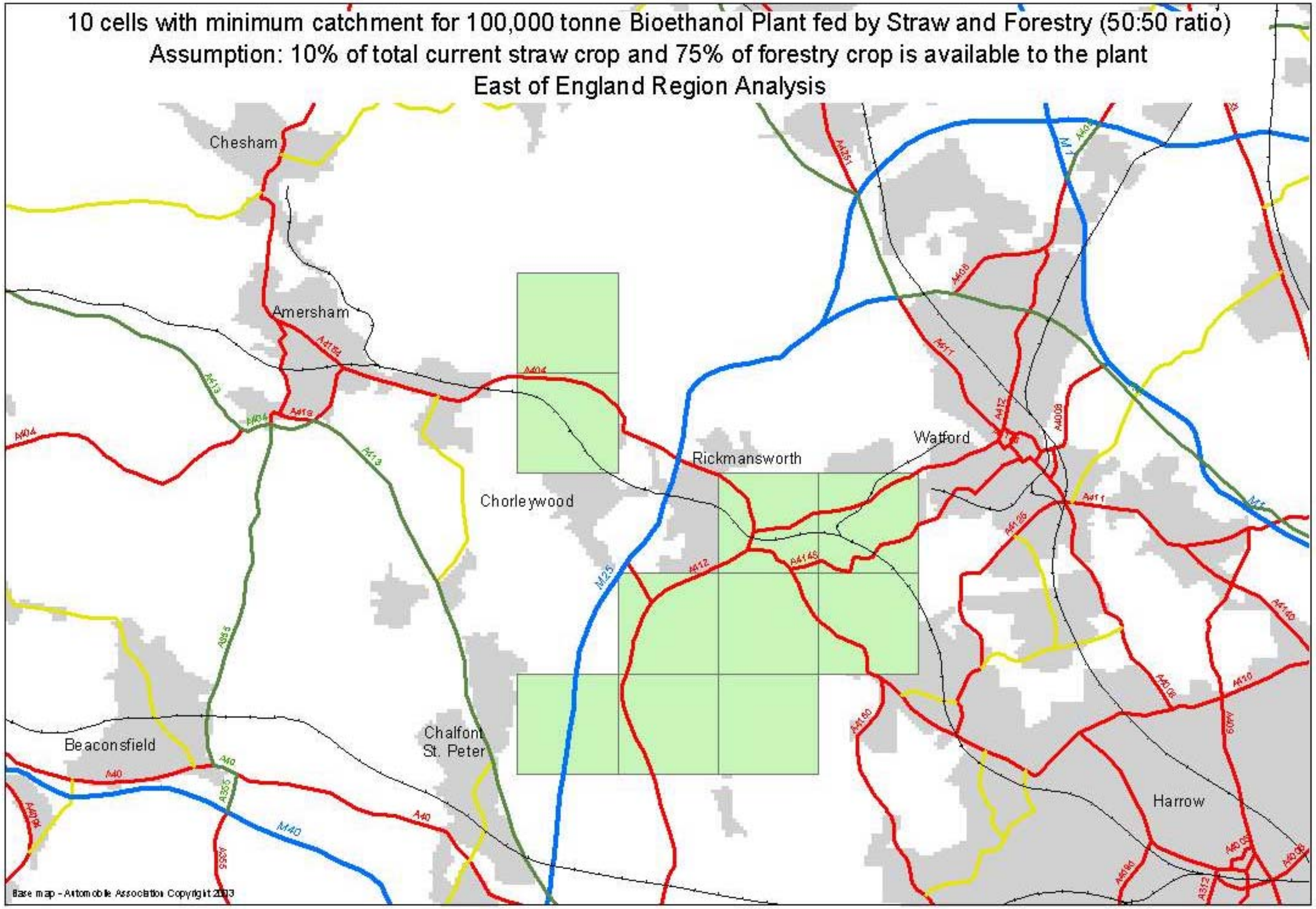
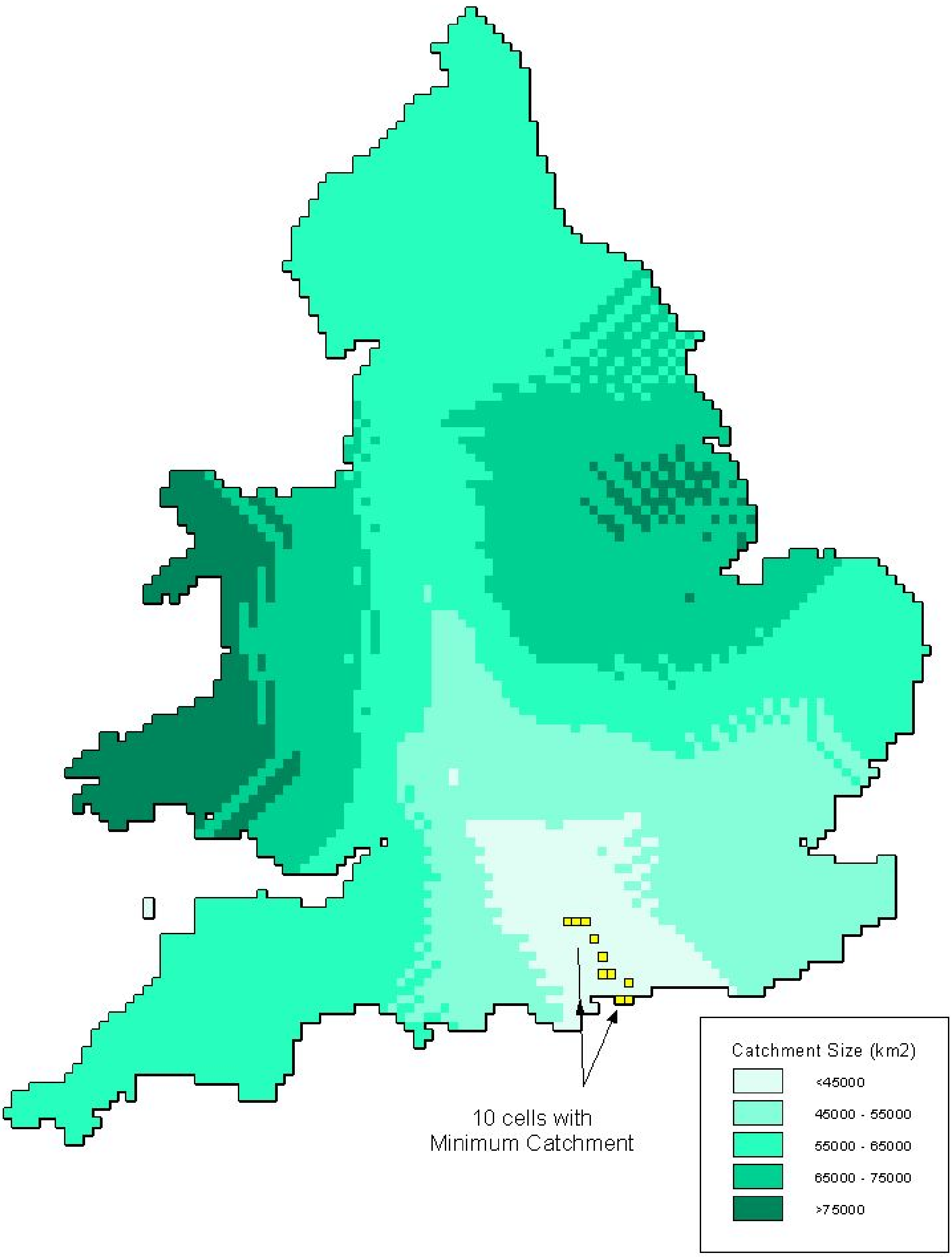

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Straw and Forestry (50:50 ratio)
Assumption: 10% of total current straw crop and 75% of forestry crop is available to the plant
East of England Region Analysis
Chesham
Amersham
Watford
Rickmansworth
Chorleywood
Beaconsfield
Chalfont St. Peter
Harrow
M25
M40
M1
Base map - Automobile Association Copyright 2003

FIGURE 5.16(b)

FIGURE 5.17(a)

Catchment for 100,000 tonne Bioethanol Plant fed by Straw and Forestry (50:50 ratio)
Assumption: 10% of total straw crop and 75% of total forestry crop is available to the plant



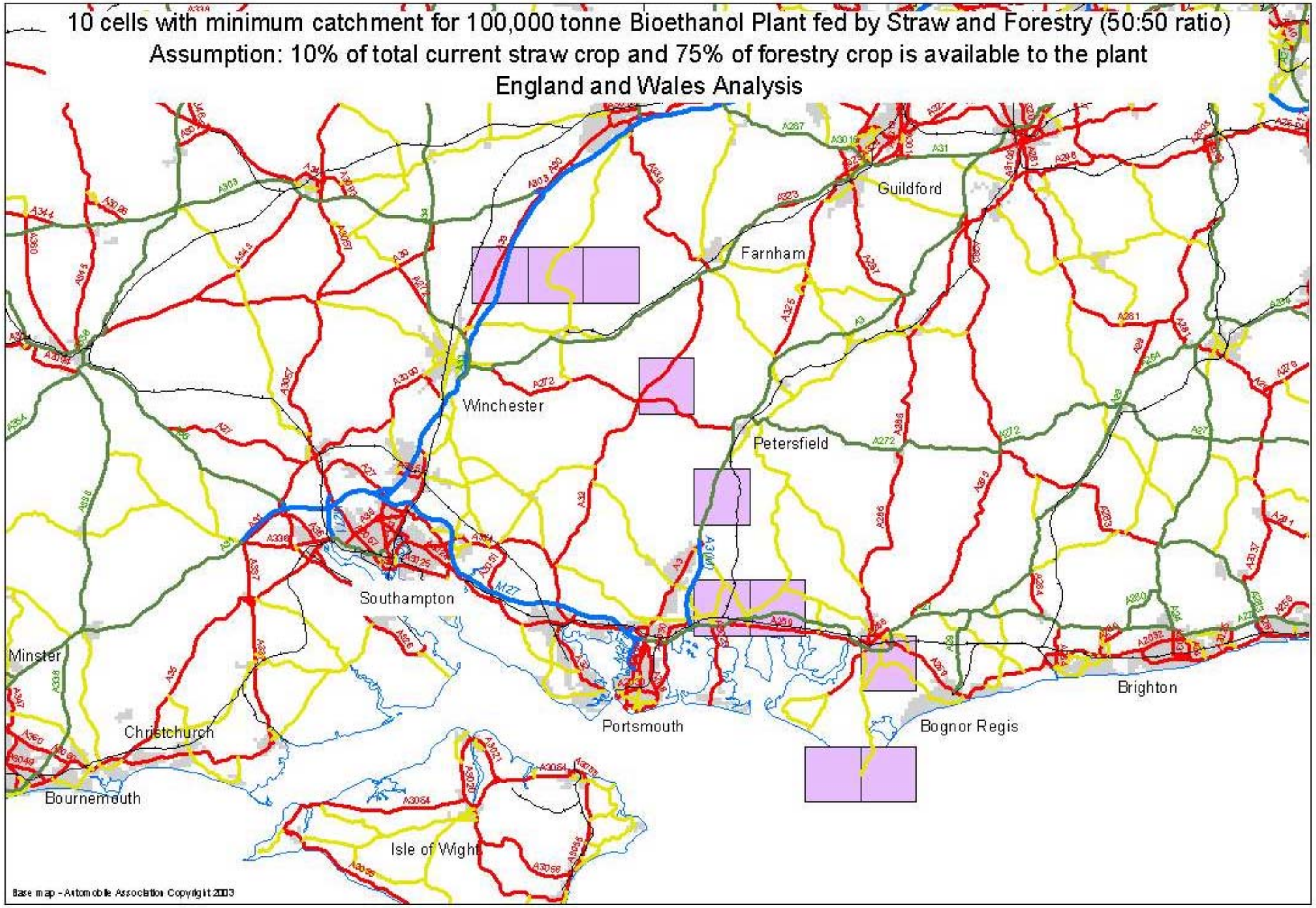
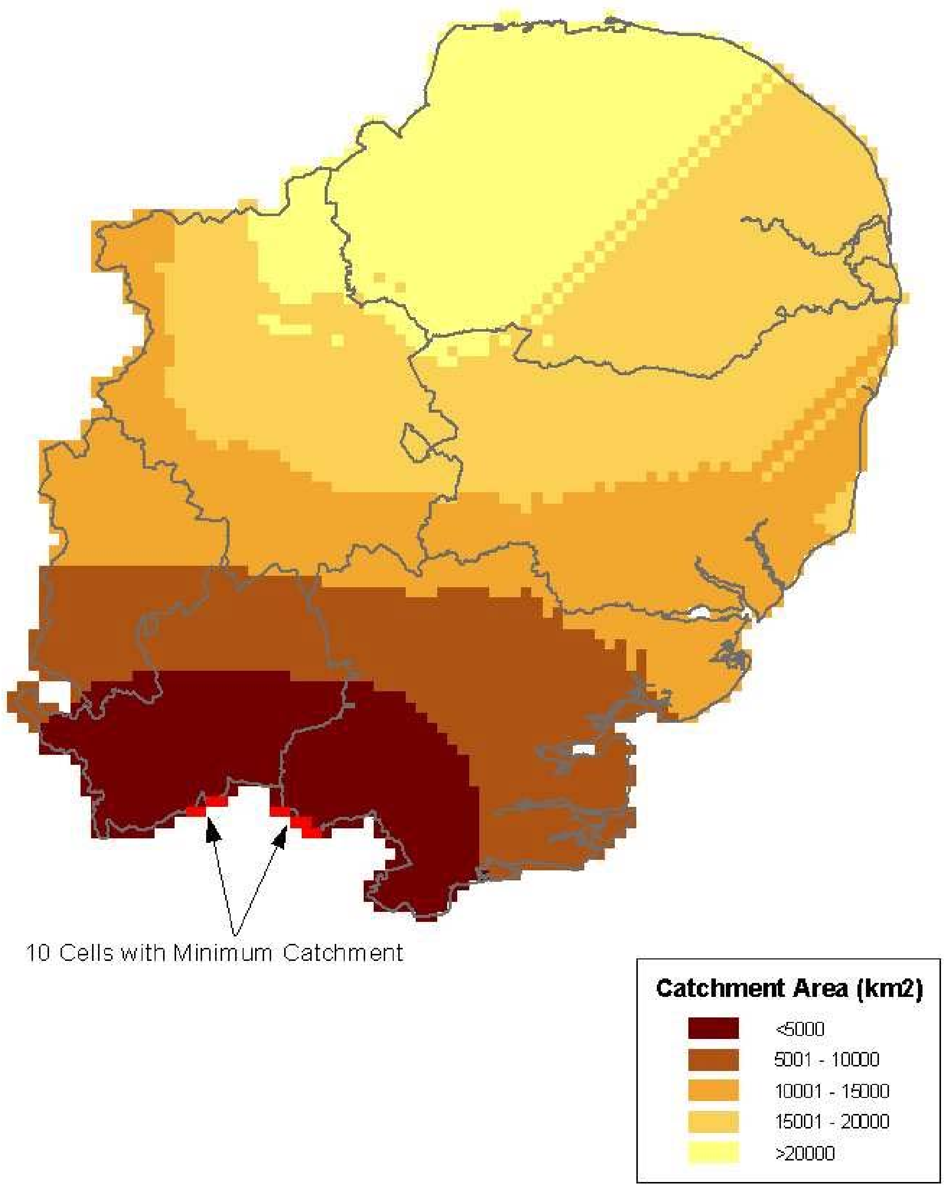
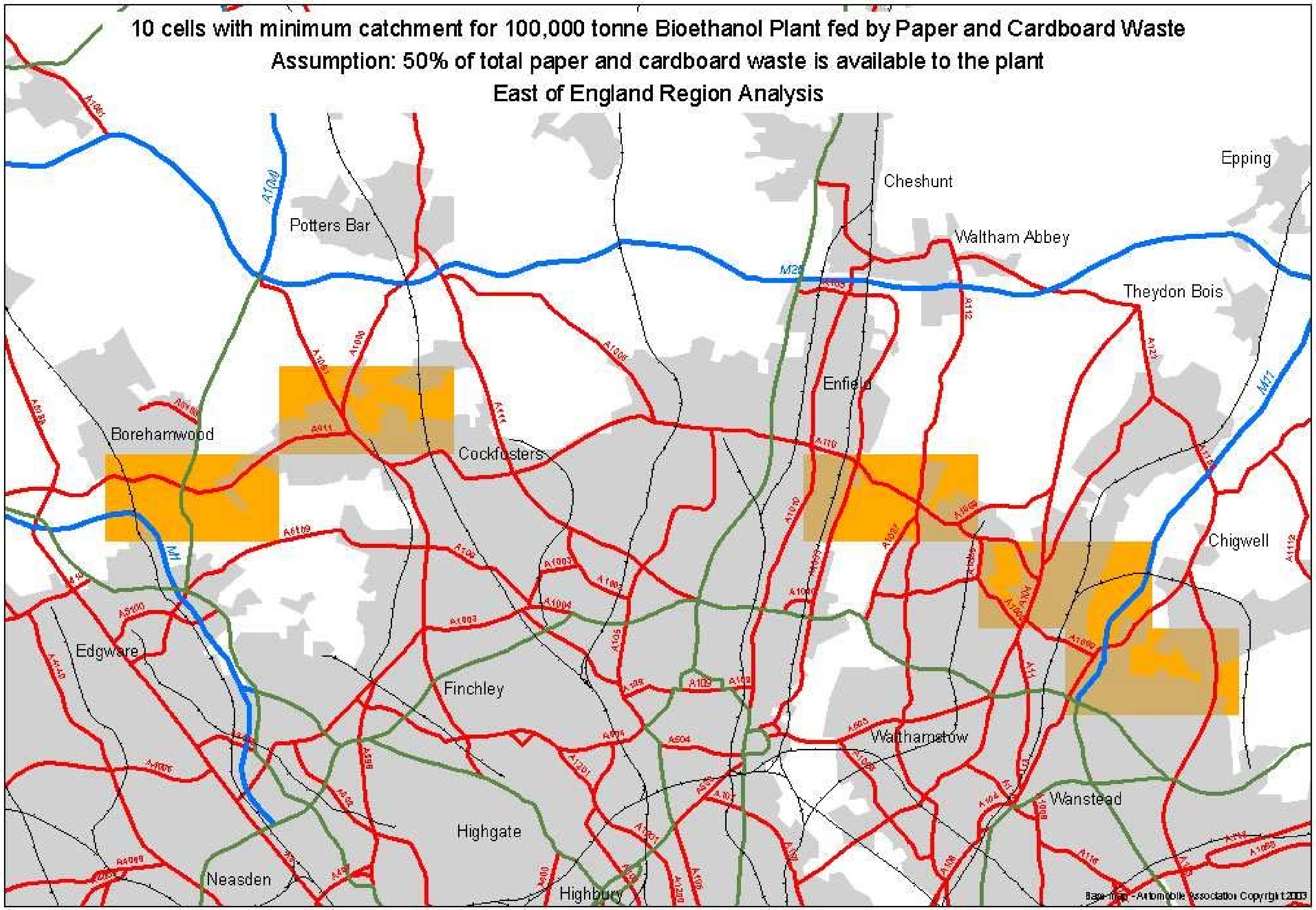

10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Straw and Forestry (50:50 ratio)
Assumption: 10% of total current straw crop and 75% of forestry crop is available to the plant
England and Wales Analysis
Guildford
Farnham
Winchester
Petersfield
Southampton
Minster
Christchurch
Bournemouth
Portsmouth
Bognor Regis
Brighton
Isle of Wight
M27
Base map - Automobile Association Copyright 2003

FIGURE 5.17(b)

FIGURE 5.18(a).

Catchment for 100,000 tonne Bioethanol Plant fed by Paper and Cardboard Waste
Assumption: 50% of total paper and cardboard waste is available to the plant





10 cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Paper and Cardboard Waste
Assumption: 50% of total paper and cardboard waste is available to the plant
East of England Region Analysis
Epping
Cheshunt
Potters Bar
Waltham Abbey
Theydon Bois
Enfield
Borehamwood
Cockfosters
Chigwell
Edgware
Finchley
Walthamstow
Wanstead
Highgate
Neasden
Highbury
Base map - Automobile Association Copyright 2003

FIGURE 5.18(b).

FIGURE 5.19

Catchment for 100,000 tonne Bioethanol Plant fed by Paper and Cardboard
Assumption: 50% of total crop is available to the plant

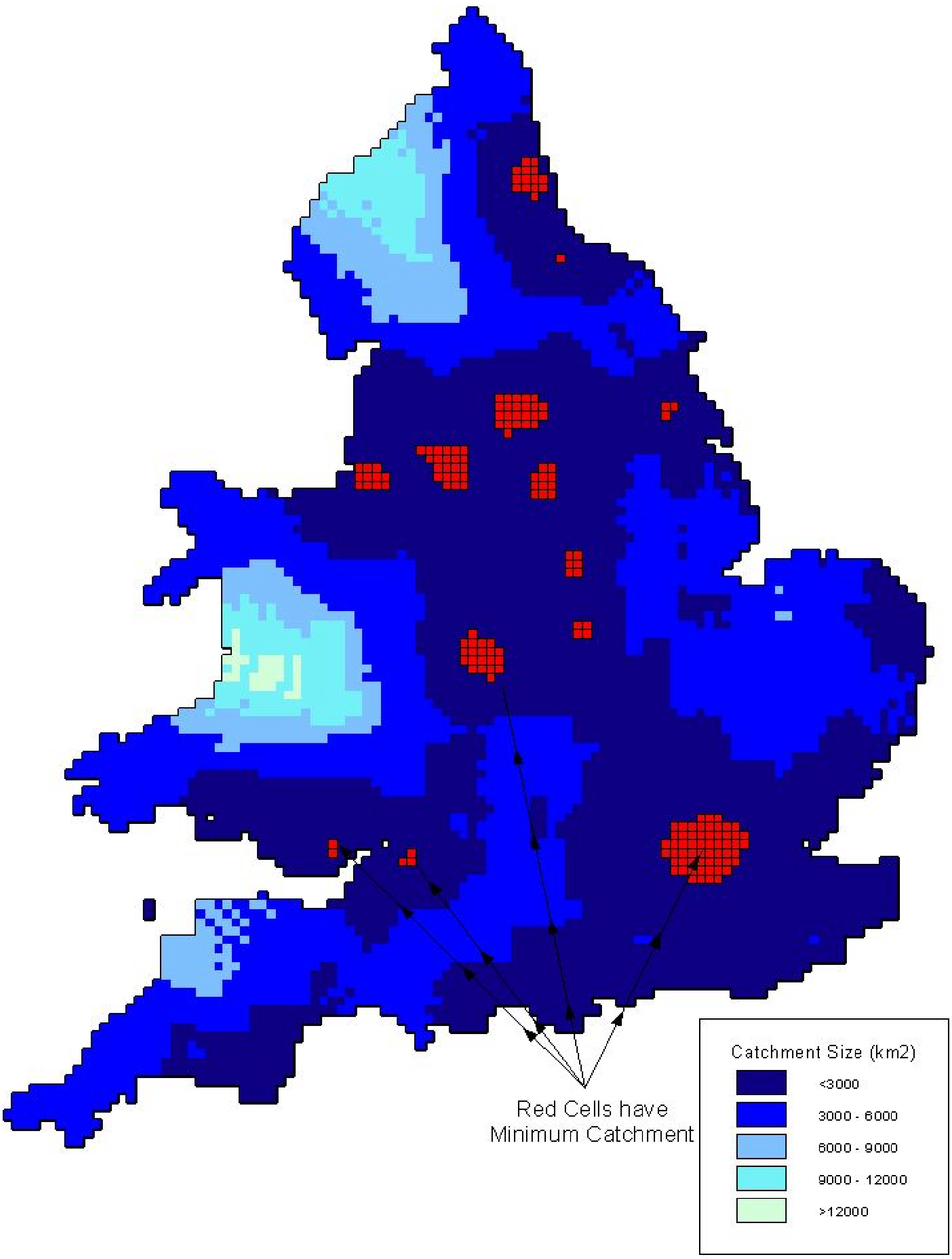
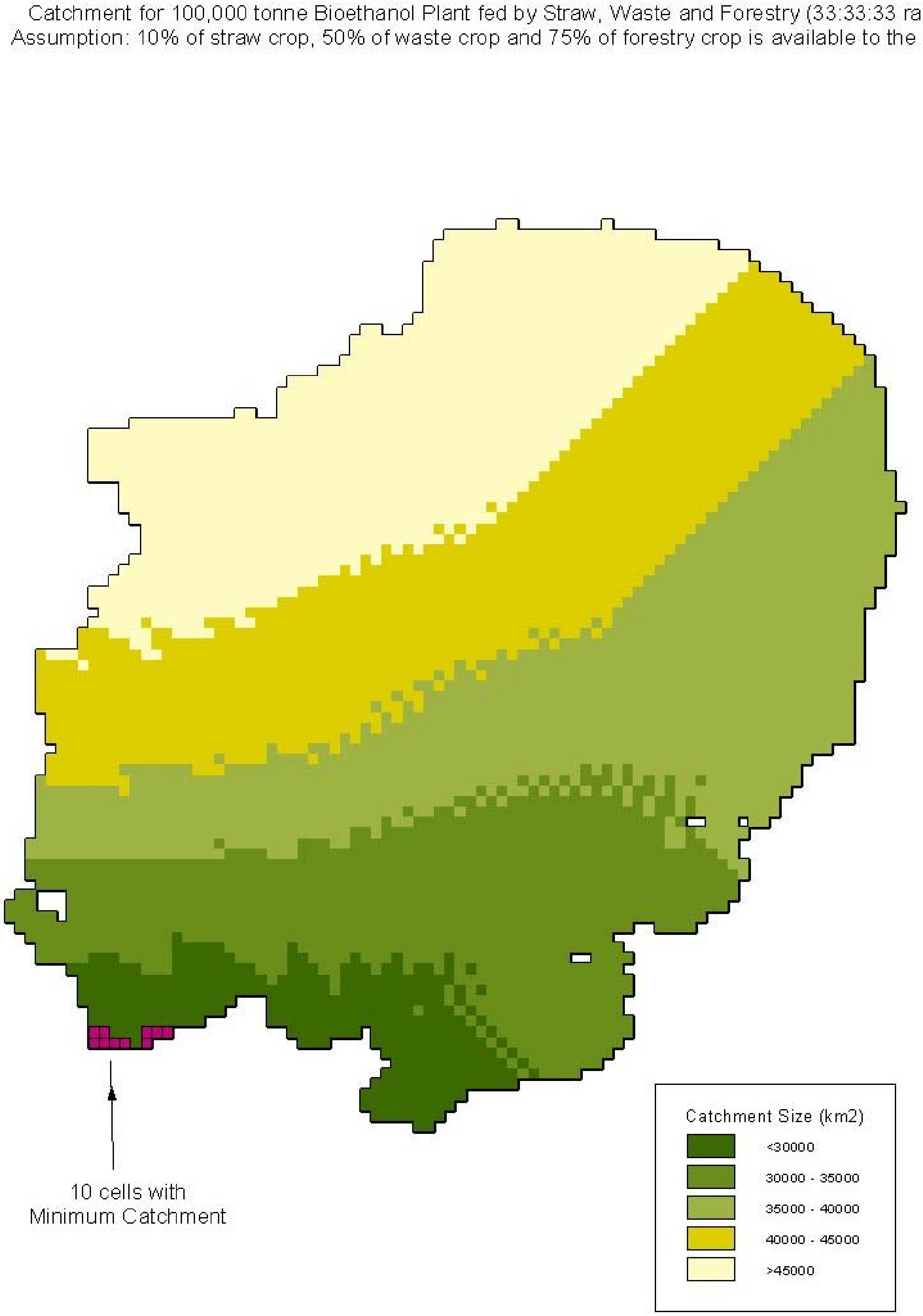


FIGURE 5.20(a)



Catchment for 100,000 tonne Bioethanol Plant fed by Straw, Waste and Forestry (33:33:33 ratio
Assumption: 10% of straw crop, 50% of waste crop and 75% of forestry crop is available to the pla
10 cells with
Minimum Catchment
Catchment Size (km2)
<30000
30000 - 35000
35000 - 40000
40000 - 45000
>45000

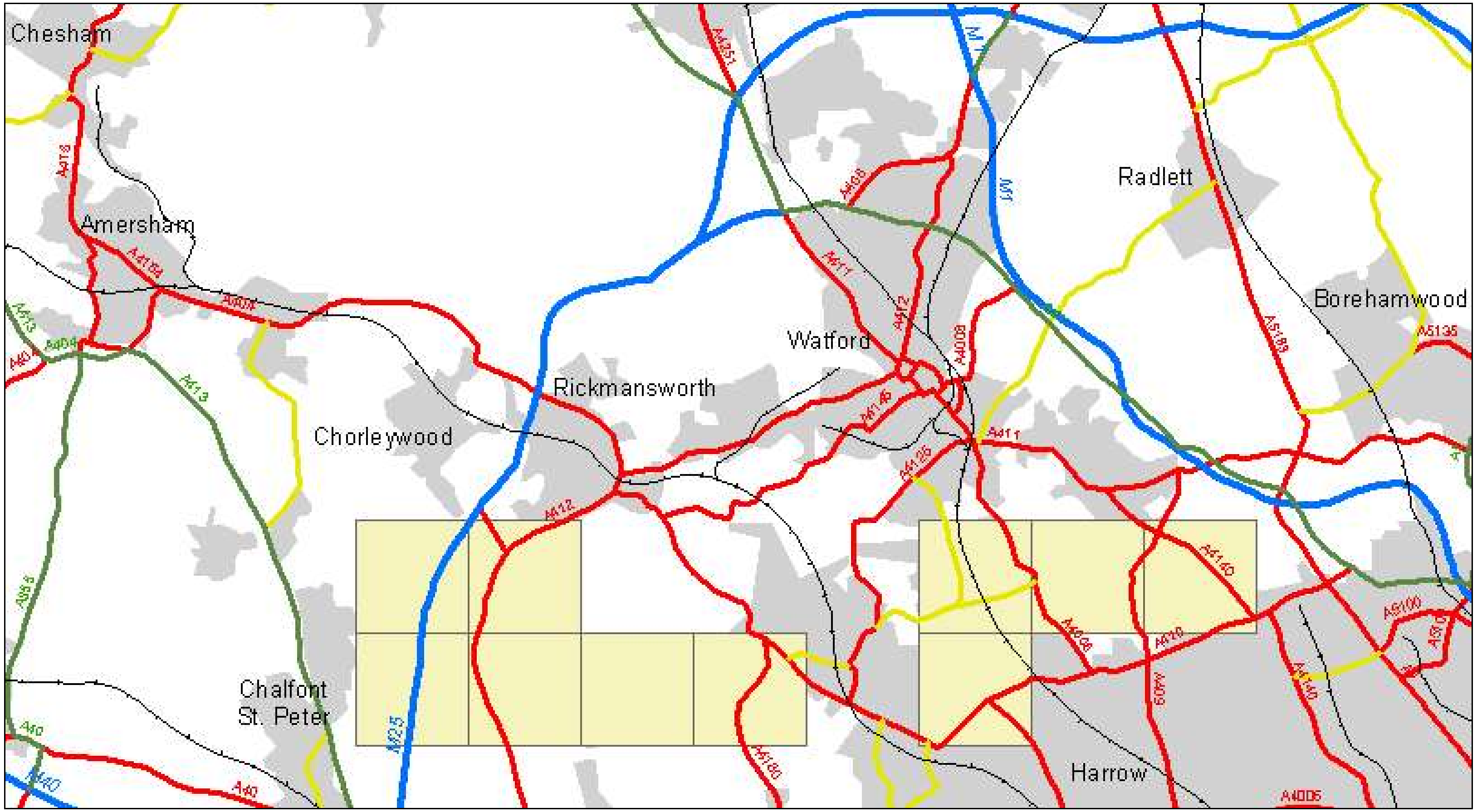
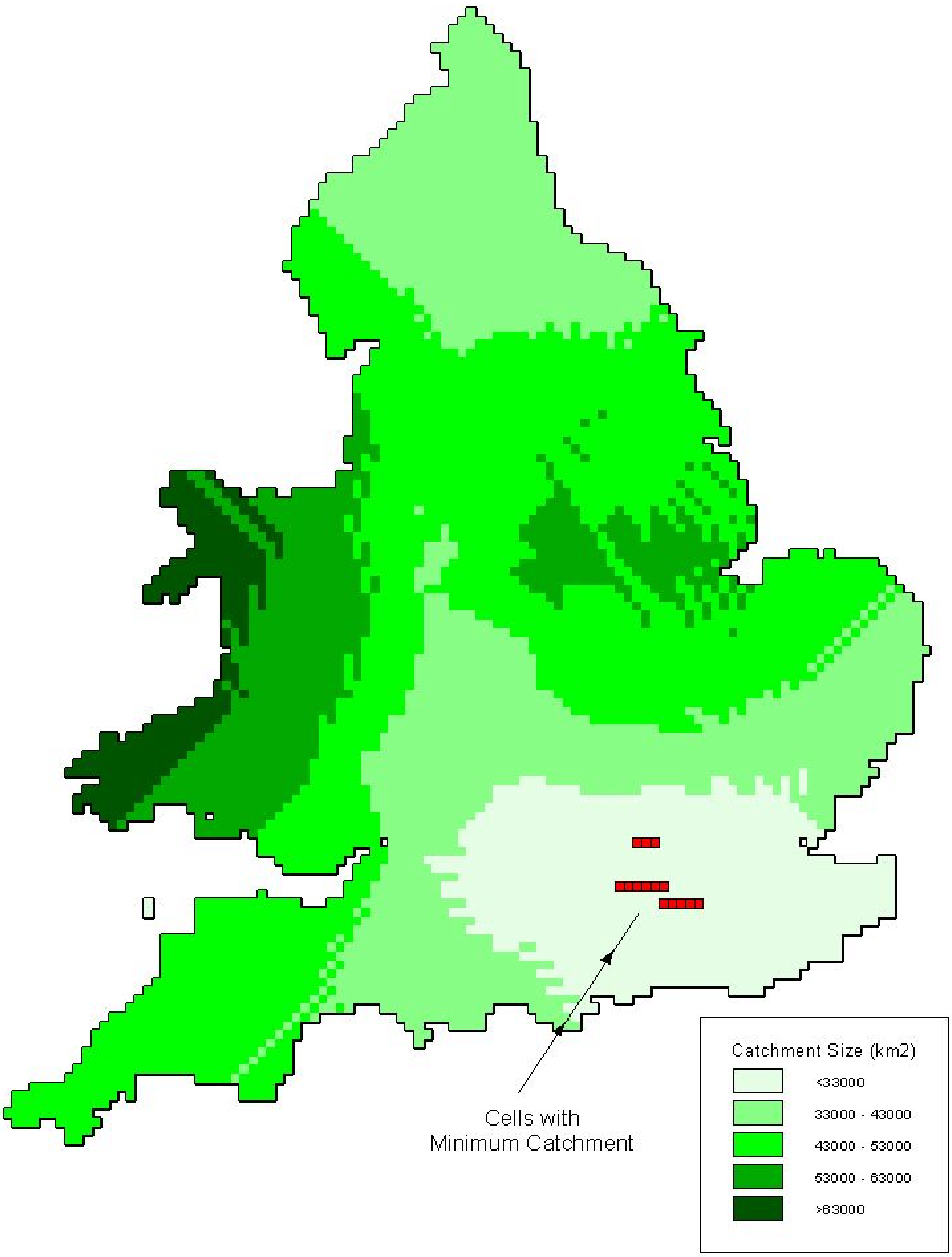

Chesham
Amersham
Radlett
Borehamwood
Watford
Rickmansworth
Chorleywood
Chalfont
St. Peter
Harrow

FIGURE 5.20(b).

FIGURE 5.21(a)

Catchment for 100,000 tonne Bioethanol Plant fed by Waste, Straw and Forestry (33:33:33 ratic
Assumption: 50% of waste, 10% of total straw crop and
75% of total forestry crop is available to the plant



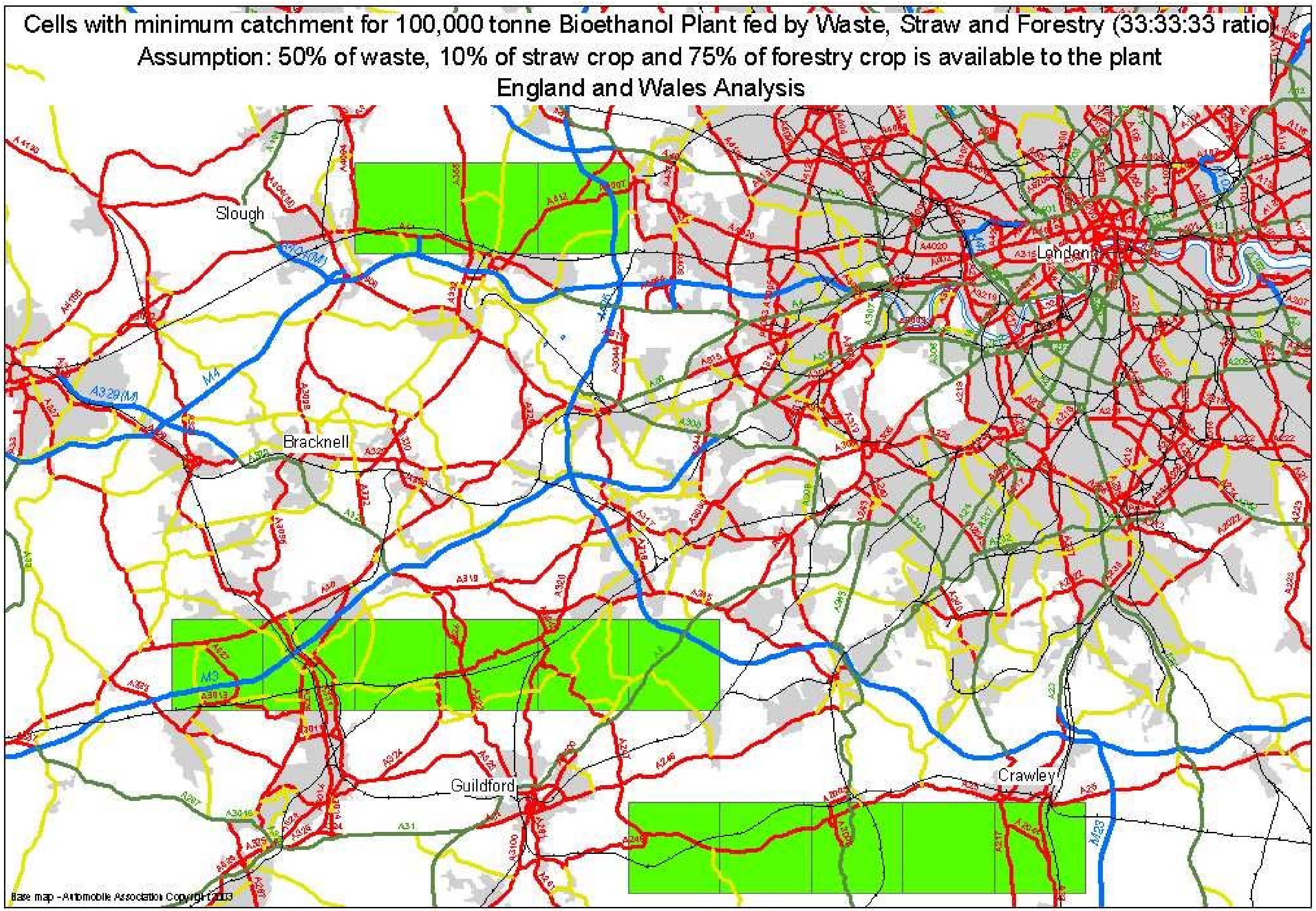

Cells with minimum catchment for 100,000 tonne Bioethanol Plant fed by Waste, Straw and Forestry (33:33:33 ratio)
Assumption: 50% of waste, 10% of straw crop and 75% of forestry crop is available to the plant
England and Wales Analysis
Slough
London
Bracknell
Guildford
Crawley
M4
M3
M25
M23
Base map - Automobile Association Copyright 2003

FIGURE 5.21(b).

6 REGIONAL IMPACTS OF A UK BIOETHANOL INDUSTRY

6.1 INTRODUCTION

Chapter 3 considered the case for a national bioethanol industry. In this section we consider what the economic impact would be at regional level if a plant, or plants, were situated in the East of England. There are two key considerations:

1. the capacity to produce feedstock within the region to capture the production benefits highlighted in the national analysis
2. the siting of the plant, such that there are sound logistics in terms of feedstock supply, access to an efficient transport network for supply and distribution and access to a supply of suitably skilled labour

A key consideration will be how much of the economic benefit, in terms of value added and employment will be retained within the region. The more localised the economy that is considered, the greater the leakage of benefits beyond its borders. In this case, the East of England represents approx. 10.5% of the UK economy in terms of GDP[45]. In principle, a proportion of the benefits will dissipate across the remainder of the national economy as they interact with the supply chain for the bioethanol industry. The methodology for estimating the regional impact is set out in section 1.4

The locations for the hypothetical conversion facilities, based upon regional crop availabilities, were presented in Chapter 5.

6.2 REGIONAL ECONOMIC IMPACT

In order to estimate the economic impacts, two methodologies have been employed:

1. Input-Output analysis, as employed in the national model
2. Micro-economic analysis of the key regional components

Input-Output analysis

Regional analysis has been undertaken for a single scenario (from the scenarios outlined in Table 2.14). This is a 100 kt plant fuelled by a 50:50 mix of wheat and sugar beet. While this only uses two of the 22 scenarios, The I-O details are available for all of them and are drawn on as necessary in the discussion.

Direct Value Added was calculated for each step in the production, namely growing the feedstock (Production) and processing at the plant (Capital cost and Operations & Maintenance). Transport is considered to an indirect activity and is considered in the indirect VA calculation. However, in view of the fact that most of this is Step 1 activity (transport within the East of England of feedstock between farms and plant), it has been allocated at 100% to the region.

From the national model (see Annex 4), indirect VA was calculated for each of the industry sectors and aggregate as follows (Table 6.1).

[45] HMSO. 2002. Region in Figures - East of England. Table 3.3.

TABLE 6.1: AGGREGATED ECONOMIC SECTORS FOR ANALYSIS

Industry sector	
[1-3]	Agriculture
[4-7]	Mining and Quarrying
[8-84]	Manufacturing
[85-87]	Electricity, gas and water supply
[88]	Construction
[89-92]	Wholesale and retail trade
[93-99]	Transport and communication
[100-123]	Other public services

Not all of this indirect VA will be retained with the East of England and the approach used to estimate the regional share was to scale each sector contribution by their presence in the region. This is based on the GDP tables in the ONS publication, Region in Figures – East of England (Table 3.3) which presents regional and UK GDP by aggregated sector.

Direct and Indirect VA are then combined to give a total regional VA for bioethanol in the East of England from the 100 kt wheat:sugar beet plant. This is detailed in Figure 6.1 along with the value added which is accounted for outside the region and the balance, which are imports. Regional Value Added (VA) or contribution to Regional GDP is estimated at £17.8m, which represents one third of the total cost of the plant. The remainder contributed to VA outside the region (52%) or to imports (14%).

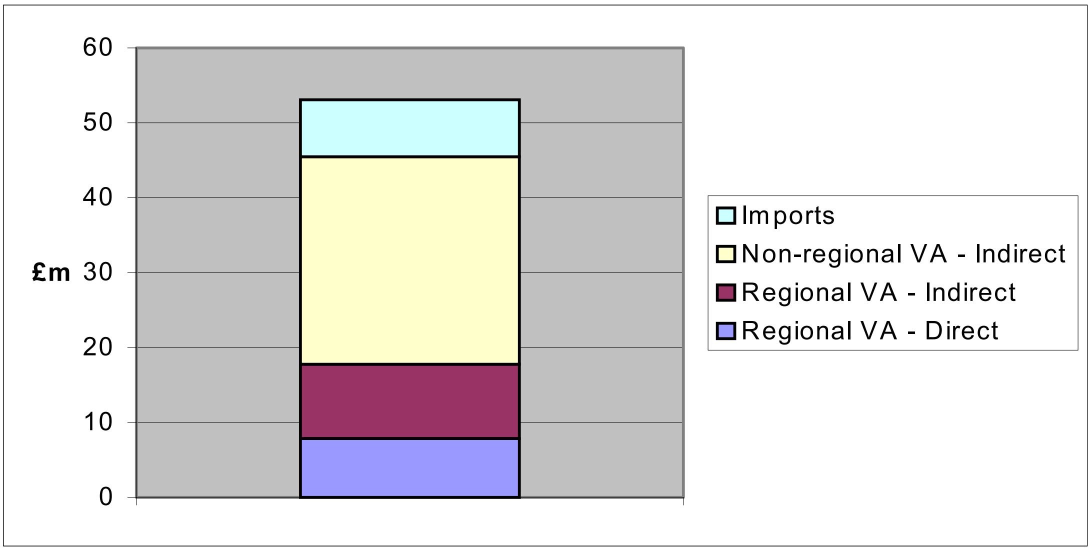


FIGURE 6.1: I-O REGIONAL ANALYSIS OF VALUE ADDED FOR A 100 KT BIOETHANOL PLANT (WHEAT/SUGAR BEET)

The main component of Regional VA is production of the feedstock or Agriculture. This accounts for £5.7m or one third of the total.

The analysis has been repeated for employment, using I-O data. Regional employment generation as a direct result of investment in a 100kt-bioethanol plant is estimated at 840 person years. Again, the main beneficiary is Agriculture, which gains an estimated 545 jobs.

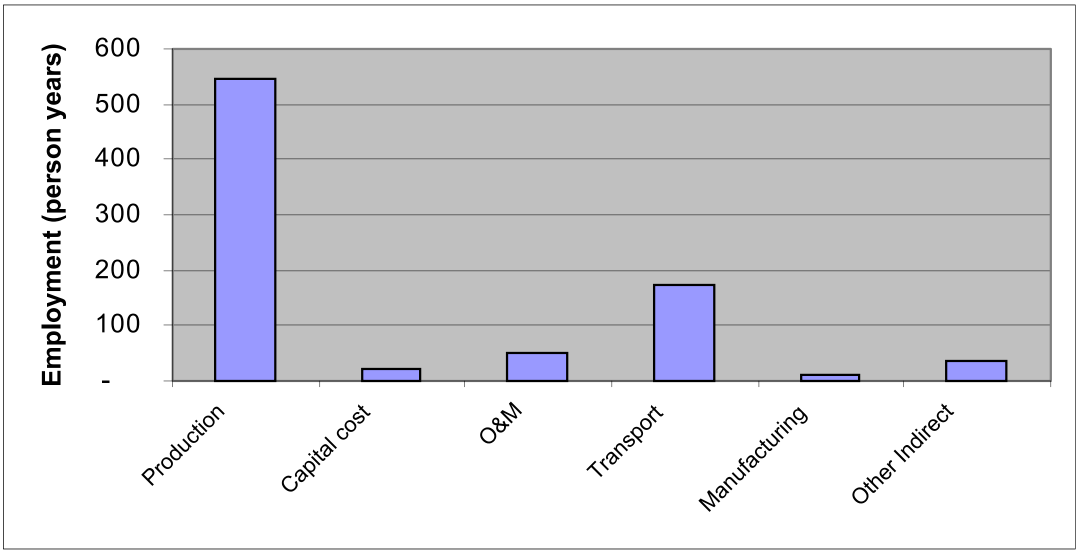


FIGURE 6.2: I-O REGIONAL ANALYSIS OF COST FOR 100,000 T BIOETHANOL PLANT

This assumes that the wheat and sugar beet is grown on uncropped land (set aside). If this was not the case and the feedstock displaced other agricultural crops, then this is equivalent to importing feedstock and the agriculture component of employment generation is nil and the total number of regional jobs then falls to 295.

Farm-level analysis

In practice, the additional area of sugar beet is likely to generate additional farm-level jobs, even if it displaces other combinable arable crops such as cereals or oilseed rape. This highlights a limitation of the I-O analysis, in that it considers Agriculture as a homogeneous sector, whereas in practice different crops generate differing levels of output (and VA) and have differing levels of resource requirement, notably labour. This is demonstrated in an analysis of labour units by farm type by the University of Cambridge[46], which showed that mixed cropping (which grow sugar beet or potatoes – 16% cropped area) farms required over 0.5 labour units per 100 ha more than mainly cereal farms (3.1% sugar beet and potatoes). The difference is highlighted in table 6.3.

[46] University of Cambridge. 2002. Report on Farming on the Eastern Counties of England 2001/02.

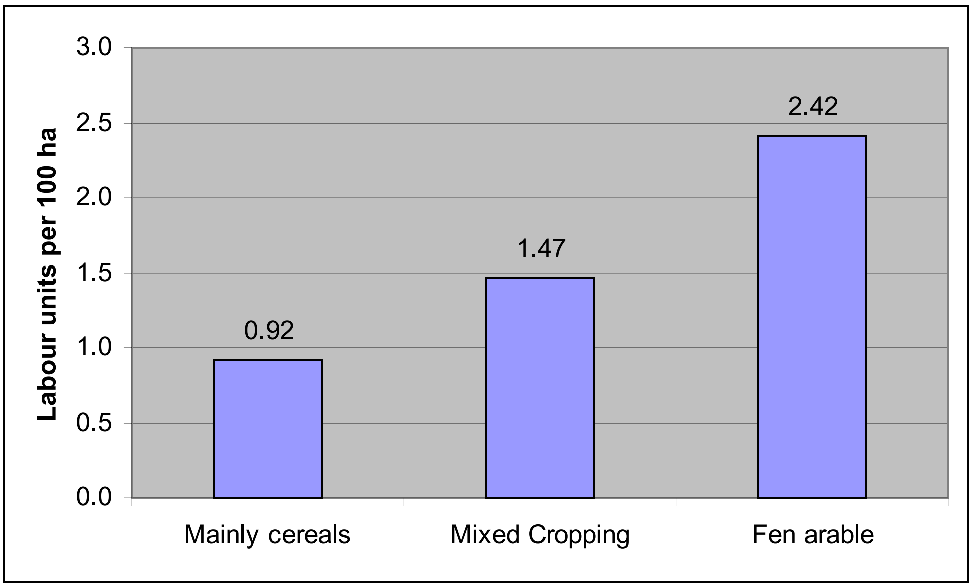


FIGURE 6.3: LABOUR USE BY FARM TYPE

If this is related to the analysis, it is apparent that growing additional sugar beet in particular would generate additional jobs, even if it displaced existing crops. The scale of this additional employment in Agriculture is estimated at 532 jobs. This assumes the following:

- Wheat displaces set aside, an industrial crop grown on set aside or a combinable crop grown for the food market but does not generate any additional employment as there is sufficient scope for labour efficiency gains on many farms

- Sugar beet displaces an industrial crop grown on set aside or a combinable crop grown for the food market and benefits from the average additional labour requirement shown in Table 6.3

The reality is likely to be that cereal farms, which demonstrate a substantial economy of scale in terms of labour up to 300 ha, grow most of the cereals and few additional jobs will be generated. Sugar beet is most likely to be grown by existing growers, even if this is not always on their own land. The Cambridge University data does show an economy of scale with farm size on beet farms but only up to 200 ha. The relevant factor is therefore the relatively constant figure for *Mixed Cropping* farms of 1.4 LU/100 ha which applies above 200 ha and the *Mainly Cereals* figure of 0.7 LU/ha above 300 ha. Assuming a one in 3 rotation and given the scale of sugar beet grown, the impact is estimated at 264 jobs (12,578 ha x 3 year rotation x 0.007 LU/ha).

The additional VA for Agriculture can be calculated from an analysis of gross margins and marginal direct costs. This exercise was undertaken using the simplistic assumption that marginal direct costs were marginal – as VA includes recompense for employed labour and trading surplus, this approach is considered to be sufficient. Much then relies on whether the feedstock crops are grown on uncropped land or displace existing crops. The following allocation of output was assumed:

TABLE 6.2: FARM LEVEL ALLOCATION OF OUTPUT BY CROP

	cereals	oilseed rape	s beet (food)	s beet (bio)	set aside
Variable costs	220	215	361	361	5
Direct costs	170	150	527	527	5
Net margin	280	275	612	112	210

Using the same cropping assumptions as for the employment calculation, the gross Value Added was estimated at £6,671. This compares with an estimate of VA from Agriculture from the I-O analysis of £5.7m.

Discussion

There are arguments for and against the I-O analysis at a regional level, which assumes average sector performance, and similarly for a simple farm level analysis that allows for marginal production but does not adequately deal with marginal costs and resource use. However, by considering both approaches in this research, some degree of consistency has been achieved.

The VA and employment generated by the processing plant and its supporting supply chain should be based on the aggregate data from other plants as set out in section 2.2 of the report. The substantial VA and employment impacts from Agriculture are much less clear, depending on the outcome of the MTR and how farmers respond to this new opportunity. However, the estimates in this analysis suggest that the contribution from the Agriculture sector is substantial.

7 MONTE CARLO ANALYSIS - COMPARING THE ECONOMIC RETURNS OF SUGAR BEET/STARCH PROCESSING AND LIGNO-CELLULOSIC PROCESSING

7.1 INTRODUCTION

This part of the study compares the potential long term economic return of two different processing technologies: (1) conventional bioethanol production through fermentation of sugar beet and cereal grain; and (2) bioethanol production by the process of converting ligno-cellulosic materials into fermentable sugars. The first technology is mature and readily available, the second is not yet available on a commercial scale, but could potentially to create advantages over the first.

The objective of this analysis is to assess the main variables that determine the economic return of the two processing technologies. To achieve this, a model has been created to calculate the economic return of two extreme options (both under predetermined assumptions on the future market for bioethanol in the UK). The first option is to produce *all* future demand using the mature technology (sugar beet/wheat), the second option is to produce *all* future demand using the alternative technology (ligno-cellulosic). By comparing these two fictitious extremes, the model magnifies any difference in economic return and makes it possible to identify the key variables.

7.2 SCENARIO

The model assumes an uptake of bioethanol based on the scenarios 2,3 and 4, as describes in previous sections of this report. To elaborate, the model assumes the following scenario:

- By 2015 the demand for UK produced bioethanol is 1.2 Mt/year, and this demand is stable until 2025. Bioethanol is blended into normal gasoline at a 5% blend and consumers do not notice any difference from normal gasoline.
- Producers of bioethanol are guaranteed a retail price of 38-42 p/litre until 2025, and this price remains stable until 2025. In other words, a reduction of fuel duty is such that a retail price of 38-42 p/litre for bioethanol is economically viable.
- The entire volume of 1.2 Mt/year is supplied by national production.
- Assumptions on bioethanol production costs are equal to previous sections of this report.

Given this scenario, the model compares the economic return of a UK wide bioethanol production industry that chooses one of two options: conventional technology or alternative technology. The two options are described in detail in section 3, but the key point are:

Option 1 - Bioethanol production from manufacturing plant using a combination of sugar beet and cereal crops as feedstock materials

Construction of the first bioethanol production facility starts in 2004 and the facility is in operation in 2006. Further facilities are built in succeeding years, each with a construction period of 24 months. Bioethanol is produced at a cost of around 39 p/litre. The conversion technology is mature and no reductions in production costs are achieved. The total production of 1.2 Mt/year by the year 2015 is delivered via a series of biomass conversion facilities, comprising:

- 2 facilities with 100,000 t/year capacity
- 2 facilities with 200,000 t/year capacity
- 2 facilities with 300,000 t/year capacity

Option 2 - Bioethanol production from manufacturing plant using ligno-cellulosic feedstock materials

At present, the processing cost of ligno-cellulosic technology is estimated at 54-55 p/litre. This is around 40% higher than the technology of Option 1, and is therefore uncompetitive at present. However, R&D investments in ligno-cellulosic conversion technology can result in a reduction of processing costs. In fact, the sole reason Option 2 is interesting from an economic point of view, is that processing cost could fall below that of the conventional technology. Since the scenario fixes the retail price of bioethanol at 38-42 p/litre, Option 2 could generate higher profit margins, and therefore a higher return.

The development of the first demonstration plant starts in 2004 and the facility is in operation and fully tested by 2007. If the planned cost reduction are accomplished, a decision is taken to proceed. The first commercial scale plant is in operation in 2012. If this plant is successful, a second generation facility is developed and is in operation in 2015. The total production of 1.2 Mt/year is reached in the year 2018 and is delivered via a series of lingo-cellulosic conversion facilities, comprising:

- 2 facilities with 150,000 t/year capacity
- 3 facilities with 300,000 t/year capacity

Net Present Value

The economic return of the two options is measured in one key variable, Net Present Value (NPV). NPV measures the sum of all future cash flows (costs and revenues) discounted to today using an appropriate discount rate. Since NPV incorporates the time value of money, it is an effective measure to compare the two options.

However, both options, especially Option 2, are characterised by high levels of uncertainty and risk, and it is therefore impossible to predict the exact NPV. To illustrate, it is uncertain how much production cost of lingo-cellulosic technology could come down in the future. An effective technique to model uncertainty is called Monte Carlo Analysis, a technique described in more detail below.

7.3 METHOD

Monte Carlo analysis involves specialised computer software that makes it possible to model various scenarios and assess the impact of uncertainties and risks on the economic return of a project. For example, how does the uncertainty of feedstock production cost impact potential revenues? Or, would the project still be viable if capital costs were 20% higher than expected?

Monte Carlo analysis techniques are routinely used in the pharmaceutical, mining and oil exploration industries to value R&D projects with uncertain outcomes. Since both Option 1 and 2 have an uncertain return, Monte Carlo analysis provides a powerful tool to analyse economic viability.

The technique works as follows. First, the variables that make up total cost and revenue are defined as a spread of potential outcomes. For example, figure 7.1 illustrates the capacity of a conventional bioethanol processing plant (which is a variable that determines revenue). Not only can the capacity be varied, the shape of the distribution of likely outcomes can also be determined (in this case a triangular distribution is assumed).

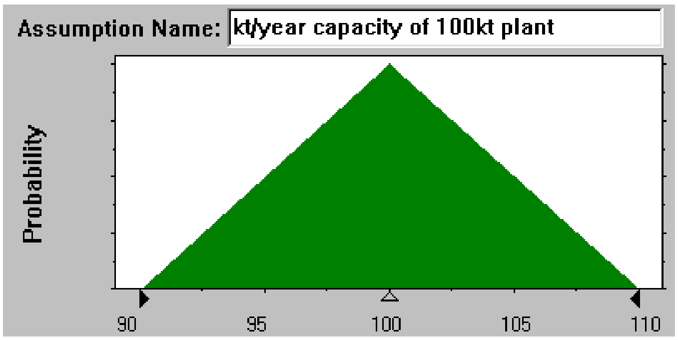


FIGURE 7.1 PROBABILITY DISTRIBUTION OF THE EXPECTED ANNUAL CAPACITY OF A 100,000 TONNE PROCESSION PLANT

To name another example, figure 7.2 illustrates the cost of blending bioethanol with regular fuel. The figure illustrates that blending costs are between 4 and 6 pence per litre, and that each value has an equal likelihood (uniform distribution).

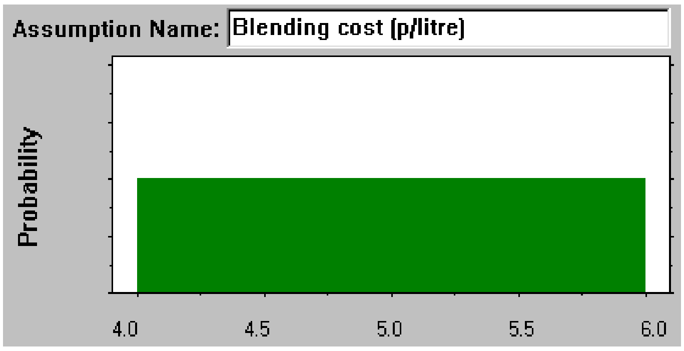


FIGURE 7.2 PROBABILITY DISTRIBUTION OF THE EXPECTED BLENDING COST OF BIOETHANOL (PENCE / LITRE)

The model also incorporates the risks involved in developing a new technology. This involves listing the main risk factors, estimating the probability that these factors will occur and defining their impact on costs and revenues. For example, the model assumes a probability of 70% that the demonstration plant of Option 2 is successful and that it proves that the technology is technically viable.

The last step is running the Monte Carlo analysis. The software generates a great number of possible permutations at random, selecting numbers from the defined distribution of costs, revenues and risks. The computer then plots the corresponding NPV of each of the many permutations on a probability distribution graph. This graph than illustrates the spread in potential NPV of the two options.

7.4 Options

This section describes the main assumptions that Option 1 and 2 are based on. Figures 7.3 illustrates the timeline for implementation of the two conversion technologies. Figure 7.4 shows the growth in volumes bioethanol produced. Table 7.1 shows the assumptions on processing plant capacities.

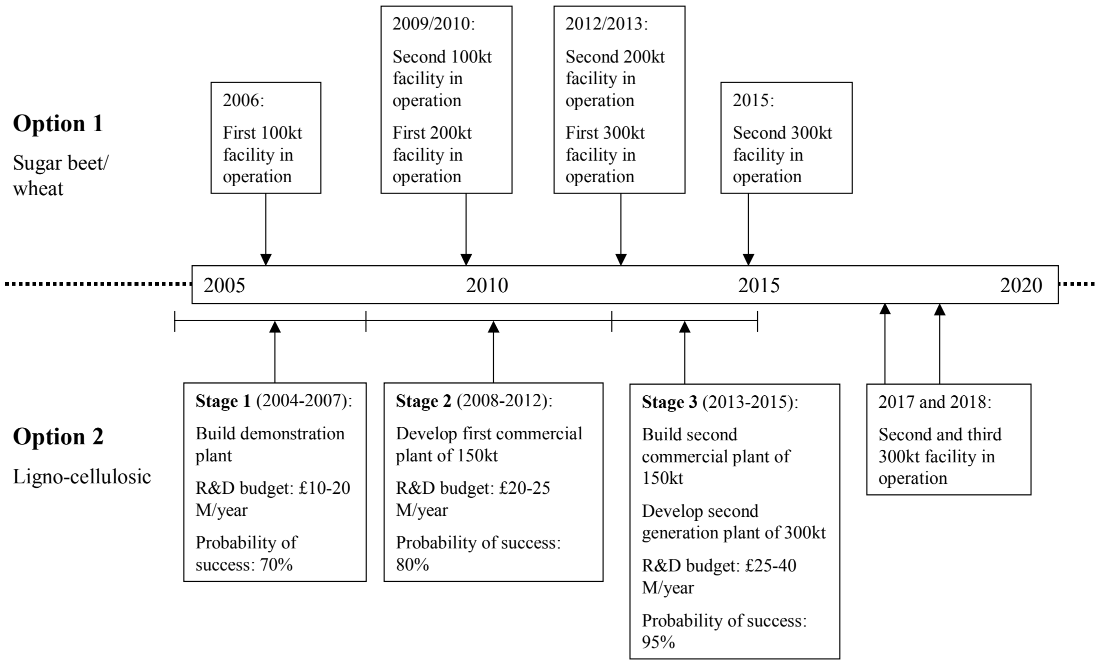


Figure 7.3 Timeline for implementation of option 1 and 2

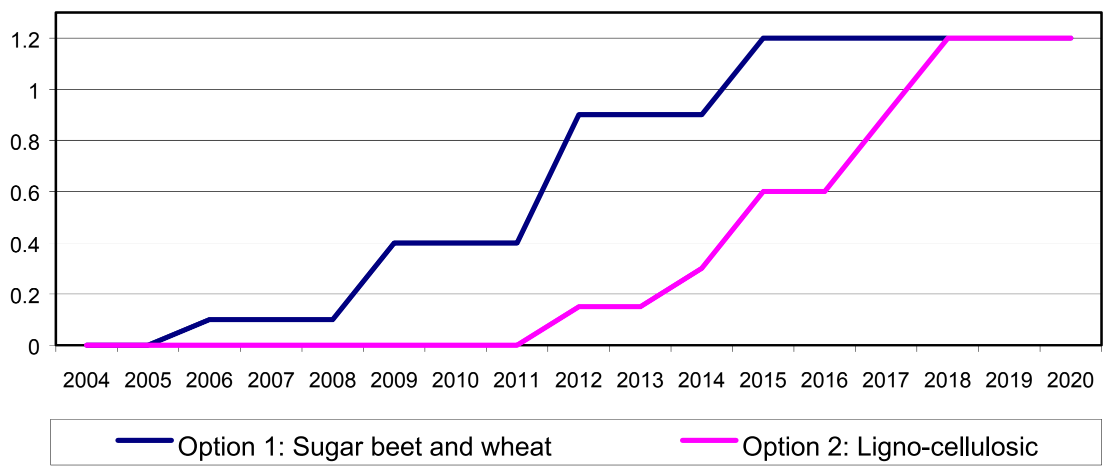


Figure 7.4 Volumes bioethanol produced of option 1 and 2 (Mt / year)

TABLE 7.1 SPREAD ON THE VOLUMES PRODUCED AT VARIOUS PROCESSING FACILITIES (KT/YEAR)

	Option 1: Sugar beet and wheat			**Option 2: Ligno-cellulosic**	
Design capacity (kt/year)	100	200	300	150	300
Minimum capacity (kt/year)	-10% (90)	-10% (180)	-10% (270)	-25% (113)	-25% (225)
Most likely capacity (kt/year)	100	200	300	150	300
Maximum capacity (kt/year)	+10% (110)	+10% (220)	+10% (330)	+5% (158)	+5% (315)

Feedstocks

The conventional processing facilities of Option 1 use two feedstocks, sugar beet and cereal grain, both at 50% of the bioethanol produced. The ligno-cellulosic processing facilities use an undefined mix of feedstocks likely to include wheat straw, coppice, forestry residues, miscanthus and possibly green waste.

Cost

The key variables that determines economic return are production and processing costs. Table 7.2 shows the production cost of Option 1, Table 7.3 the current and future costs of Option 2. Figure 7.5 compares the conversion costs of both technologies. This latter figure illustrates the likely reduction of cost of Option 2, as well as a reduction of average costs of Option 1 because of scale economies as the larger processing facilities become operational.

TABLE 7.2 BIOMASS CONVERSION COSTS OPTION 1: BIOETHANOL PRODUCTION USING WHEAT OR SUGAR BEET FEEDSTOCK (PENCE/LITRE)

Feedstock		Sugar beet			Wheat		
Capacity (kt/year)		100	200	300	100	200	300
Feedstock production	Minimum (-10%)	13.07	13.07	13.07	15.33	15.33	15.33
	Average	14.52	14.52	14.52	17.03	17.03	17.03
	Maximum (+10%)	15.98	15.98	15.98	18.73	18.73	18.73
Transport	Minimum (-10%)	3.76	3.76	3.76	1.36	1.36	1.36
	Average	4.18	4.18	4.18	1.51	1.51	1.51
	Maximum (+10%)	4.60	4.60	4.60	1.66	1.66	1.66
Conversion (capital)	Minimum (-10%)	7.65	5.74	4.90	7.65	5.74	4.90
	Average	8.50	6.38	5.44	8.50	6.38	5.44
	Maximum (+10%)	9.35	7.02	5.98	9.35	7.02	5.98
Conversion (O&M)	Minimum (-10%)	9.72	8.96	8.69	9.72	8.96	8.69
	Average	10.8	9.95	9.65	10.8	9.95	9.65
	Maximum (+10%)	11.88	10.95	10.62	11.88	10.95	10.62
Blending	Minimum (-20%)	4.00	4.00	4.00	4.00	4.00	4.00
	Average	5.00	5.00	5.00	5.00	5.00	5.00
	Maximum (+20%)	6.00	6.00	6.00	6.00	6.00	6.00
Distribution	Minimum (-10%)	4.50	4.50	4.50	4.50	4.50	4.50
	Average	5.00	5.00	5.00	5.00	5.00	5.00
	Maximum (+10%)	5.50	5.50	5.50	5.50	5.50	5.50
By-products credit	Minimum (-20%)	-4.72	-4.72	-4.72	-4.72	-4.72	-4.72
	Most likely	-5.90	-5.90	-5.90	-5.90	-5.90	-5.90
	Maximum (+20%)	-7.08	-7.08	-7.08	-7.08	-7.08	-7.08
Total	**Average**	**42.14**	**39.17**	**37.84**	**41.98**	**39.00**	**37.67**

Resulting spread in production costs (p/litre):

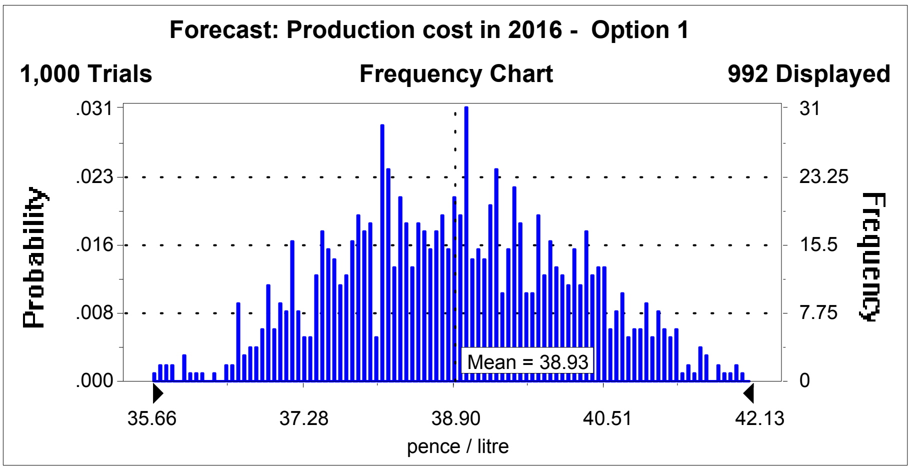


TABLE 7.3: FUTURE REDUCTION IN LIGNO-CELLULOSIC CONVERSION COSTS COMPARED WITH YEAR 2000 TECHNOLOGY STATUS

	2000/03	2005	2010	2015
Improvements				
Increased yield (affects feedstock production and transport costs)		+20%	+38%	+65%
Increased throughput (affects O&M conversion costs)		+16%	+35%	+64%
Reduced capital costs (affects capital conversion costs)		-8%	-15%	-14%
Reduced production costs (affects O&M conversion costs)		-24%	-44%	-48%
Cost (p/litre)				
Feedstock production	4.76	3.81	2.95	1.67
Transport	2.50	2.00	1.55	0.88
Conversion (capital)	15.52	14.28	13.35	13.19
Conversion (O&M)	21.55	13.76	7.84	4.03
Blending	5.00	5.00	5.00	5.00
Distribution	5.00	5.00	5.00	5.00
Total	**54.33**	**43.84**	**35.69**	**29.77**
Spread on cost		-5% +25%	-5% +25%	-5% +25%

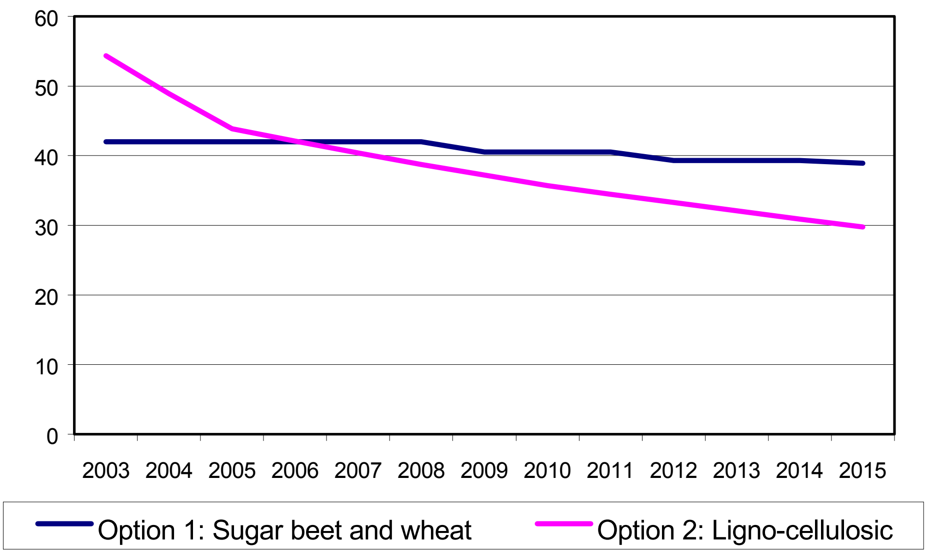


FIGURE 7.4 DEVELOPMENT OF PRODUCTION COST OF OPTION 1 AND OPTION 2 (PENCE/LITRE)

R&D funding

Figure 7.5 shows the assumptions on the time line of developing Option 2. Indicated is the likely level of R&D funding as well as the probabilities that this R&D achieves key outcomes. To elaborate, the first stage from 2004 to 2007 involves the development of a demonstration plant. The total R&D spend in this first stage is £40-80 million (£10-20 million per year). Only if the demonstration plant creates sufficient confidence in the technical and economic viability of ligno-cellulosic technology, do investors decide to carry on developing the first commercial plant. To reflect the level of uncertainty in this R&D process, a probability of success of stage 1 of 70% is assumed. This means that the likelihood is 30% that the development of ligno-cellulosic technology is abandoned after 2007 and that the R&D investment is not recouped. Over time the probability of success increases.

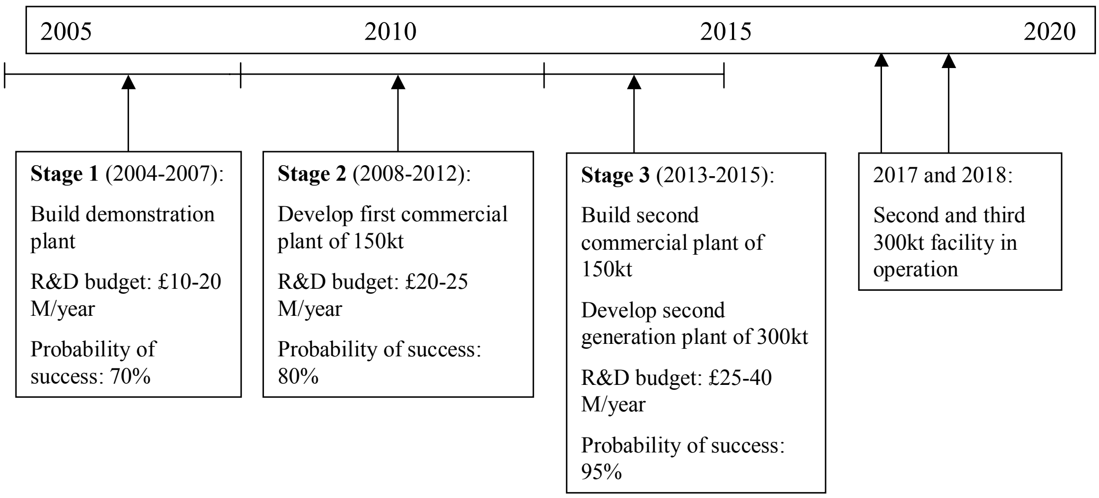


FIGURE 7.5 TIMELINE FOR IMPLEMENTATION OF OPTION 2

Other assumptions

- All processing facilities run at full capacity from the first year the are operational.
- Capital costs are fully annualised and no upfront equity commitment is assumed.
- Inflation is ignored. Since inflation tends to influence costs and revenues similarly, inflation would not greatly influence the outcome of this analysis.
- The retail price of bioethanol is between 38 and 42 p/litre. There is no correlation between prices of consecutive years. It is assumed that retail price remain stable until 2025.
- In Option 2, the retail price of bioethanol does not decrease as processing costs reduce.
- The discount rate to calculate NPV is set at 5%.

7.5 MONTE CARLO ANALYSIS

Figures 7.6 and 7.7 show the spread in Net Present Value (NPV) of Options 1 and 2 (using the assumptions detailed above). In these two figures the horizontal axes indicate the economic value of the investment, expressed in £ million NPV. Red colour indicates a negative return, blue a positive. The vertical axes indicate probability, expressed in percentage and frequency.

Figures 7.6 and 7.7 are therefore probability distributions of all likely economic returns of option 1 and option 2. The fact that both distributions have a similar mean (£90M for Option 1, £92M for Option 2), indicates that both option have a similar expected economic return. However, the spread in potential NPVs of Option 2 is much larger than that of Option 2 (from negative £172M to positive £598M), which illustrates the higher level of uncertainty of Option 2. Furthermore, the probability in Option 2 that the NPV is positive is around 50% (against 97% of Option 1).

The red peaks in the NPV plot of Option 2 illustrate the relatively high level of development risk. To illustrate, if the development is abandoned after a demonstration plant is build, between £40-80 million of R&D money is not recouped, which results in a negative NPV of around £35-70 million. Since the probability that this occurs is set at 30%, the highest cluster of red peaks represents around 30% of the surface of the graph.

In summary, the analysis indicates that ligno-cellulosic conversion technology could in principle generate a higher return than conventional technology. However, the higher level of risk associated with the development of ligno-cellulosic technology, makes the spread in return much greater and the likelihood of a negative return higher.

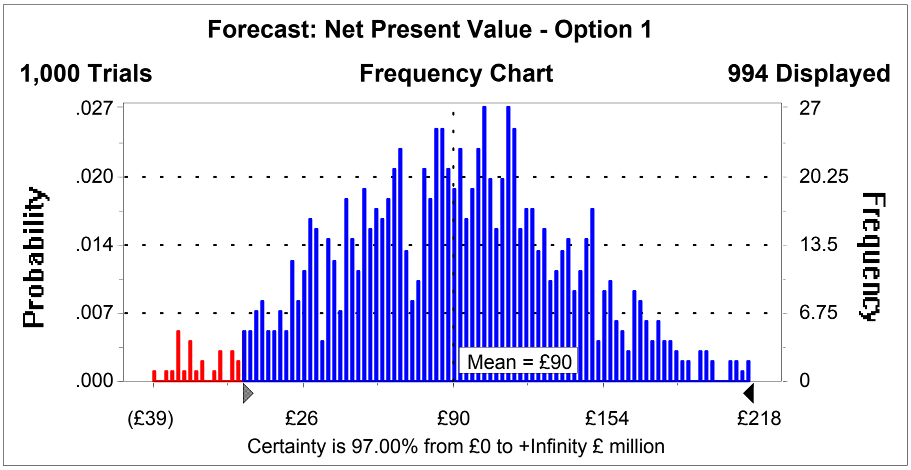


FIGURE 7.6 DISTRIBUTION OF THE EXPECTED NPV OF OPTION 1

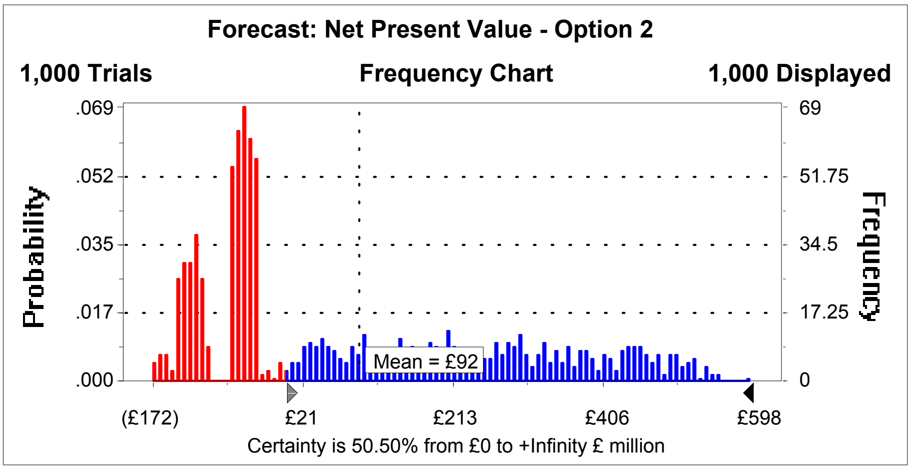


FIGURE 7.7 DISTRIBUTION OF THE EXPECTED NPV OF OPTION 2

THE IMPACTS OF CREATING A DOMESTIC UK BIOETHANOL INDUSTRY

ANNEXES TO THE MAIN REPORT

A REPORT FOR
EAST OF ENGLAND DEVELOPMENT AGENCY

PREPARED BY

ADAS CONSULTING LTD
ECOFYS UK LTD
ECOFYS bv

ANNEX 1

EC DIRECTIVE ON BIOFUELS

1.1 BACKGROUND

In November 2001, the European Commission made proposals for an EU directive on the use of biofuels. This would set targets for the introduction of biofuels in transport from 2005 onwards across the EU, and require each Member States to report annually the proportion of their transport fuel sales that is biofuel. The directive aims to align national biofuel taxation schemes, to help Member States establish the necessary economic and legal conditions to achieve greenhouse gas emission reductions through the use of biofuels in transport, and to reduce the EU's future reliance on external energy sources.

The proposed directive would require the UK (and other Member States) to ensure that targets for the proportion of transport fuel containing biofuel were met by certain dates, starting in 2005. These targets are set out below:

TABLE 1.1: PROPOSED TARGETS FOR THE SALES OF BIOFUEL IN TRANSPORT

Year	Minimum amount of biofuel sold for transport as % of gasoline and diesel sold	% of which blended with gasoline or diesel
2005	2	0
2006	2.75	0
2007	3.5	0
2008	4.25	0
2009	5	1
2010	5.75	1.75

The proposal would allow Member States to reduce excise duties on biofuels when they are used for heating or transport purposes. The level of taxation of the biofuel product, if intended for motor fuel, may not be lower than 50% of the normal rate of excise duty applied by the Member State on the corresponding conventional motor fuel. The intention of this provision in the directive is to mitigate the potential loss of Member State budget revenues from fuel duties. Furthermore, in order to limit any distortions of competition between fossil and non-fossil fuels, and to maintain the incentive of aiming for reductions in costs for producers and distributors of biofuels, the proposal requests Member States to take account of changes in raw material prices so that in the event of, for example, a sustained rise in crude oil prices, the lower tax rates do not over-compensate for the extra cost of manufacturing biofuels.

The proposal also contains an additional optional reduction for biofuels used by local public passenger transport, including taxis, and by public authority-operated vehicles on alternative fuels for transport as appropriate and setting a good example.

If the duty on biofuels were set at the minimum level allowed by the proposed directive, the fuel duty on both biodiesel and bioethanol could be set at 22.9 p/litre.

1.2 OPTIONS FOR MEETING THE TARGETS

The Department for Transport (DfT) has proposed that there are three broad options for meeting these targets[47]:

1. implementation of fuel duty reductions in favour of biofuels, for use either in pure form or as blends with conventional transport fuels;
2. specifying a minimum biofuel blend in conventional transport fuels;
3. setting up formalised voluntary measures with fuel producers and suppliers to meet the targets.

DfT note that on the basis of the Commission's own estimates of the extra production costs of biodiesel, the costs of achieving the greenhouse gas emissions benefits could range from around £475M to £875M per year. However, the different options lead to the costs being borne by different groups. If a regulatory or voluntary agreement were used to meet the targets by blending biofuel with conventional fuels, then the costs would eventually be borne by conventional fuel consumers. A biofuel duty reduction would lead to taxpayers generally bearing the costs, and biofuel consumers would benefit. A voluntary agreement to increase sales of biofuels for dedicated vehicles would benefit biofuels consumers at the expense of conventional fuel consumers.

[47] "Preliminary regulatory impact assessment of draft EU directive on the use of biofuels", Department for Transport, London, July, 2002.

ANNEX 2

THE PRODUCTION OF BIOETHANOL FROM BIOMASS

2.1 INTRODUCTION

Many agricultural products can be converted into bioethanol by a variety of chemical processes. Relevant products include:

- ***Sugars***, which can be extracted from sugar rich plants such as sugar cane, sugar beet or sweet sorghum, and can be directly fermented by the action of yeast to produce bioethanol;

- ***Starches,*** which can be converted to sugars by hydrolysis using the enzyme amylase, and which in turn can be fermented to produce bioethanol. Suitable starches include grains such as wheat, corn and barley;

- ***Cellulosic materials,*** which are derived from agricultural wastes, including straw and molasses, as well as grasses and wood or wood residues from forestry plantations. In principal, each of these types of cellulosic materials can also be converted to sugars by hydrolysis using specialist enzymes or acidic processes, and then fermented to yield bioethanol.

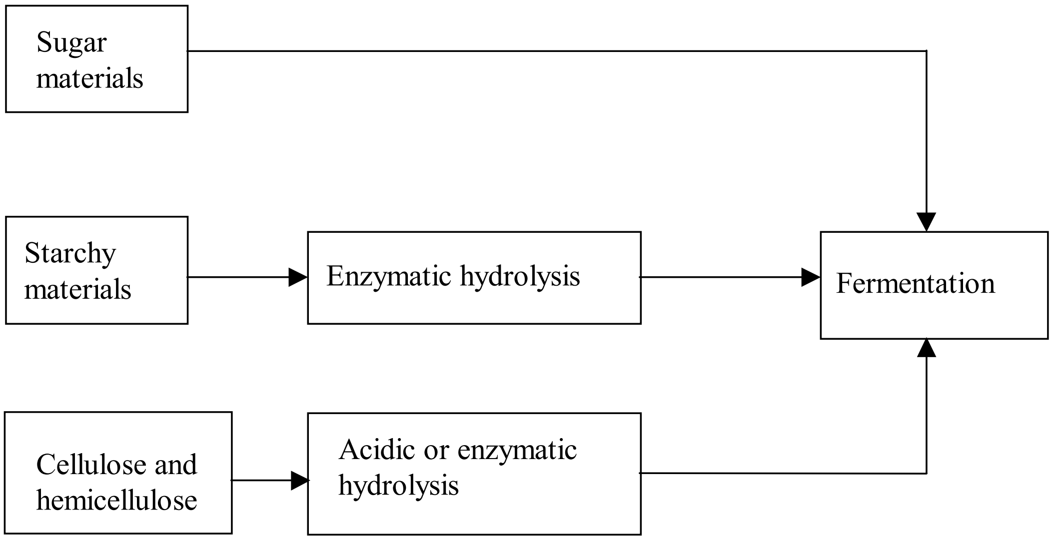
The key to bioethanol production is the fermentation of sugar. This involves the conversion of simple hexose (six carbon) sugars to ethanol and carbon dioxide through anaerobic respiration by the yeast. In general half the weight of the sugar is converted into carbon dioxide and half to ethanol. The energy content of the ethanol is about 90% of that in the sugar, and the remaining 10% is required for metabolism by the yeast.

The overall fermentation reaction and theoretical yield of bioethanol are:

$\mathbf{C_6H_{12}O_6}$	$\rightarrow$	$\mathbf{2C_2H_5OH}$	+	$\mathbf{2CO_2}$
glucose	$\rightarrow$	**ethanol**	+	**carbon dioxide**
180kg	$\rightarrow$	**92kg**	+	**88kg**

The routes to fermentation and bioethanol production for the different classes of agricultural raw materials are illustrated in Figure 2.1. Fermentation can be carried out either as a batch process or as a continuous process. In batch processing the sugar solution is placed in large tacks, yeast is added and then the tanks are sealed to allow anaerobic fermentation. The fermentation finishes when the alcohol content is high enough to prevent the yeast from being active. This process produces around 3g of ethanol per litre of fluid input per hour. In the continuous process the sugar feed solution is continuously fed into the system to allow continuous fermentation. This process has a higher yield rate of between 10-25g of ethanol per litre per hour. During fermentation, the yeast produces a large amount of carbon dioxide, which can be retained and sold as by-product, usually to the food industry. In batch processes it is necessary to inoculate the sugar solution with yeast, and then to allow the yeast to metabolise the sugar aerobically until all oxygen in the solution is exhausted. Only then does ethanol production occur. In continuous processes, a high proportion of the solution is recycled and it is therefore unnecessary to go through this preparation stage.

FIGURE 2.1: ROUTES TO FERMENTATION



2.2 PRODUCTION PROCESSES FOR SUGAR AND STARCH MATERIALS

The basic technologies involved in converting sugar crops and starch materials to bioethanol are mature and are widely used in many industries[48]. These technologies originally grew out of the alcoholic beverage production techniques, but have been modified to give higher energy conversion efficiencies. Fuel grade bioethanol is produced commercially (with government support) from sugar beet and various grain crops in France, Sweden and Spain. Bioethanol is also produced from sugar cane on a large scale in Brazil, Zimbabwe and other tropical countries. Corn is also extensively used as a feedstock in the US and Canada for the large-scale production of bioethanol directly for transport fuels and other applications.

The main process steps for the production of fuel grade bioethanol from sugar and starch materials are as follows:

1. Feedstock reception and storage;
2. feedstock preparation to produce fermentable sugars, involving physical pre-treatment such as milling, sugar juice extraction by pressing and/or hydrolysis of starch materials to sugar;
3. fermentation to produce bioethanol in solution as described above;
4. distillation to produce a bioethanol/water azeotrope;
5. dehydration of bioethanol to a suitable purity standard;
6. waste disposal/by-product preparation.

Feedstock preparation of sugar materials involves the simple extraction of sugar juices under pressure, and concentration into a suitable substrate material. For starches the feedstock preparation involves milling the grain into a coarse powder with bran as a by-product. The powder is mixed with hot water to form a slurry, which is fed into the cooking process, where the enzyme amylase is added. This breaks down the grain starches into simpler sugars such as glucose and fructose. In modern operation, the slurry is heated to 110-150^{o}C, under pressure to speed up the starch conversion process.

[48] For a general description of ethanol production, see "Handbook of Energy for World Agriculture", B A Stout, Elsevier Applied Science, 1989.

Following the fermentation stage, distillation is normally carried out as a continuous process, with most of the yeast and stillage being recycled to be mixed with fresh sugar solution. A purge stream must be extracted to dispose of spent yeast, toxins and water. A number of processes have been developed using multiple pressure distillation columns. The product from distillation is a constant boiling azeotropic mixture of ethanol and water, containing around 94-95% by volume of ethanol.

Where anhydrous bioethanol is required, as is the case for blending with gasoline, it can be obtained by further distillation using a chemical entrainer such as cyclohexane or gasoline itself. This distillation process is very energy intensive, consuming the greater part of the total energy required for the bioethanol production process.

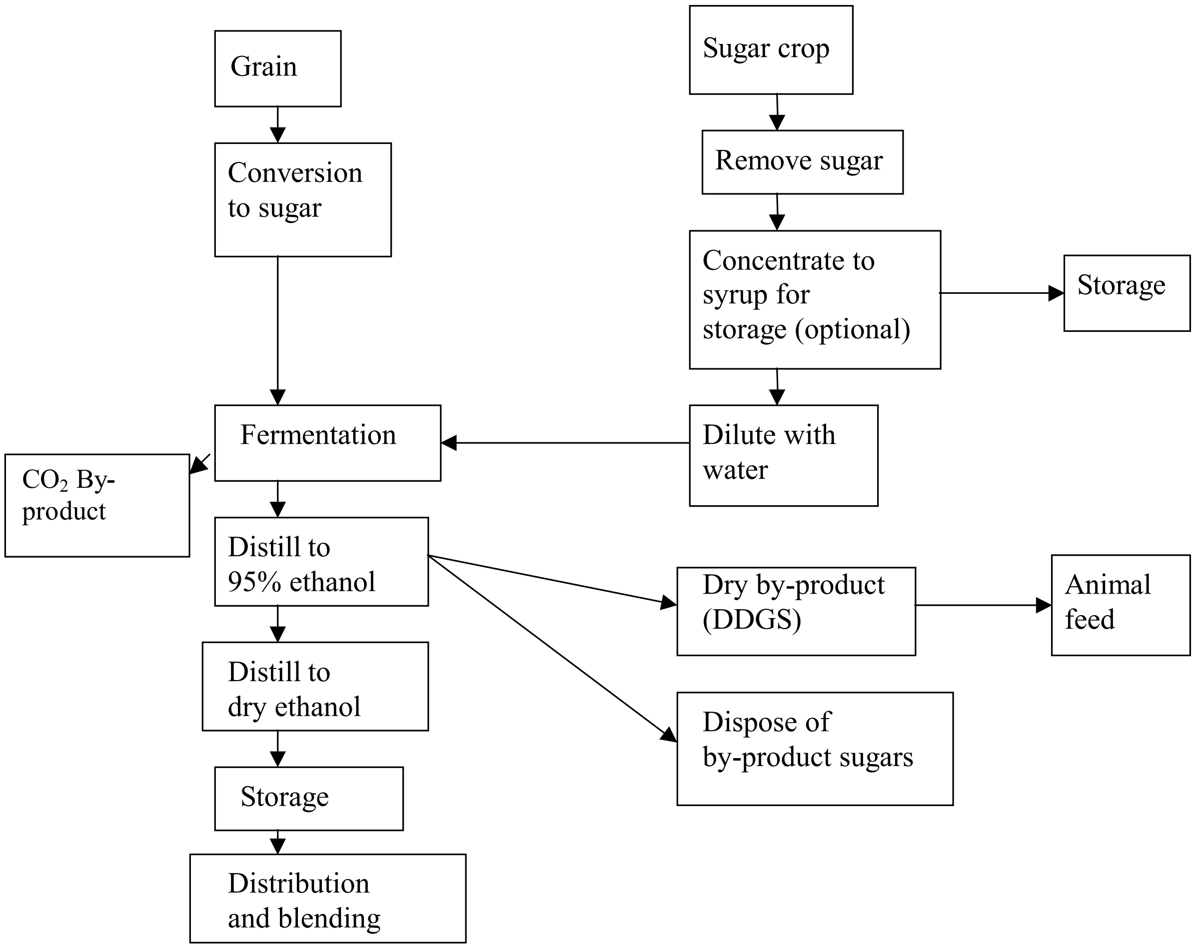
Stillage is produced at a rate of about 15 litres/litre of ethanol. Stillage must be treated before disposal, and it contains unfermented sugar and in some case components of the feedstock which cannot be fermented. These waste materials can be concentrated to provide animal feed (Distillers Dried Grains Solids – DDGS), or it can be digested to produce biogas. The solids are extracted by a drying process, which consumes a considerable amount of energy. Nevertheless, the economics of bioethanol production are very dependent on the production of a high value by-product, and the most likely route at present is the production of animal feed for which a by-product credit can be obtained.

Incremental improvements of these bioethanol production technologies is ongoing. Since the energy use in the process is considerable, being in the range of 30-40% of the energy content of the bioethanol produced from wheat, efforts are being made to improve the energy efficiency of the process. Most of the energy requirement is for distillation of the product and hydrolysis of the feedstock, and is usually supplied in the form of process steam. Heat recovery is an important feature of improving the energy efficiency through heat transfer from the distillation stage for use in the hydrolysis and fermentation stages, although this can only be applied in continuous production systems. Since both heat and electricity are needed in bioethanol production, combined heat and power plant with greater overall energy efficiency than separate on-site boilers and mains electrical supply can give energy savings benefits.

The enzymatic hydrolysis of starch materials is a cheap, simple, and effective process. This well developed process sets the baseline that other hydrolysis processes are compared against. The drawback to producing bioethanol from sugar crops or starch materials is that the feedstock tends to be expensive and in demand for other applications as foods. These costs are offset by the sale of co-products such as DDGS. The North American bioethanol industry is spending considerable effort on finding new co-products that are higher in value and thus capable of making the bioethanol from grain industry more cost competitive. Other pilot plants have been operated in North America using steam explosion and variations on dilute and concentrated sulphuric acid hydrolysis. Cellulose conversion to glucose sugar in these plants can be as high as 80%, but they have not yet been commercialised.

Figure 2.2 illustrates the general production route for the synthesis of bioethanol from sugar crops and starch materials:

FIGURE 2.2: BIOETHANOL PRODUCTION ROUTE FOR SUGAR CROPS AND STARCH MATERIALS



2.3 PRODUCTION PROCESSES FROM LIGNO-CELLULOSIC MATERIALS

Ligno-cellulosic materials such as agricultural residues are seen as long-term potential sources of sugars for ethanol production. The cellulose and hemi-cellulose components of these materials are essentially molecular chains of chains. They are protected by lignin, which is the 'glue' that holds all of this material together. Ligno-cellulose requires separation into its constituents of lignin, cellulose and hemi-cellulose, of which only the last two can be fermented to give ethanol. Ligno-cellulose separation requires relatively aggressive chemical treatments, such as acid hydrolysis at raised temperatures and pressures. Alternative approaches to lingo-cellulose separation include steam explosion, treatment with alcohol/water mixtures and treatment with alkalis. Enzymatic separation of the lignin is a further alternative, requiring relatively lower temperatures and pressures and potentially giving a higher yield of fermentable sugars. In these processes, all components of the feedstock, which cannot be fermented into sugars, must be separated at the feedstock preparation stage.

Bioethanol from ligno-cellulosic materials is still at a development stage. A range of processes and production methods are being developed, although none of them can be truly described as being capable of full-scale commercial operation. Fermentable sugars from wood can be obtained by hydrolysis using dilute sulphuric acid or concentrated hydrochloric acid. These systems have only been able to use the cellulose fraction of the wood and conversion rates are generally in the range of 40-55%. Most existing pilot and demonstration plant work on a batch basis, which is generally a less efficient process than operating on a continuous basis.

Cellulosic biomass is a complex mixture of carbohydrate polymers known as cellulose, hemi-cellulose, lignin, and a small of amount of compounds known as extractives. Examples of cellulosic biomass include agricultural residues, such as wheat straw, forestry residues, municipal solid waste (MSW), herbaceous and woody plants, and underused standing forests. Cellulose is composed of glucose molecules bonded together in long chains that form a crystalline structure. Cellulose is a fibrous, tough, water-insoluble substance. Hemi-cellulose is not soluble in water. It is a mixture of polymers made up from xylose, mannose, galactose, or arabinose. Hemi-cellulose is much less stable than cellulose. Lignin is a complex aromatic polymer of phenyl propane building blocks, and is resistant to biological degradation. The carbohydrate fraction of cellulosic biomass contains a mixture of polysaccharides, only some of which can be hydrolysed and fermented to ethanol. The yield of ethanol is dependent on the particular wood species and is generally in the range of 230 to 320 kg per tonne (dry weight) of wood.

Woody materials would generally be milled or chipped and dried prior to hydrolysis. In the hydrolysis step, the carbohydrates are reduced to the corresponding sugars by the catalytic action of heat, acid or enzymes. The overall reaction for cellulose is:

$$(C_6H_{10}O_5)_n \quad + \quad nH_2O \quad \rightarrow \quad nC_6H_{12}O_6$$

cellulose + **water** → **glucose**

162kg + **18kg** → **180kg**

For production of bioethanol, the cellulosic feedstock is first pre-treated to convert the hemi-cellulose into soluble sugars such as xylose sugars. The cellulose fraction is then hydrolyzed by acids or enzymes to produce glucose, which is subsequently fermented to bioethanol. The soluble xylose sugars derived from hemi-cellulose are also fermented to bioethanol. Lignin, which cannot be fermented into bioethanol, can be used as fuel to produce heat or electricity, by means of combined heat and power plant.

In processes using strong acids, the acid must be separated from the sugars and lignin after the hydrolysis step and then concentrated for reuse. The sugars are also usually concentrated by evaporation prior to fermentation. These operations require a considerable amount of energy, so additional wood must be burnt as fuel. Recycled yeasts are then added to the syrup, some nutrients may be added and the solution is allowed to ferment. Competing side-reactions (including yeast growth) mean that the maximum bioethanol yield in the laboratory is around 95% of the theoretical yield. Allowing for the additional inefficiencies of large-scale processing in practical operations, the actual yield based on the fermentable sugars present in the syrup is usually closer to 90%. After centrifuging to recover the yeast, the broth is then distilled to recover an alcohol-water mixture, which can be distilled further to recover bioethanol of the desired purity. The residue from the distillation step, called stillage, contains unrecycled yeast, unreacted sugars and other organic materials from the wood, so it has a very high biological oxygen demand and must be treated prior to disposal.

The different types of hydrolysis currently under development are:

- *Enzymatic hydrolysis; simultaneous saccharification and co-fermentation (SSCF)*: The steps in the conversion of cellulosic materials to bioethanol in processes featuring enzymatic hydrolysis include pre-treatment, biological conversion, product recovery, and inputs to heat and power utilities and waste treatment. SSCF is an adaptation to the process, which combines hydrolysis and fermentation in one vessel. Sugars produced during hydrolysis are immediately fermented into bioethanol. By fermenting the sugars as soon as they form, this eliminates problems associated with sugar accumulation and enzyme inhibition.

- *Dilute acid hydrolysis:* This process uses low concentration acids and high temperatures to process the cellulosic biomass. Ligno-cellulose biomass is pre-treated with approximately 0.5% acid in liquid at up to 200ºC to hydrolyze the hemi-cellulose and expose the cellulose for hydrolysis. The hemi-cellulose hydrolysis yields mostly pentose (C5) sugars, principally xylose and arabinose, which are fermented to bioethanol and distilled. The remaining solids, cellulose and lignin, enter the second stage hydrolyzer where cellulose is converted to glucose with approximately 2% acid in liquid at up to 240º C. The resulting sugars are then fermented to ethanol and distilled.

- *Concentrated acid hydrolysis*: This process uses high concentration halogen acids and near ambient temperatures to convert cellulosic biomass to sugars. The decrystalization and hydrolysis of cellulose with nearly 100% yields may be accomplished with 40 wt% hydrochloric acid, 60 wt% sulphuric acid, or 90 wt% hydrofluoric acid. The liquid phase hydrochloric acid process is the only halogen process to have reached commercial development. The feedstock is pre-treated with approximately 10 wt% acid liquid stream, which is recycled from cellulose hydrolysis. Pre-treatment hydrolyzes the hemi-cellulose into C5 and C6 sugars and exposes the cellulose for hydrolysis. The subsequent liquid acid and sugar stream is separated from the solids, neutralized, fermented and distilled. The solids, mostly cellulose and lignin, enter the second stage hydrolyzer and are mixed with 40-90 wt% acid (the concentration depends on acid type). Cellulose is converted into C6 glucose sugars. After another liquid-solid separation step, the liquid containing about 10% acid and 10% glucose is recycled to the hemi-cellulose hydrolysis / pre-treatment vessel. The remaining solids are washed, dried and used as fuel source for power production.

It is clear that there are many pathways to produce bioethanol using cellulosic feedstock. The US National Renewable Energy Laboratory (NREL) has extensively researched several of these pathways as part of the US Department of Energy Biofuels R&D Programme. Figure 2.3 shows the general system layout for one design of NREL biorefinery for the conversion of cellulosic feedstock to ethanol[49].

All of the ligno-cellulosic conversion processes that are being investigated in the US and elsewhere are much more complex than the conversion of sugar or starch based materials. This has implications for the capital and operating costs of the process plant, and on the overall economics of bioethanol production from ligno-cellulosic materials.

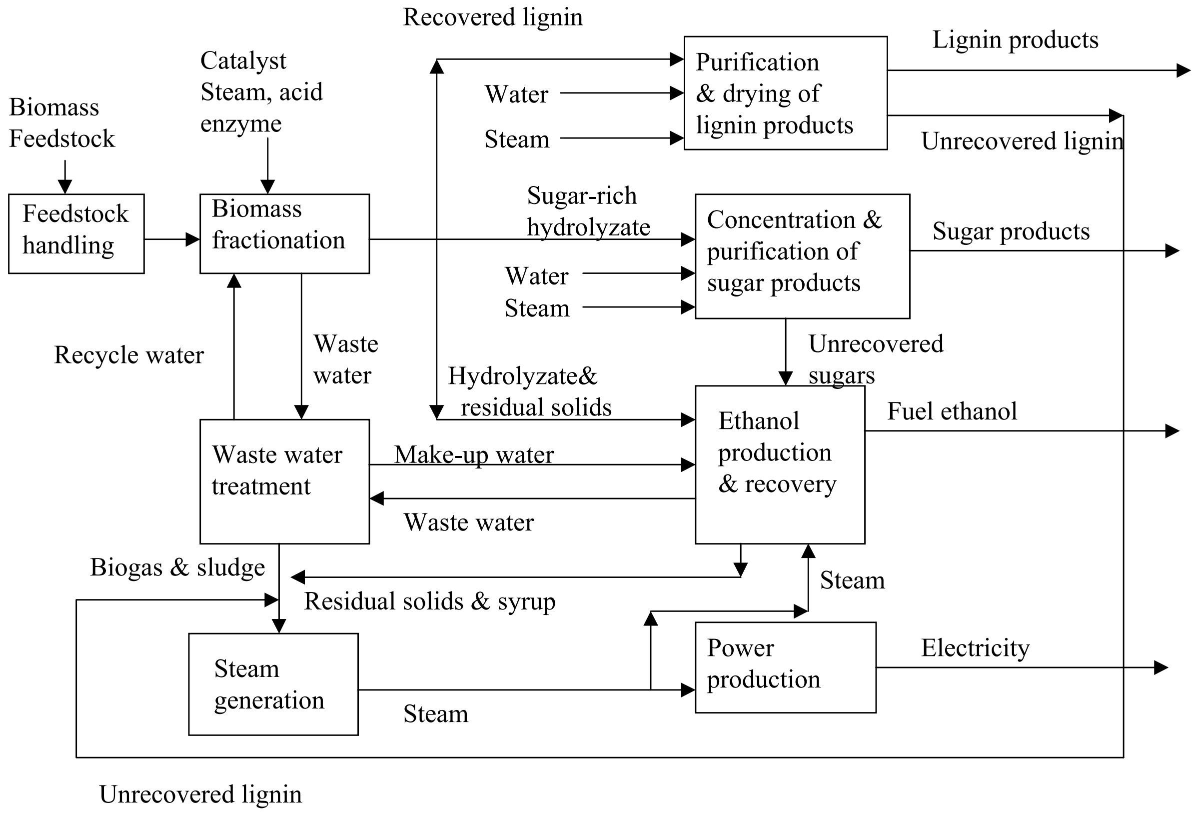
Data have been obtained from a variety of sources; in particular the bioethanol yield data have been obtained from the most recent estimates of yields from North American and EU studies[50] and

[49] See, for example “Determining the cost of producing ethanol from corn starch and ligno-cellulosic materials”, NREL, Golden, Colorado, October 2000.

[50] Published information on costs, yields and operating requirements were obtained from several sources:
“Ligno-cellulose biomass-to-ethanol process design and economics utilising co-current dilute acid pre-hydrolysis and enzymatic hydrolysis current and futuristic scenarios”, National Renewable Energy Laboratory, Golden, Colorado, July 1999 (NREL/TP 580-26157);
“Determining the cost of producing ethanol from corn starch and ligno-cellulose feedstocks”, National Renewable Energy Laboratory, Golden, Colorado, October 2000 (NREL/TP 580-28893).
“Co-production of bioethanol, electricity and heat form biomass residues”, Energy Centre Netherlands, 12th European Conference and Technology Exhibition on Biomass for Industry and Climate Protection, June 2002, Amsterdam, Netherlands;
“Costs and benefits of a biomass to ethanol production industry in California”, California Energy Commission, March 2001;
“Assessment of net emissions of greenhouse gases from ethanol-blended gasolines in Canada: Ligno-cellulosic feedstocks”, Levelton Engineering, January 2000.
“GM Well-to-wheels analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems – a European study”, LB Systemtechnik GmbH, Ottobrunn, Germany, September 2002;

adapted, where necessary, to account for UK conditions of moisture content of the feedstock material.

FIGURE 2.3: NREL BIOREFINERY GENERAL SYSTEM LAYOUT FOR ETHANOL PRODUCTION FROM LIGNO-CELLULOSIC MATERIALS



Prospects for ligno-cellulosic feedstock production of bioethanol

The technology behind converting cellulosic biomass to bioethanol has yet to pass the most important test of being demonstrated in a commercially viable facility. Despite there being many different technologies available i.e. dilute acid, concentrated acid, and enzyme based hydrolysis, none are in use in a fully developed commercial facility. Currently there are several facilities in various stages of planning and or under construction in North America, and at least one that is operating as a practical demonstration plant.

One of these developments is being undertaken by the Canadian company Iogen, which has been pursuing enzymatic hydrolysis for 25 years[51]. The bioethanol production facility in Ottawa is co-located with Iogen's industrial enzyme production facility, and the facility is currently in use. As a pilot demonstration, the facility has a capacity of around 250 t/year. This technology involves steam explosion followed by enzymatic hydrolysis and a mix of yeast and microbes to ferment the different sugars. Microbes that will allow for SSCF are in testing, but not currently operational. The facility can process approximately 40-50 t/day of cellulosic biomass. Shell has established a joint investment with Iogen for the development of this process, and the design and planning for a full-scale commercial facility are being undertaken.

"Effects of fuel ethanol use on fuel-cycle energy and greenhouse gas emissions", Argonne National Laboratory, January 1999 ANL/ESD-38.

[51] See the Iogen Corporation, Ottawa, Canada, information leaflet, 2003.

Similar to the oil refining industry, the cost of biofuels will be impacted by the range and number of high value co-products produced by a bio-refinery. In the oil industry it is generally accepted that refining petroleum to manufacture gasoline and diesel fuel alone is not commercially viable. The complexity of developing both the full product line and the processes associated with them should be taken into account in assessing the range of possible technological issues that follow.

The main problems with current technologies for the production of bioethanol from ligno-cellulosic materials such as woody biomass are the low yields obtained, the large amount of extra fuel required to recycle the acid and concentrate the sugars, and the high capital cost of the equipment required for the hydrolysis/acid recycle/concentration steps. The high cost of raw materials and process materials such as the specialist enzymes, is another reason for the overall high cost. If cheaper materials become available in sufficient quantities, then that component of the cost would decrease. Recent research has identified enzyme hydrolysis techniques, recombinant organisms capable of utilising pentose sugars, and alternative techniques for the acid recycle/concentrations steps. However, enzyme hydrolysis consumes some of the sugars for the production of the enzymes and the microorganisms. In addition, the recombinant organisms are not as robust as common yeasts such as bakers' yeast and often require antibiotics to maintain selection, having lower yields on hexose sugars and lower alcohol tolerance.

Research and development is on-going into organisms and enzymes which can degrade lingo-cellulose, hydrolyse cellulose and hemi-cellulose, and ferment the five-carbon sugars (pentoses) from hemi-cellulose. The pentose sugars are particularly difficult to ferment, but useful organisms have been identified for all of these functions, and some pilot plants have been built. In principle, enzymatic approaches to hydrolysis could give very high yields of fermentable sugars, in excess of 90% from both cellulose and hemi-cellulose.

Nevertheless, pretreatment methods for urban wastes and materials such as wheat straw have now reached the point where enzyme hydrolysis represents a practical alternative to acid hydrolysis and costs considerably less. A recent report from NREL, describes the enzyme hydrolysis process in considerable detail[52], but published literature for the fuel requirements for acid recycle/concentration in the acid hydrolysis process indicate that the process has not developed to the point where the process is self sufficient in fuel. Capital costs also remain high, and bioethanol from this production route is still not competitive with conventional processing of sugar crops and starch materials[53].

Ligno-cellulosic technology developments include pilot schemes and designs from several other US or Canadian companies including BC International and Arkenol. It is difficult to compare these technologies since they are all at different stages of development and thus the level of certainty surrounding each process is different. Table 2.1 is a qualitative comparison of three technologies with the established grain to ethanol technology[54]. The costs for the grain plant do not include interest, taxes, depreciation or profit, as these are project dependent.

It can be seen that none of the technologies reviewed are at the same development stage as the proven grain to bioethanol technology. The new technologies cannot be considered to be commercial today. Nevertheless, all of these technologies have substantial room for further development with the potential to make them competitive in the future, as indicated below:

[52] "Ligno-cellulose biomass to ethanol process design and economics utilising co-current dilute acid pre-hydrolysis and enzymatic hydrolysis – current and futuristic scenarios", NREL, July 1999, Golden, Colorado, USA.
[53] See for example, "Costs and benefits of a biomass to ethanol production industry in California", California Energy Commission, March 2001, Sacramento, California, USA.
[54] "Wood ethanol technology review", Environment Canada, 1999.

TABLE 2.1: COMPARISON OF LIGNO-CELLULOSE PROCESS ECONOMICS

	Wheat	**Iogen**	**BC International**	**Arkenol**
Status	Commercial (in US and Canada)	Pilot demonstration	Commercial demonstration	Laboratory
Capital cost	$0.5/litre	Higher	Higher	Much higher
Process	Enzyme fermentation	Enzymatic hydrolysis	GMO and fermentation	Concentrated acid hydrolysis
Feedstock	Grain	Agricultural residues	Sugar cane bagasse	Softwood
Feedstock cost	$0.3/litre	Lower	Lower	Lower
Co-product value	$0.15/litre	Lower	Lower	Lower
Operating Cost				
Energy	$0.05/litre	Higher	Higher	Higher
Labour	$0.045/litre	Higher	Higher	Higher
Chemicals	$0.03/litre	Higher	Higher	Higher
Maintenance	$0.025/litre	Higher	Higher	Higher
Overheads	$0.04/litre	Higher	Higher	Higher
Totals	$0.34/litre	Higher	Higher	Higher

- **Iogen.** Improvements in enzyme productivity and effectiveness can be expected to reduce capital costs and operating costs. The demonstration plant being built will help to further define the process. Even more work is required for softwood feedstock, as the higher lignin levels require much higher enzyme use and thus have poorer economics. Lignin is relatively uncondensed and may have a higher value than fuel, but the lignin potential requires further work. The pentose sugar fermentation is still to be demonstrated.

- **BC International.** Pentose sugar fermentation capability is their strength. Little work has been done to date on softwoods. The two-stage dilute acid hydrolysis is capital and operating cost intensive compared to grain hydrolysis. A unique low capital cost commercial demonstration project is reported to be underway. The lignin by-product may not be very reactive, and much more work is required on lignin.

- **Arkenol.** Very high capital cost at this time. Cost may come down after the first plant is built and a better understanding of the process is gained. The lignin by-product is not very reactive and it will be difficult to get a high value for it.

In addition, the US company Masada is reported to be investigating the potential use of municipal solid waste as the feedstock material. There are also R&D activities underway to examine entirely new routes to ethanol production, such as biomass gasification followed by anaerobic fermentation, and biomass gasification followed by Fischer-Tropsch condensation to yield ethanol. Assessment of these routes is beyond the scope of this study, since they are still at the laboratory scale and require considerable R&D effort before they can be considered for commercial deployment.

2.4 CAPITAL AND OPERATING COSTS OF BIOETHANOL FROM SUGAR AND STARCH FEEDSTOCKS

In general, bioethanol manufacturing from starch (such as wheat) or sugar crops is carried out in well-established and reliable process plant using technologies that have been developed over a long time period. Innovations and design improvements have been made only on parts of the process, such as continuous fermentation; energy management; and increased recycling of water to minimise energy consumption and save water. However, these types of improvements have resulted in quite large differences in the manufacturing costs of the final product. There are also differences in the production costs per unit output of ethanol for different plant capacities, where the economies of larger-scale production can be obtained. Differences in feedstock costs for the range of different types of feedstock are also significant.

In estimating the capital costs of bioethanol production, some of the key elements to be considered are:

- The use of modern designs of process plant, including combined heat and power systems for energy production;
- Using the benefits of economies of relatively large-scale operation;
- The costs of equipment for feedstock handling and storage;

The size of the production plant has a major impact on the capital costs. A commonly used relationship is the exponential scaling expression:

$$\text{New cost} = \text{Original cost} * \left(\frac{\text{New size}}{\text{Original size}}\right)^{\alpha}$$

Where α = scale factor, based on engineering estimates of the costs associated with different sizes of the same production plant equipment. The scaling factor is normally based on a physical dimension such as the volume capacity, but could be based on some other characteristics directly related to size. In general, engineering estimates show that the value of α ranges between about 0.60 and 0.80. A value of 0.65 is used in this study.

Costs currently quoted in the literature range from 55M € (£34M) for a grain based bioethanol plant of 70,000 m^3/year capacity (55,000 t/year)[55], to 100 M € (£62M) for a wheat based bioethanol plant of 100,000 t/year capacity[56]. These cost estimates apply to EU Member States in general, and not to the UK in particular. However, a previous UK study[57] indicated an investment cost of £400/kW (1986 prices) for a wheat-based production plant with a capacity of about 132,000 t/year (equivalent to 140 MW). This investment cost estimate equates to approximately £73M in 2003 prices[58]. A later UK study[59] gave an investment cost equivalent to an annuitised cost of £4.02/GJ ethanol (1994 prices) for a wheat-based plant producing 45,000 t/year of bioethanol. British Sugar estimate[60] in a current feasibility study that a UK-based production plant on a brown-field site of 100,000 t/year capacity would cost around £60M.

[55] "Automotive fuels survey – raw materials and conversion", International Energy Agency, Paris, December 1996.
[56] "Techno-economic analysis of bio-alcohol production in the EU", Institute for Prospective Technological Studies, (IPTS), Seville, May 2002.
[57] "An appraisal of UK energy research, development, demonstration and dissemination", ETSU, London, 1994.
[58] Using a 30% uplift based on the increase in the producer prices index for machinery and equipment over the period 1986 to 2003.
[59] "ETSU Contractor's Report, A V Bridgwater, 1994.
[60] British Sugar, private communication.

The various studies indicate a broad agreement regarding the investment costs. The average investment cost from these literature sources is £592/t for a 100,000 t/year production plant. The approximate division of the total investment costs into components is shown in Table 2.2:

TABLE 2.2: COMPONENTS OF THE TOTAL INVESTMENT COST: WHEAT FEEDSTOCK PLANT

Component	% of total
Land	10
Construction services	30
Capital equipment	40
Labour	15
Engineering design	5

These studies also enable the approximate investment costs for bioethanol production broken down into operating costs, capital and feedstock costs to be identified. The main aspects of estimating operating costs include:

- Annuitisation of initial capital costs
- Feedstock costs
- Labour costs
- Energy and water costs
- Maintenance costs

Table 2.3 shows the operating costs estimates from the recent IPTS study, and the resulting ethanol production costs as a function of feedstock price. Annuitisation is calculated using a capital cost of 100 M € for a 100,000 t/year plant, assuming a discount factor of 10% and an economic plant lifetime of 15 years:

TABLE 2.3: TOTAL PRODUCTION COSTS: WHEAT FEEDSTOCK PLANT

Cost heading	Item	€ / 1000 litre bioethanol	€ / 1000 litre bioethanol
Capital cost	Annuitised investment cost	12	
Operating costs	Energy	60	
	Labour	50	
	Chemicals	30	
	Overheads	20	
	Maintenance	50	
	Total operating costs	210	
Fixed income	By-products credit	114	
	Total fixed factors	108	108
Variable costs	1 litre bioethanol requires 2.86 kg of wheat		Wheat price*2.86
	Total production costs		**108 + Wheat price*2.86**

The estimated costs for bioethanol production in Europe from the IPTS study are estimated from feedstock costs, processing costs and a credit for the value of by-products. The wheat prices used in the study ranged between 343 and 220 € / 1000 litre bioethanol, dependent on current market conditions (giving the higher price) and the prospect of set-aside subsidies (giving the lower price).

For sugar beet, the range of prices indicates the current producer price for sugar as B-quota (high price) and the world sugar beet price (low price). Table 2.4 shows the cost estimates calculated by IPTS:

TABLE 2.4: PRODUCTION COSTS OF BIOETHANOL (€ / 1000 LITRE BIOETHANOL)

Feedstock	Feedstock cost	Processing cost	By-product credit	Total production costs
Wheat	343 (high) 220 (low)	284	145	482 (high) 359 (low)
Sugar beet	324 (high) 200 (low)	218	3	539 (high) 415 (low)
Straw	240	355	38	557

The production costs for sugar beet take advantage of the existing industrial base of sugar and alcohol processing, which results in lower levels of processing costs than for wheat or straw. In the case of wheat, the estimates are based on technology transfer from the sugar beet/alcohol production industry for the fermentation and distillation stages of ethanol production. Assumptions are also made regarding the process plant required for the pre-treatment, milling and enzymatic hydrolysis to sugars in the preparation of the starch component of wheat into fermentable sugar.

A further source of data on the German and United States bioethanol industries can also be used as reference[61]. Table 2.5 lists the composition of estimated production costs for different plant capacities and feedstocks in Germany. Table 2.6 lists the composition of actual production costs for a facility in South Dakota using corn as feedstock. The effects on the overall cost in Germany due to differences in feedstock costs and economies of scale can be seen in Table 2.5. In Table 2.6, the effect of State subsidies, and a low feedstock cost, give an overall cost of less than half the estimated cost for Germany.

TABLE 2.5: PRODUCTION COSTS IN GERMANY (€ / 1000 LITRE BIOETHANOL)

Capacity	**50 M litres/year**		**200 M litres/year**	
Feedstock	Wheat	Sugar beet	Wheat	Sugar beet
Buildings	12.8	12.8	8.2	8.2
Machinery	82.8	82.8	53.0	53.0
Labour	42.6	42.6	14.0	14.0
Overheads	16.0	16.0	10.2	10.2
Feedstock	277.5	351.0	277.5	351.0
Other costs	186.8	159.3	186.8	159.3
By-product credits	-68.0	-72.0	-68.0	-72.0
Total	**550.5**	**592.5**	**481.6**	**523.7**

TABLE 2.6: PRODUCTION COSTS IN THE UNITED STATES (€ / 1000 LITRE BIOETHANOL)

Capacity	**53 M litres/year**
Feedstock	Corn
Buildings	39.0
Machinery	34.0
Labour	28.3

[61] "Fuel ethanol production in the USA and Germany – a cost comparison", World Ethanol and Biofuels Report, F O Licht, February, 2003.

Overheads	6.1
Feedstock	209.3
Other costs	113.1
By-product credits	-67.1
State subsidies	-79.3
Total	**248.4**

2.5 CAPITAL AND OPERATING COSTS OF BIOETHANOL FROM LIGNO-CELLULOSIC MATERIALS

Bioethanol production from ligno-cellulosic materials has not yet been shown on a commercial scale, and there are few operating data available from current R&D developments. As described above, North America is the focus of most of the R&D and demonstration effort underway in this technology. Hence for this study it is necessary to use theoretical projections of the capital and operating costs of a full-scale conversion plant, and to assume that UK conditions can be taken as similar to those in other countries. Several relevant studies have been undertaken in recent years, but no published references are available for specific UK conditions. Instead data have been assembled from a range of US and European studies, and conclusions drawn on the relevance of these data for the UK.

For example, recent US studies have estimated the total project investment costs for a lingo-cellulose biomass-to-ethanol process plant[62]. These studies examined a conceptual design of a plant using woodchips, and corn stover as feedstocks, and producing bioethanol at an output volume of between 25-55 M gallons (US) per year. The data apply to US conditions, but can be used to give an indication of the overall costs involved through this technology route. For the woodchips study, the total project investment costs were estimated to be US $ 234M (in 1999 prices), sub-divided as shown in Table 2.9.

TABLE 2.9: PROJECT INVESTMENT COSTS: LIGNO-CELLULOSE FEEDSTOCK PLANT (NREL STUDY)

Cost heading	Item	US $M	US $ M
Installed equipment costs	Feed handling	4.9	
	Pre-treatment	26.3	
	Simultaneous saccharification/co-fermentation	13.4	
	Cellulase production	15.5	
	Distillation	13.0	
	Waste water treatment	10.4	
	Storage	1.8	
	Boiler/turbogenerator	44.5	
	Utilities	5.2	
	Total equipment cost	135.0	135.0
	Warehouse		2.0
Site development	Site roads, fencing, drainage etc		6.6
Field expenses	Consumables, temporary buildings etc		28.7

[62] "Ligno-cellulose biomass-to-ethanol process design and economics utilising co-current dilute acid pre-hydrolysis and enzymatic hydrolysis current and futuristic scenarios", National Renewable Energy Laboratory, Golden, Colorado, July 1999 (NREL/TP 580-26157); and "Determining the cost of producing ethanol from corn starch and ligno-cellulose feedstocks", National Renewable Energy Laboratory, Golden, Colorado, October 2000 (NREL/TP 580-28893).

Home office and construction fee	Engineering design, technical support and purchasing functions	35.9
	Project contingency	4.3
Other costs	Land, insurance, taxes, etc	21.3
	Total	**233.8**

The total operating costs comprise the variable costs, which include feedstock materials, waste handling charges and by-product credits, together with fixed operating costs, which include labour and various overhead items. The operating cost estimates in the US woodchips study are shown in Table 2.10, based on the plant operating at full capacity.

TABLE 2.10: OPERATING COSTS: LIGNO-CELLULOSE FEEDSTOCK PLANT (NREL STUDY)

Cost heading	Item	US $ M	US $ M
Variable costs	Biomass feedstock	19.3	
	Chemicals	9.0	
	Electricity credit	(3.7)	
	Net total variable costs	24.6	24.6
Labour costs	Salaries for 53 staff		1.6
Overheads	Includes payroll overhead, security, office utilities etc		0.9
Maintenance	2% of total equipment cost		2.7
Insurance and taxes	1.5% of total installed cost		2.2
		Total	**32.0**

The resulting production cost of ethanol was estimated using a discounted cash flow analysis. At a discount rate of 10%, and with assumptions regarding items such as the cash out-flows during construction, methods and costs of financing and the amounts due for federal taxes, the production cost was calculated to be US $1.44/gallon (equivalent to US $ 0.38/litre).

Another reference source is a Dutch study, which examined the economics of bioethanol production from a range of ligno-cellulosic materials[63]. Table 2.11 lists the conversion costs in the model system developed in the Dutch study. The estimated costs are considerably higher than the current costs of fuel ethanol from corn starch, and a sensitivity analysis showed that the cellulase enzyme costs will have to be reduced by at least a factor of 10 and capital costs need to be reduced by 30% to reach ethanol production costs that are competitive with ethanol from starch crops.

TABLE 2.11 SUMMARY OF ECONOMIC EVALUATION FOR A 156,000 T/YEAR BIOETHANOL PLANT (DUTCH STUDY)

Feedstock		SRC/forestry residues	Wheat straw
Feedstock costs (€/t)		70	80
Investment costs M€		285	235
Operating costs (M€/year)	Feedstock	39	38
	Cellulase[64]	97	59

[63] "Co-production of bioethanol, electricity and heat form biomass residues", Energy Centre Netherlands, 12th European Conference and Technology Exhibition on Biomass for Industry and Climate Protection, June 2002, Amsterdam, Netherlands.
[64] Enzyme costs are estimated in the Dutch study at 6000 €/t

	Other costs	14	11
	Total	149	108
Production costs (€/litre)	Feedstock	0.19	0.19
	Cellulase	0.48	0.30
	Other O&M	0.07	0.06
	Capital	0.34	0.28
	Electricity credit	-0.10	-0.07
Net ethanol cost		0.99	0.75

Potential future developments in ligno-cellulosic conversion technology

Future developments in ligno-cellulosic conversion technology have the potential to reduce capital and operating costs, and increase the yields of bioethanol from the feedstocks. These developments could also demonstrate the commercial potential for a wide variety of feedstocks. For example, it is thought that pre-treatment can produce higher conversions of hemicellulosic sugars and that the current cellulase industry can provide a micro-organisms to produce the enzymes more efficiently. NREL[65] have estimated the potential improvements in the process economics over the next 10-12 years, and a summary of these estimates is shown in Table 2.12.

TABLE 2.12: FUTURE IMPROVEMENTS IN LIGNO-CELLULOSIC CONVERSION ECONOMICS COMPARED WITH YEAR 2000 TECHNOLOGY STATUS

	2005	2010	2015
Increased yield	+20%	+38%	+65%
Increased throughput	+16%	+35%	+64%
Reduced capital costs	-8%	-15%	-14%
Reduced production costs	-24%	-44%	-48%

It should be emphasised that these improvements in conversion processes still require demonstration at pilot and commercial scales. Nevertheless, there is the potential for ligno-cellulosic conversion technologies to deliver bioethanol at overall costs that are lower than the costs of sugar or starch-based processes. Recent UK estimates indicate that, if these future developments are successful, the conversion costs for wheat straw and short rotation coppice could be as little as 18 p/litre[66].

[65] "Ligno-cellulose biomass-to-ethanol process design and economics utilising co-current dilute acid pre-hydrolysis and enzymatic hydrolysis current and futuristic scenarios", National Renewable Energy Laboratory, Golden, Colorado, July 1999 (NREL/TP 580-26157).
[66] Woods, Imperial College, London, private communications, 2003.

ANNEX 3

FUEL DISTRIBUTION, STORAGE, BLENDING AND END-USE

3.1 FUEL DISTRIBUTION NETWORK

The supply chain considerations once the bioethanol has been produced are examined in this annex[67].

The UK has a well-established oil refining and product distribution network, which is operated by all the major international oil companies, together with several independent oil companies.

Figure 3.1 shows the locations of refineries and the petroleum products distribution network throughout Great Britain. There are nine major refineries, all of which are located on coastal sites around the country at:

- Fawley, near Southampton
- Stanlow, Cheshire
- Coryton, Essex
- Grangemouth, Scotland
- South Killingholme, Lincolnshire
- Killingholme, Lincolnshire
- Pembroke, South Wales
- Milford Haven, South Wales
- North Tees, Teesside.

All these refineries produce a wide range of petroleum products, including gasoline. Substantial storage facilities exist at these refineries, but, given their location, there are also other large storage terminals around the country. There are at present over 40 oil terminals, and these are generally situated near major conurbations, as shown with the letter T in Figure 3.1. The terminals are mainly supplied from the refineries by pipeline, rail and by sea. Rail and road distribution is not used to move large volumes of products form refinery to terminals due to the relatively high cost involved. However, road transport using road tankers is the preferred method for the delivery of most products to the retail outlets at the filling stations. This is because road transport is very flexible, and can readily serve the needs of the 12,000 or so filling stations around the country.

At the oil terminal, the road tanker driver loads products onto the tanker by a pipe connection on a loading gantry. The connection also captures vapours expelled during filling, with a vapour recovery unit to convert the vapours back into liquid form. Road tankers are usually of 44 tonnes gross weight (a maximum size of 18 tonnes is often used in rural areas).

[67] Sources: "Alternative fuels in the automotive market", CONCAWE report no. 2/95, Brussels, 1995; and petroleum industry private communications, 2003.

FIGURE 3.1: OIL REFINERIES AND DISTRIBUTION NETWORK[68]

[68] Source: UK Petroleum Industries Association, web site www.ukpia.org

3.2 INTRODUCTION OF BIOETHANOL INTO THE FUEL SUPPLY SYSTEM

Gasoline distribution systems reach an equilibrium position where varnish, gums and small amounts of sludge and water are deposited around the system. Thereafter, normal good housekeeping practices avoid the pick-up of such materials by gasoline in transit. The addition of bioethanol to the gasoline system will disturb this equilibrium and can lead to handling and performance problems. Hence it is important that distribution systems are cleaned and dried before the introduction of ethanol/gasoline blends. This will include the tanks used to store the blended product, in depots and at the retail outlets, together with the road tankers and pumping equipment used for transport and delivery of the fuel.

Whereas ethanol is completely miscible in gasoline, the presence of even small amounts of water will rapidly lead to phase separation, i.e. the ethanol will be absorbed by any water present in the system. This can result in poor vehicle performance and, possibly, engine damage. The actual phase separation conditions are a function of ethanol content, temperature and properties of the gasoline phase, but the effect is particularly marked at low ethanol concentrations such as those around 2-5% by volume. Therefore, only anhydrous ethanol should be used for blending in gasoline. Furthermore all contact between the blend and water should be avoided, and any mixing of the blend and other gasoline products must also be avoided.

Blends of ethanol and gasoline form azeotropes, which cause a disproportionate increase in vapour pressure together with a reduction in the front-end distillation temperature. This effect varies with ethanol concentration but is particularly significant at ethanol concentrations up to around 10%. Such an increase in vapour pressure would cause hot driveability problems in vehicles. As a result, the base gasoline for the blending mixture must be tailored to accept the ethanol. This tailoring of the base gasoline requires the omission from the gasoline pool of high-performance components such as butane, so that there is “vapour pressure room” for the ethanol component. The displaced products must be incorporated in alternative market outlets, where their properties and economic value may not be fully utilised. This implies an economic penalty, and the less efficient use of a valuable energy resource from the petroleum supply. Mixing of ethanol/gasoline blends with gasoline that has not been tailored to accept the ethanol may also lead to hot driveability problems in some cases.

The higher latent heat and fuel/air mixture leaning effect, resulting from the high oxygen content of ethanol may lead to cold start and driveability problems at the higher ethanol concentrations in a blend.

Blending of ethanol into the modified base gasoline is best undertaken at the fuel depot, rather than in the petroleum refinery. This is because of the need to minimise any potential exposure of the ethanol to water, and to avoid cross-contamination of non-blended gasoline. The blending can take place at the gantry delivery system directly into the road tanker, with the mixture concentration being controlled by computer. Separate storage of the base gasoline and the ethanol would be used at the depot prior to the blending process being carried out. Care will be needed to ensure that adequate fire fighting equipment (foams) and the site health and safety requirements are appropriate and observed.

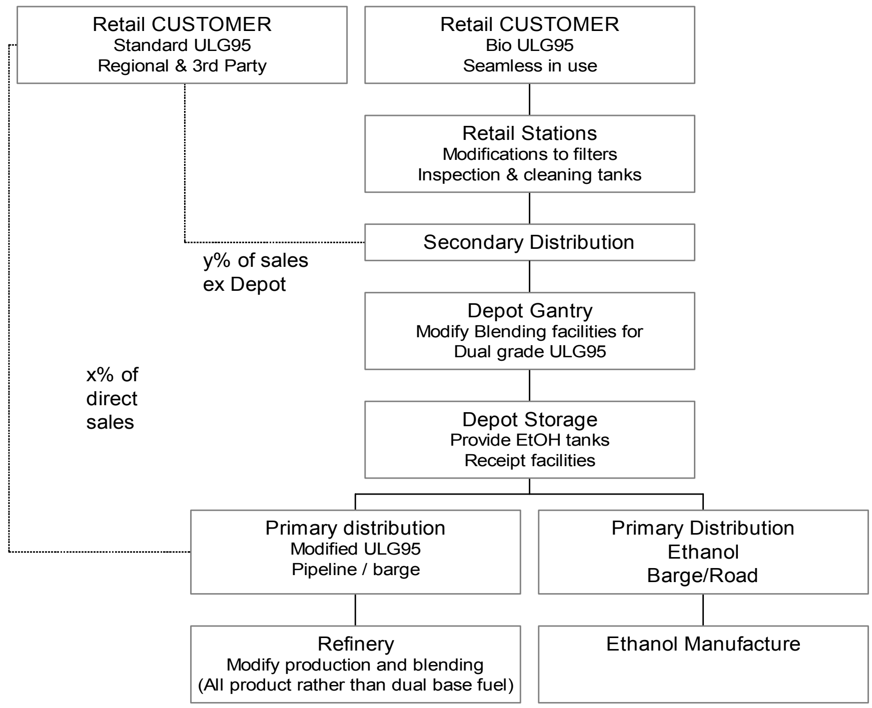
It is assumed in this study that the bioethanol blend in gasoline will be at a concentration of 5% wt. The costs of blending bioethanol into gasoline have been estimated in discussions with oil industry sources[69] at up to 10p/litre of ethanol. For the purpose of this study, however, a lower figure of 5p/litre has been used, because it was felt that the oil industry would adapt its refinery operations

[69] Source: Petroleum industry private communication, 2003.

and blending processes quickly and thereby reduce the additional costs if a robust and secure market for bioethanol developed.

Figure 3.2 illustrates, in conceptual form, the distribution and retail stages in the supply chain for gasoline and gasoline/bioethanol blended fuels. Retail customers (petrol filling stations, supermarkets, garages etc) receive supplies of gasoline fuel either directly via the primary distribution from the refinery, or via secondary distribution from the depot. Gasoline/bioethanol blended fuel must be supplied via secondary distribution, where the blending is done at the depot, as outlined above. The depot must provide reception facilities and storage tanks for the bioethanol supply from the manufacturing plant. The blending system into base gasoline takes place at the depot gantry, and secondary distribution by road tanker is then carried out. The retail stations need to undertake modifications to filters, inspection and cleaning tanks.

FIGURE 3.2: DISTRIBUTION AND RETAIL SUPPLY CHAIN[70]



It is not clear whether the petroleum retailing industry will view bioethanol blends as requiring any special promotional or marketing support. Furthermore, the "greenness" of bioethanol blends may or may not be seen as offering a product differentiation, which can be offered to the consumer, and which could possibly command a premium price on the forecourt. For the purposes of this study, it has been assumed that there is no price premium available in the market for bioethanol blends.

At the retail sites, there will need to be one (or more) separate filling pump station for the gasoline/bioethanol blended fuel. This will require additional capital investment by the retail supplier, and appropriate signage and forecourt information about the blended fuel.

As a liquid fuel offering little or no environmental impact on spillage and requiring no more special handling precautions other than a more rigorous exclusion of water, bioethanol blends can, in principle, be distributed and dispensed in much the same way as gasoline or diesel fuels. The

[70] Source: Petroleum industry private communication, 2003.

disadvantages are that more expensive corrosion-resistant materials must be used in both the distribution network and the vehicle on-board fuel systems.

The costs of distribution of blended bioethanol, including the retailer's margin, transport to the retail sites from the oil depot, and any marginal costs of altering facilities at the retail sites is assumed to be equivalent to 5p/litre ethanol[71].

3.3 VEHICLE PERFORMANCE

It is impractical to use pure bioethanol as a fuel for spark ignition engines because its low vapour pressure and high latent heat of vaporisation make cold starting very difficult. As indicated above, a 5% wt blend with gasoline is assumed in this study. Motor vehicle manufacturers will normally continue to maintain their performance warranties at this concentration, as there should be no problems experienced by the driver in operating any of the current gasoline-fuelled vehicle models with such a blend.

There are developments of flexi-fuelled vehicles, capable of operating on gasoline or any blend of gasoline and bioethanol. The flexibility is obtained through automatic adjustment of the fuel volume injected and ignition timing based on a signal from a fuel sensor. In theory, dedicated bioethanol engines could give an improvement in thermal efficiency, as the fuel's high octane rating would allow a high compression ratio.

Energy consumption and emissions performance of a sample of current production cars fuelled with a 10% ethanol blend has been studied recently[72]. The main conclusions of this work were that:

- Emissions of particulate matter and carbon monoxide were significantly reduced;
- For some of the vehicle tested, carbon dioxide emissions and fuel consumption were significantly reduced;
- Emissions of nitrogen oxides were not significantly influenced;
- For some of the vehicles tested, acetaldehyde emissions were significantly increased.

The observed effects of ethanol addition were consistent with the anticipated effects on combustion chemistry and the response of different vehicle technologies to these. In particular, the two vehicles that showed the greatest enhancement of fuel economy were those with modern engine management systems incorporating knock sensors, which would confer the ability to optimise timing in response to an octane number increase. A further assessment of the impacts of bioethanol combustion on vehicle performance and any other aspects of end-use do not form part of this study.

[71] Source: Petroleum industry private communication, 2003.
[72] "Ethanol emissions testing – a study for the Department of Transport, Local Government and the Regions", AEA Technology, Harwell, March 2002.

ANNEX 4

DESCRIPTION OF MACRO-ECONOMIC MODELLING AND THE MODIFIED INPUT-OUTPUT ANALYSIS

4.1 MACRO-ECONOMIC MODELLING

The basic principles of the economic modelling methodology are as follows:

- Assessment of the "with and without" cases of a UK bioethanol industry. The macro-economic analysis of the introduction of a new product (bioethanol) and the related industry is best based on a *with/without* basis. The economic impact of implementing the change (eg by certain government measures) needs to be compared with the economic impact of not implementing this change. Often such an analysis is done on a *before/after* basis (comparing of the present situation with a certain future situation). This does however not fully reflect the fact that the business as usual scenario (in this case using 100% gasoline derived from fossil fuels in the UK transport sector) may also change in the future, because measures regarding energy efficiency improvement that will be undertaken anyway in the transport sector.

- Combining efficiency with accuracy. Full scale dynamic macro-economic modelling (eg by general equilibrium models) will require the use of rather complex and expensive models, although their results will generally model reality relatively accurately. Simple Input-Output models, combined with micro economic analysis of the product chain under consideration, are relatively time efficient to undertake, but less reliable in terms of results. In previous work it has been shown that by adapting Input-Output analysis in order to overcome its most important disadvantages, the analysis will lead to a cost effective and relatively reliable model that can give good insight in both direct and indirect macro-economic impacts. An in-depth description of these adaptations and its application to bio-energy chains has been done in previous work[73].

- Technology development. It is important to include explicitly the technology development over time in the analysis of the macro-economic impacts.

The macro-economic analysis is based on the use of a national Input-Output assessment. This is described in more detail later in this Annex.

The main steps in the macro-economic analysis are:

Definition of the scenarios to be analysed (representing several "with" cases) and of a reference scenario (representing the "without" case).

An important role in this respect is which government measures will be used in order to introduce bioethanol in the market and what will be the consequence for the bio-ethanol market penetration over time. This can include various technologies (eg sugar or starch based

[73] "Electricity generation from eucalyptus and bagasse by sugar mills in Nicaragua: A comparison with fuel oil electricity generation on the basis of costs, macro-economic impacts and environmental emissions", R van den Broek et al, in *Biomass and Bioenergy*, Vol. 19, Issue 5, pp. 311-335, 2000

bioethanol production in the short term competing with ligno-cellulose biomass based bioethanol in the long term), and the possibility of import of feedstocks from abroad.

Technological and micro-economic definition of the bioethanol chains and the fossil fuel chain as defined in step 1.

Adaptation of the UK Input-Output model, according to the methodology as presented above and following the sectoral input requirement in the respective bioethanol chains.

Execution of Input-Output analysis on the various fuel supply chains to be analysed.

Based on the general results of the Input-Output analysis, a more detailed analysis for determining the indirect effects) of:

Impact on the Treasury, consumers and taxpayers: costs and income for the Treasury and consumers/taxpayers which are relevant for the bioethanol chains under consideration, and for both the with and without scenarios.

Analysis of the value added and the direct employment: for both the bioethanol and the reference case, the total amount of value added to the UK economy and the employment impact.

Analysis of North Sea oil depletion: for the case that less North Sea oil consumption will lead to more export of oil or to more net reserve of oil.

An assessment of the net CO_2 emission reduction: examining the various chains in comparison with the reference chain. This can be combined with both the macro-economic additional cost and with the net cost for the Treasury in order to calculate the cost per net tonne of CO_2 avoided for the various bioethanol scenarios.

4.2 NATIONAL MACRO-ECONOMIC ANALYSIS

In order to estimate the effect on the GDP and employment of the production of bioethanol (to replace gasoline) in this study the economic methodology of a national input/output analysis has been used. The advantages of using the input/output (IO) analysis are that the method is:

- Time and cost efficient;
- Relatively accurate, because of the modification to the IO analysis that will be applied;
- Usable to make comparisons between the macro versus the micro-economic impact.

This Annex describes in more detail the theoretical basis of the modified input/output analysis that has been used for this study.

The impact of an individual project (or product) on the Gross Domestic Product (GDP) and employment

The total cost (c) of a product can be split into three segments:

(3) value added,
(4) intermediate expenditures in the productive sector of the economy and
(3) imports (see “round 0" in Figure 4.1).

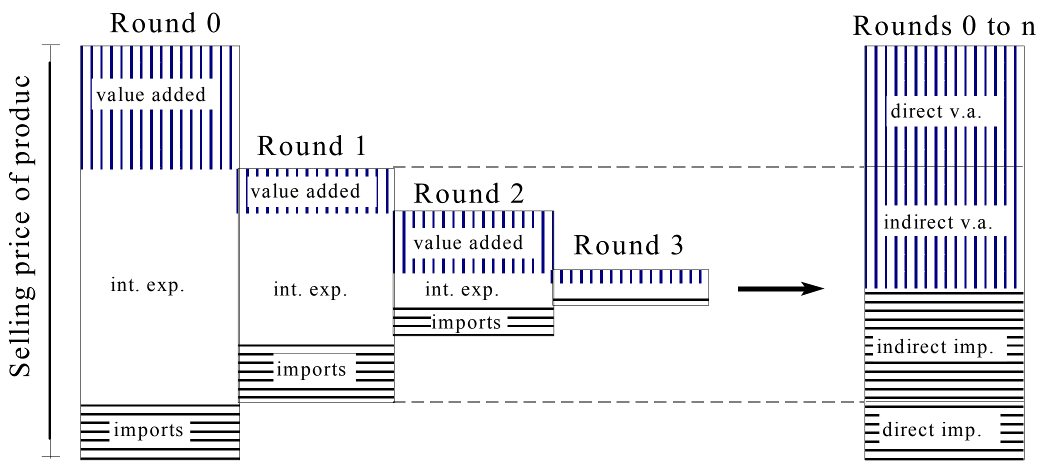
Value added consists of all types of income for the various economic actors in society, such as salaries (income from labour), interest (income from capital), land rent, profit (income from entrepreneurship) and taxes minus subsidies (government income). The total gross value added in an economy (which includes depreciation) adds up to the GDP. Therefore a project's contribution to the GDP can be represented by the amount of value added in its cost. In turn, the intermediate expenditures can be subdivided into the same three components, and so on (see "round 1" and further in Figure 4.1). Finally, the cost can be divided into imports (direct and indirect) and value added (direct and indirect).

The split into segments in round 0 in Figure 4.1 can be derived directly from the calculation of the cost. Using the standard input-output method it is possible to come directly from the cost breakdown of round 0 to that of round n. In the section below, this standard IO method is discussed in more detail, after presenting the normal structure of the standard input-output table.

Employment creation can be included as a non-monetary variable that is important in view of the macro-economic objectives that EEDA have as part of their Regional Economic Strategy.

Figure 4.1 shows the division of the cost into the segments of import, intermediate expenditures and value added. (In the figure Int. exp. means intermediate expenditure, v.a. means value added and imp. means import).

FIGURE 4.1: PRODUCT COST SEGMENTATION



The standard input-output table

The starting point for the standard input-output method is the input-output transaction table (Equation 4), which is available as standard statistical information for most countries in the world.[74] For this study, the UK Input-Output table was readily available from the Office of National Statistics[75].

[74] In this description, capital letters represent matrices (including vectors) and lower case letters are scalars.

[75] "UK Input-Output Analytical Tables, 1995 – 2002 Edition", HMSO, London , 2002, available from www.statistics.gov.uk

The elements z_{ij} form the intermediate (inter-industry) section (Z matrix), representing the demand of sector j for products from sector i. The final demand for products of sector i is represented by y_i, m_i indicates the imports by sector i and x_i is its total production. The production factors (w_i) consist of wages (for the production factor labour), rent (for land), interest payment (for capital) and profit (for entrepreneurship). Government income is represented by g_i, representing taxes minus subsidies.

Because demand has to equal supply, IO must meet:

$$\forall i: \; x_i = \sum_{j=1}^{n} z_{ij} + y_i = \sum_{j=1}^{n} z_{ji} + w_i + g_i + m_i \qquad \textbf{(1)}$$

The value added created by sector i can be calculated as:

$$v_i = w_i + g_i \qquad \textbf{(2)}$$

This value added is called the gross value added if depreciation is included in the profit (gross profit) and is the net value added if the profit is a net profit (without depreciation). The sum of the gross value added of all n sectors in the economy gives the gross domestic product of a country:

$$GDP = \sum_{i=1}^{n} (w_i + g_i) \qquad \textbf{(3)}$$

$$\textbf{IO} = \left|\begin{array}{ccccc|cc}
z_{11} & z_{12} & z_{13} & \cdots & z_{1n} & y_1 & x_1 \\
z_{21} & z_{22} & z_{23} & \cdots & z_{2n} & y_2 & x_2 \\
z_{31} & z_{32} & z_{33} & \cdots & z_{3n} & y_3 & x_3 \\
\vdots & \vdots & \vdots & \cdots & \vdots & \vdots & \vdots \\
z_{n1} & z_{n2} & z_{n3} & \cdots & z_{nn} & y_n & x_n \\
\hline
w_1 & w_2 & w_3 & \cdots & w_n & & \\
g_1 & g_2 & g_3 & \cdots & g_n & & \\
m_1 & m_2 & m_3 & \cdots & m_n & & \\
\hline
x_1 & x_2 & x_3 & \cdots & x_n & &
\end{array}\right| \qquad \textbf{(4)}$$

<u>The standard input-output method</u>

The aim of the standard input-output method in the application under consideration is to split the cost of a product (or project) into (direct and indirect) value added and (direct and indirect) imports, or in other words: to come from round 0 to round n of Figure 4.1. The assumption is made that the elements z_{ij} in the intermediate part of the IO matrix are linear with the total production of commodity j:

$$z_{ij} = a_{ij} x_j \qquad \textbf{(5)}$$

In this way it is possible to define a normalised A matrix, called the technological matrix, with the element a_{ij}

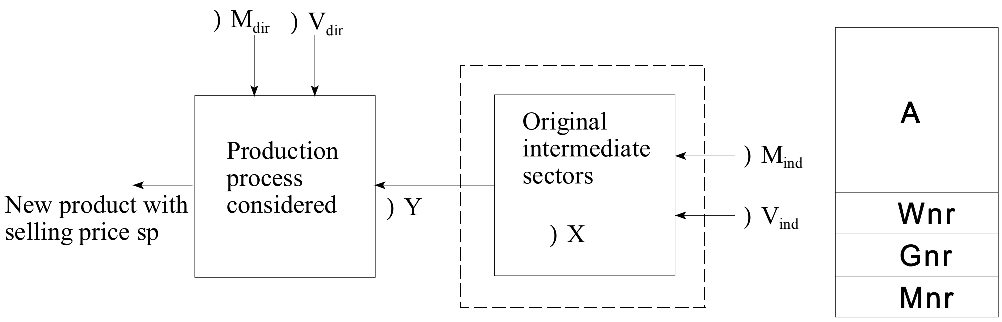
$$\forall_{i,j}: \ a_{ij} = \frac{z_{ij}}{x_j} \qquad \textbf{(6)}$$

In the same way it is possible to normalise (subscript “nr”) the value added and import parts of the IO matrix.

$$\forall_i: \ w_{nr,i} = \frac{w_i}{x_i}; \ g_{nr,i} = \frac{g_i}{x_i}; \ m_{nr,i} = \frac{m_i}{x_i} \qquad \textbf{(7)}$$

Figure 4.2 shows the structure of this normalised matrix and is a schematic representation of the economic system analysed (a, left-hand side) and the technological matrix and its normalised value added and import vectors (b, right-hand side). The arrows represent the flow of products.

FIGURE 4.2: SCHEMATIC OF THE ECONOMIC SYSTEM



The first part of Equation 1 can now be rewritten in matrix terms:

$$X = AX + Y \qquad \textbf{(8)}$$

or

$$(I - A)\, X = Y \qquad \textbf{(9)}$$

where I is the unit matrix. Assuming the inverse of (I-A) exists, multiply both sides by it:

$$(I - A)^{-1} (I - A)\, X = (I - A)^{-1}\, Y \qquad \textbf{(10)}$$

leading to:

$$X = (I - A)^{-1}\, Y \qquad \textbf{(11)}$$

The term $(I\text{-}A)^{-1}$ is called the Leontief inverse. Under the assumption that the average values of the A matrix are also representative for the marginal variation of vector X as a result of a marginal variation in vector Y, then:

$$\Delta X = (I - A)^{-1}\, \Delta Y \qquad \textbf{(12)}$$

In turn, the marginal variation in X has repercussions on the value added and the imports in the economy. The marginal (indirect) variation in imports and value added can now be calculated as:

$$\Delta m_{ind} = M_{nr}\, \Delta X$$
$$\Delta v_{ind} = \Delta W + \Delta G = (W_{nr} + G_{nr})\, \Delta X \qquad \textbf{(13)}$$

Application of the standard IO method to new products

In the application of the standard IO method it is assumed that there is an additional demand for the product (e.g. additional demand for bioethanol) whose macro-economic impact needs to be assessed. Therefore, the production process for this product (e.g. production of bioethanol from biomass) is not yet included in the standard IO table and the direct (round 0) demand for inputs from the existing intermediate sectors (e.g. fertilisers, tractors or diesel) can thus be considered to be exogenous. Therefore, this direct demand of the new production process can be represented as an additional final demand vector ΔY, which will cause an additional production ΔX of the existing productive sectors.[76]

In order to calculate the impact of a certain project or product on the gross domestic product, the cost (c) has to be broken down into direct value added, v_{dir} (=w_{dir}+g_{dir}), direct import, m_{dir}, and direct intermediate expenditures, ine_{dir} (round 0 of Figure 4.1). These direct intermediate inputs have to be converted into a (n x 1) ΔY vector, which means that for each separate cost item it has to be decided in what sector of the national economy it is produced (Equation 14).

$$c = v_{dir} + m_{dir} + ine_{dir} = v_{dir} + m_{dir} + \sum_{i=1}^{n} \Delta y_i \qquad \textbf{(14)}$$

With this ΔY vector, representing the first order (round) of the demand for intermediate products for the project under consideration, the total resulting additional production ΔX in all sectors in the economy can be derived from Equation 12 and the indirect marginal induced imports and value added (Δm_{ind} and Δv_{ind}) from Equation 13. The total value added and import part of the cost can than be calculated as:

$$v = v_{dir} + \Delta v_{ind} = v_{dir} + (W_{nr} + G_{nr})\, \Delta X$$
$$m = m_{dir} + \Delta m_{ind} = m_{dir} + M_{nr}\, \Delta X \qquad \textbf{(15)}$$

By definition, the sum of these two items equals the cost (c) of the product considered:

$$c = v + m \qquad \textbf{(16)}$$

With data on the employment per sector (e_i) and the direct employment creation of the project under consideration (e_{dir}) it is now also possible to calculate the total employment created by the project. Therefore, it is again necessary first to normalise the employment figures:

$$\forall_i : \quad e_{nr,i} = \frac{e_i}{x_i} \qquad \textbf{(17)}$$

after which the total employment creation can be calculated in a similar way as in Equation 15 :

[76] In the specific case of electricity supply to a national grid, it can also be stated that the consumer cannot determine the way in which the electricity is produced and is therefore ignorant about this. Therefore, the forward linkage of electricity is independent of the way in which it is produced.

$$e = e_{dir} + \Delta\, e_{ind} = e_{dir} + E_{nr}\, \Delta X \qquad \textbf{(18)}$$

Employment per sector could be split into different types of employment, such as low, medium and high cost employment. In this case, each type of employment gives one input vector e_i and one resulting vector e.

Level of aggregation in standard input-output tables

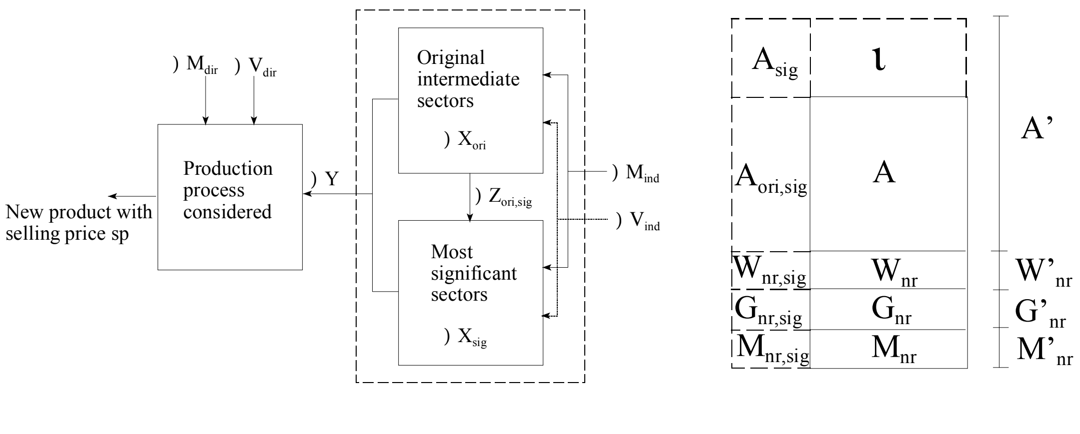
In addition to some general shortcomings of the input-output methodology, the most important shortcoming of this application for bioethanol is likely to be the level of aggregation of the input-output transaction table that is normally available. This may lead to significant distortions in the calculation of indirect impacts of the project under consideration. For example, if in a biomass energy system one needs a certain amount of chemical fertiliser, in the standard input-output method this may be seen (dependent on the level of detail of the input-output transaction table available) as a product produced by the sector "chemical industry". The indirect impact that is calculated is the indirect impact of an average product from this industry. This could be not at all representative of the indirect impact actually caused by the production of the additional chemical fertiliser. Therefore, the next section presents a way of dealing with this level of aggregation by collecting additional data on the most significant economic sectors for the product under consideration.

Modified input-output method: the use of an extended IO table

Figure 4.3 shows a schematic representation of adapted analysis of the economic system (a, left-hand side) and modified structure (b, right-hand side) of the transaction matrix (A') and the normalised value added and import vectors.

Here a modified IO method is described in which an extended IO table is used. In this method additional data have to be collected (at national statistical institutes or by interviews in the field) for those sub-sectors that give a significant direct or indirect supply of intermediate goods for the production of the considered product. These products were included in aggregated sectors in the original input-output table. This means that part of the additional intermediate production (ine_{dir}, converted into ΔY) comes from these newly created sectors, which in turn require intermediate products from other sectors ($\Delta Z_{ori,sig}$ in Figure 4.3a and $A_{ori,sig}$ in Figure 4.3b). The dotted line in Figure 4.3a indicates the economic system considered in the extended transaction table A' of Figure 4.3b.

FIGURE 4.3: USE OF EXTENDED IO TABLE



Because in this method the marginally created intermediate demand only serves the production of the product considered (being the marginal final demand ΔY in this method), the newly created sectors do not supply to the original sectors of the standard IO table. Therefore this intermediate part of the input-output table contains zeros only (Figure 4.3b). The inputs (columns) of each of these new sectors can consist of input from other newly created sectors (A_{sig}), input from one of the original n sectors of the standard input-output table ($A_{ori,sig}$), imports (M_{sig}), and value added (W_{sig} and G_{sig}).

The extent to which additional data are collected for newly created disaggregated sectors depends on the time available, the level of aggregation of the original input-output table and the required accuracy of the analysis. With the newly created A', W'_{nr}, G'_{nr} and M'_{nr} the calculation method is the same as with the standard input-output method.

Adaptation of the I/O table in practice

It is necessary to consider whether to adapt a sector in the IO table. There are basically four reasons for a sector i in the I/O table to be adapted:

1. If the product under consideration has a relatively large share in a certain sector i.
2. If the sector i is inhomogeneous
3. If the sector i is indeed homogeneous, but the product under consideration is not represented by the average of the sector i.
4. If the way in which the sector is represented in the IO table is unreliable, e.g. if the sector is outdated or based on data that are assumed to be incorrect.

A consideration that has to be made is the time needed for the adaptation of the sector, and the importance of the adaptation. It is also important to consider how to adapt the IO table. Adaptation of the IO table is time-consuming since some major and/or representative producers in the sector under consideration need to be questioned. Basically three questions have to be answered by these producers - What do they produce? Who do they buy from (including labour)? Who do they sell to?

With the answers to these questions the IO table can be extended with a new sector. However, for this study it was not considered necessary to extend the IO table because on the scale envisaged in the UK the prospective bioethanol industry does not have any of the characteristics listed above.

Allocation to sectors

The national Input-Output tables contain 138 industry/product groups, comprising 123 market sectors, 6 non-market central government sector and 9 other non-market sectors. A large number of these sectors are redundant for the purposes of this analysis, since they are not directly relevant to the costs of bioethanol production. However, an allocation has to be made, using an assessment of the contributions to costs from each component of the production, conversion and supply pathways.

Data were used from the national Input-Output tables[77], as outlined above.

Table 4.1 lists the sectors to which allocations have been made for the bioethanol production chain (and for the gasoline reference production chain).

[77] "UK Input-Output Analytical Tables, 1995 – 2002 Edition", HMSO, London , 2002, available from www.statistics.gov.uk

TABLE 4.1: ECONOMIC SECTORS USED IN THE INPUT-OUTPUT ANALYSIS

Ref.	Industry/product group
1	Agriculture and related service activities
2	Forestry, logging and related service activities
5	Extraction of crude petroleum and natural gas
12	Grain mill products, starches and starch products
13	Prepared animal feeds
15	Sugar
37	Other inorganic basic chemicals
38	Other organic basic chemicals
39	Fertilisers and nitrogen compounds
40	Pesticides and other agro-chemical products
61	Other fabricated metal products
63	Other general purpose machinery
64	Agricultural and forestry machinery
66	Other special purpose machinery
85	Production and distribution of electricity
86	Gas, distribution of gas fuels, steam and hot water
88	Construction
91	Retail distribution
94	Other land transport
100	Banking and finance
101	Insurance and pension funding
110	Accounting and auditing
111	Market research and management consultancy
112	Architectural and engineering consultancy

ANNEX 5

BIOMASS-TO-ETHANOL AND PETROLEUM-TO-GASOLINE FUEL CYCLES

5.1 INTRODUCTION

In recent years, there have been many studies of the life-cycle of transport fuels, including both petroleum-derived fuels, and biomass fuels. Such "well-to-wheels" studies have generally aimed at identifying the energy use and greenhouse gas emissions associated with each stage of the life-cycle of various fuels, and thereby producing comparisons between different fuel types of the energy and environmental impacts of the complete life-cycles.

The total fuel cycle energy use and greenhouse gas emissions for biomass-to-ethanol and petroleum-to-gasoline fuel cycles are normally calculated by adding the energy use and emissions for each stage in the production and processing chain. The chain comprises essentially the production and transport of the feedstock, followed by the processing, manufacturing and transport of the vehicle fuel. The complete life cycle includes the final use of the fuel in the vehicle through combustion in an internal combustion engine, but for the purpose of this study, it is not proposed to examine the fuel end-use in the vehicle. Hence the analysis for this study will cover the "well-to-tank" or "field-to-tank" stages of the fuel cycle. Analysis of the fuel cycles for both biomass-to-ethanol and petroleum-to-gasoline are required in this study, with the gasoline fuel cycle being used in the reference scenario for baseline comparison.

A literature review, covering studies from UK, other EU and US sources, was undertaken in order to assess the most useful reports and data sets for this present study. Key issues in these various studies are the differing methodologies, and differing energy and emissions assumptions regarding the boundaries of the fuel production and utilisation processes. Other differences occur in the ways in which processing and production energy use is allocated to the particular fuel under investigation, and in the treatment of co-products (eg diesel fuel in the case of petroleum) and by-products (eg animal feed products in the case of biomass fuels) in the processing stage. Furthermore, there can be large variations in the actual fuel feedstock, and in the efficiencies and techniques used in different stages of each life-cycle, as reported in the various studies. Hence it is important to set transparent and consistent assumptions, and to use data that are as robust as possible.

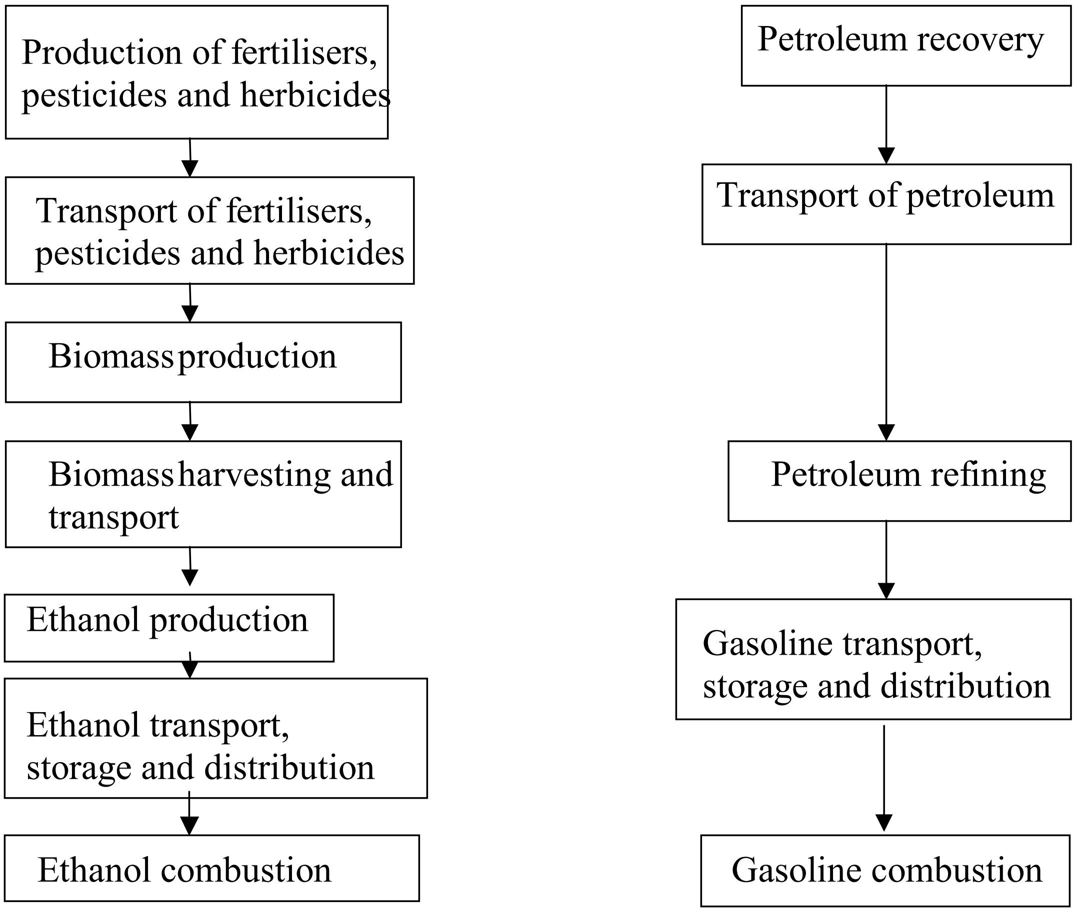
The fuel cycles for biomass-to-ethanol and petroleum-to-gasoline are illustrated in Figure 5.1:

5.2 PETROLEUM TO GASOLINE

The principal stages that make up the life-cycle of petroleum-to-gasoline are:

1. Petroleum recovery from crude oil extraction;
2. Transport of petroleum from the extraction site to the refinery;
3. Petroleum refining in order to manufacture gasoline;
4. Gasoline transport, storage and distribution;
5. End-use of the fuel in vehicles through gasoline combustion.

FIGURE 5.1 FUEL CYCLES



Oil refineries convert crude petroleum oil into a number of useful products. These include liquefied petroleum gases (LPG), naptha for petrochemical feedstocks, gasoline (motor spirit), kerosene for aircraft fuel and burning oil, diesel, gas oil, heavy fuel oils and bitumen. A proportion of the product streams is also used internally in the refinery for process fuel. The refinery itself involves a range of complex steps that can be optimised to meet the product mix required. To analyse the energy use, CO2 emissions and economics of modern oil refining it is necessary to consider a number of issues:

- The crude oil feedstocks;
- The refinery configuration;
- The demand for products;
- The specification of products.

The UK produces more than enough crude oil from its North Sea fields to meet domestic demand, but both export and import trade takes place. This is because UK crude oil generally contains lower levels of contaminants such as sulphur, and it can command a higher price than other crude oils on the international market. UK crude oil also has a higher proportion of lighter hydrocarbons, resulting in higher yields of valuable products such as gasoline. Hence it is financially attractive to export some of the UK's crude oil production. Around 75% of UK oil production was exported in 2000, and imported crude oil accounted for 60% of UK requirements. For the purposes of this study, the imported crude oil can be considered to be sourced from Middle East oil fields.

There is a large variation in the efficiency of extraction of crude oil from the North Sea fields. These variations are mainly due to differences in operation. Transportation of crude oil from the North Sea to UK refineries is carried out by sea tankers and to a lesser extent by pipeline. Transport from Middle East fields is by large capacity crude tankers.

In the refinery, crude oil is initially distilled at atmospheric pressure and the various fractions are separated according to their boiling point for further processing to the useful end-products. Light fractions are used primarily to make naptha and gasoline, whilst middle fractions are used to produce gas oil and kerosene. The heaviest fractions are distilled again under vacuum to produce gas oil and other residues. Several different processes are used in the production processes. The vacuum gas oil can be upgraded by fluid catalytic cracking (FCC) and/or hydrocracking. Fluid catalytic cracking converts vacuum gas oil to a gasoline blending component and light cycle oil with a low cetane number for blending into the diesel/gas oil pool. Hydrocracking units crack vacuum gas oil, in the presence of hydrogen, to produce naptha, high quality kerosene and a high cetane number diesel.

Not all refinery products require the same amount of energy for production. This means that energy use and emissions have to be attributed to the correct products, by using data on production efficiencies and the quantities produced for the different products. Data have been obtained from several studies in order to assess the extent of currently available information to provide the baseline for costs, energy use and CO_2 emissions from the petroleum-to-gasoline fuel cycle.

The most recent European-based study of the “well-to-wheels” greenhouse gas emissions from a wide range of different fuels was initiated by General Motors (GM) in 2001. Major global energy companies BP, ExxonMobil, Shell and TotalFinaElf were active participants in the study. The results of the GM study have been published by L-B Systemtechnik of Germany[78]. This work provides a comprehensive analysis of greenhouse gas emissions throughout the whole fuel supply chain for fossil fuels, biofuels and other vehicle fuel pathways, and offers a set of data which are derived from a consistent methodology applied in a rigorous manner.

Greenhouse gas emissions during vehicle operation are 73.4 g CO_2/MJ gasoline, assuming that all of the carbon contained in the fuel is released as carbon dioxide. However, because combustion of the fuel is not fully complete, some of the carbon is emitted as carbon monoxide, and other emissions such as nitrous oxides, both of which are more powerful greenhouse gases than carbon dioxide.

Greenhouse gas emissions expressed as grams of CO_2 equivalent/MJ gasoline for the manufacture of gasoline are shown in Table 5.1 below, which includes results from several studies carried out in recent years:

[78] “GM Well-to-wheels analysis of energy use and greenhouse gas emissions of advanced fuel/vehicle systems – a European study”, LB Systemtechnik GmbH, Ottobrunn, Germany, September 2002.

TABLE 5.1: GREENHOUSE GAS EMISSIONS FROM THE PETROLEUM TO GASOLINE FUEL CHAIN

	GM	ADL[79]	ETSU[80]	Concawe[81]	IEA[82]	Shell[83]
Crude oil production	3.7	3.0	3.4	2.5-4.25	2.1	3.4
Crude oil transport	0.9	0.7	0.6	1.0-2.67	1.0	1.3
Refining	7.4	4.5	6.1	13.0-17.17	5.6	6.5
Distribution	1.1	1.0	0.2	1.49-1.5	0.8	0.4
Total	**13.1**	**9.2**	**10.3**	**18.0-25.5**	**9.5**	**11.6**

As can be seen, there is a very wide range of values of greenhouse gas emissions from these various studies. In the GM study, the assumptions are that a representative European crude oil mix is delivered via maritime vessel or pipeline from the North Sea to a UK coastal oil refinery. Refining of crude oil to gasoline (<10ppm sulphur content), diesel (<10ppm sulphur content) and naptha (<0.4ppm sulphur content) is carried out. Each of these products is delivered via pipeline, coastal shipping or rail to an oil depot. Final distribution to the retail refuelling station is over a distance of 150 km via road tanker.

5.3 BIOMASS TO ETHANOL

The principal stages that make up the life-cycle of biomass-to-ethanol are:

1. Production of fertilisers, pesticides and herbicides;
2. Transport of fertilisers, pesticides and herbicides to the biomass production site;
3. Biomass production through farming and cultivation;
4. Biomass harvesting and transport to the processing site;
5. Biomass processing in order to manufacture ethanol;
6. Ethanol transport, storage and distribution;
7. End-use of the fuel in vehicles through ethanol combustion.

Ethanol from sugar beet

For the conversion of sugar beet to ethanol, the GM study made the assumptions that sugar beet is cultivated, collected and transported over an average 50 km to an ethanol production plant. There the biomass is split up by fermentation and via distillation converted to ethanol. The ethanol is transported over an average 150 km in road tankers to the oil depot and blended into gasoline at 5% concentration.

The assumptions on the use of by-products, the reference crop system and field emissions of N_2O can have a dramatic impact on the energy and greenhouse gas balances. The results from the GM study for the greenhouse gas emissions from a range of different options are shown in g CO_2/MJ ethanol in Table 5.2:

[79] "Analyses and evaluation of GAVE chains", AD Little, Utrecht, December 1999.
[80] "Alternative road transport fuels – a preliminary life-cycle study for the UK", ETSU R92, Harwell, 1996 (study co-funded by DTI and DoT).

[81] "Alternative fuels in the automotive market", Report 2/95, Concawe, Brussels, October 1995.
[82] "Automotive fuels survey – raw materials and conversion", International Energy Agency, Paris, December 1996.
[83] "Well-to-wheels energy use and greenhouse gas emissions for various vehicle technologies", Shell Global Solutions, London, 2001

TABLE 5.2: GREENHOUSE GAS EMISSIONS FROM THE ETHANOL FROM SUGAR BEET FUEL CHAIN

Option	**1 a**	**1 b**	**1 c**	**2 a**	**2 b**	**2 c**	**3 a**	**3 b**	**3 c**
Cultivation	33.3	33.3	23.5	29.7	29.7	20.9	10.3	10.4	7.3
Feedstock transport	4.1	4.1	2.9	4.1	4.1	2.9	4.1	4.1	2.9
Ethanol production	-70.7	-52.2	-24.2	-70.7	-54.5	-24.2	-70.7	-46.5	-24.4
Ethanol distribution	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Total	**-32.4**	**-13.9**	**3.0**	**-36.0**	**-19.8**	**0.5**	**-55.4**	**-31.2**	**-13.3**

The different options used in these calculations are set out in Table 5.3:

TABLE 5.3: OPTIONS FOR THE AGRICULTURAL REFERENCE SYSTEM AND BY-PRODUCT UTILISATION

Option	**Agricultural reference system**		**By-product utilisation**
1	Rotational set-aside planted with Egyptian clover with N_2O calculated according to the IPCC[84] guidelines	1 a	Sugar beet pulp used as fuel
		1 b	Sugar beet pulp used as animal feed
		1 c	Ethanol produced in sugar refinery
2	Rotational set-aside planted with rye grass with N_2O calculated according to the IPCC guidelines	2 a	Sugar beet pulp used as fuel
		2 b	Sugar beet pulp used as animal feed
		2 c	Ethanol produced in sugar refinery
3	Production of ethanol from beets in conjunction with sugar production and N2O emissions calculated according to Ecobilan[85]	3 a	Sugar beet pulp used as fuel
		3 b	Sugar beet pulp used as animal feed
		3 c	Ethanol produced in sugar refinery

A recent UK study by Sheffield Hallam University has examined in detail the greenhouse gas emissions from a variety of biomass conversion processes[86]. For sugar beet and wheat feedstocks, this study calculated greenhouse gas emissions at the point of distribution for bioethanol as:

- Sugar beet = 40 g CO_2 equivalent/MJ bioethanol;
- Wheat = 29 g CO_2 equivalent/MJ bioethanol;

The data for sugar beet are broadly comparable with the data for scenario 2a in Table 3.2 of the GM study.

Another UK study[87] has given the following values greenhouse gas emissions for the whole production, conversion and supply chain:

- Gasoline = 87 g CO_2 equivalent/MJ gasoline;
- Sugar beet = a range between 30 and 106 g CO_2 equivalent/MJ bioethanol;
- Wheat = a range between 56 and 77 g CO_2 equivalent/MJ bioethanol;

[84] "Guidelines for national greenhouse gas inventories – reference manual agriculture", Intergovernmental Panel on Climate Change, New York, 1996
[85] "Eco-balance of ETBE from sugar beet: comparison with MTBE", Ecobilan SA, Paris, March 1996
[86] "Carbon and energy balances for a range of biofuels options", draft report by N Mortimer et al, Sheffield Hallam University, March 2003.
[87] Woods, Imperial College, London, private communication, 2003.

A further recent study has reviewed results from several EU projects[88]. The data have been collected from different projects around Europe that use a variety of assumptions, not all of which are consistent. However, the overall picture can be indicated by looking at the average figures for greeenhouse gas emissions savings with and without animal feed credits. These data are for the use of wheat as the feedstock material, and give a 37% reduction with these credits and 26% without.

Ethanol from ligno-cellulosic biomass

In the GM study, the assumptions are that ligno-cellulosic biomass in different form such as crop residue (eg straw), sugar beet pulp or dedicated crop plantation (eg poplar) is collected and transported over an average 50 km to an ethanol plant. There the biomass is split up by enzyme hydrolysis and fermented and via distillation converted to ethanol. The ethanol product is transported over an average 150 km in road tankers to the oil depot and blended into gasoline fuel at 5% concentration.

The GM study results for greenhouse gas emissions expressed as grams of CO_2 equivalent/MJ ethanol are shown in Table 5.4:

TABLE 5.4: GREENHOUSE GAS EMISSIONS FROM THE ETHANOL FROM LIGNO-CELLULOSIC BIOMASS FUEL CHAIN

	Crop residue straw	**Sugar beet pulp**	**Poplar plantation**
Biomass supply	6.2	-	29.9
Ethanol production	-62.8	-71.3	-60.1
Distribution	0.9	0.9	0.9
Total	**-55.7**	**-70.3**	**-29.3**

The greenhouse gas emissions from ethanol production have a negative value because, in the analysis used in the GM study, the carbon from the biomass partly leaves the pathway as product. During operation of the vehicle, the biomass-derived carbon will be emitted at the rate of 71.3 g CO_2/MJ ethanol.

The recent UK study on greenhouse gas emissions from a variety of biomass conversion processes[89] gave the following data for greenhouse gas emissions from ligno-cellulosic feedstock at the point of distribution for bioethanol as:

- Wheat straw= 16 g CO_2 equivalent/MJ bioethanol;

Another recent UK study[90] has given the following values greenhouse gas emissions for the whole production, conversion and supply chain:

- Wheat straw = a range between 23 and 72 g CO_2 equivalent/MJ bioethanol;
- Short rotation coppice = a range between 4 and 39 g CO_2 equivalent/MJ bioethanol.

[88] "Energy and greenhouse gas balance of biofuels for Europe – an update", CONCAWE, Brussels, April 2002.
[89] "Carbon and energy balances for a range of biofuels options", draft report by N Mortimer et al, Sheffield Hallam University, March 2003.
[90] Woods, Imperial College, London, private communication, 2003.

ANNEX 6

DETAILED INFORMATION ON CROP AND WASTE STREAM COST INPUT DATA

6.1 WHEAT (INCLUDING STRAW)

DESCRIPTION OF CROP

Wheat accounts for the greatest single area of any arable crop, in recent years accounting for between 1.8 and 2.0 million hectares per year in the UK. Modern wheat varieties have been bred to produce high grain yields in response to a range of management practices. They have achievable potentials of between 9 to 12 t of grain per ha., with a harvest index of 50 to 55%.
Across the UK the actual achieved yield is lower due to a number of factors including the growing of take-all infected non-first wheats, foliar disease epidemics, errors in fertiliser rates etc. In practice the average yield is close to 7.5 t/ha @ 85 % dry matter, which is equivalent to 6.4 t dm/ha. Using the harvest index stated above this would indicate a total biomass production of 13-14 t dm/ha. Wheat grown as an industrial crop is unlikely to be grown as a first wheat, as these produce the highest gross margin on many arable farms. The level of production of wheat grown as an industrial crop is therefore likely to be closer to the national average than the potential stated above.

PHYSICAL DESCRIPTION

The majority of winter wheat is planted in September or October. It emerges usually in about 10-14 days and produces fairly complete ground cover 6-8 weeks later. It growth habit remains prostrate, producing leaves and shots over the winter and early spring until the stems extend in April. Stem extension is usually complete in June producing a crop 80-100 cm tall. The crop remains predominantly green until July when the grain is ripening and the crop turn a golden colour.

BIOLOGICAL LIMITS TO DISTRIBUTION

Wheat can be grown on a range of soil types with reasonable water holding capacity. Modern varieties respond to good fertility. Yield can be affected by previous cropping. If planted as a second or third wheat crop, take-all can depress yield.

TABLE 6.1 CROP DESCRIPTION WHEAT

1.1	Crop Name (+ Latin): Winter wheat (*Triticum aestivum*)
1.2	Crop Type (i.e. domestic/industrial bi-product or annual/perennial crop) <u>Annual crop</u>
1.3	Physical characteristics: Winter wheat is sown between September and February and grows slowly until the stem extension in April. Stem extension is usually complete by June, and the crop remains predominantly green until July when the grain is ripening and the crop turns a golden colour. At Harvest the grain accounts for approximately 50-55% of the total above ground biomass of the crop. Average UK wheat yield 7.68 tonnes (mean 1997 –2002. Source Defra)
1.4	Chemical composition of cereals[91]. Gross Energy (MJ/kg DM) Starch, small carbohydrates: 75.6% (+/- 8) Protein 14.5% (+/- 4) Lipid 2.0% (+/- 1) Cellulose Hemicellulose, Pentosans 5.7% (+/- 1) Minerals 2.2 (+/- 0.3)
1.5	Harvesting Period (Month[s] of the year in which crop is available) **August - Sept**

* *These values are available from proximate analyses of feedstuffs where appropriate*

[91] Kent, N.L. and Evers, A.D. (1994) . Technology of Cereals. *4th Edn.* Pergamon

TABLE 6.2. WHEAT PRODUCTION COSTS Production Costs (All figures per ha, assuming 8.00 tonnes of grain)[92]

		Nix	Crop Centres	ADAS	Cambridge
2.3.1	Seed/planting material	33.60	40	38.6	37.4
2.3.2	Cultivations + In crop operations (application of sprays and fert) Plough Heavy Discs Power Harrow / Drill Spray x 5 Fertiliser x 3	 36 23 33.50 35 24.90	 38 24 29.5 37.5 22.5	 **	 37 23.5 31.5 36.25 23.7
2.3.3	Fertiliser	82.7	80	69.7	77.47
2.3.4	Herbicides	40			
2.3.5	**Insecticides**	1.50			
2.3.6	Fungicides	48.13			
2.3.7	Other (Growth regulators etc)	5.94			
2.3.8	Sprays	95.57	105	115.7	105.42
	Harvest and Storage	£/ha			
2.3.9	Cost of harvesting	56.83	66.00	**	
2.3.10	Cost of transport from field to on farm storage area	13.75	**13.75**	**	13.75
2.3.11	Cost of Storing the crop#	25.34	**25.34**		25.34
	Costs of transport to processing plant				
2.3.12	On farm Loading/Handling cost	11.52	**11.52**		11.52
2.3.13	Haulage cost	41.32*	41.32*	41.32*	41.32
2.3.14	Total Labour			105	
2.3.15	Total Machinery**			178	
	Total for field operations & lab.	259.84~	268.11~	283	270.32

** Figures for Eastern Region at 7.68 t/ha and £5.38/tonne (Costs per 50 mile journey) Source HCGA Haulage Costs Survey*
 # Assume 3 months storage
~ Total from field operations and harvest values in table above

Labour and Machinery Costs

The various sources of farm operating costs offer data on field operations in various ways. Nix gives the most comprehensive view with Farmer and Contractor costs listed showing the total labour and machinery costs per specific operation. The ADAS field operation figures are from the

[92]Sources of data J. Nix Farm management pocketbook 2003, ADAS Gross Margins (Crop Centres 2002) Farming in the Eastern Counties (University of Cambridge) 2000-2001. Publ 2002

an ADAS database mean values representing a composite from various farmer, trade and reference sources and aim to represent the cost of farm operations with average machinery.

Both Nix and the University of Cambridge present composite labour and machinery data as fixed costs per hectare figures. These are listed in the table below. The data is for mainly cereal farms and for mixed cropping farms. The latter being more applicable for sugar beet production

TABLE 6.3. FIXED COSTS BREAKDOWN (£/HA)

	Nix (100-200 ha farm)		Cambridge	
	Mainly Cereals	Mixed Cropping	Mainly Cereals	Mixed Cropping
Labour	175	200	105	198
Machinery				
Depreciation	75	80	88	119
Repairs	40	60	46	77
Fuel, Oil, Elec	40	50	35	51
Tax & Insurance	10	12.5	9	12
SUB TOTAL	165	202.5	178	259
Contract	45	52.5	32	35
	210	255	210	294

The Cambridge data are for 2000/1whereas the Nix values are forecast for application in 2003. The indices for price adjustment between the 2000/1 financial year and the calendar year just finished are 1.086 for the repair of motor vehicles; 1.080 for the repair of plant; 1.009 for tyres and tubes; 0.972 for machinery and other equipment; 0.988 for tractors ; 0.908 for energy and lubricants. The net effect of such changes to update the Cambridge values would be small.

The Nix values for grouped fixed costs are higher than the per hectare totals of the field operations. The difference is a reflection of the costings based on individual field operations per crop, and a more inclusive approach taking the farm business as a whole

6.2 THE SUPPLY CHAIN – WHOLE CROP WHEAT

It is unlikely that whole crop wheat will be an option for harvesting for ethanol production at present. The mixture of starch based material from the grain and ligno-cellulosic material from the straw would provide a sub-optimal mixture for storage and fermentation. Harvesting, storage and handling of the grain and straw as separate entities will give lower handling and storage losses and greater flexibility of trading and processing

Production Costs (£/ha)

The production costs would be the same as for normal cereal production, as on most farms conventional grain harvesting would also be likely.

The net effect on costs would be and additional £20 per hectare for each hectare harvested. (*This is the extra cost of contract forage harvesting and carting, over and above the contract costs of combining and carting cereals. Source Nix 2003*)

6.3 SUGAR BEET

PHYSICAL DESCRIPTION

Sugar beet is sown in late March or early April in drills 50 cm apart and seeds 15 cm apart. The target plant population is between 75,000 and 90,000 plants per hectare. The dicotyledonous seedlings emerge 2-3 weeks after drilling. The plants continue to produce leaves from a crown, increasing the level of green cover so that full leaf canopy is achieved by mid to late June. Leaves reach a maximum height of 60-70 cm. This canopy remains until destroyed by pest, disease, wilting or the beet is lifted. From mid June until winter the root develops. The shoulders of the expanding roots are hidden by the green canopy. The roots are harvested from the end of September through to January. (October/November being the main harvesting period). The roots are removed from the field whilst the tops are left for grazing, or are ploughed-in. As sugar beet is a biennial plant no flower or seed is produced in the first year.

BIOLOGICAL LIMITS TO DISTRIBUTION

As sugar beet is harvested in the Autumn/Winter, such crops need to be confined to light and medium soils in order to minimise damage to the soil structure and to reduce soil tares.
Sugar yield is directly related to the amount of sunlight intercepted, this is affected by crop management more than location within the UK. There is a need for adequate soil moisture either naturally or through irrigation so as to prevent premature wilting. Drought susceptible soils should be avoided unless irrigation is available.

TABLE 6.4. THE SUPPLY CHAIN – SUGAR BEET

4.1.1	Crop Name (+ Latin): Sugar beet (Beta vulgaris)
4.1.2	Crop Type (i.e. domestic/industrial bi-product or annual/perennial crop) <u>Biennial crop producing sugar storing beet in the first year, shooting to produce seeds in the second year.</u>
4.1.3	Physical characteristics: Beet is sown in spring when the risk of serious frosts has passed. usually from mid-late March, with late crops being sown in early May. It is vulnerable to weed competition in the early stage of growth and herbicide costs make up a significant proportion of the growing costs. Average yields of beet are between 40 and 60 t /ha fresh weight, with sugar typically making up 16 -18% of the crop.
4.1.4	Chemical composition of sugar beet roots[93]. 23 –24.6% dry matter Gross Energy (MJ/kg DM) 17.6 MJ/kg DM Sucrose 64.7 – 70 Crude Protein 4.7 – 6.8 Lipid (Ether extract) 0.3 – 0.6 Crude fibre 4.9 – 6.3 Ash 5.0 –8.1 α-amino nitrogen 0.7 – 1.1 Molasses (73 –79% dry matter) which will be the base material for fermentation, has the composition below Sucrose 43.0 –50.5 Crude Protein 6.6 – 11.1 Lipid (Ether extract) 0.0 – 0.3 Crude fibre 0.0 – 0.3 Total N-containing compounds 11- 16 Betaine 4 – 5 Amino acids, pyrrolidone carboxylic acid, peptides, nucleic acids 3 – 4 Amino acid sugar complex 1 – 2 Anions Chloride 1.0 – 3.0 Sulphate 0.6 – 2.0 Phosphate 0.1 – 0.5 Nitrate 0.3 - 0.8 Nitrite 3.0 – 170 mg/kg
4.1.5	Harvesting Period (Month[s] of the year in which crop is available) **Harvest in normally from late September/ early October to February. Severe frosts can cause some crop damage and increase rotting in lifted stored beet.**
4.1.6	Storage losses (% loss of ethanol source material over time) consensus of the findings. It is estimated that beet in store lose 0.1% of their total sugar per day whilst in store

[93] OECD. 2002. Consensus Document on Compositional Considerations for New Varieties of Sugar Beet: Key Food and Feed Nutrients and Antinutrients

TABLE 6.5. SUGARBEET PRODUCTION COSTS (£/HA) (ALL FIGURES PER HA UNLESS STATED. YIELD ASSUMED TO BE 53 T/HA [MEAN OF 1996 –2001])

		Nix	Crop Centres	ADAS	Cambridge
4.3.1	Seed/planting material (if perennial indicated that this is a one off payment)	147.7	130	141	139.57
4.3.2	Cultivations + In crop operations (application of sprays and fert) Ploughing Power Harrowing Precision Drilling Spray x 5 Fert x 2	 35 23.50 31.5 35 16.6	 38 24 31.5 37.50 15	 **	
4.3.3	Fertiliser	82.0	90	154.8	108.93
4.3.4	Herbicides	60.7			
4.3.5	Insecticides	8.1			
4.3.6	Fungicides	10.5			
4.3.7	Other (Growth regulators etc)	4.4			
	Sprays	83.7	130	148.0	120.57
	Harvest and Storage				
4.3.8	Cost of harvesting	(150)	150	(150)	
4.3.9	Cost of transport from field to on farm storage area	45		**	42.50
4.3.10	**Cost of Storing the crop** Assumption that 0.1 % of the total sugar is lost per day of storage	6*	6*	6*	
4.3.11	Costs of transport to processing plant				
4.3.12	On farm Loading/Handling cost		60.4		
4.3.13	Haulage cost	(169.6)	169.6	180#	205
4.3.14	Total Labour			198	
4.3.15	Total Machinery**			259	
	Total for field operations & lab.~	506	526	457	496.33

Mean of farmer and contractor operations minus £7.50 /ha for non-loading&haulage activities
* Mean value of production 1996 –2001 (Defra) stored for 30 days at 0.1% loss
~ *Total from field operations and harvest values in table above*

Unlike cereals, the price of which has recently come into line with world markets, reform of the sugar market is likely to see reductions in prices paid for beet, with decoupled compensation making good some of the impact on farm incomes.

Table 6.6, based on the data in the Cambridge costings show the impact on Net Farm Income if the gross output of beet enterprises are reduced by 50% for mainly cereal and mixed cropping farms.

TABLE 6.6. SENSITIVITY OF FARMING VENTURES TO THE VALUE OF SUGAR BEET

All farms	2000/1 data	Beet output @ 50%
Mainly cereals	51.8	27.3
Mixed cropping	66.3	-23.5

Top 10% of farms		
Mainly cereals	235	184
Mixed cropping	534	440

Average mixed cropping faces the most severe impact on income, largely as a result of a greater area percentage of the total gross margin coming from beet. The same effect can be seen in the top 10% of farms, but the much higher performance keeps the net farm income strongly positive

All the above 50% scenarios assume there is no change in input levels, or farm structure. Clearly with a 50% reduction in gross output this is unlikely to be the case. However as with all economic change the figures clearly show it will be the poorer performers who are hardest hit, and it is they who will get out of the crop. This may be accompanied by the movement of quota to other, more efficient growers, but scope for this may be affected by reforms and trade agreements.

One knock on effect of reduced beet prices could be a reduction in the amount of C quota beet. A 50% reduction in beet price will reduce the fertiliser optimum slightly. However such changes are small, any reductions in fertiliser use on cereals over the last 5 or 6 years has been minimal.

6.3 OATS

DESCRIPTION OF CROP

The growing of oats has declined over the past century from being the most widely grown cereal occupying an area of 1.2 -1.3 million hectares at the end of the 19th century to approximately 0.12 million hectares in 2002 . Roughly half of the oats currently produced are for human consumption the remainder either being used for animal feed (principally horses) or exported.

The yield of oats whilst on average 1.5 -2.0 t/ha less than wheat are on a par with barley. This equates to a yield of 5.5 t/ha @ 85% dm, included in this figure are both winter (70%) and spring (30%) oats if only winter oats are included this figure could be expected to be 6.0 t/ha @ 85% dm or a dry matter yield of 5.1 t/ha. The harvest index of oats is close to that of wheat at about 45% which would result in a total biomass using the average yield 5.1 t dm/ha of 11.3 t dm/ha.

Oats are a relatively 'low input' crop compared to other arable crops. They have rotational benefits in a cereal dependant arable system by virtue of their resistance to the main strain of take-all attacking either wheat or barley. The grain has a unique protein composition. It also has a high oil and soluble fibre content. There are industrial opportunities for the fractionation products of the oat crop.

PHYSICAL DESCRIPTION

The majority of winter oats are planted in September. It emerges usually in about 10-14 days and produces fairly complete ground cover 6-8 weeks later. It remains low growing producing leaves and shots over the winter and early spring until the stems start to extend in late April or early May. Stem extension is usually complete in June producing a crop 100 - 120 cm tall. The crop remains predominantly green until July when the grain is ripening and the crop turns a golden colour. Harvest usually occurs a week or two before the main winter wheat harvest.

BIOLOGICAL LIMITS TO DISTRIBUTION

Oats can be grown over a range of soils and climates and are suitable for most arable areas in the UK. Highly fertile situations could create a risk of lodging. Oats are more tolerant of low lime status than other cereals. The winter hardiness of some varieties maybe a concern in some exposed locations.

TABLE 6.7.PRODUCTION COSTS FOR OATS (ALL FIGURES PER HA, ASSUMING 5.85 TONNES OF GRAIN)

		Nix	ADAS	Cambridge	
2.3.1	Seed/planting material	39	40	29.7	
2.3.2	Cultivations + In crop operations (application of sprays and fert) Plough Heavy Discs Power Harrow / Drill Spray x 4 Fertiliser x 3	 36 23 33.50 28 24.90	 38 24 29.5 30 22.5		
2.3.3	Fertiliser	65.3	65	60.9	
2.3.4	Herbicides	31.3			
2.3.5	**Insecticides**	1.5			
2.3.6	Fungicides	37.2			
2.3.7	Other (Growth regulators etc)	5.8			
2.3.8	Sprays	75.8	55	52.7	
		[redacted]			
	Harvest and Storage	[redacted]			
2.3.9	Cost of harvesting	56.83	66		
2.3.10	Cost of transport from field to on farm storage area	13.75	**13.75**		
2.3.11	Cost of Storing the crop#	**19.24**	**19.24**		
		[redacted]			
	Costs of transport to processing plant	[redacted]			
2.3.12	On farm Loading/Handling cost	**8.78**	**8.78**		
2.3.13	Haulage cost	31.47*	31.47*		
2.3.14	Total Labour	[redacted]		105	
2.3.15	Total Machinery**	[redacted]		178	
	Total for field operations & lab	244	252	283	

** Figures for Eastern Region at 5.85 t/ha and £5.38/tonne (Costs per 50 mile journey) Source HCGA Haulage Costs Survey*
 # Assume 3 months storage
~ Total from field operations and harvest values in table above

6.4 Rye

DESCRIPTION OF CROP

Rye (*Secale cereale*) is a minor crop in the UK. It accounted for approximately five thousand hectares in 2002. It is usually sown in the 2nd and 3rd week of September. Largely grown on light infertile sandy or stony soils, where yields are poor for other cereals. Yields would clearly be higher on better soils, but then rye has difficulty in competing with wheat and barley. Rye is drought tolerant and very hardy. It has all-round resistance to wheat and barley diseases and suffers less from take all than wheat. Its vigour also keeps weeds down. It is also harvested before mid august making it earlier than wheat. In a wet harvest it sprouts in the ear creating harvesting difficulties. It grows very tall and lodges easily. Hence high levels of nitrogen are not possible. The large quantity of straw means very slow combining. New varieties with shorter stiffer straw are being developed

TABLE 6.8. PRODUCTION COSTS – Rye. (All figures per ha, assuming 5.7 tonnes of grain)

		Nix	ADAS	Cambridge	
2.3.1	Seed/planting material	65	75		
2.3.2	Cultivations + In crop operations (application of sprays and fert) Plough Heavy Discs Power Harrow / Drill Spray x 4 Fertiliser x 3	 36 33.50 28 24.90	 38 29.5 30 22.5		
2.3.3	Fertiliser	66.6	60		
2.3.4	Herbicides	18.0			
2.3.5	**Insecticides**	1.5			
2.3.6	Fungicides	34.0			
2.3.7	Other (Growth regulators etc)	9.7			
2.3.8	Sprays	63.2	75		
	Harvest and Storage				
2.3.9	Cost of harvesting	56.83	66		
2.3.10	Cost of transport from field to on farm storage area	13.75	**13.75**		
2.3.11	Cost of Storing the crop#	**18.64**	**18.64**		
	Costs of transport to processing plant				
2.3.12	On farm Loading/Handling cost	**8.55**	**8.55**		
2.3.13	Haulage cost	30.66	30.66*		
2.3.14	Total Labour			147	
2.3.15	Total Machinery**			165	
	Total for field operations & lab	220.17	226.9	312	

** Figures for Eastern Region at 5.70 t/ha and £5.38/tonne (Costs per 50 mile journey) Source HCGA Haulage Costs Survey. # Assume 3 months storage*

6.5 Barley

DESCRIPTION OF CROP

Barley is the second largest arable crop in the UK after wheat. It accounted for approximately 1.1 million hectares in 2002. Modem barley varieties have been bred to produce high grain yields in response to a range of management practices, although yields are still well below those of winter wheat. They have achievable potentials of between 8 to 9 t of grain per ha., with a harvest index of 50 to 55%.
Across the UK the actual achieved yield is lower due to a number of factors including the growing of take-all infected non-first cereal positions, foliar disease epidemics, errors in fertiliser rates etc. In practice the average yield is close to 6.3 t/ha @ 85 % dry matter, which is equivalent to 5.4 t dm/ha. Using the harvest index stated above this would indicate a total biomass production of 11 t dm/ha. Barley grown as an industrial crop is unlikely to be grown as a first cereal crop, as these produce the highest gross margin on many arable farms. The level of production of barley grown as an industrial crop is therefore likely to be closer to the national average than the potential stated above.

The majority of winter barley is planted in September. It emerges usually in about 10-14 days and produces fairly complete ground cover 6-8 weeks later. It growth habit remains prostrate, producing leaves and shoots over the winter and early spring until the stems extend in early April. Stem extension is usually complete in June producing a crop 80-100 cm tall. The crop remains predominantly green until early July when the grain is ripening and the crop turns a golden colour.

BIOLOGICAL LIMITS TO DISTRIBUTION
Barley can be grown on a range of soil types, and is better suited to light land than wheat by virtue of its more rapid development. Yield can be affected by previous cropping, if planted as a second or third cereal crop, take-all can depress yield.

TABLE 6.9 PRODUCTION COSTS FOR BARLEY (All figures per ha, assuming 6.05 tonnes of grain)

		ADAS (light land)	ADAS (heavy land)	Nix	Cambridge
2.3.1	Seed/planting material	31.18	31.18	40	40.3
2.3.2	Cultivations + In crop operations (application of sprays and fert) Plough Heavy Discs Power Harrow / Drill Spray x 5 Fertiliser x 3	36 33.50 35 24.90	36 23 33.50 35 24.90	38 24 29.5 37.5 22.5	
2.3.3	Fertiliser	76.70	79.80	67.5	58.7
2.3.4	Herbicides	18.00	46.50		
2.3.5	**Insecticides**	3	3		
2.3.6	Fungicides	28.35	39.93		
2.3.7	Other (Growth regulators etc)	7.5	9.69		
2.3.8	Sprays	56.85	99.12	77.5	92.0
	Harvest and Storage	£/ha			
2.3.9	Cost of harvesting	56.83	56.83	66.00	
2.3.10	Cost of transport from field to on farm storage area	13.75	13.75	**13.75**	
2.3.11	Cost of Storing the crop#	20	**20**	**20**	
	Costs of transport to processing plant				
2.3.12	On farm Loading/Handling cost	9.07	**9.07**	**9.07**	
2.3.13	Haulage cost	32.55*	32.55*	32.55*	
2.3.14	Total Labour				105
2.3.15	Total Machinery**				178
	Total for field operations & lab.	229.05~	252.05~	260.32~	283

** Figures for Eastern Region at 6.08 t/ha and £5.38/tonne (Costs per 50 mile journey) Source HCGA Haulage Costs Survey*
 # Assume 3 months storage
~ Total from field operations and harvest values in table above

6.6 Miscanthus

General

Miscanthus species are woody, perennial, rhizomatous grasses, originating from Asia which have the potential for very high rates of growth. Miscanthus may be familiar to many as a flowering garden ornamental, but it is the non-flowering forms that are of interest agriculturally. Since 2001 Miscanthus has been eligible for planting grants from Defra of £920/ha, where there is a contract to supply the resultant straw produced for energy conversion. To-date about 300 hectares have been planted for energy purposes (G Green, Defra, pers. comm.) so it is clearly not a fully established crop yet within the UK cropping landscape. However, high yields and ease of husbandry, alongside an increasing interest in the installation of bio-energy systems, suggests that this crop will gain wider uptake. Provision of the biomass for fermentation and production of bioethanol would be consistent with an energy end-use.

Miscanthus agronomy

Miscanthus is ideally planted in April using specially modified potato planters which can accommodate the irregular dimensions of rhizome pieces. The optimum planting rate is 20,000 plants per hectare. Canes that develop during the spring and summer are harvested in autumn or late winter/early spring in every year except the year of establishment. These canes reach 1 m (exceptionally 2 m) in height by late August of the year of planting, with a diameter of 10 mm. In subsequent years maximum heights may approach 4 m. The canes are usually unbranched and contain a solid pith. Harvesting is undertaken usually by cutting and conditioning the stems followed by drying in the swathe and subsequent square or round baling. Full size Hesston-type bales, weighing 600kg each, is the most efficient method of baling. In the year of establishment the crop is cut, in order to allow safe herbicide application the following spring for the control of weeds, but the crop is not harvested (there is generally insufficient top growth to make this economic). Cutting and baling will normally be undertaken in February or March but occasionally may take place in autumn, in instance where springtime soil conditions do not allow travelling. Moisture content upon baling can be in the range 10-40% (ADAS unpublished data). A figure of 30% is assumed in this study.

This growth pattern is repeated every year for the lifetime of the crop, which will be at least 15 years. Miscanthus differs from short rotation coppice willow (an alternative energy crop) in that it gives an annual harvest and thus an annual income to the farmer. Miscanthus spreads naturally by means of underground storage organs (rhizomes). However, their spread is slow and there will not be any uncontrolled invasion of hedges or fields. These rhizomes can be split and the pieces re-planted to produce new plants.

From late July the lower leaves start to dry. Crop drying accelerates during autumn, as nutrients move back to the rhizome. Leaves then fall and a deep leaf litter develops. Any remaining foliage dies following the first air frost, and the stems dry to a relatively low moisture content (30-50%) during winter. By February, free standing, almost leafless, canes remain and it is these which are harvested mechanically by first cutting with a rape swather or mower-conditioner, leaving in the swathe to dry and then baling. On sites where winter harvesting activity may be difficult because the soils is wet an alternative harvest window in late autumn may be appropriate.

This growth cycle is repeated once spring-time temperatures increase again. Key determinants of yield are sunshine, temperature and rainfall. The old ‘maize growing zone’; south of a line drawn between the Ouse and Wash estuaries, will satisfy the environmental requirements for high yield, but many lowland sites far north of this line will also be suitable. Within these areas, summer rainfall levels will effect yield.

Crop and bioethanol yield

Long-term mean yields on productive sites equate to approximately 21.4 t/ha (@30% moisture[94]) and this figure has been adopted in the current study. There is little evidence in the literature of ethanol yield figures for miscanthus straw. The chemical composition of miscanthus more closely resembles that of cereal straw than wood residues[95], and so we have assumed similarity to cereal straw for the current analysis.

Short Rotation Coppice

Approximately 1,500ha of short rotation coppice (SRC) is now growing within the UK; 1,300ha of which are grown commercially for fuel, mainly in the Yorkshire region, with the remainder made up of trial plots or speculative plantations with no market as yet.

The vast majority of SRC is willow with very small areas of poplar. There are too many problems with the latter at the moment e.g. it does not coppice well, the ridged stems block commercial planter mechanisms, an apical bud is necessary near the top of the cutting, removal is difficult, etc.

[94] Bullard & Nixon (2001)
[95] Papatheofanous MG, Koukios EG, Marton, G and Dencs J (1996). Characterisation of miscanthus sinensis potential as an industrial and energy feedstock. In: Biomass ofr energy and the environment – Proceedings of 9th European Biomass Conference, 24-27 June 1996, Copenhagen, Denmark, Elsevier Science Ltd, Oxford **1**, 504-508.

SRC Agronomy

Land preparation

Efficient weed control in the land preparation stage is *essential*, especially full control of invasive perennials. Ex-arable land should be sprayed with a glyphosate-based herbicide late summer/early autumn prior to planting the following spring. Set-aside land should be sprayed twice in the year prior to planting, the first application in mid-summer followed by the second in late summer/early autumn to control any further flush of weeds. A further herbicide application may be necessary on some sites in the spring prior to planting but spring spraying alone will *not* be fully effective. Ideally, weed control on land that has been in long-term set-aside should begin 18 months prior to planting to ensure weed free conditions.

Sludge cake, well-rotted farmyard manure or other bulky organic manure with a low available nitrogen content can be incorporated prior to ploughing which, on the majority of soils, takes place during the autumn/winter prior to planting the following spring. Ploughing to a depth of 25cm is necessary and sub-soiling to 40cm to remove any compaction is often required. The site should be power harrowed immediately before planting.

British standard rabbit fencing should be erected if and where necessary.

Establishment

15,000 18-20cm long cuttings are planted/ha ideally between March-May. Commercial planting utilises 4-row Step Planters which plant two pairs of twinned rows at a time set at standard widths: 0.75m between the rows with 1.5m between each pair of rows. This allows agricultural machinery fitted with wide tyres to work across the crop without causing damage. Willow rods of between 1.5 to 3m in length are manually fed into the planter's mechanism, which cuts the rods into the required lengths, inserts the cuttings vertically into the soil and then firms the soil around each cutting. Five or more willow varieties (12 are now available) are planted in a random mix on commercial sites to help with disease and pest control.

The site should be rolled immediately after planting to consolidate the soil which helps to prevent slug damage and also ensures effective herbicide application. Pre-emergence residual herbicide should be applied within 3-5 days of planting. Two to three shoots will grow from each cutting, reaching up to 4m in height at the end of the first growing season depending on variety and soil condition. The crop should be monitored carefully during the establishment year to check for pests, weed growth and general health.

No fertiliser should be applied during the establishment year i.e. from planting to cutback.

Cutback takes place ideally in the February after planting, definitely before bud-break. The stems should be cleanly cut to within 10cm of the ground surface to encourage the growth of the true coppice i.e. multiple stems. Pre-emergence herbicide should be applied, preferably using a mix of residual and contact herbicides but it is essential that spraying takes place before bud-break on the coppice otherwise the crop could be severely damaged.

Digested i.e. treated sewage sludge can be applied as fertiliser after the herbicide has taken effect if the local Water Company consider it feasible under the local and UK sludge regulations. Sludge can be applied in the form of slurry, pellets or compost depending on Water Company operational practices. SRC has a low nitrogen requirement. Current UK recommendations are 40, 60 and 100kg N^{-1} ha^{-1} yr^{-1} for years 1-3 of the harvest cycle although this is generally impractical in years 2 and 3 due to the height of the crop.

The crop should be monitored for pests (rabbits, deer, willow beetles, giant willow aphids, etc) and disease (*Melampsora* rusts). Random planting of a mix of varieties, as recommended, has helped to protect the commercial UK SRC crop to date from serious rust infection. A number of plantations have however had to be sprayed due to willow beetle infestation.

Harvesting

The first harvest usually takes place 3 years after cutback and is carried out during the winter, after leaf fall and before bud-break, generally from mid-October to early March. As with cutback, the stems must be cut cleanly to within 10cm of the ground surface. Stem height prior to harvest can be up to 8m. All harvesting machinery currently used harvests two rows in one operation. As harvesting is carried out when ground conditions are likely to be wet, it is important to fit both harvesters and trailers with either wide or flotation tyres or tracks to prevent compaction and/or rutting of the site. Generally it has been found that trailers are likely to cause more damage than the harvesters.

Harvesting can produce chips (up to 5cm in size), billets (5-15cm) or whole rods (stems) depending on the machinery used, the preferred method of storage or the requirements of the end-user. End-users will generally require the fuel in the form of wood chip of a maximum size and may also need the wood chip dried to a particular moisture content (MC), for example below 30%, the willow being in the range 45-60% MC at harvest. End-users set the fuel specification in terms of chip size, quality, MC, etc. and suppliers will have to work to those specifications. This will similarly be the case for bioethanol facilities.

The commonest method of harvesting to date has been direct chip harvesting using a Claas Jaguar forage harvester (or similar) fitted with a specifically designed SRC header which will produce chip of the required size. The stems are cut, chipped and then blown into an accompanying trailer. Depending on the quality of the crop, the harvesting rate is usually between 2-5ha per day. This is the cheapest method of harvesting SRC at the moment.

The crop will regrow in the spring after harvest and, if land preparation and establishment have been carried out effectively, no herbicide will be required after cutback, as any ground flora present will be non-competitive and beneficial. Harvesting normally takes place every 3 years but can be between 2 to 4 years depending on the quality of the crop.

SRC yields will vary according to the location of the site, soil type, water availability, weed and pest control and general husbandry of the crop. Commercial yields have been low to date, 3 – 8 oven dry tonnes (odt) ha^{-1} yr^{-1}, as the first sites established were on poor soils and small fields and the new, high-yielding willow varieties were not available at planting. Yields should increase to 12odt ha^{-1} yr^{-1} as the better sites come into harvest. Future yields could reach more than 15odt ha^{-1} yr^{-1} with the new varieties becoming available but this will depend heavily on land preparation, establishment and crop husbandry being carried out effectively. Second and third harvests should produce higher yields than the first as the crop reaches maturity. Average yields from experimental trial plots growing new varieties have reached more than 18odt ha^{-1} yr^{-1} but this is unlikely to be achieved from commercial plantations for some years.

Storage

Storage and drying of fresh wood chip does have some complications but, for most situations and as the fuel will be needed all year, storage, drying and the prevention of decomposition must all be dealt with. Stored, fresh wood chip can heat up to 60°C within 24 hours and start to decompose. During decomposition calorific value, i.e. the energy value of the fuel, is lost. Also the fungal and bacterial spores produced during decomposition constitute a health hazard. The use of grain driers, ventilated-floor-driers and low-rate aeration using ducts are all being investigated to assess whether they can economically assist the drying and storage of wood chip although it is currently considered uneconomic to attempt to dry wood chip by any method other than natural air-drying. It is important to ensure that the energy used in producing wood chip for use as fuel is kept to a minimum in order to maintain the energy balance of the SRC.

Ideally the wood chip should be stored undercover, on hard standing and preferably with perforated pipes placed under the pile to assist with ventilation. Wood chip can however be stored outside but the outer layer or cap will deteriorate to such an extent that it will not be available for use as fuel. Care must also be taken when handling chip that has not been stored on hard standing to prevent contamination with soil, stones, etc.

Basically, SRC cropping consists of 1-year establishment followed by 3-yearly harvest cycles with an estimation that a plantation should remain viable for 25-30 years.

WOOD FUEL AVAILABILITY FROM EXISTING FOREST AREA AT A SUSTAINABLE LEVEL

Assessing potential availability of timber for wood fuel from the regions woodlands at a level that is annually sustainable is a complex process. This requires an understanding of the biological potential of the woodland resource and market related factors which influences how that material may come forward. This analysis provides a reasonably robust and sustainable prediction of the annual outturn available for the wood fuel market that could be achieved if market conditions stimulate demand.

This assessment attempts to arrive at a predictable output, based on recognised forest yeild prediction methods . The objective is to move away from the assumption often made by wood fuel enthusiasts that because an area may be well wooded there is likely to be large quantities of "waste" or residues from normal forest operations available for wood fuel.

The term waste is often used to describe wood materials left on the forest floor to rot or be burnt following a harvesting operation. This is an inappropriate term in the context of woodland management operations. What is left on the forest floor after all possible markets for the timber have been exploited is more accurately described as residue. As a residue it may be desirable to leave it in situ providing an important role at an ecological or environmental level or in helping to improve the fertility of the site for future crops. If there is a market for that residue it will then become a commodity.

Timber Market

Market forces dictate whether or how much of a woodland crop may find it's way off the site of production and through primary and secondary processing into value added products. The key factors affecting the ratio of crop for added value processing relate to quality of the woodland and tree management along with climatic and economic factors prevalent in the international market place.

This study indicates the volume of material from an existing woodland resource that could be available for wood fuel given that the price paid per cubic metre can compete with the low quality end of the traditional timber markets.

An appreciation of what constitutes low quality is important in order to gauge the element of the timber crop that, with a sufficient financial incentive, would divert from traditional market outlets to an energy market.

This timber may include small branch wood normally left on the forest floor, tops below 7 cm top diameter, timber that may find a market as firewood logs and include that which goes to processing plants, such as thinnings, where it is either pulped or pressed into paper or board products. A sufficiently depressed timber market and a strong market for wood energy may also make available some timber that would traditionally go into dunnage, external fencing, mining timber, pallet wood and even low quality saw logs.

These markets are supplied by the timber producer often at a lower return than will meet the costs of harvesting, extraction and transport. This happens because the other parts of the timber crop may be subsidising operations. There are no substantial markets in the region to take large quantities of these materials and this means a higher than average cost of transport to access markets on the northern and western borders of the region.

Data Collection

The most recent data available to assess the regions woodland on an area basis has been derived from the National Inventory of Woodland and Trees undertaken by the Forestry Commission and published on a county by county basis in 2002.

Where special designations on woodlands occur such as Sites of Special Scientific Interest or Ancient Semi Natural Woodlands these are included in the survey. It is considered that these woodlands have a requirement to be managed and would be productive at a sensitive and appropriate level.

Total Woodland Areas for the East of England Region and Counties Within Region

Using the Forestry Commission National Inventory data the following information in Table 6.10 reveals the extent of the recorded woodland on an area basis.

Using GIS we are able to interpret the data in map form. This provides a better indication of the geographic location of the woodland cover.

TABLE 6.10. AREAS OF WOODLAND TYPES IN COUNTIES IN THE EAST OF ENGLAND (HA)

County	County Area	ITF Area all categories	% of County Area	Coniferous	Broadleaved	Mixed	Coppiced	Coppiced with Standards	Felled	Open Space
Bedfordshire	123,525	7,656	6.2	1,983	4,743	449	0	24	0	457
Cambridgeshire	340,151	12,325	3.6	737	10,023	1,327	0	78	39	121
Essex	367,286	19,454	5.3	1,245	15,574	1,523	88	441	0	583
Hertfordshire	163,872	15,503	9.4	2,094	11,126	1,454	75	85	57	612
Norfolk	537,521	52,739	9.8	14,328	26,631	7,136	0	503	754	3,387
Suffolk	381,242	31,436	8.2	10,313	15,466	3,526	6	141	192	1,792
Total	1,913,597	139,113	7.3	30,700	83,563	15,415	169	1,272	1,042	6,952

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<u>Conversion of Woodland Area Data to Volume Outputs</u>

Area of woodland cover is meaningless in predicting outputs for the purposes of strategic planning and therefore estimations of volume at a sustainable annual level are more desirable.

Whilst this approach is predictive and subject to a series of assumptions it is likely to be much more reliable and provide more confidence in arriving at the potential output of woodland crop that could be accessible to the wood fuel market place.

To obtain a volume based figure forestry mensuration conventions have been applied to the areas indicated by the National Inventory of Woodlands.

Measurement Conventions[96]

Yield Class - To derive an annual figure of production the forest industry uses *Yield Class* (YC) to estimate the maximum *Mean Annual Increment (MAI)* of stem volume per hectare per year. Whilst this figure may vary between different crop types and be affected by geographic and physiological influences an average for conifer crops in the region has been agreed at 10 cubic metres per year (YC 10) and for broadleaves 4 cubic metres per year (YC4).

Thinning Cycle - Commercially managed timber is thinned regularly to create space for the better trees and to increase overall yields of better quality timber[97]. The intervals at which this takes place is called the *Thinning Cycle* and it is dependent on the YC potential for the woodland. For the East of England region the thinning cycle of 5 years for conifers and 10 years for broadleaves has been used. It is usual to aim to thin the crop at approximately 70% of *MAI* to avoid over thinning. Many small and undermanaged woodlands will not receive any thinning at all and in these woods the ratio of good quality to poor quality timber will normally be adversely affected.

Stocking Density - It is unlikely that any single woodland is fully stocked with trees due to failed crop, rides and tracks, provision for utilities etc. and a general consensus is that any single hectare is unlikely to have a stocking density of more than 85%.

Woodfuel Potential - To assess that proportion of the timber crop that falls within the low quality fraction of the final outturn, and is therefore potentially available as a source of wood fuel a figure of 20% of wet volume is applied to conifer crops and 50% of wet volume to broadleaves. These figures are price dependent as mentioned earlier.

Mixed Woodland – The National Inventory data does not detail the ratios of conifer to broadleaf in the mixed woodland type. To interpret the area information into a volume output this study uses an average of the data available for the two principal woodland types.

It should be noted that the figures quoted in the measurement conventions are based on historical information on the regions woodlands. They are also based on the "timber" yield and do not account for the fine branch wood. This element of the crop has been considered and a number of trials to estimate how this material can be quantified have been made by Forestry Commission Research. However the results suggest that this is actually a relatively small amount of material

[96] Forestry Commission Booklet 39, Forest Mensuration Handbook
[97] *Thinning Control* Forestry Commission Field Book 2

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in relation to the crop timber, it is difficult to gather in isolation and prone to contamination in the process. They have therefore not been included in the calculations.

Table 1 shows 6 types of woodland in National Inventory data. .

- Coniferous
- Broadleaved
- Mixed woodland
- Coppice
- Coppice with Standards
- Felled areas

In this interim report only the first three of the six listed classes is used.

Data Analysis

The conversion equations below Table 6.11 produce the indicative volumes of potential wood fuel availability in the table on a county basis. What is less easy to determine from this exercise is where the optimum concentrations are at a regional scale and how this effects the potential outturn of wood fuel material.

TABLE 6.11. POTENTIAL ANNUAL SUSTAINABLE OUTPUT FROM EAST MIDLANDS WOODLANDS BY COUNTY

County	Coniferous		Broadleaved		Mixed		Total Volume
	Area (Ha)	Volume (m^3)	Area (Ha)	Volume (m^3)	Area (Ha)	Volume (m^3)	(m^3)
Bedfordshire	1,983	2,360	4,743	5,644	449	655	8,658
Cambridgeshire	737	877	10,023	11,927	1,327	1,934	14,739
Essex	1,245	1,482	15,574	18,533	1,523	2,220	22,235
Hertfordshire	2,094	2,492	11,126	13,240	1,454	2,120	17,851
Norfolk	14,328	17,050	26,631	31,691	7,136	10,403	59,144
Suffolk	10,313	12,272	15,466	18,405	3,526	5,140	35,817
Total	30,700	36,533	83,563	99,440	15,415	22,471	158,444

Conifer Volume =	Area x YC x Thinning Cycle @ 70% x Stocking Density @ 85% x Low Quality/Residue Proportion @ 20%
Broadleaved Volume =	Area x YC x Thinning Cycle @ 70% x Stocking Density @ 85% x Low Quality/Residue Proportion @ 50%
Mixed Woodland Volume =	Area x YC x Thinning Cycle @ 70% x Stocking Density @ 85% x Low Quality/Residue Proportion @ 35%

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What is also not understood by relying on volume figures alone is the dry matter value of potential wood fuel yield, as this varies between species. The biomass renewables industry use oven dry tonnes (odt) as a standard value by which to assess projects. It is therefore considered appropriate to convert existing woodland outputs to this standard.

To arrive at this by woodland type the moisture content values for the principal tree species in the three classifications for the East of England have been assessed [98] and averaged to give a woodland type odt value.

TABLE 6.12 POTENTIAL VOLUME OUTPUT PER HECTARE BY WOODLAND TYPE

Woodland Type	YC	Thinning Cycle	Stocking Density %	Low Quality & Residue Proportion %	Yield m3	Oven Dry Tonnes
Conifer	10	5	85	20	1.19	0.52
Broadleaves	4	10	85	50	1.19	0.68
Mixed woodland	7	7.5	85	35	2.08	0.73

Assumes 1 cubic metre is approximately 1 tonne fresh weight

Average conifer dry matter 44%
Average broadleaved dry matter 57%
Average mixed woodland dry matter 50%

In Table 6.12 the volume of a hectare of the selected woodland types are given a value and it is apparent that conifer woodland yields less wood fuel as a proportion of their volume than broadleaved and mixed woodland, primarily due to there being less branch material. The relevance of this is that a substantial area of conifer woodland in a given location may yield less available wood fuel resource in oven dry tonnes than a similar sized broadleaved and mixed woodland area.

Another important aspect of the conifer to broadleaved ratio is that in a buoyant market for timber products it is likely that the low quality fraction of the conifer timber yield is more likely to find alternative markets than will the broadleaved element.

At a regional level the total area detailed in Table 2 suggests that as much as 103,020 oven dry tonnes are potentially available to the wood fuel market on an annual basis.

Production costs of forestry

Forest residues, whilst abundant, are produced at a cost and the cost of production varies significantly dependent upon market conditions, type of plantation, size, location. Typical production costs for a range of products is presented in Table 6.13. Clearly a bio-ethanol plant would need to utilise whatever material was available and therefore we cannot be too precise about the actual costs of forest products. Hence we have derived a generic figure based on pole top extraction and chipping from forestry, to generate our input data in the macro-economic sections of the report.

[98] Forestry Commission Booklet 39, Forest Mensuration Handbook

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TABLE 6.13 WOOD FUEL COSTS FROM BROADLEAVED FORESTRY

Crop type	**System**	**Extraction machines**	Wood chip Production cost **£/tonne@ 30% m.c.**
Beech	Pole length	Tractor skidder	28.5
Oak		Farm forwarder	24.75
		Tractor skidder	24.29
Mixed	Short wood	Wire loader	39.3
	Pole length	Portable winch	33.6
		Tractor skidder	32.7
Oak	Short wood	Wire loader	39.64
		Tractor cradle	34
		Large Farm forwarder	28.9
Oak	Short wood	Farm forwarder	28.68
		Large Farm forwarder	27.69
		Wire loader	45.09
	Pole length	Tractor skidder	27.28
Average			**30**
Minimum			**24.29**

TABLE 6.14: WOOD FUEL COSTS FROM CROWNWOOD, SCRUB AND RESIDUES

Crop type	**System**	**Extraction machines**	**Wood chip Production cost £/tonne@ 30% m.c.**
Beech	Short wood	Portable winch	49.16
	Pole length	Tractor skidder	27.28
Oak	Terrain chip	Tractor & trailer	94.13
Beech	Short wood	Farm forwarder Wire loader	22.62
Scrub	Whole tree	Tractor skidder	69.7
Mixed	Short wood	ATC forwarder	47.84
	Pole length	ATC Skidder	52.44
Mixed	Short wood	Forwarder	34.08
		ATC forwarder	36.69
	Pole length	ATC Skidder	44.64
Conifer	Part pole	Purpose built FWD	51.38
Average			**44.16**
Minimum			**22.62**

All the above costs include £ 5.06 transport costs for 3km to the combustion.

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From the above information it can be seen that with the selection of appropriate methods of harvesting and machinery that the cost of extraction of the residues from thinning s can be under £30 per tonne for material with an energy content of 11.6 GJ/tonne. The above costs are produced for smaller private woodland it would be expected that on larger areas that the costs would be at or below the minimum values. However, significant variation exists around this figure both seasonally , annually and most importantly, as determined by the harvesting techniques used and the prior quality of management. Therefore, to use one generic figure for extracted wood is slightly misleading.

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WASTE STREAMS

England and Wales produce over 100 million tonnes of waste a year from households, commerce and industry. Some of which could be a useful source of starch and cellulose for the production of ethanol. The diversion of some of this waste could go along way to helping the Government meets its target for waste reduction, under EU Landfill Directive (99/31/EC), which require the amount of biodegradable municipal waste sent to landfill to be reduced to 75% of that produced in 1995 by 2010, 50% by 2013 and 35% by2020. As well as solving the problem of the lack of available sites in the future. England and Wales has only 1,530 site (46,000 ha) with around 635m m3 of remaining landfill void-space left, the equivalent to just 6.1 years of landfilling at the current levels. The East of England has one of the largest remaining void-spaces left in England and Wales, but only 4.8 years of landfill left, because of the considerable amount of waste from London and the South East region which is landfillied in this region.

There were around 28 million tonnes of municipal waste (household waste, street litter, waste delivered to council recycling points, municipal parks and gardens, council office waste, civic amenity site waste and some commercial waste from shops and small trading estates where local authority waste collection agreements are in place) produced in England and Wales in 2000/01 (Table 1). The amount of municipal waste being produced in England is growing at a rate of 3-4% per year. Household waste accounts for over 25 million tonnes of the municipal waste produced, household waste includes waste from household collection rounds, bulky waste collection, hazardous household waste collection and separate garden waste collection, plus waste from services such as street sweeping, litter and civic amenity sites and school waste. These vast quantities of waste are made-up of a number of different types of waste: garden waste (5.6m tonnes), paper and board (5.1m tonnes), kitchen waste (4.8m tonnes), sweepings (2.5m tonnes), glass (2m tonnes), wood (1.4m tonnes), miscellaneous non-combustible (1.4m tonnes), dense plastics (1.1m tonnes), plastic film (1.1m tonnes), textiles (0.8m tonnes), metal packaging (0.8m tonnes), Soil (0.8m tonnes) and nappies (0.6m tonnes), some of which could be recycled and others which could be used to produce energy. Currently over 80% of the wasted produced is landfilled [3] (Table 2).

There were around 78 million tonnes of industrial and commercial waste produced in England and Wales in 2000/01, of which 48 m tonnes was industrial waste (factories and industrial plants) and 30 m tonnes was commercial waste (wholesalers, catering establishments, shops and offices). This waste is made-up of a number of different waste stream: construction (2m tonnes), paper and card (7m tonnes), food (3m tonnes), biodegradable (9m tonnes), metal (6m tonnes), contaminated (5m tonnes), mineral (6m tonnes), general commercial (23m tonnes) and industrial (13m tonnes), some of which could be recycled and others which could be used to produce energy (Table 3 and 4), but most of which is currently landfilled[99].

The Government is committed to reducing our reliance on landfill through the use of Landfill Tax. This tax on the disposal of waste to landfill was introduced in October 1996 at a rate of £7 per tonne for active wastes and a lower rate of £2 per tonne for inactive wastes. The tax was designed to promote the *polluter pays* principle by increasing the cost of landfill to reflect its environmental costs, and to promote a more sustainable approach to waste management in which less waste is produced and more is recovered or recycled. From April 1999, the Government increased the rate for active wastes to £10 per tonne, and is committed to continuing to increase it by £1 per tonne per year; the current landfill tax is £13/tonne (2002) [3]. The current cost of the waste management

[99] BIFFA Future Perfect (2002)

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options are; collecting and landfilling waste (£45 - 65/t excluding tax), collection and incineration (£45 - 100/t); composting via kerbside collection (£70 - 120/t) and recycling via collection (£55 - 145/t). The reason for the large differences in the cost of the waste management options are the considerable capital cost required for the non landfilling option and the number of process that are require to sort the waste into useful product streams. This processing can be done at the kerb side or in material recovery facilities. These facilities can either take sorted mixed recyclables or dirty MRF which accept mixed solid waste (Figure 1) from residential, commercial and industrial sources. This scenario is likely to change in the future, the Strategy Unit believes a rise to 35/t is required in the medium term to reduce the amount of waste going to landfill. If this happens then the alternative methods of waste disposal will look more attractive. Especially, when you consider that the raw products will be available all the year round, in large quantities, reasonably uniformed and that a supply chain system already exists. The calorific value of these products depends on how and if they have been sorted, unsorted waste has a value of around 9 Gj/t compared to 20 Gj/t for pre-sorted waste [100].

Therefore, the diversion of some of the 27 million tonnes of waste which contains sources of starch and cellulose from both municipal, industrial and commercial into ethanol production could help meet both the EU Landfill Directive targets as well UK's Government commitment to renewable energy. This approach would also help the Eastern Region meet some of its regional environmental goals and objective; to increase waste minimisation, recycling and reuse (En2.3) and to increase the use of renewable energy (En2.4).

[100] Strategy Unit Waste not, want not "A strategy for tackling the waste problem in England" 2002

TABLE 6.15. MUNICIPAL WASTE ARISINGS FROM 1996/97 TO 2000/01 IN ENGLAND AND THE EASTERN REGION

thousand tonnes

	England					East				
Household waste from:	**1996/97**	**1997/98**	**1998/99**	**1999/00**	**2000/01**	**1996/97**	**1997/98**	**1998/99**	**1999/00**	**2000/01**
Regular household collection	15,660	16,069	16,135	16,549	16,820	1,687	1,854	1,807	1,846	1,864
Other household sources	951	890	980	1,002	1,187	36	18	27	48	94
Civic amenity sites	4,257	4,461	4,340	4,540	4,273	424	474	462	418	367
Household recycling	1,682	1,912	2,131	2,539	2,824	221	274	309	378	415
Total household	22,549	23,333	23,586	24,630	25,104	2,367	2,620	2,604	2,690	2,740
Non household sources (excl. recycling)	1,970	2,226	2,358	2,288	2,416	104	78	101	116	128
Non household recycling	68	152	398	544	630	11	26	26	50	51
Total municipal waste	24,588	25,711	26,342	27,461	28,150	2,482	2,723	2,732	2,856	2,918

Notes:

1 1999/00 figures have been revised and may differ from previous publications

2 2000/01 figures are provisional

3 Totals might not add up due to rounding.

4 'Regular household collection' means wastes within Schedule 1 of the Controlled Waste Regulations 1992; it is acknowledged that small amounts of commercial
and industrial wastes may also be included in the case of collections that include mixed domestic and commercial hereditaments

5 'Other household sources' refers to Schedule 2 wastes under the Controlled Waste Regulations 1992~ those from household sources not collected as part
of the ordinary waste collection round service.

6 'Civic Amenity Sites' refers to household waste collected at sites provided by local authorities for the disposal of excess household and garden waste free of charge,

as required by the Refuse Disposal (Amenity) Act 1978.

7 'Household recycling' contains materials collected for recycling by local authorities as well as those collected from household sources by 'private/ voluntary' organisations.

8 'Non household sources (excl. recycling)' includes any wastes collected by a local authority from non-household sources (i.e. not covered by 'Schedules 1 and 2 of the controlled Waste Regulations 1992).

9 'Non household recycling'' includes municipally collected materials for recycling from commercial sources.

Source: Department for Environment, Food & Rural Affairs

TABLE 6.16. MANAGEMENT OF MUNICIPAL WASTE FROM 1996/97 TO 2000/01 IN ENGLAND AND THE EASTERN REGION

thousand tonnes / percentage

Method	England					East				
	1996/97	1997/98	1998/99	1999/00	2000/01	1996/97	1997/98	1998/99	1999/00	2000/01
Landfill	20,631	21,765	21,506	21,933	22,055	2,250	2,416	2,361	2,386	2,407
(percentage)	84%	85%	82%	80%	78%	91%	89%	86%	84%	82%
Incineration with EfW	1,446	1,624	2,146	2,326	2,479	0	6	36	42	46
(percentage)	6%	6%	8%	8%	9%	0%	0%	1%	1%	2%
Incineration without EfW	614	66	17	8	20	0	0	0	0	0
(percentage)	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
RDF manufacture	147	156	133	106	67	0	0	0	0	0
(percentage)	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%
Recycled/composted	1,750	2,063	2,530	3,083	3,454	232	300	335	429	465
(percentage)	7%	8%	10%	11%	12%	9%	11%	12%	15%	16%
Other	0	36	10	4	75	0	1	0	0	0
(percentage)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total	24,588	25,711	26,342	27,461	28,150	2,482	2,723	2,732	2,856	2,918

Notes:
1 1999/00 figures have been revised and may differ from previous publications
2 2000/01 figures are provisional
3 Totals might not add up due to rounding.
4 EfW is energy from waste
5 RDF is refuse derived fuel
6 'Recycled/composted' includes household and non-household sources collected for recycling or for centralised composting; home composting estimates 'are not included in this total.
7 'Other' treatment and disposal processes excludes any processing prior to landfilling and materials sent to Materials Reclamation Facilities

(MRFs).

Source: Department for Environment, Food & Rural Affairs *Waste Strategy 2000 for England and Wales*

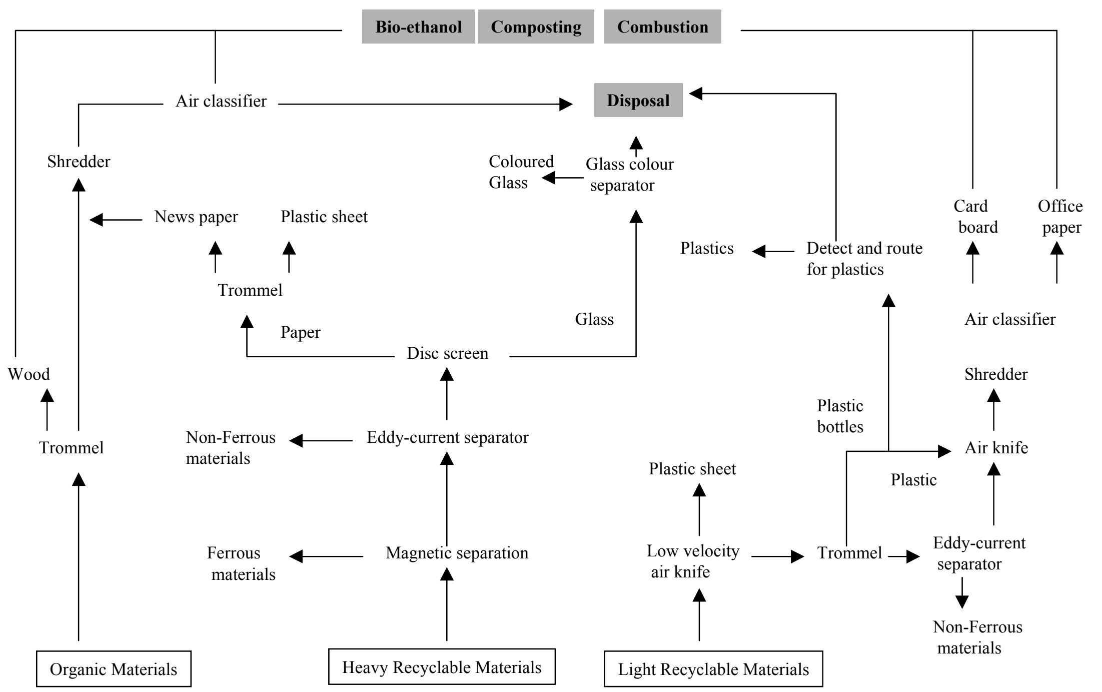
TABLE 6.17. COMPOSITION OF WASTE PRODUCED BY COMMERCE AND INDUSTRY IN THE EAST OF ENGLAND REGION 1998/9 ('000 TONNES) [101]

	Paper & Card	Food	Total
Industry	280	239	3650
Commerce	261	46	2487
Total	**541**	**285**	**6137**

TABLE 6.18. WASTE MANAGEMENT METHODS FOR COMMERCE AND INDUSTRY IN THE EAST OF ENGLAND REGION 1998/9 ('000 TONNES)

	Commercial	Industrial
	Landfill	Landfill
Beds	138	150
Cambs	195	221
Essex	539	553
Herts	333	208
Norfolk	170	215
Suffolk	203	315
Total	1579	1664

FIGURE 1. METHODS AND PROCESSES, FOR THE RECYCLING AND REUSE OF WASTE STREAMS.



101 Defra Regional Waste Management Strategy

Department for Environment, Food & Rural Affairs 1

BIFFA Future Perfect (2002) 2

Strategy Unit Waste not, want not "A strategy for tackling the waste problem in England" 2002 3

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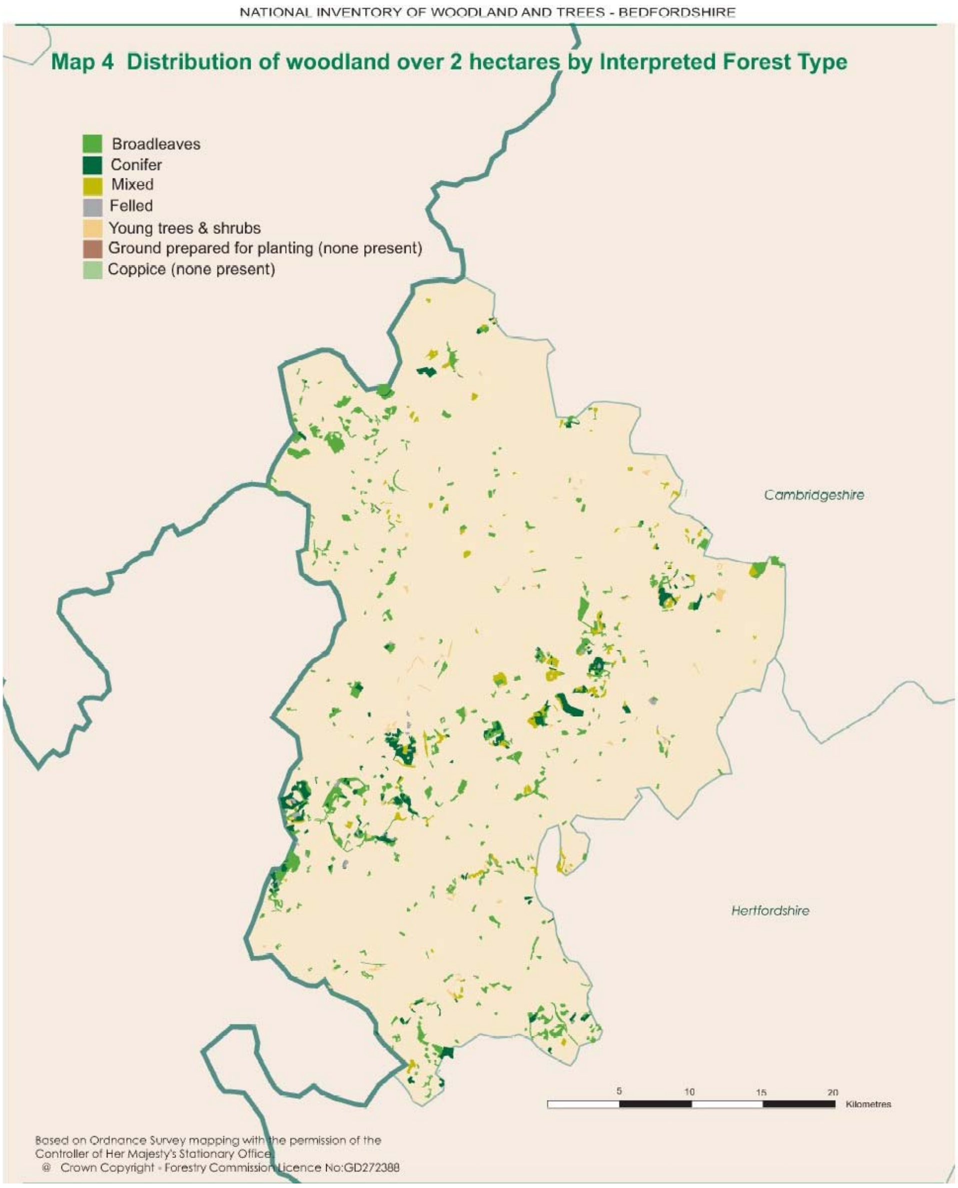
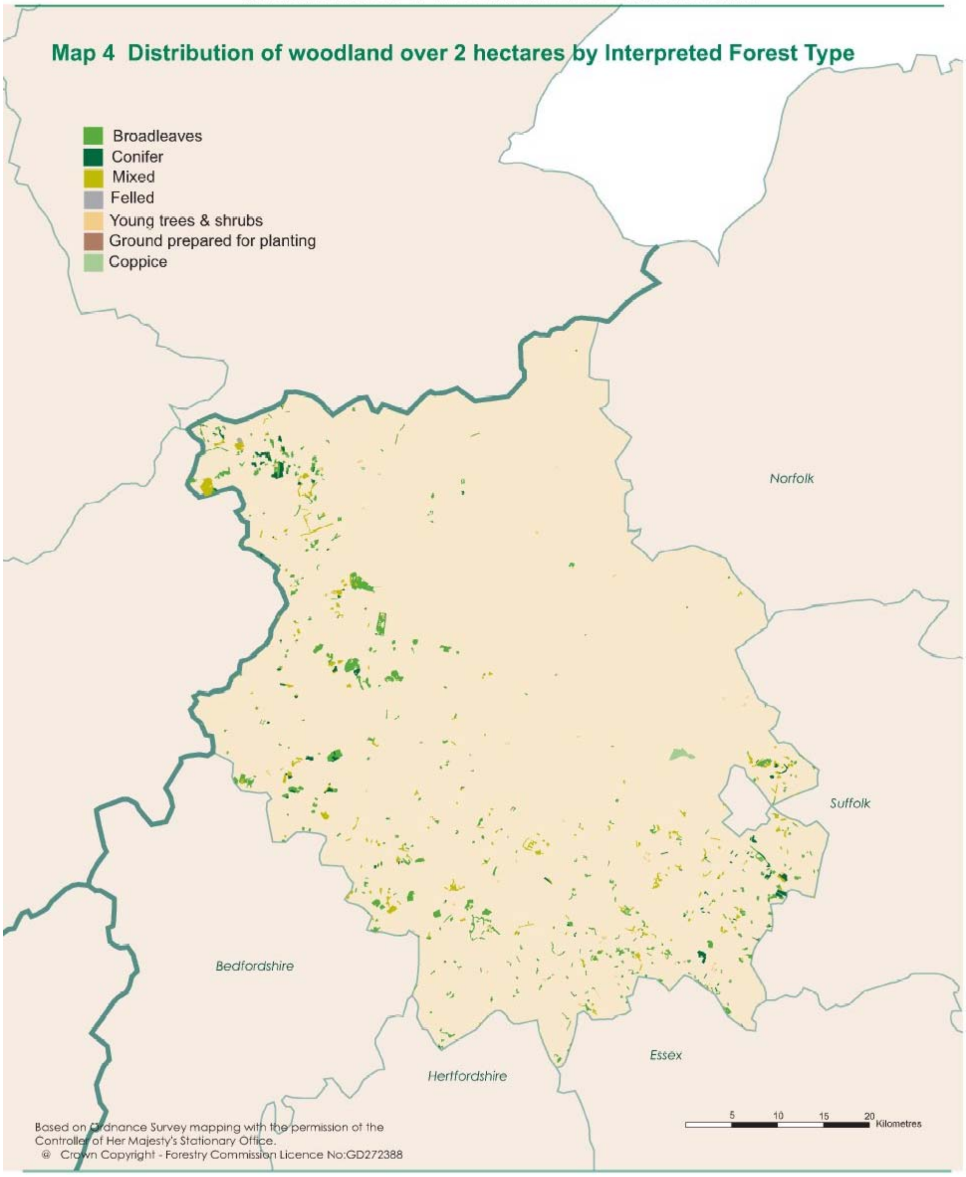
ANNEX 7

WOODLAND COVERAGE MAPS FOR EAST OF ENGLAND




Map 4 Distribution of woodland over 2 hectares by Interpreted Forest Type
Broadleaves
Conifer
Mixed
Felled
Young trees & shrubs
Ground prepared for planting
Coppice
Norfolk
Suffolk
Bedfordshire
Essex
Hertfordshire
5
10
15
20
Kilometres
Based on Ordnance Survey mapping with the permission of the Controller of Her Majesty's Stationary Office.
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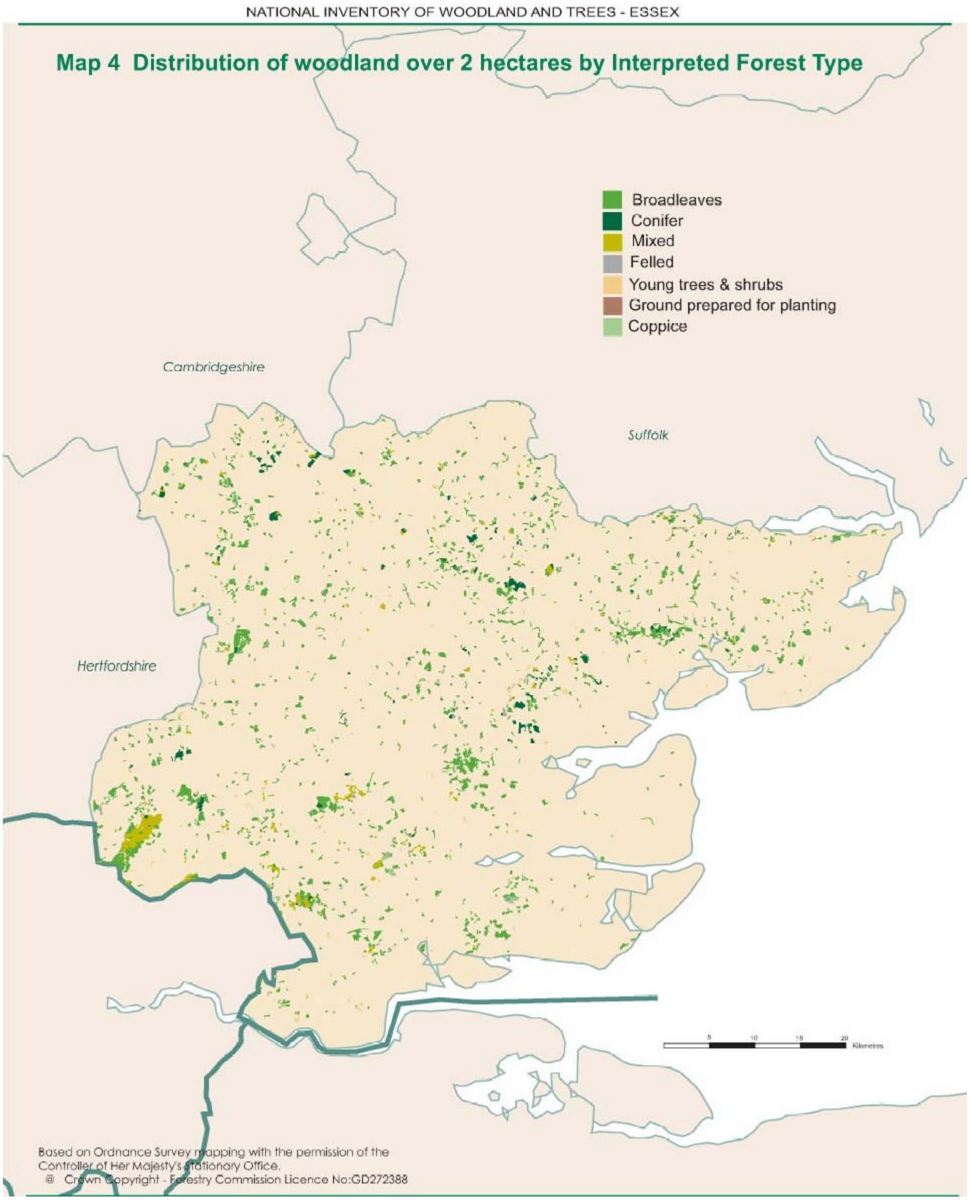

NATIONAL INVENTORY OF WOODLAND AND TREES - ESSEX
Map 4 Distribution of woodland over 2 hectares by Interpreted Forest Type
Broadleaves
Conifer
Mixed
Felled
Young trees & shrubs
Ground prepared for planting
Coppice
Cambridgeshire
Suffolk
Hertfordshire
Kilometres
Based on Ordnance Survey mapping with the permission of the Controller of Her Majesty's Stationary Office.
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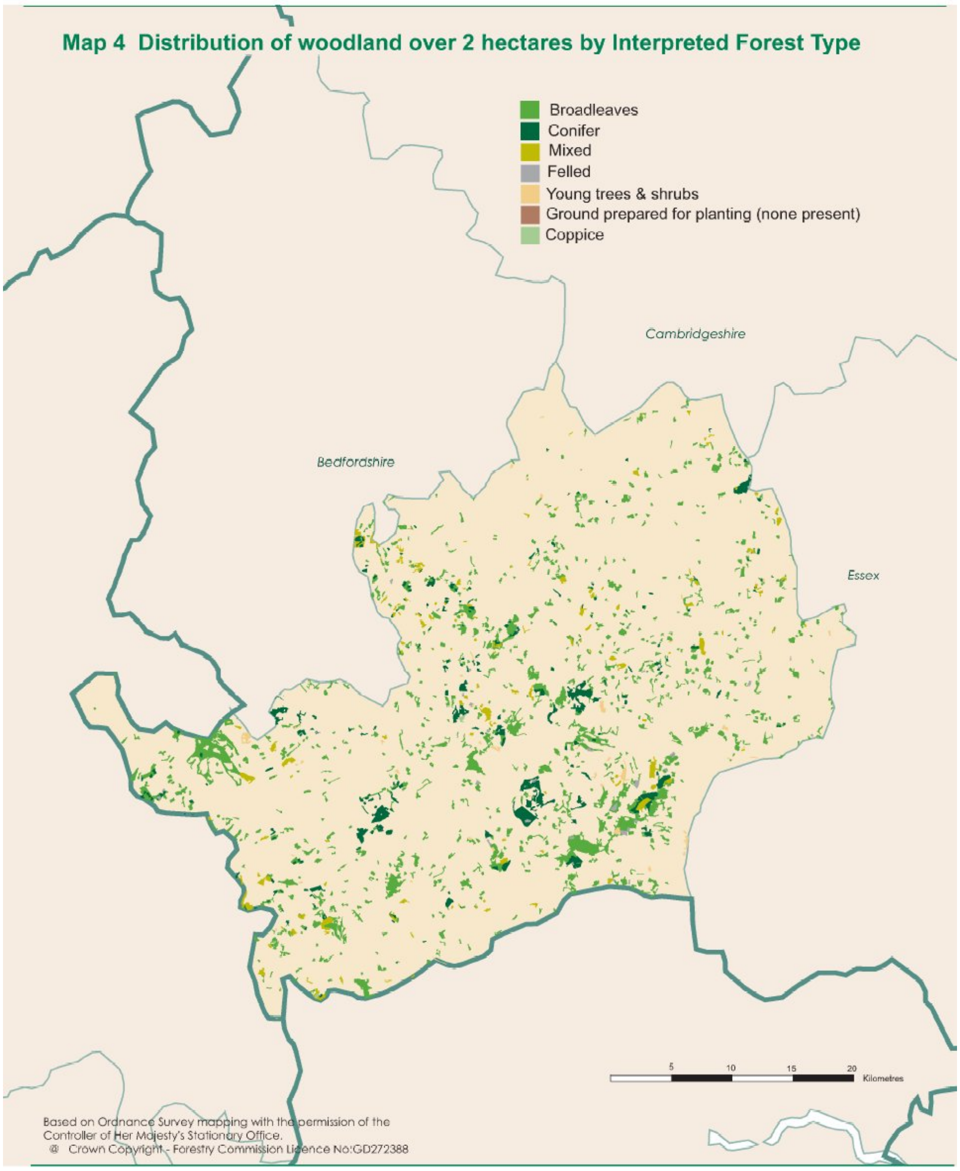
Map 4 Distribution of woodland over 2 hectares by Interpreted Forest Type
Broadleaves
Conifer
Mixed
Felled
Young trees & shrubs
Ground prepared for planting (none present)
Coppice
Cambridgeshire
Bedfordshire
Essex
5
10
15
20
Kilometres
Based on Ordnance Survey mapping with the permission of the
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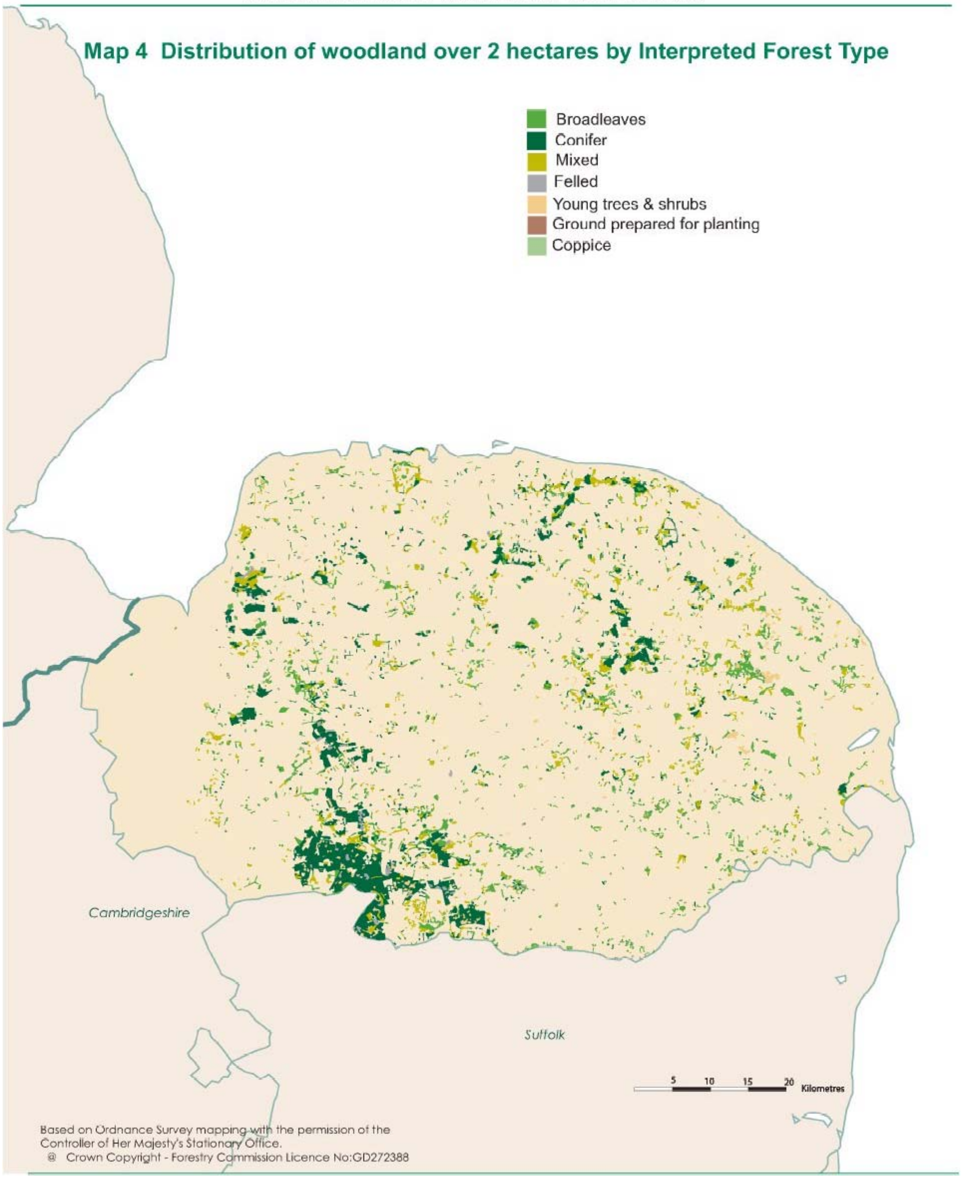
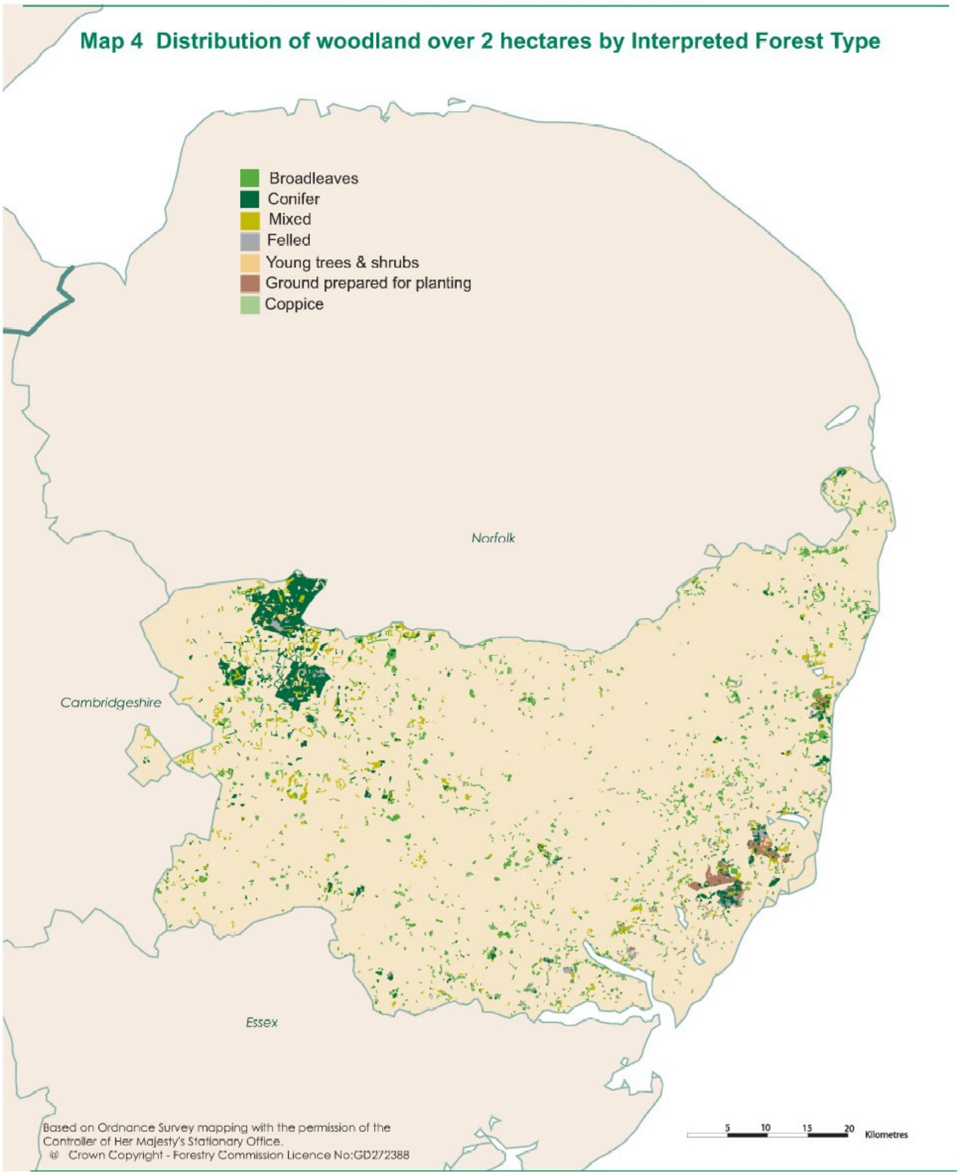
NATIONAL INVENTORY OF WOODLAND AND TREES - NORFOLK



NATIONAL INVENTORY OF WOODLAND AND TREES - SUFFOLK



Map 4 Distribution of woodland over 2 hectares by Interpreted Forest Type