# Indirect Effects of Biofuels

# Study by the Renewable Fuels Agency

## Evidence provided by Ensus Limited

**April 2008**

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## EXECUTIVE SUMMARY

The key conclusions from this analysis of the indirect effects of biofuels are:

High carbon stock land: - The increased production of biofuels from protein crops such as wheat, maize and rapeseed will, after including indirect effects, reduce the pressure on global deforestation and high carbon stock land.

GHG Emissions: - The increased production of biofuels from protein crops such as wheat, maize and rapeseed, after including indirect effects, will give GHG emissions savings that are substantially higher than those of the GHG emissions of the respective mineral fuels that they replace i.e. the savings will be greater than 100% of the emissions from fossil fuels.

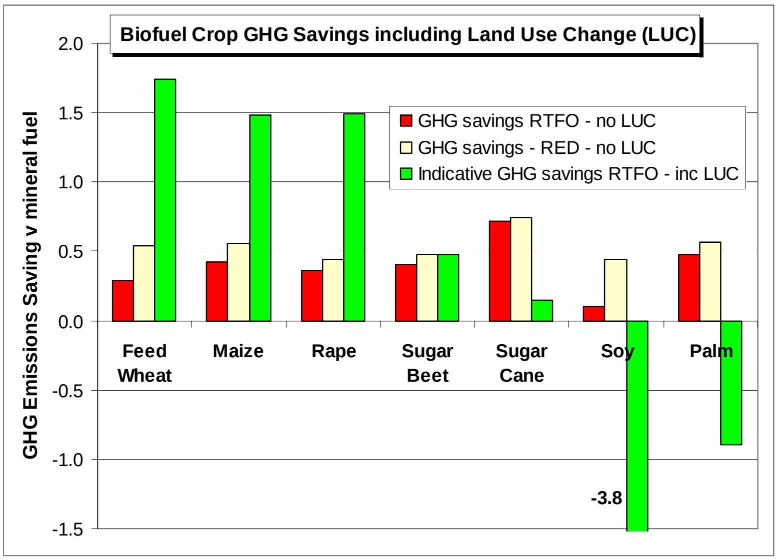


Figure 1) Biofuel crop GHG savings including land use change
Source: Ensus analysis

Land Use: - Through the effective use of EU based crops, the part of the 10% energy target in biofuels that relates to petrol use in the EU can be met with no net increase in global land use.

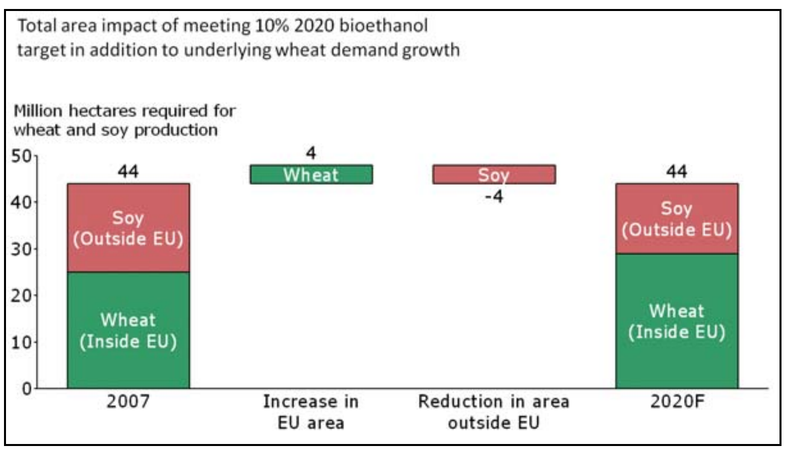


Figure 2) Total EU area impact of bioethanol and food demand in 2020
Source: FAOSTAT, Ensus analysis

Food and Fuel Security: - The increased production of bioethanol from wheat and maize in the EU will give increased security of both food and energy in the EU.

## SUMMARY RESPONSES TO QUESTIONS

**Question 1)** What are the key drivers of land use change and food insecurity and to what extent will increasing demand for biofuels affect these to 2020? What evidence is available of impacts upon areas of high conservation value and/or carbon stocks?

### 1.1) Drivers of land use change

The increased demands for different crops are met in different ways in terms of increased yield and increased land use. Over the last 30 years, the increase in demand for cereal crops has been met primarily by yield increases, while the increase in demand for oilseeds and sugar cane has been met primarily by using more land.

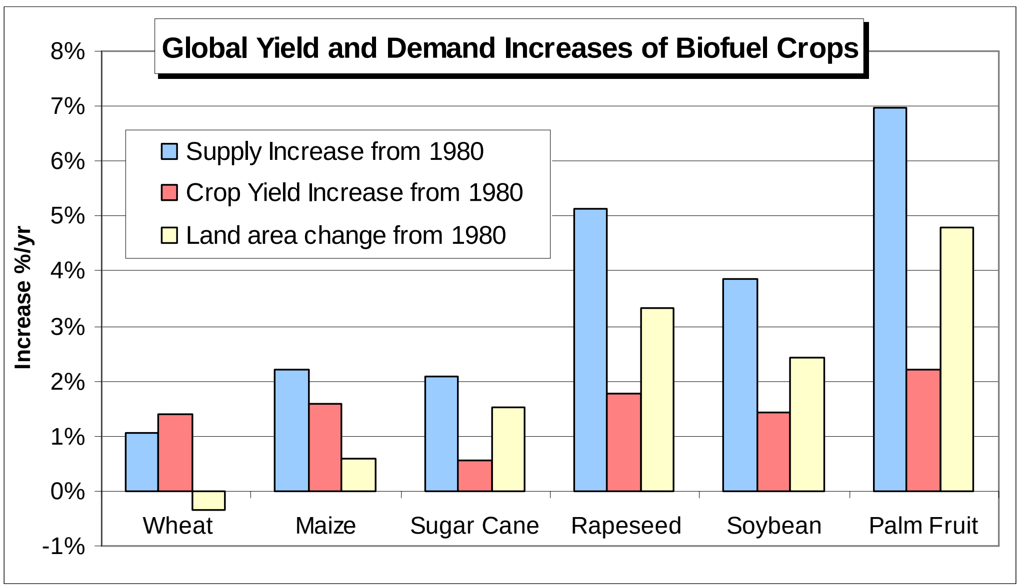


Figure 3) Global yield and demand increases of biofuel crops
Source: FAOSTAT, USDA

When crops such as wheat, maize and rape are used to make biofuels, only part of the crop is used. The co-product, containing all the crop protein is critical for the animal feed supply chain and needs to be accounted for. Indeed, as the co-product protein will be in a more concentrated form as a result of the manufacture of the biofuel, it can and will displace soy meal. When the food and fuel requirements are looked at as a whole, the impact on land change is very different and considerably more favourable than looking at biofuel product in isolation.

### 1.2) Drivers of food insecurity

The production of bioethanol from wheat and biodiesel from rape, will substantially improve the security of supply of food by decreasing the reliance on soy meal imports.

### 1.3) Effect of 2020 EU bioethanol demand on land use change and food insecurity

The overall impact of increasing European grain production to meet the 10% bioethanol target in 2020, alongside underlying demand growth will be:

- ~4Mha (3.4%) increase in area under cultivation within Europe from the use of set-aside and historic arable land brought back into crop production.

- ~4Mha reduction in demand for cultivated land area outside Europe, in areas where the agricultural land pressures have contributed to deforestation and substantial associated GHG emissions.

The part of the 10% energy target in biofuels that relates to petrol use in the EU can therefore be met with no net increase in global land use.

### 1.4) Evidence of impact on high carbon stock land

Analysis of land use change data compiled by the UN's FAO (United Nations Food and Agricultural Organisation) indicates that historic area increases for temperate crops such as maize, rape, wheat and sugar beet have occurred in countries with little or no high carbon stock land use change. Increased areas of these crops are principally from existing arable land. In contrast, the increases in areas of soy, sugar cane and palm have occurred in countries with a high proportion of high carbon stock land, such as forest and which have seen high rates of deforestation since 1995.

| Source of Agricultural Area Expansion 1995 - 2005 | | | |
|---|---|---|---|
| | Ratio of historic land displacement | | |
| | Forest | Grassland | Cropland |
| Maize | 0% | 0% | 100% |
| Rape | 0% | 0% | 100% |
| Soy | 52% | 27% | 21% |
| Sugar Cane | 12% | 67% | 21% |
| Palm | 82% | 5% | 13% |

Table 1) Crop land use change summary 1995-2005
Source: FAOSTAT, Ensus analysis

**Question 2)** How are GHG-savings of different biofuels affected by displaced agricultural activity and resulting land-use change? How may this be affected in the future by the introduction of advanced technologies, use of marginal land and other improvements in production?

### 2.1) GHG emissions due to displaced agriculture and resulting land use change

The current proposals for the calculation of direct land use change will not be effective in accounting for land use change from growing biofuel crops.

The GHG emissions from land use change including indirect land use changes and any credit for the displacement effects of biofuel co-products can be effectively calculated by considering the global land use changes for each biofuel crop and the average type of land that is displaced by the crop.

The increased production of biofuels from protein crops such as wheat, maize and rapeseed, after including indirect effects, will give GHG emissions savings that are substantially higher than those of the GHG emissions of the respective mineral fuels that they replace.

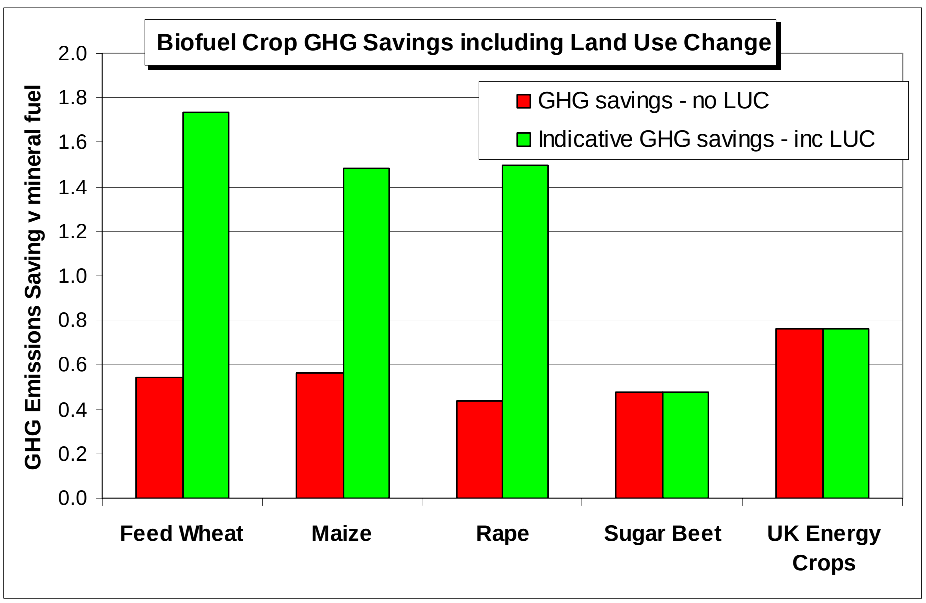


Figure 4) Biofuel crop GHG savings including land use change
Source: Ensus analysis

### 2.2) Advanced biofuel technologies and process improvements

Advanced technologies can utilise low cost feedstocks including ligno-cellulosic materials such as wood and straw, but require more complex and costly processing. In the short term it will be better to use starch and vegetable oil feedstocks for biofuels and to burn ligno-cellulosic feedstocks to replace coal fired energy generation. However as time moves on and progress is made in decarbonising power generation and improvements are made in second generation biofuels technology, the balance of the argument will change and biofuels from wastes using advanced technologies will provide an important additional route to the current production of biofuels from starch and vegetable oil.

There is no case for growing energy crops for advanced technology biofuels on arable land in the UK.

Potential advances in existing production technologies offer substantial GHG improvement potential. Some of these improvement potentials are tabulated below for the production of bioethanol from wheat:

| **Process improvement** | **Increased GHG savings vs. mineral fuel** |
|---|---|
| Improved fermentation to give high digestibility co-product | 50% |
| Nitrous Oxide ($N_2O$) abatement in nitric acid plants | 13% |
| Carbon sequestration from Bioethanol Plants | 38% |

Table 2) GHG savings from potential process improvements
Source: Ensus analysis

The establishment of a European bioethanol industry based on existing process technology will enable investment to develop and take the technology forward.

## 2.3) Marginal land

The use of new marginal land for either food or energy crop production will incur land use change penalties. These penalties will determine whether there is an overall benefit in using marginal land for new crops for biofuel use. In order to give a net GHG benefit from the use of marginal land after the land use change penalty, it will be important to obtain high biofuel crop yields.

**Question 3)** What are the relationships between demand for biofuel feedstock, commodity prices, land conversion and food insecurity? How might these be affected in the future by yield improvements and other factors?

### 3.1) Relationship between wheat supply/demand changes and wheat price

The changes in the price of wheat are primarily driven by changes in global supply (generally driven by bad weather), rather than demand and low global crop output drives high wheat prices. High wheat prices have historically driven increases in supply which have rectified the supply/demand balance. This higher global supply has historically arisen from increases in global yield, rather that increases in land use.

### 3.2) Relationship between bioethanol demand and wheat price

The growth in global wheat consumption from 2000 to 2007 due to bioethanol was less than 0.2% p.a. and therefore the effect of bioethanol demand on price has been negligible. Price increases (such as the recent price rises) have been driven by poor supply as a result of poor harvests as a consequence of adverse weather conditions.

### 3.3) Effect of biofuel feedstock demand on food insecurity

Agriculture has typically responded to price signals over a 2-3 year period. The EU's proposal to establish a long-term biofuels target for 2020 provides an appropriate time frame for the required agricultural expansion, alongside the associated changes in soy and wheat production overseas, without significantly contributing to short term price volatility and consequent global food insecurity.

The EU's animal feed protein deficit is a significant and growing source of European food insecurity. The expansion of high protein animal feed output from bioethanol production in Europe should be recognized as a valuable new source of supply to mitigate this increasing food insecurity.

**Question 4)** What economic benefits arise from production of biofuels/ feedstock in the South?

Several economic benefits to the South are identified:

- Increased agricultural prices generally
- Reduced subsidised exports from Europe
- Technology transfer opportunities
- Contribution to developing meat sectors
- Local biofuel industries

## DETAILED RESPONSES TO QUESTIONS

The Ensus evidence for the RFA study on the indirect effects of biofuels deals primarily with the effects of land use change for the main biofuel crops that will be used in the EU, and the effects of the increases in demand for grain for the production of bioethanol in the EU.

The effects of the increase in demand for biodiesel in the EU are not considered.

The evidence is provided as far as possible according to the structure set by the RFA questions.

**Question 1)** What are the key drivers of land use change and food insecurity and to what extent will increasing demand for biofuels affect these to 2020? What evidence is available of impacts upon areas of high conservation value and/or carbon stocks?

### 1.1) Drivers of land use change

The principal drivers for land use change with regard to a particular crop are:

- Changes in demand
- Changes in yield
- Change in utilisation of co-products that offset demand for other crops

Many studies assume that changes in demand for crops lead primarily to land use change and do not take fully into effect the large increases in yields obtained with most crops and the effects of protein co-products from the manufacture of biofuels from some crops. For cereal crops, most of the increase in demand is met by increased yield and there is a substantial credit in land use from co-products.

#### 1.1.1) Changes in demand and yield

It is shown below that the increased demands for different crops are met in different ways in terms of increased yield and increased land use.

As the demand for crops for food and fuel increases, this will lead to higher prices for the crop, which will encourage farmers to increase output. Some of the increase is met by farmers increasing crop yields, while the rest is met by farmers clearing and planting new land for the crops and hence causing land use change.

If the demand can be met by increased yield, then there is no need for the extra use of land. This is shown below for wheat.

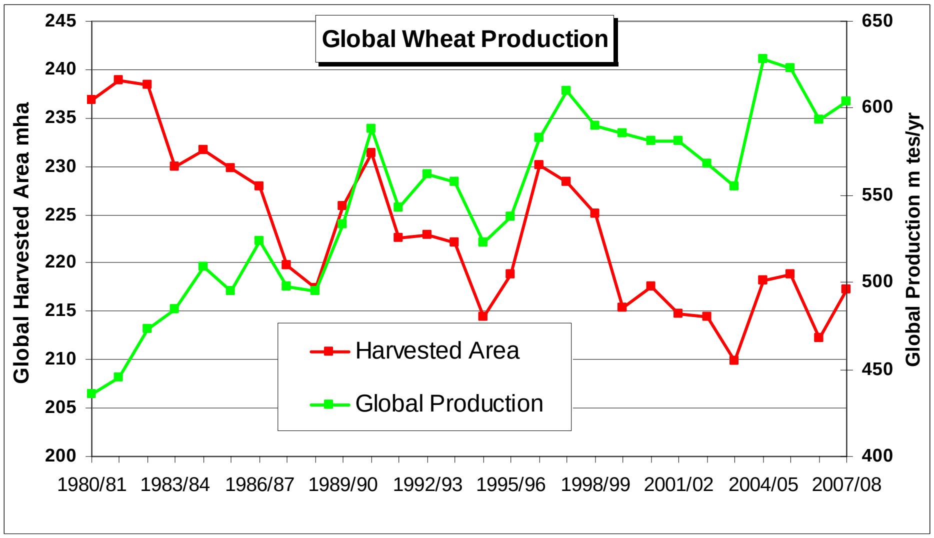


Figure 5) Global wheat production
Source: USDA

It can be seen that despite a steady increase in the global production of wheat, the global harvested area has actually decreased. The extent to which increased yields affect the change in land use from increased production varies substantially from crop to crop.

The detailed data for wheat, as an example, from 1980 to 2007 and the rate of change of production, yield and land are shown in the appendix. The data for wheat and other crops is summarized below.

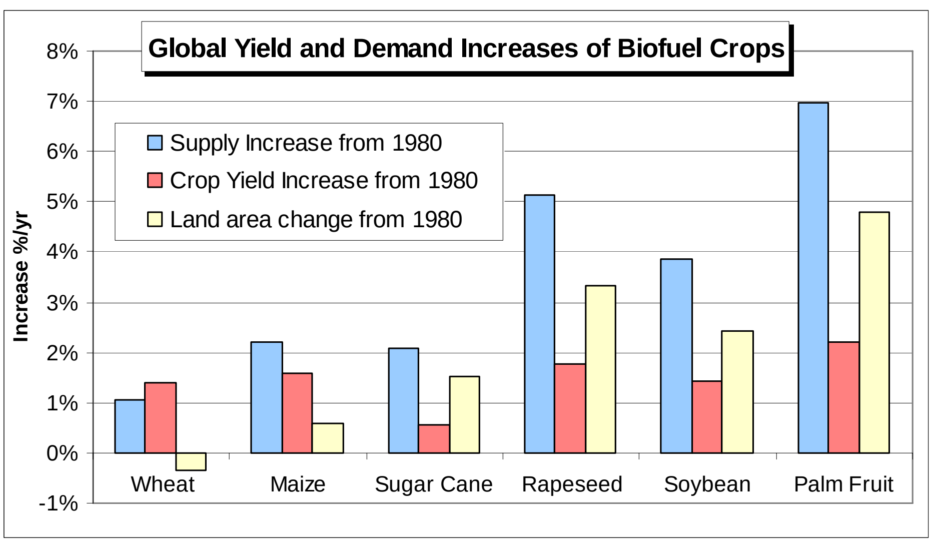


Figure 6) Global yield and demand increases of biofuel crops
Source: USDA, FAOSTAT

Historically the increased demand for different crops has been met by both increased yield and increased land use. However it is important to note the difference between cereal crops, where the increase in demand has primarily been met by yield increases, and oilseeds and sugar cane where the increase in demand has primarily been met by using more land.

There is a large variation in wheat yields across the world and also across countries within Europe. Small improvements in wheat yields across many countries have delivered global increases in wheat demand from a reduced land area over the past 20 years.

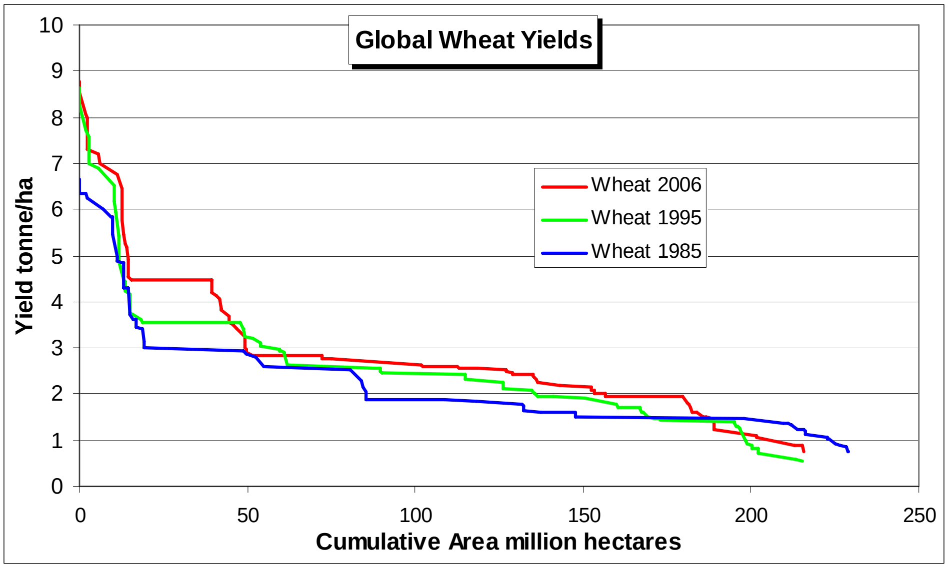


Figure 7) Global wheat yields
Source: FAO

Substantial remaining 'yield gaps' between potential and actual wheat yields provides scope for continuing to increase global average wheat yields at or above historic improvement rates.

### 1.1.2) Change in utilisation of co-products that offset demand for other crops

It is shown below that when crops such as wheat, maize and rape are used to make biofuels, only part of the crop is used. The co-product, containing all the crop protein, is critical for the animal feed supply chain and needs to be accounted for. Indeed, as the co-product protein will be in a more concentrated form as a result of the manufacture of the biofuel, it can and will displace soy meal. When the food and fuel requirements are looked at as a whole, the impact on land change is very different and considerably more favourable than looking at biofuel product in isolation.

If the whole crop is used in a direct application, for example wheat for animal feed, then the land use change is related to the production rate and yield. However, if only part of the crop is used in a direct application, then co-products may also affect land use change. For example, if wheat is used for flour, the co-product "wheat feed" is used as an animal feed.

In order to produce meat efficiently, animals are fed with a range of feeds: mainly seed crops including wheat, maize, rape meal and soy meal. About 70% of the wheat grown in the UK and 50% of wheat grown in the EU, is used directly as animal feed, whereas most of the higher protein feeds, such as soy are imported into the EU. The optimum level of protein in animal feed e.g. for cattle is around 20%, whereas cereal grains have a level of protein of 8-13% and oilseed meals such as soy and rape have protein concentrations of 35-45%. Currently therefore cereals need to be blended with imported oil seed meals to give the optimum protein concentration. However when biofuels are produced from cereal crops, such as wheat and maize, the non starch part of the grain is concentrated into a co-product

– distillers dried grain and solubles (DDGS), at a concentration of 30%-38%. Therefore, DDGS can be used to replace some of the soy meal for blending, to lift the protein concentration to that required for animal feed.

The total protein yield per hectare of wheat and maize is comparable with that of soy, and the fermentation process produces additional protein by growing yeast. Therefore little or no additional land is required to produce biofuels from wheat and maize, after taking into account the land saved by not having to grow soy. Few, if any, previous studies on comparing biofuel yields have taken credit for the biofuel co-products. While the direct bioethanol yield from wheat is about 2.5 t/ha, the effective yield after taking into account the DDGS co-product can be much higher at 13 t/ha or more. The production of bioethanol from cereal crops is thus a very effective way to minimise the requirement for extra land to meet growing food and fuel needs by enabling a global re-optimisation of cropping for animal feed.

The calculation of the net land area required for biofuel crops is shown in appendix 2. The replacement may be affected by the amino acid profiles and digestibility of different high protein animal feeds, so a conservative assumption has been made that the protein value of the biofuel co-products is 80% of that of soy meal. The diagram below shows the areas of soy and cereal displaced per area of biofuel crop grown in N W Europe.

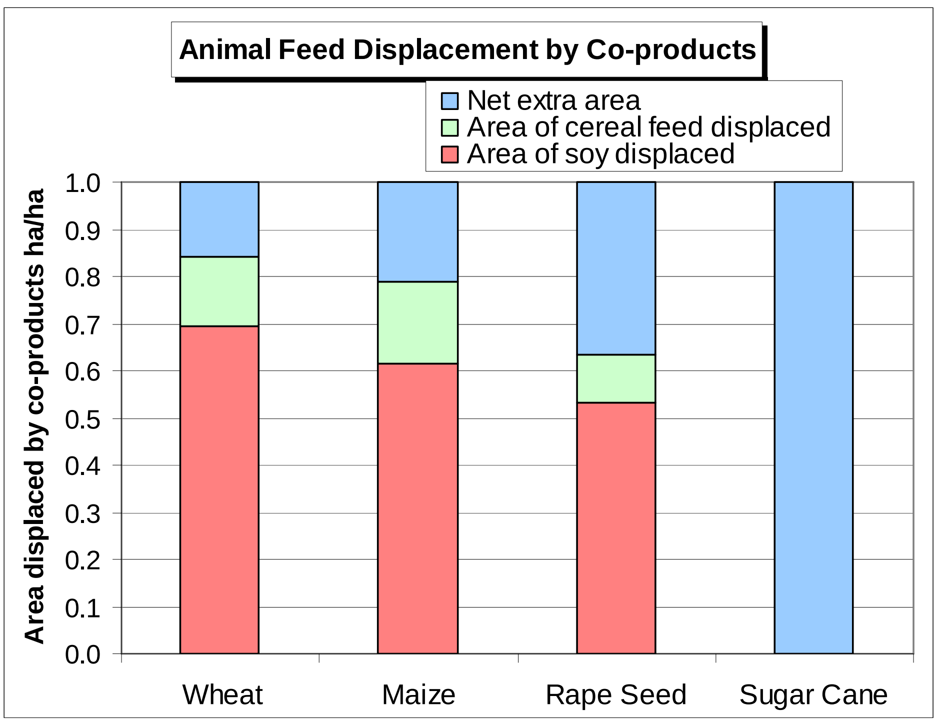


Figure 8) Animal feed displacement by co-products
Source: USDA, Ensus analysis - appendix 2

The diagram shows the credit in terms of land area to grow displaced animal feed per direct area needed to grow the biofuel crop. The net extra land is given by the blue bar.

For example, one ha of wheat grown in NW Europe to produce biofuel, gives co-product DDGS that will displace the soy meal from soy grown on 0.69 ha of land and feed wheat grown on 0.15 ha of land, so the net extra land area needed to grow one ha of wheat for biofuel is only 0.16 ha.

Sugar cane gives no co-products that could displace other crops, so the net land area is equal to the direct area to grow the sugar cane.

This analysis shows that when crops such as wheat, maize and rape are used to make biofuels, only part of the crop is used. The co-product, containing all the crop protein is critical for the animal feed supply chain and needs to be accounted for. Indeed, as the co-product protein will be in a more concentrated form as a result of the manufacture of the biofuel, it can and will displace soy meal. When the food and fuel requirements are looked at as a whole, the impact on land change is very different and considerably more favourable than looking at biofuel product in isolation.

### 1.2) Drivers of food insecurity

The drivers for food insecurity are:

- High prices caused by volatility in production and demand.
- Trade restrictions due to regional imbalances in supply and demand

Wheat prices and volatility in production and demand are discussed in section 3.1.1

#### 1.2.1) Trade restrictions and EU balance

Trade restrictions can be imposed by countries exporting grain and oil products due to high prices and trade imbalances. This has been seen recently in response to high food prices. This heightens food insecurity issues for countries which are net importers. The production of bioethanol from wheat and biodiesel production from rape, would improve our security of supply of food as it will reduce our reliance on imports of high protein products such as soy.

The impact of depressed global wheat supplies in 2006 and 2007 has been exacerbated for wheat importing regions by trade restrictions imposed by exporting regions such as Russia, Argentina and the Ukraine, as reported by the Economist newspaper in March 2008[1]:

> *In the past two weeks Cambodia, Indonesia, Kazakhstan, Russia, Argentina, Ukraine and Thailand have taken the easy option, restricting food exports in an attempt to shore up domestic supplies..the restrictions on supply send prices even higher on world markets. Last month, when Kazakhstan threatened to limit wheat exports, some wheat prices soared by 25%. Joseph Glauber, chief economist at America's Department of Agriculture, reckons that restraints on the export of wheat may have added as much as 20% to wholesale prices*

Another example is how some countries that have historically exported rice are, in response to the high prices of rice, restricting the export of rice in order to ensure that there is sufficient rice to satisfy their needs.

The trade position of the EU for products associated with biofuels is shown below.

[1] The Economist 'Cereal offenders' 27 March 2008

| EU Trade Position | | |
|---|---|---|
| | Imports | Exports |
| | million tonnes / year | |
| Bioethanol | | |
| Feed Wheat | | 13 |
| Maize | 3 | |
| Raw Sugar eq. | 3 | |
| Rapeseed | 0 | |
| Soy Meal | 33 | |
| Soy + Palm Oil | 7 | |

Table 3) EU trade position
Source: USDA, FAO, Strategie Grains 12 April 2007, Ensus analysis

The table shows that the EU is self sufficient in rapeseed and exports significant quantities of wheat. However the EU imports large quantities of vegetable oil, sugar and soy meal. The soy meal provides about 80% of all the EU high protein animal feed. The EU is therefore very reliant on global palm, soy and sugar cane crop imports for its food use.

Through the production of high concentration animal feed as a result of the manufacture of bioethanol from wheat the amount of soy meal imported into the EU will be reduced (This is explained in section 1.3). However the import of bioethanol made from sugar cane would increase the demand for sugar cane products and the import of vegetable oil to make biodiesel would increase the demand for vegetable oil.

In conclusion, the production of bioethanol from wheat and biodiesel production from rape, will substantially improve our security of supply of food by decreasing reliance on soy meal imports. However import of bioethanol from sugar cane and vegetable oil for biodiesel would exacerbate our reliance on imported foodstuffs and increase EU food insecurity.

### 1.3) Effect of 2020 EU bioethanol demand on land use change and food insecurity

European bioethanol demand met through bio-refining EU wheat to produce ethanol and a high protein animal feed (called distillers dried grain and solubles or DDGS) can have a positive impact on global food security and land use change. By using the EU's excess agricultural capacity to reduce imported animal feed meal, over 4 million ha of land outside Europe that is currently used for soy bean production can be freed up for human food production by 2020. The land use impact of increasing pressure on land in Europe is offset by reduced pressure on land use outside the EU, where agricultural practices and controls to manage land resources sustainably are currently less well developed.

Proposed RED legislation calls for 10% of the EU road transport fuel energy requirements to be met with biofuels by 2020. Displacing 10% of the EU's forecast petrol consumption in 2020 would require ~20 billion litres of bioethanol (16 million tonnes) compared to less than 2 billion litres of bioethanol produced in Europe in 2007[2].

If produced entirely from wheat, this new biofuel production would create an additional demand for 38 million tonnes of wheat compared to 2007 output. The additional demand for food is expected to rise by 1% p.a.[3], adding a further 17 million tonnes by 2020. Meeting Europe's combined wheat requirements for food and fuel will therefore need an additional 55 million tonnes in total by 2020. This represents ~46% increase on 2007 production levels.

[2] Shell & IEA gasoline consumption data; EBIO website
[3] EU Commission – Prospects for Agricultural Markets 2007-2014

The EU has considerable scope to increase the amount of wheat grown. This expansion can be realised by the effective use of set-aside, temporary pastureland and uncultivated agricultural land area and realising the significant potential to increase yields, in particular in Eastern Europe.

In 2007, the EU produced a total of 256MT of cereal crops including 120MT of wheat, of which 11MT total exports are forecast by the beginning of the 2008 harvest[4]. By 2020 the EU is capable of delivering the necessary 55MT growth in wheat output whilst maintaining its current high sustainability standards of agriculture, as only 40% of this output growth (17MT) is projected to come from crop area increases, with around 4 million hectares (~50%) of former set-aside and other uncultivated land area brought into wheat production.

The majority (60%) of required wheat output growth can be achieved through yield increases, particularly in Eastern Europe where current wheat yields are substantially lower than the agronomic potential of the land and climate. Eastern European accession countries together have over 7MHa of cultivated wheat area whose output is typically 50% or less than yields achieved on land of similar potential in EU15 countries[5]. Delivering half of these yield gaps, together with the forecast continuation of historic yield increases in all EU27 countries would deliver ~33MT additional wheat by 2020.

In considering the yield improvements achieved in East Germany since reunification, the USDA supports this view[6]:

> *"Crop yields in the central and eastern European countries have historically lagged behind their western counterparts for a number of reasons. However, if the changes that have taken place in eastern Germany over the last decade are an indication of what can be expected, then western and central European yields will converge over time."*

No changes to the EU's wheat export balance are required to achieve the necessary wheat supply in Europe. Furthermore, expansion of EU wheat and maize area in place of sugar beet production following reform of the EU's sugar regime has the potential to increase the EU's export balances.

However, should bioethanol demand growth impact the EU's wheat exports in the short term, there is considerable potential outside the EU for wheat output growth, particularly in Former Soviet Union countries where an estimated 23 million hectares of arable land has fallen out of production since the collapse of the Soviet Union[7].

45 million tonnes of high protein feed meal were imported into Europe in 2007[8], and this is expected to increase by 1-2% p.a. in line with increased meat production and consumption in Europe[9]. 13 million tonnes of DDGS) coproduced by Europe's bioethanol industry in 2020 will be sufficient to reduce soy meal import requirements by 8MT, equivalent to 4.4MHa of soy bean crop production. Furthermore, the Central and Eastern European regions offering greatest potential for wheat and DDGS output expansion are also the areas where meat consumption is forecast to rise most rapidly, as per capita income in these accession countries moves towards average EU levels.

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[4] Strategie Grains monthly report – March 2008
[5] FAOSTAT – EU27 yield & output
[6] USDA (2003) Eastern Germany crop yield increases herald changes in Central Europe
[7] EBRD & FAO press release, 10 March 2008
[8] FAO Food Outlook, November 2007
[9] EC - Prospects for agricultural markets and income 2007-2014

Compared to 2007 land use, the overall impact of increasing European wheat production to meet the 10% bioethanol target in 2020, alongside underlying EU demand growth, will therefore be:

- ~4Mha (3.4%) increase in area under cultivation within Europe. This increase comes from relatively low carbon stock set-aside and historic agricultural land brought back into crop production, and will not impinge on Europe's pasturelands and high carbon stock forests which have increased in area since 1990

- ~4Mha reduction in demand for cultivated land area outside Europe, where agricultural land pressures have contributed to deforestation and substantial associated GHG emissions in recent decades. The increasing pressure on global agriculture due to population growth and prosperity will make this freed up area increasingly valuable for both land use GHG avoidance and for global food security.

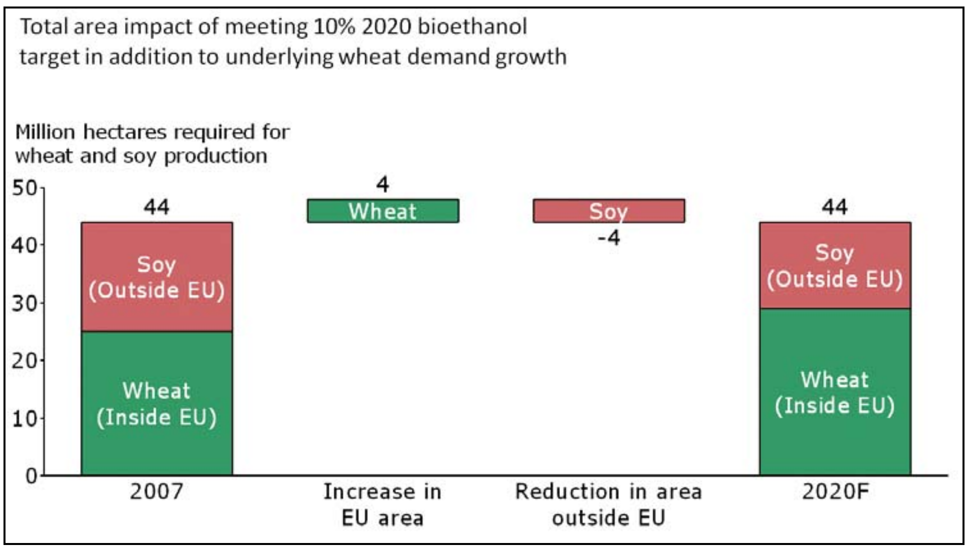


Figure 9) Total EU area impact of bioethanol and food demand in 2020
Source: FAOSTAT, Ensus analysis

In practice some of bioethanol feedstock demand growth is likely to be met through other European cereal crops such as maize where it is economic to do so, given agronomic and market conditions. For such crops, the yield improvement potential and co-product displacement of soy meal is similar to that of wheat, and so the actual cereal feedstock mix that is used does not alter the land use and food security conclusions drawn here.

### 1.4) Evidence of impact on high carbon stock land

An assessment has been made to determine the land use changes that have taken place in order to increase the production of biofuel crops since 1995. The increase in biofuel crop areas in the main producing countries has been compared with the changes in areas of forest and permanent grassland in those countries. Where increases in crop land area correspond to decreases in forested area it has been assumed that the crop has been grown on deforested land. Whilst this analysis does not directly link areas of deforestation to the corresponding crop growth it does provide an indicative view of the land use changes that are taking place.

The details of land use changes for palm are:

| Palm - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area Mha | | | Ratio of Historic Land Use Change | | |
| | Palm | Forest | Permanent Grassland | Forest | Grassland | Cropland |
| Malaysia | 1.9 | -1.1 | 0.0 | 58% | 0% | 42% |
| Indonesia | 3.0 | -18.7 | -0.6 | 97% | 3% | 0 |
| Nigeria | 1.1 | -4.1 | -0.9 | 82% | 18% | 0 |
| **Average** | | | | **82%** | **5%** | **13%** |

Table 4) Palm land use change
Source: FAOSTAT

It may be seen that all the countries where there has been substantial increases of oil palm production are countries where there has also been substantial deforestation. In Malaysia the amount of deforestation from 1995 to 2005 has been lower than the increase in oil palm and there has been no reduction in grassland, so the remaining oil palm is assumed to have been grown on land with low carbon stocks. For Indonesia and Nigeria the increased area for oil palm is allocated between forest and grassland according to the ratio in the reduction in forest and grassland. The average land allocation is a weighted average between the three countries.

The details of land use changes for each crop are shown with further explanation of the assumptions in appendix 4 and are summarised below.

| Source of Agricultural Area Expansion 1995 - 2005 | | | |
|---|---|---|---|
| | Ratio of historic land displacement | | |
| | Forest | Grassland | Cropland |
| Maize | 0% | 0% | 100% |
| Rape | 0% | 0% | 100% |
| Soy | 52% | 27% | 21% |
| Sugar Cane | 12% | 67% | 21% |
| Palm | 82% | 5% | 13% |

Table 5) Biofuel feedstock crop land use change
Source: FAOSTAT, Ensus analysis – appendix 4

The results for maize, rape, soy and palm are as expected. Increases in the land areas of maize and rape are in countries that are converting arable land to grassland and forest, so these crops are displacing other arable crops, rather than creating new arable land.

Most of the increases in the production of soy and palm are in areas where there are high levels of deforestation.

The FAO data for sugar cane in appendix 4 showed historically high rates of deforestation in Brazil, where sugar cane production has been expanding. However, we recognise the position of Brazilian cane producers who assert that much of the current development of sugar cane plantations in Brazil is taking place in southern areas of cerrado (tropical savanna grassland) and not in recently deforested areas. We have therefore modified our assumptions to reflect this position, and assumed that 85% of Brazilian sugar cane production is on historic grassland, and only 15% is on areas that were forested before 1995.

Wheat and sugar beet show only very small increases in any country and since they are grown in the same regions as maize and rape, it is expected that any increases will also displace other cropland.

Based on this analysis of land use change data compiled by the UN's FAO, we conclude that historic area increases for temperate crops such as maize, rape, wheat and sugar beet have occurred in countries with little or no high carbon stock land use change Increased areas of these crops are principally from existing arable land. In contrast, the increases in areas of soy, sugar cane and palm have occurred in countries with a high proportion of high carbon stock land such as forest, and which have seen high rates of deforestation since 1995.

**Question 2)** How are GHG-savings of different biofuels affected by displaced agricultural activity and resulting land-use change? How may this be affected in the future by the introduction of advanced technologies, use of marginal land and other improvements in production?

### 2.1) GHG emissions of biofuels due to displaced agricultural activity and resulting land use change

Where an increased global demand for a crop is causing land use change, the increased use needs to take account of the GHG emissions resulting from the increase in land use for that crop.

While this issue should be addressed for all industries, it is particularly important for the renewable energy industry. It is vital to be able to show that each biofuel will give a net reduction in GHG emissions, including the GHG emissions from the indirect land use change. The GHG emissions from increased crop production are dependent on:

- Proportion of increased production from land use change
- The historic carbon stock of the new crop land

As outlined in section 1.1.1, the increased demand for crops for food and fuel, will lead to higher prices for the crop, which will encourage farmers to increase output. Some of the increase is met by farmers increasing crop yields, while the rest is met by farmers clearing and planting new land for the crops and hence causing land use change.

#### 2.1.1) Land use change

The extent to which the increase is met by yield or land increases will depend mainly on the crop, but will also be affected by the rate of increase in demand. For annual crops, such as cereals, the tendency will be to increase yields by growing more disease resistant or higher yielding varieties, or utilising more advantageous husbandry practices. For perennial crops the yield of any mature plantation from year to year is more constant, so additional output will tend to be obtained by planting more land. Because perennial crops take three to four years to mature, the response to changes in price is slow and difficult to measure.

The extent by which crop output is obtained by higher yields or land use change must be taken into account in the GHG calculation to determine the proportion of the production increase attributable to land use change. An effective way of achieving this would be to use a moving average based on the proportion of production due to increased land use. In order to avoid volatility due to poor harvests and to provide a stable environment for investment the time frame should be of the order of 15 years.

The data over the last 15 years is shown in the diagram below for crops used for biofuels in Europe.

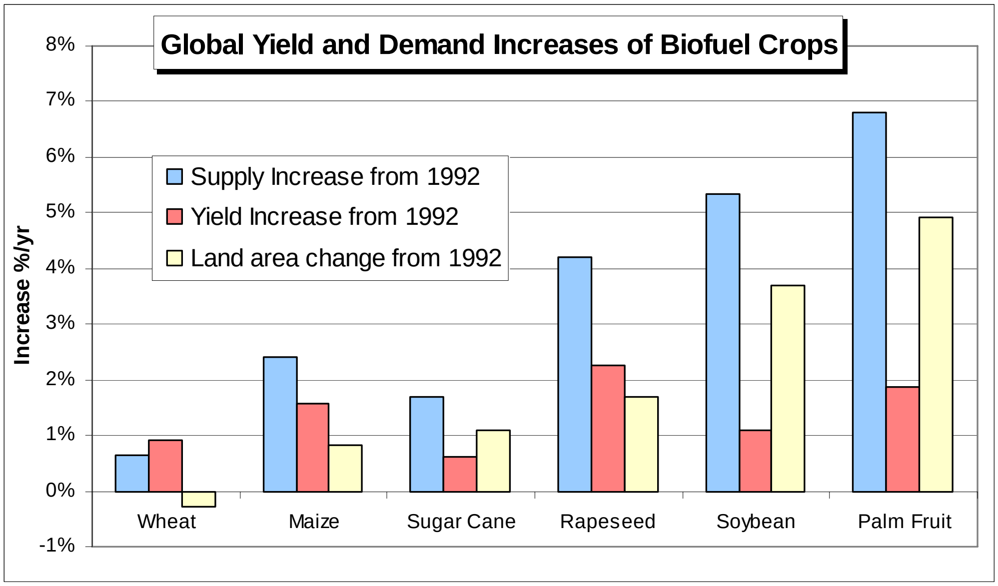


Figure 10) Global yield and demand increases of biofuel crops
Source: FAOSTAT, Ensus analysis

The relative proportion of the increase in demand that is met by land use change is summarised below.

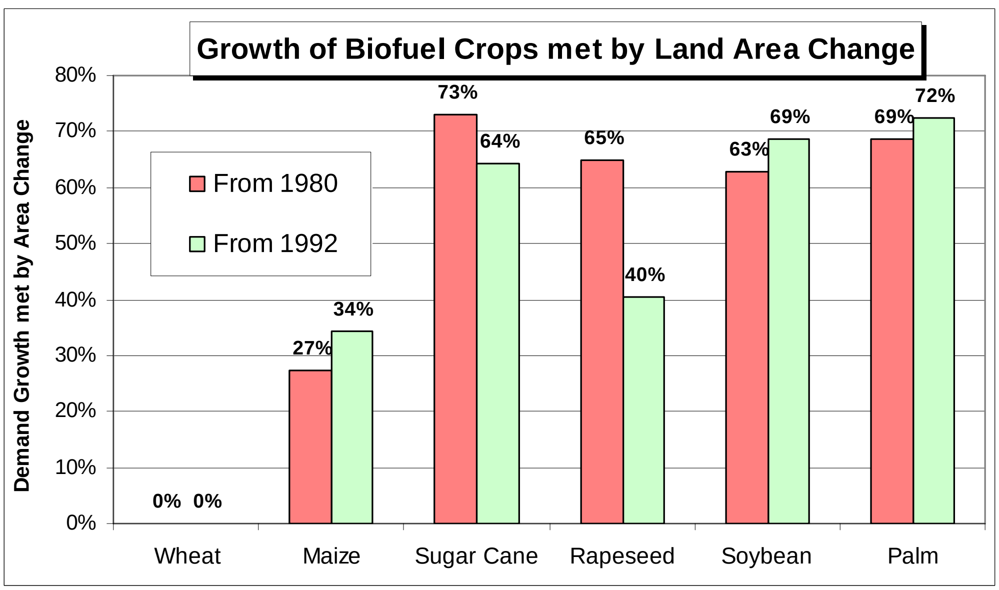


Figure 11) Demand growth of biofuel cops met by area expansion
Source: FAOSTAT, Ensus analysis

### 2.1.2) Carbon stock of land

The carbon emissions from land use change for different crops will depend on the type of land it is displacing and will be very different for different crops. Typical land types are: existing cropland, (for example set-aside land and rotational grassland that is not currently being fully utilised for arable crops), grassland or forest. For example palm has mainly displaced tropical rain forest, or peat lands; while temperate combinable crops, such as cereals and rapeseed are displacing set aside land or temporary pasture land in the EU, or unused historic arable land in Eastern Europe.

More work must be done to determine the land use changes that are being made for different crops in different countries in order to determine an average. However, in order to obtain an indication of the effects of land use change, the average land changes shown in para. 1.4) have been used.

### 2.1.3) Direct land use change penalty

It is shown below that the current direct land use change calculation will not be effective in accounting for land use change from growing biofuel crops.

The current proposals within RTFO and RED calculate a land use change penalty if a particular batch of biofuel is deemed to come from land that has undergone land use change since 2005. Indicative data for biofuel use and land use changes in 2007 is shown below.

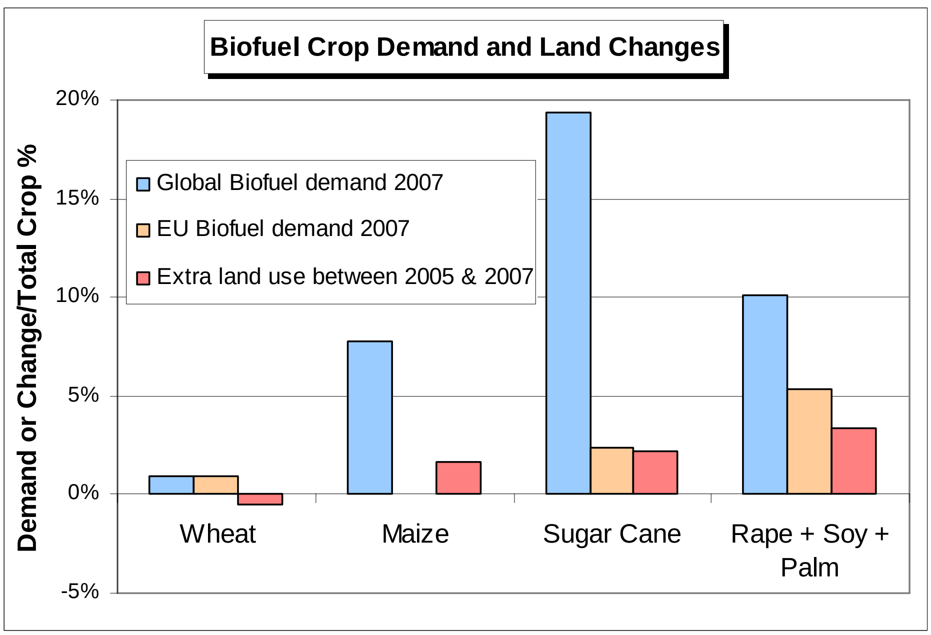


Figure 12) Biofuel crop demand and land changes
Source: FAOSTAT, Ensus analysis

The blue bars show the proportion of the total global crop used for biofuel in 2007. The yellow bars show the proportion of the global crop used for biofuel within the EU in 2007. For example the sugar cane used to produce bioethanol for the EU biofuels market is about 2.3% of the total global biofuel crop.

The pink bars are an estimate of the land use change for the crops between 2005 and 2007 after extrapolating the land use data since 1992. For example the land use for sugar cane is estimated to have increased by 2.2% between 2005 and 2007.

The direct land use change penalty is only incurred if, for example with sugar cane, some of the 2.3% of the total sugar cane used for EU bioethanol is deemed to originate from the 2.2% of the sugar cane crop that is grown on new land.

Since these crops are generally bought and sold through large traders, there is no reason why the farmers that plant new land are any more likely to supply new markets e.g. biofuels than farmers who grow their crops on historic arable land. It is therefore unlikely, even by chance, that the field or plantation used to supply biofuel in the EU is the same field or plantation that is grown on land incurring land use change. Traders are likely to buy from several crop growers using a mixture of established and new land and to sell crop for a variety of uses, including food, non EU biofuel and EU biofuel. The trader can therefore ensure that using a mass balance approach, the crops used for EU biofuel are deemed to come from established plantations.

The rules as currently proposed by the RTFO on accounting for land use change will be a chore for traders and farmers, who will need to establish systems to match biofuels from established crops and plantations against biofuel supplied to the EU. However, they do not prevent the batches of biofuel used in the EU from physically coming from deforested land and will not prevent the continued land use change associated with the increased use of some biofuels. Even if a track and trace system were used to ensure that the batches of biofuel used in the EU are physically coming from established crops, there will be displacement, whereby established land would be used for crops to produce EU biofuel, while the previous crops are displaced to new cropland, which has incurred land use change. The current RTFO and RED proposals that only apply the land use change calculation to direct land use changes do not address the land use change issue caused by displacement effects.

This analysis shows that the current direct land use change calculation will not be effective in accounting for land use change from growing biofuel crops. This has led to campaigning by NGOs against the whole biofuels industry, with no differentiation between those biofuels that increase GHG emissions from land use change and those biofuels that indirectly reduce land use change.

It is therefore essential that the current proposal to calculate GHG emissions from land use change should be extended to cover indirect land use changes, including credit for the displacement effects of biofuels co-products.

### 2.1.4) Indirect land use change penalty

The GHG emissions from land use change (LUC) including indirect land use changes and credit for the displacement effects of biofuel co-products can be effectively calculated by considering the global land use changes for each biofuel crop and the average type of land that is displaced by the crop.

We recognise that in some countries, such as Malaysia with its long established plantations, a proportion of palm oil production is on land that has not been recently deforested. Our land use change calculations take account of FAO land use data for each country that produces palm oil, which supports the view that in Malaysia over 40% of plantation expansion since 1995 has not been established on recently deforested land area.

However, the use of palm oil to produce biodiesel reduces supply of palm oil for food applications, raising the price of palm oil and encouraging the production of palm from deforestation in other countries.

The annual releases of carbon stocks (using a 25 year time period) from the land which is changed from grassland and forest to arable land are uncertain and more work is needed to assess these. However, given the concerns of many groups of the effects of indirect LUC, we cannot wait for all the work to be completed and have to take the best view we can. In order to obtain a calculation of direct LUC, both RTFO and RED have developed lists of default figures for the GHG emissions from LUC. These are just as valid for the indirect LUC calculation, so to obtain an indication of indirect LUC effects, data has been used from RTFO[10]. The carbon stock released by using existing cropland is zero.

Many biofuel crops produce a food co-product as well as the biofuel and the co-product must either be given a LUC credit, or must be allocated between the biofuel product and co-product. For most crops, the co-product can be credited by substitution for soy meal in animal feed. However this can't be done for soy itself. Since the decision to grow more soy is an economic decision which depends on the free market values of the soy oil and soy meal, the products can be allocated by market value. Using quoted US prices for soy oil and soy meal, the average value allocation between the co-products in 2005/6 was:

- Soy oil 36%
- Soy meal 64%

The allocated LUC penalty per GJ of biofuel is calculated as:

Annual carbon stock release (te $CO_2$ / ha)
x Proportion of demand growth met by LUC
x Allocation of LUC to biofuel (for soy)
÷ Biofuel yield (GJ / ha)

The data and results are shown in appendix 5.

**2.1.5) Co-product credit**

As was outlined in section 1.1.2, wheat, maize and rape give high protein co-products that can be used as animal feed. These co-products will displace low protein cereal and imported soy meal for high protein additive. The value of high protein co-products from biofuel crops, such as wheat, maize and rapeseed in displacing soy is vital in assessing the LUCs associated with these crops, but has been ignored in most studies, including in particular the Searchinger and Fargione studies.

The co-product credit for displaced soy is calculated as:

Annual carbon stock release (te $CO_2$ / ha)
x Proportion of demand growth met by LUC
x Allocation of LUC to soymeal

[10] Carbon & Sustainability Reporting within the RTFO, Technical Guidance, Part 2, RFA, Jan 2008, Table 27

This is shown below:

| Co-product Credit for displaced soy | | | | | |
|---|---|---|---|---|---|
| Soy meal Value/(Soy oil + soymeal value) 2005/6 | 64% | | | | |
| Proportion of soy demand growth from LUC | 69% | | | | |
| Soy displaces | | Other Cropland | Grassland | Forest | Average |
| Land source for soy growth | | 21% | 27% | 52% | |
| Carbon stock | te CO2/ha/yr | 0 | 10 | 37 | 22 |
| Soy LUC allocated to biofuel crop | te CO2/ha/yr | 0 | 4 | 16 | 10 |

Table 6) Wheat co-product credit for displacement of soy
Source: Ensus analysis – appendix 5

The LUC credit for the co-product per GJ of biofuel is calculated as:

Co-product credit for displaced soy (te $CO_2$/ha)

x Soy displaced by co-product (ha soy / ha biofuel crop)

÷ Biofuel yield (GJ / ha)

The results are shown in appendix 5.

#### 2.1.5) Net land use change penalty and GHG emissions

The net land use change penalty is determined by subtracting the co-product credit from the crop LUC penalty. The calculation of net LUC penalty, and GHG savings are calculated in appendix 5 and the GHG savings are shown in the diagram below.

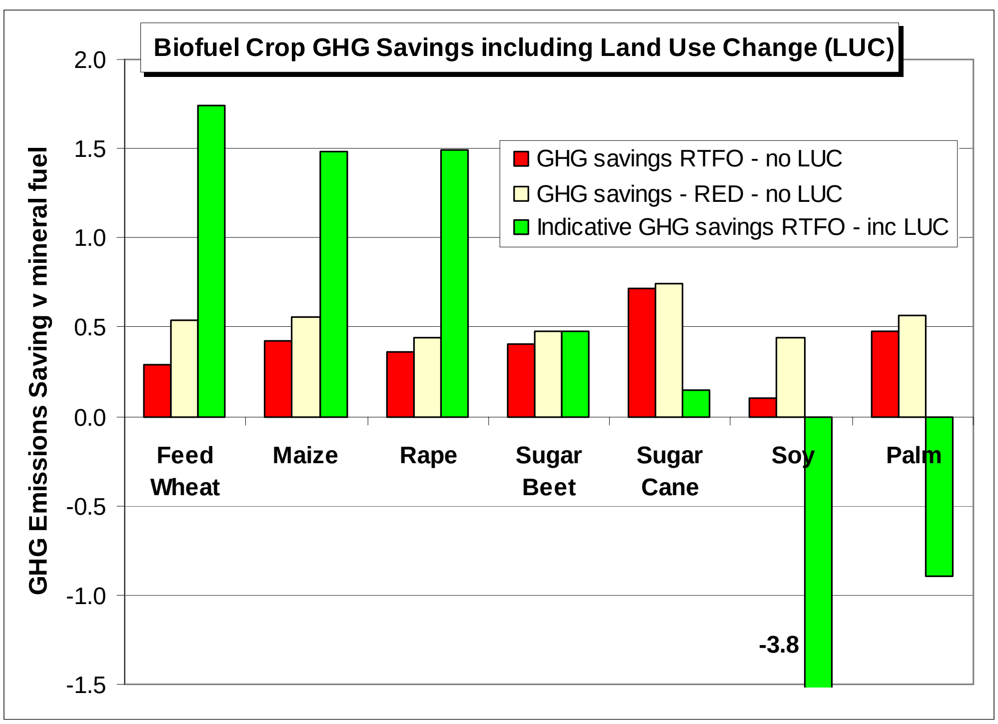


Figure 13) Biofuel crop GHG savings including land use change
Source: Ensus analysis – appendix 5

The GHG savings without land use change are default values taken from the RED, Feb 2008. Annexe VII and RTFO technical guidance Jan 2008.

It can therefore be seen that the GHG emissions from land use change including indirect land use changes and credit for the displacement effects of biofuel co-products can be effectively calculated by considering the global land use changes for each biofuel crop and the average type of land that is displaced by the crop.

The increased production of biofuels from protein crops such as wheat, maize and rapeseed, after including indirect effects, will give GHG emissions savings that are substantially higher than those of the GHG emissions of the respective mineral fuels that they replace.

There have been challenges from scientists working in the area of land use change, that it is too early to incorporate indirect land use change effects in GHG calculations, due to the uncertainty in the carbon stocks on different types of non arable land and what non arable land is being decarbonised as a result of the expansion in area of different biofuel crops. Whilst there is uncertainty in a number of the factors, the results of the analysis above clearly show the importance of taking account of the impact of indirect effects on GHG emissions.

The analysis clearly shows that crops such as wheat, maize and rape in the EU have an even better GHG impact when indirect factors are taken into account. More consideration is required on crops where there is a high risk of land use changes having a significant detrimental effect. The EU can, however, proceed with confidence on a strategy to use its own crops for biofuels. The analysis shows, for example, that the EU can meet its target to replace 10% of its gasoline with Bioethanol in 2020 in a way that requires no net increase in land and which reduces the pressure on deforestation.

**2.2) Advanced biofuel technologies and process improvements**

Advanced technologies can utilise low cost feedstocks including ligno-cellulosic materials such as wood and straw, but require more complex and costly processing. Advanced and improved technologies also enable substantial savings in GHG emissions from existing biofuel chains. The following technologies are considered:

- Processing of cellulosic and ligno-cellulosic materials to produce biofuels.
- Production of high digestibility DDGS
- $N_2O$ abatement of nitric acid plants
- Carbon capture and storage
- Improved nitrogen fertiliser application
- Improved energy integration of process plants

### 2.2.1) Processing of cellulosic and ligno-cellulosic materials for biofuels

Many technologies are being developed to process cellulosic and ligno-cellulosic materials to produce biofuels. These include: advanced fermentation, pyrolysis, and gasification of these materials. Following gasification biofuels such as methanol, dimethyl ether and synthetic diesel can be made using existing synthesis and Fischer Tropsch technologies. The cellulosic and ligno-cellulosic materials may be derived from waste materials, or from so-called energy crops grown specifically for this purpose. These sources have different implications on land use and are dealt with separately.

#### 2.2.1.1) Cellulosic and ligno-cellulosic wastes

A critical question to consider is whether it is better to use such biomass for biofuel or whether it is better to burn it for energy. The comparison of these options is shown below. Data and assumptions are provided in appendix 6.

Figure 14 shows the GHG savings per tonne of ligno-cellulosic biomass in different applications. The options considered are:

- Advanced fermentation to bioethanol using current best technology
- Advanced fermentation to bioethanol using a technology target
- Conversion via Fischer Tropsch technology to biodiesel
- Co-firing in coal fired power station to replace coal
- Burning in biomass power station to replace coal fired power
- Burning in biomass power station to replace gas fired power

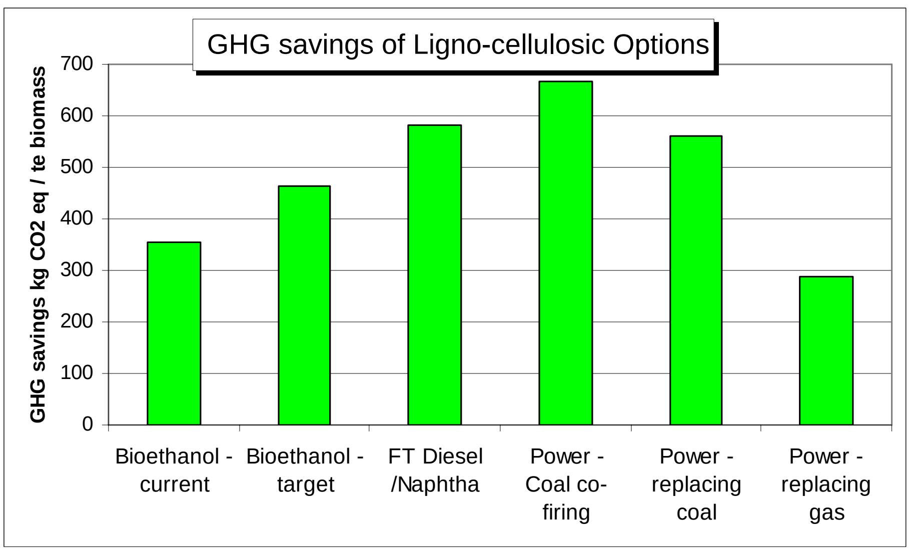


Figure 14) GHG savings of biomass options
Source: Ensus analysis – Appendix 6

The analysis shows that the GHG savings from burning biomass waste to replace coal, are higher than from producing biofuels. However, there are many alternative options for decarbonising power generation, and the range of options and the need to make progress in decarbonising energy and transport fuels needs to be considered. Without doubt the technology to produce biofuels from second generation feedstocks is going to improve in response to the level of development funding and this will impact on the assessment and the relative benefits.

In the short term it will be better to use starch and vegetable oil feedstocks for biofuels and to burn ligno-cellulosic feedstocks to replace coal fired energy generation. However as time moves on and progress is made in decarbonising power generation and improvements are made in second generation biofuels technology, the balance of the argument will change.

In the long term biofuels from wastes using advanced technologies will provide an important additional route to the current production of biofuels from starch and vegetable oil. Many of the developments that are made on first generation fermentation technology will be applicable to advanced fermentation and enable more rapid progress to large scale application of advanced fermentation when the current technical problems are solved.

#### 2.2.1.1) Cellulosic and ligno-cellulosic energy crops

There has been widespread interest on the benefits of producing biofuels from energy crops (where the whole of the crop is used make biofuels), compared to cereals. It is claimed that the bioethanol produced from energy crops does not compete with food and that the yields from ligno-cellulosic feedstocks are significantly higher than from food crops.

However, these claims need to be tested and other factors need to be considered:

- Are the energy crops are grown on land that can be used for food crops? If energy crops, such as miscanthus or SRC are grown on land that could grow food crops, the biofuel product is competing with food just as much as biofuel from wheat or rape.

- Consideration needs to be factored in for the high protein co-products for animal feed from grain crops – often calculations fail to give this an appropriate credit.

- If technology becomes economic for making bioethanol from ligno-cellulosic crops such as SRC and miscanthus, it will also be economic to produce bioethanol from wheat straw and corn stover i.e comparisons need to be made on a like for like basis.

Since the benefit of energy crops is claimed to be a higher yield, the GHG savings per unit area of wheat and energy crops in the UK is determined in appendix 6 and the results are shown in Figure 15.

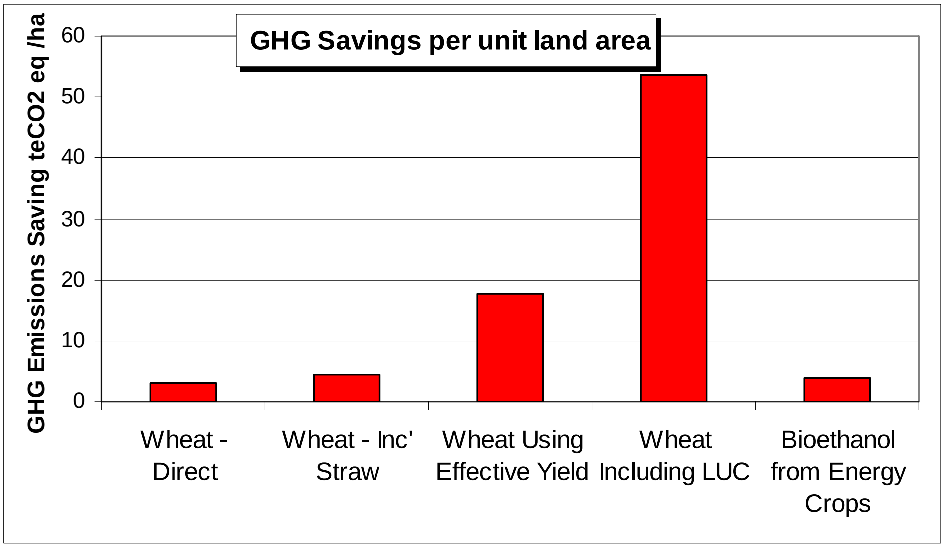


Figure 15) Biofuel crop GHG savings including land use change
Source: Ensus analysis – appendix 6

The first case for wheat takes the direct bioethanol yield from the wheat grain. The second case includes the bioethanol that can be made from the associated wheat straw. Due to the land that is freed up by the bioethanol co-product displacement of soy and feed wheat the effective yield based on the net land area is much higher and is shown in the third case. The fourth case for wheat also includes GHG credit from the reduction in land use change due the reduced demand for soy meal.

It can be seen that including straw and indirect effects, the GHG savings per unit area for bioethanol from wheat are many times higher than from growing energy crops for biofuel in the UK. There is therefore no case for growing energy crops for biofuels on arable land in the UK.

### 2.2.2) Improved fermentation to give high digestibility DDGS

In section 1.1.2 the results were presented for the net land use changes from producing bioethanol from wheat associated with DDGS protein effectiveness of 80%. The effectiveness of the DDGS protein is dependent on the amount of degradation that occurs in the fermentation and DDGS drying process. With improvements in technology, it is likely that the digestibility of the DDGS protein can be increased to be similar to that of soy meal. The higher protein value in the DDGS means that the DDGS would displace more soy meal. The benefits from this in terms of land use change and GHG savings are shown below.

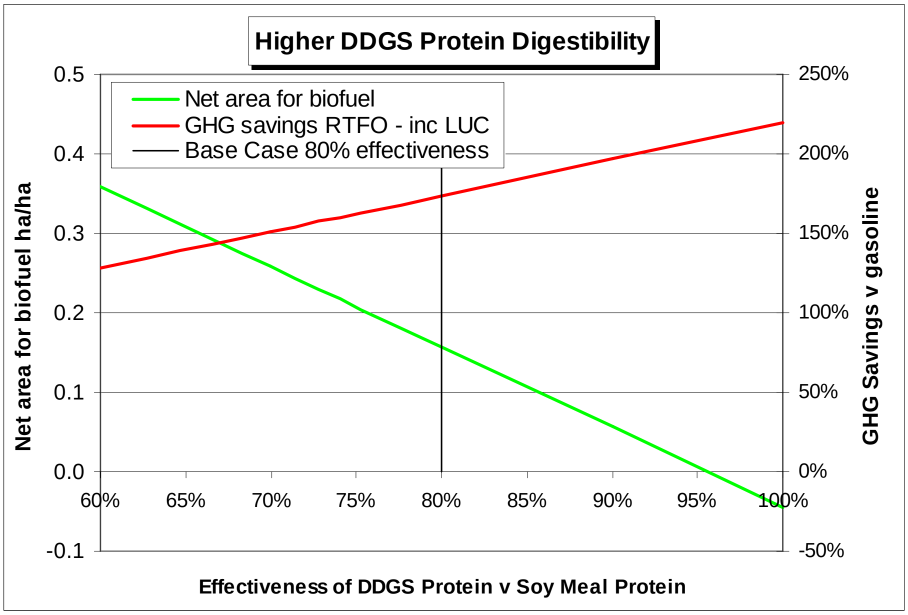


Figure 16) Impact of higher DDGS protein digestibility
Source: Ensus analysis

Figure 16 shows that if the DDGS protein effectiveness were increased from the base 80% assumption (see section 1.1.2) to 100%, the net area for the biofuel after credit for higher soy displacement would be negative. This means that the area of the land needed to grow the animal feed displaced by the DDGS would be less than the amount of land needed to grow the wheat. The GHG savings w.r.t. mineral fuel would be increased from 150% to 200%, due to the additional credit for reductions in carbon losses of land use change for the extra displaced soy.

### 2.2.3) Nitrous Oxide ($N_2O$) abatement in nitric acid plants

A significant part of the GHG emissions associated with bioethanol and biodiesel are currently due to $N_2O$ emissions from nitric acid plants for the production of nitrogen fertilisers used to grow wheat and rape. However, technology is available from Uhde[11] and Johnson Matthey[12] that can be used for $N_2O$ abatement on nitric acid plants, at a cost of 0.5-3 Euro/te $CO_2$[13] .

The economic returns of GHG savings from installing $N_2O$ abatement on nitric acid plants to reduce GHG emissions are very attractive, compared to biofuels. It should therefore be a priority to find ways to achieve the benefits of $N_2O$ abatement as quickly as possible, either by mandate or by inclusion of $N_2O$ emissions into $CO_2$trading arrangements. The case for maximum GHG savings for biofuels assumes 80% $N_2O$ abatement in nitric acid plants.

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[11] $N_2O$ Abatement in an EU Nitric Acid Plant - A Case Study, Michael C E Groves and Rainer Maurer, Uhde GmbH, Dortmund, Germany., The International Fertiliser Society - Proceeding 539 (2004)

[12] $N_2O$ Abatement in an EU Nitric Acid Plant - A Case Study, Michael C E Groves and Rainer Maurer, Uhde GmbH, Dortmund, Germany., The International Fertiliser Society - Proceeding 539 (2004)

[13] Energy Research Centre of the Netherlands (ECN) website

It is shown in appendix 7 that nitrous oxide abatement on nitric acid plants supplying ammonium nitrate fertiliser will add GHG savings of 13% and 15% for bioethanol from wheat and biodiesel from rape respectively.

### 2.2.4) Carbon sequestration from bioethanol plants

Carbon capture and storage is being widely considered for new coal fired power stations. However this is very expensive in terms of capital cost and energy usage when applied to existing power stations because the carbon dioxide is at a relatively low concentration. The carbon dioxide co-product from fermentation is almost pure and can be recovered using only $CO_2$ compression.

The net benefit of carbon sequestration from bioethanol plants is:

| CO2 Sequestration | | |
|---|---|---|
| Stoichiometric CO2 from bioethanol | t CO2/t | 0.96 |
| Power for liquefication | MJ/t | 612 |
| Power GHG requirement | t CO2 eq/t | 0.093 |
| Net CO2 reduction | t CO2 eq/t | 0.86 |
| Saving from CO2 sequestration | kg CO2/GJ | 32 |
| **Saving from CO2 sequestration v gasoline** | | **38%** |

Table 7) $CO_2$ sequestration potential
Source: Ensus analysis

Incentives from carbon linking would be needed to justify $CO_2$ sequestration.

For each of the potential conversion process enhancements described here, the establishment of a European bioethanol industry and infrastructure based on existing process technology will enable market-based investment in the necessary innovation and development to take place.

### 2.2.5) Improved nitrogen fertiliser application

Advanced technology has been developed[14], that automatically determines crop areas that are nitrogen deficient during fertiliser application and accordingly adjusts the application rate. This enables optimum nitrogen application to increase crop yields, maximise the efficiency of nitrogen uptake by the crop and avoid nitrogen run-off.

### 2.2.6) Improved energy integration of process plants

Fermentation plants have traditionally been built as small scale stand alone plants to produce distinctive relatively high value products, with little incentive to improve the efficiency of the plant by energy integration. By contrast, fuel bioethanol plants in the UK are being built as large scale plants on integrated process sites to produce relatively low value commodity products. In this new scenario, there is tremendous scope to improve the plant efficiency and reduce plant capital cost, by plant and site energy integration, increased fermentation ethanol concentrations and advanced distillation designs. This learning will also enable rapid development and improvement of large scale second generation bioethanol, when the current technical problems with second generation bioethanol technology have been resolved.

[14] Environmental award to Hydro Agri, Yara website

**2.3) Marginal land**

Land is defined as being marginal when it is not economic to grow crops for reasons such as low rainfall, poor drainage, nutrient deficiency, excess salinity, slope, inaccessibility, or lack of capital. Price is also important in particular if the increasing demand for food and fuel gives rise to a shortage of land and higher crop prices. In such circumstances it can become economic to grow crops on more marginal land. This may be done by accepting low yields on the land, or by spending capital for irrigation, drainage, soil improvements, roads or farming infrastructure, which enables much higher crop yields to be achieved.

However, the use of new marginal land for either food or energy crop production will incur land use change penalties. These will determine whether there is an overall benefit in using marginal land for new crops for biofuel use. In order to give a net GHG benefit from the use of marginal land after the land use change penalty, it will be important to obtain high biofuel crop yields.

Although some marginal land may currently not be needed for growing food crops, it does not mean that it is best to use that land for energy crops. It may be better to grow crops to provide food and fuel, even though the yields on this land are lower than on prime agricultural land. In order to justify using energy crops, rather than cereals to produce bioethanol, it needs to be shown that energy crops will give higher effective yields of biofuel, or greater carbon savings per unit land area, than producing biofuels from cereal crops. As far as is known, the reasons why land is marginal for growing food crops will also make the land marginal for growing energy crops and little if any work has been published to show that it is more economic to grow energy crops, rather than food crops on any particular piece of land.

**Question 3)** What are the relationships between demand for biofuel feedstock, commodity prices, land conversion and food insecurity? How might these be affected in the future by yield improvements and other factors?

This question appears to assume that demand is the main driver of commodity prices, that high prices drive land use change and that yield improvements might affect this relationship. This may be correct for some crops, but it is important to recognise that the market drivers and effect are quite different for different crops.

It is shown below that for wheat, these assumptions are entirely wrong. The changes in the price of wheat are primarily driven by supply, not demand and high wheat prices drive higher yields, not land use change. The effect of the use of wheat for bioethanol on the wheat price is negligible.

### 3.1) Cereal prices

It is shown below for wheat, the changes in the price of wheat are primarily driven by changes in supply, rather than demand and low crop output drives high wheat prices.

There has been concern over the high prices of cereals over the last 15 months and this has been blamed by some people on their use for biofuels. The prices over the last 35 years in real terms (£ of 2006) are shown below.

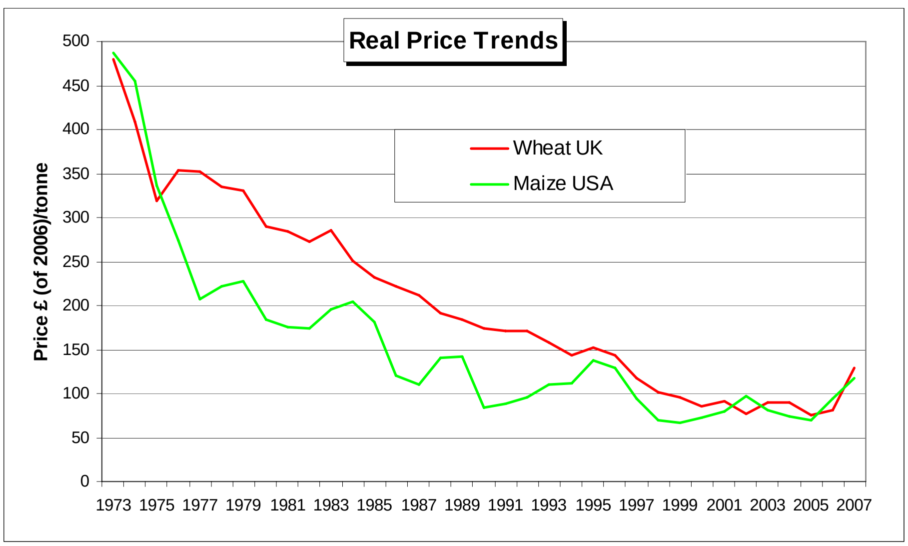


Figure 17) Real price trends
Source: FAOSTAT

It may be seen that although the price increases over the last year have been substantial, current prices are still low in long term historic terms.

### 3.1.1) Volatility in production and demand

The variations in the global production and demand for wheat are shown below.

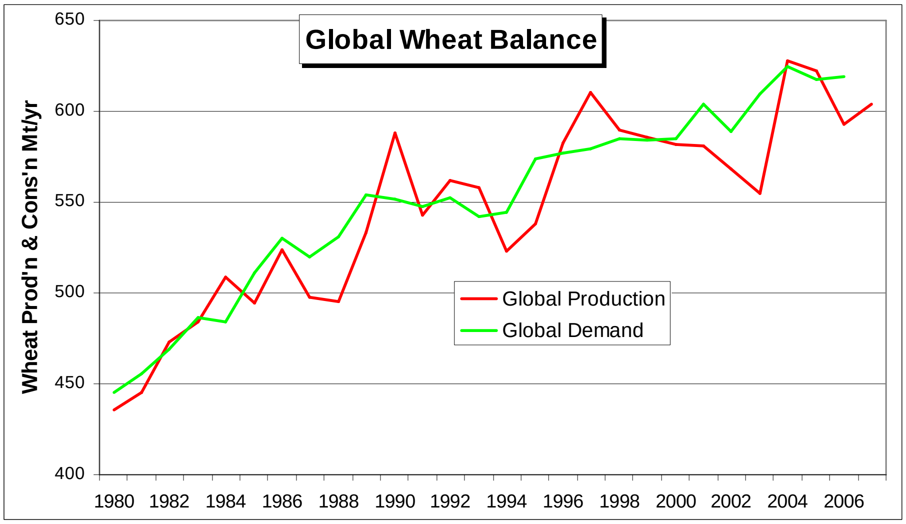


Figure 18) Global wheat balance
Source: USDA

It can be seen that there is a large variation in the production in different years, while the variation in demand is fairly smooth. When this is quantified it is shown that the variation in production compared to a moving average is 2.4 times that of the variation in demand. Therefore the price fluctuations of wheat are primarily due to the variations in production, rather than to variations in demand.

The effect of bioethanol on the growth of wheat is shown below.

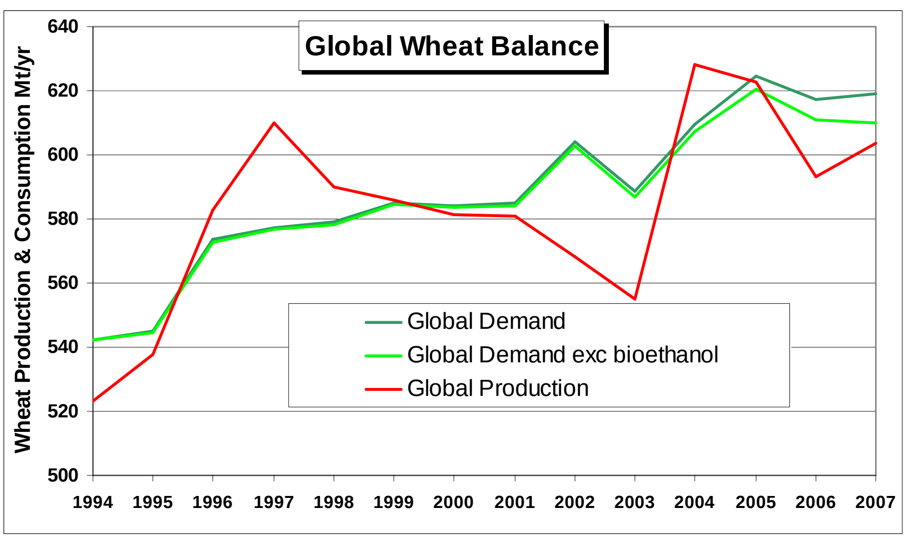


Figure 19) Global wheat balance – including bioethanol impact
Source: USDA, F.O.Licht

The growth in global wheat consumption from 2000 to 2007 due to bioethanol was less than 0.2% p.a. and the effect of bioethanol demand on price is negligible, compared to variations in supply.

### 3.1.2) Affect of crop supply and demand changes on wheat prices

The variations in supply of crops from year to year, due to good or poor harvests, changes in area, or changes in the demand, effect the world stocks of that crop. As world stocks of any crop decrease, crop prices will rise to reflect the shortage. The relations between stocks and prices of some crops in the USA are well established.

Since it usually needs two or more years of poor harvests to deplete stocks and prices take time to rise and fall, the relationship is best established by using two year moving averages for outputs and prices. Also since there is a delay for the price to react to poor harvest, the best relationship is given by introducing a one year lag between output changes and price changes.

The results of supply changes for wheat are:

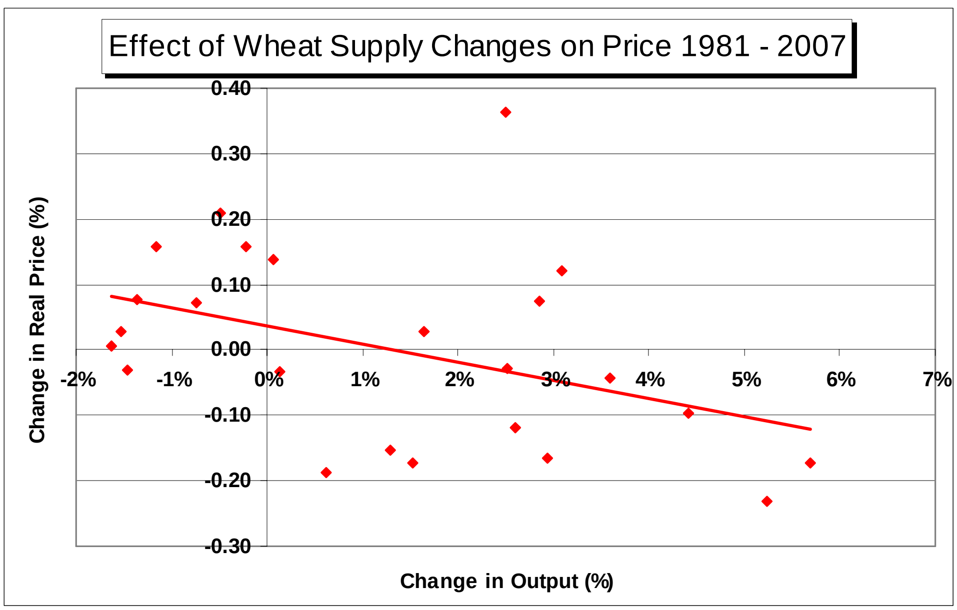


Figure 20) Effect of global wheat supply changes on price
Source: FAOSTAT
Note: Each point represents one year and the line shows the linear regression fit to the data

This shows that increased supply of wheat leads to lower prices and vice versa. The relationship is:

% Change in real price / % change in supply = -2.5 ($R^2$ = 0.33)

Where $R^2$ is a statistical measure of the significance of fit of the relationship

The variations in the demand for wheat have been small and there is no statistically significant relationship between wheat demand and wheat prices. Therefore the changes in the price of wheat are primarily driven by changes in supply, rather than demand and low crop output drives high wheat prices.

### 3.2) Effect of wheat prices on land use and yield changes

It is shown below that high prices of wheat drive higher supply and that this arises from increases in yield, rather than increases in land use. Commodity prices are expected to drive changes in output, which in turn can be achieved by changes in land use or changes in yield.

Farmers like to see a sustained high price, before reacting to prices, so a two year moving average price is used and a lag of one year before affecting output changes. Also since poor harvests and other factors can affect land use change and yields a three year rolling average for the factors is used. The effect of price on land use changes for wheat is shown below:

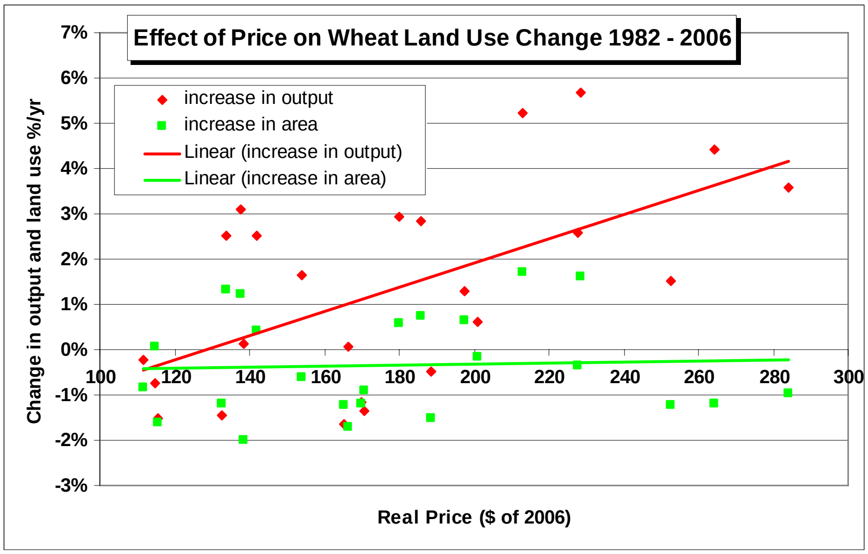


Figure 21) Effect of global price on wheat land use change
Source: FAOSTAT

While there is a clear relationship between the price of wheat and increases in wheat output, the relationship between wheat price and increases in land use is insignificant. The effect of price on yield changes for wheat is shown below:

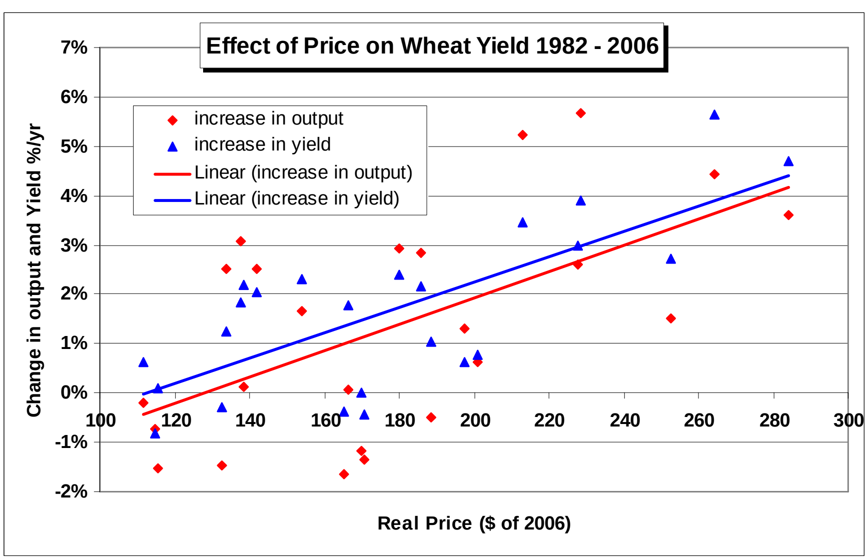


Figure 22) Effect of global price on wheat yield
Source: FAOSTAT

It can be seen that the increase in wheat output has historically been entirely accounted for by increased yields.

The relationships are:

| | | |
|---|---|---|
| Change in output / Real price | = 2.2% per $100 | ($R^2 = 0.34$) |
| Change in yield / Real price | = 2.4% per $100 | ($R^2 = 0.54$) |

This shows that the effect of prices on changes in wheat yields is actually greater than changes in the total wheat output. This analysis shows that the data for wheat in section 1.1.1 is not just due to long term increase in wheat yields leading to reduced wheat area, but is a short term causal relationship associated with higher wheat prices driving increased yields. The fact that high wheat prices do not drive increases in land area is not surprising. Wheat in the EU is grown as part of a crop rotation and it can be shown that it is not worth displacing a break crop with an extra crop of wheat, due to disruption of the rotation and lower yields from the extra wheat crop. Also when wheat prices are high, the prices are also high for other crops.

This analysis shows that high prices of wheat drive higher supply and that this arises from increases in yield, rather that increases in land use.

### 3.3) Effect of biofuel feedstock demand on food insecurity

Global wheat prices have risen sharply over the past 3 years as stock-to-use ratio has fallen to 20%, near historic lows. This has prompted speculation about the impact of biofuel feedstock demand on global price and food security.

The principal cause of recent high prices is supply variability, rather than increased demand. Periodic and weather-related regional crop failures such as experienced in Australia in 2007 are not uncommon, and when two or more years are impacted in succession, the global shortage drives up price and reduces stocks. Such global wheat price spikes have occurred four times since 1970:

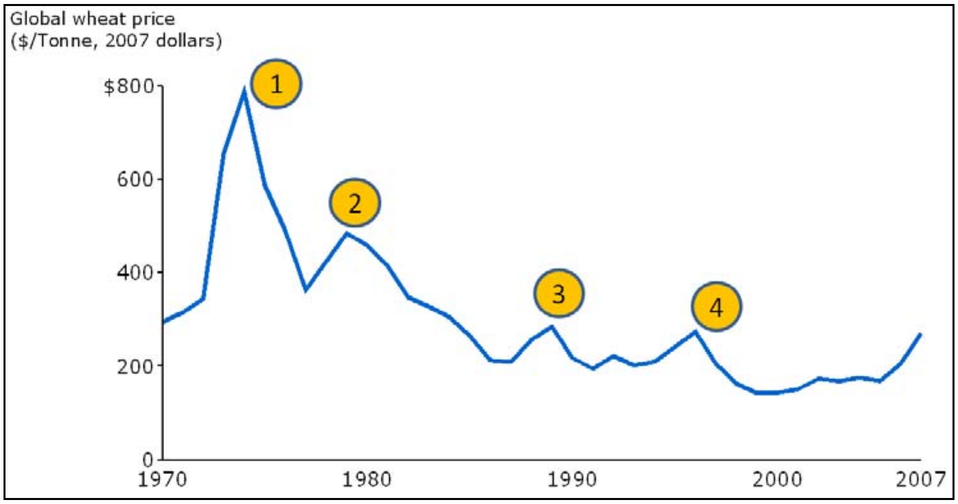


Figure 23) Global wheat price history (2007 dollars)
Source: UNCTAD, EIU

In each case, these high prices were reversed by global wheat output responding over the following 2-3 year period. Three years after the peak price, the stock-to-use ratio had increased by 1-5 percentage points, whilst prices fell back by 20-50%.

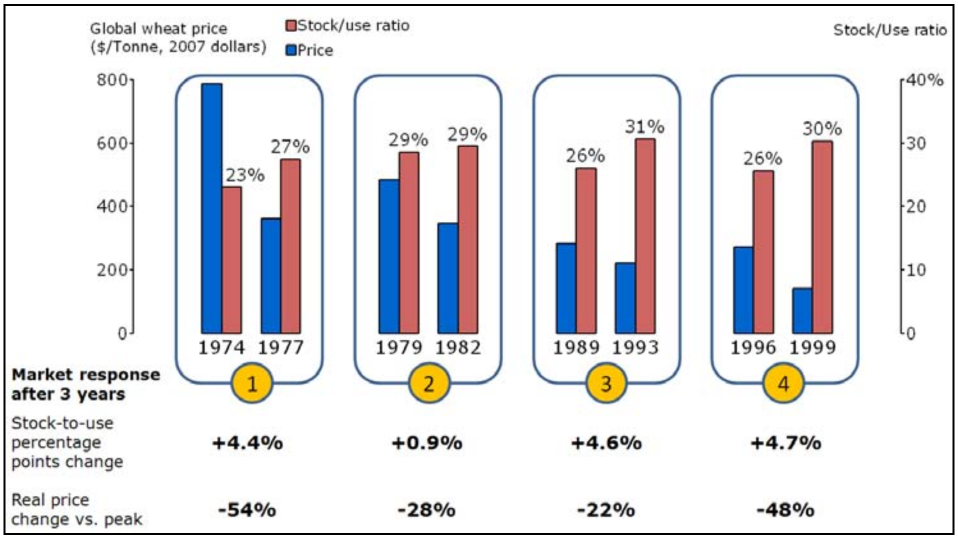

Figure 24) Market response to wheat prices
Source: UNCTAD, USDA WASDE, EIU

Europe can expand its agricultural output to meet a 10% bioethanol target. Given that agriculture has typically responded to price signals over a 2-3 year period, the EU's proposal to establish a long-term biofuels target for 2020 is prudent. It provides an appropriate time frame for this expansion, alongside the associated changes in soy and wheat production overseas, without significantly contributing to short term price volatility and consequent global food insecurity.

In contrast to wheat, which Europe exports, the EU is a net importer of high protein animal feed. As Europe's meat demand grows by a forecast 1-2% per annum, this import requirement may exceed 55 million tonnes by 2020. This animal protein deficit is a significant and growing source of European food insecurity. The expansion of high protein animal feed output from bioethanol production in Europe should be recognised as a valuable new source of supply to mitigate this increasing food insecurity.

**Question 4)** What economic benefits arise from production of biofuels or feedstock in the South?

Several benefits can be identified:

- Increased agricultural prices generally
- Reduced subsidised exports from Europe
- Technology transfer opportunities
- Contribution to developing meat sectors
- Local biofuel industries

### 4.1) Increased prices

It is generally recognised that higher prices benefit the agricultural sector. More investment in modern and secure agricultural practices can be justified, and the additional income generated can contribute to economic growth and potentially reduce dependency on cash crops.

Whilst the present price levels are not expected to continue after the new crops are harvested, it is expected that the general increased demand from India and China, coupled with the reduced global stocks of several commodities, will result in an increased price level above the norm prior to 2007. This should provide a general benefit to the agricultural sector, including the South. Ensus does not believe this price increase is caused by biofuels, but does recognise that many will see it as a contributory cause.

### 4.2) Reducing subsidised exports from Europe

A major complaint against Europe's CAP by WTO/GATT in the past has been the accusation of Europe dumping its surplus produce in the South at subsidized prices, and hence detracting from local agricultural activity. Additionally it was criticised within Europe as being wasteful and very expensive. This situation could now be totally obviated, with biofuels and growing food/feed needs using virtually all of the agricultural surplus in Europe, thereby certainly removing the need for intervention stocks to be held, and reducing the amount of material exported as well. Any exports would be at prices that should not undermine products in South. There should thus be a benefit all round.

### 4.3) Technology transfer opportunities

Europe is clearly leading the way in understanding how biofuel processes can be harnessed and optimised to the maximum benefit of both the food/feed sectors, and to tackling GHG reduction. The rules which it is developing and the associated growth methodologies are a vital part in delivering the above, and will need to be applied for all biofuel feedstock. There is therefore an opportunity to transfer this learning to the South – indeed a requirement if the South is to supply feedstock into Europe.

The requirement that growth and/or production of the raw materials for such biofuels must be done is a manner fully compliant with the defined rules, in a way to achieve low carbon footprint and meet all the requirements of sustainable production is necessary.

Such controls on agricultural production are not consistently achieved currently. Thus biofuels perhaps provide a better vehicle with which to attempt delivery and compliance with these rules than has been available to date. However, achieving this end is difficult, and will require much more strict application of the rules, coupled with high penalty defaults for non-compliance or lack of/poor quality supporting data, than has been achieved with any import situation to date.

A move from rather extensive, poorly managed and controlled agriculture to more intensive, highly managed and controlled production will not only increase yields and reduce land area pressure, but facilitate increase in the global capacity to support population growth, whilst minimising damaging environmental impacts.

### 4.4) Contribution to developing meat sectors

Previous answers have demonstrated the benefits of the biofuel industry based on cereals to provide alternate sources of protein concentrates for the meat sector, which release substantial amounts of land otherwise required to grow those concentrates. Given the developing world's likely requirements for developing meat production, particularly in India and China, local use of cereal feedstock for biofuels can relieve some of the pressure that will undoubtedly continue to develop on (tropical) land use for growth of protein concentrates.

Although currently the majority of the global cereal production is used directly for human food use, once populations move more towards a taste for meat, then the requirement for animal feed will begin to balance out and then exceed that of direct human food use, as it does for example in Europe, where at least 50% of cereal use is for animal feed, <u>and</u> there is the requirement for yet more significant land use outside Europe, for protein concentrate production. Thus not only can biofuels substantially alleviate this demand from Europe (which clearly has put substantially pressure on deforestation in the recent past, and indeed still is), they can be a major tool in alleviating some of the future demand from the developing world, which otherwise has the potential to be a massive component of future land use requirements.

### 4.5) Biofuel processes

Clearly in areas where there is substantial land available of a type not involving high carbon deposits or high biodiversity value, and where soil and moisture conditions permit, optimised cropping of that land is highly desirable. Given global agricultural prices which will reward investment also, then the opportunity exists to make a significant contribution, be it for food or biofuel feedstock production, providing the good management practices and consequent control referred to above have been achieved.

The answers to previous questions have shown there are currently very significant concerns about indirect land use change, which do make several existing raw materials very poor from a GHG point of view for biofuel use. However, it could be that with careful sustainability compliance and land use selection, raw materials like sugar cane could be the basis of developing a larger biofuels industry to the benefit of the South.

## MAIN CONTRIBUTORS

### Warwick Lywood

Warwick is a chemical engineer with 35 years experience in the process industries. He has had experience in process design, plant management, technology assessment, licensing and strategic planning in a wide range of senior management positions in ICI. He has worked as a consultant doing strategic planning, technology assessment and market and environmental modelling work associated with biofuels for several companies and related studies. He is currently Technology and Planning Manager for Ensus Ltd.

### John Pinkney

John is a chemical engineer who has spent the majority of his career, which begun in 1968, with ICI/AstraZeneca where he has had a number of senior management roles. Specific activities have included leading the development of the 'Quorn' foods business, and being General Manager of a range of biotech/ fermentation oriented businesses based in North America. Latterly he has focused on the food industry, and has served on the board of Marlow Foods, producers of Quorn. He is currently Technical Director for Ensus Ltd.

### Sam Cockerill

Sam is an engineer with 15 years experience in technology development, general management and strategy consulting roles, most recently with Bain and company. He is a non-executive director of Providence Holdings, one of the UK's major agricultural supply chain management companies.

## APPENDICES

### Appendix 1 Global production yield and land use change data for wheat

The data for increased demand for land for wheat is shown below:

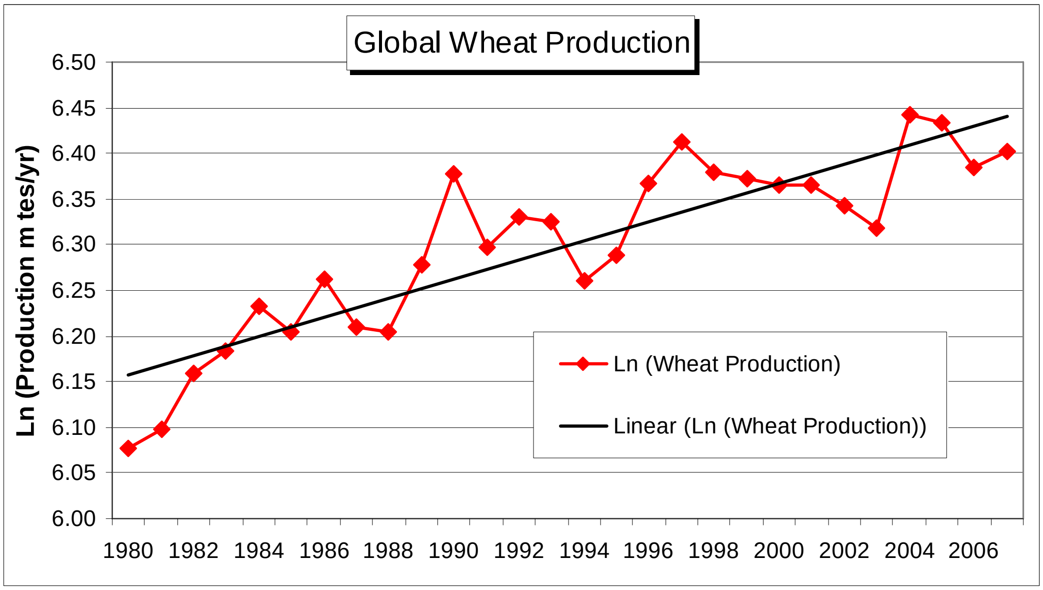


Table A 1.1
Source USDA

The rate of production increase is given by the slope of the linear regression fit and is 1.1%/yr.

The data for increased global yield of wheat is:

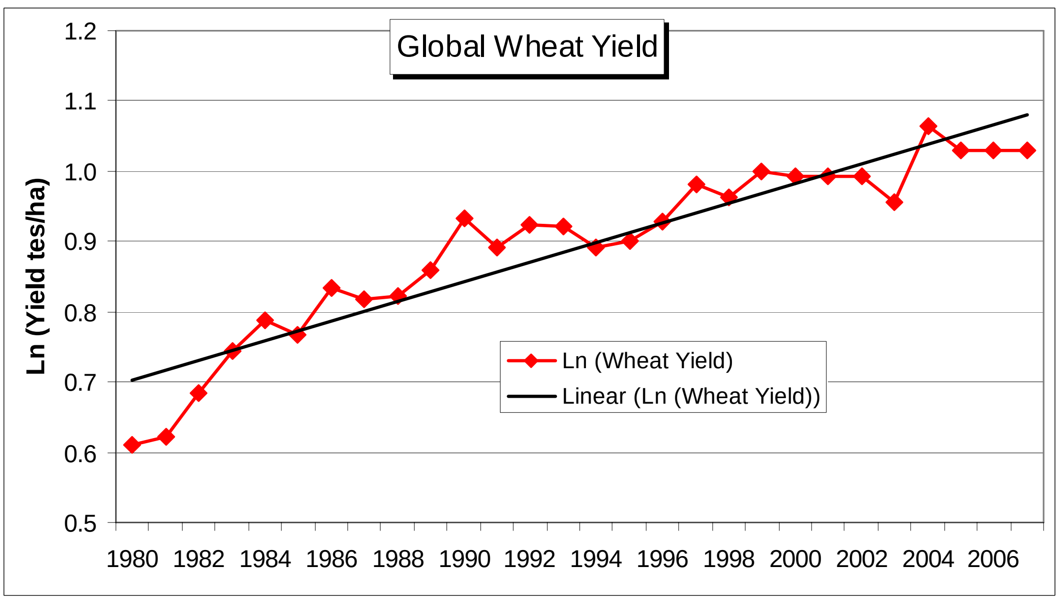


Table A 1.2
Source USDA

The rate of increase of global yield given by the linear regression fit is 1.4% p.a.

The data for increased global land use of wheat is:

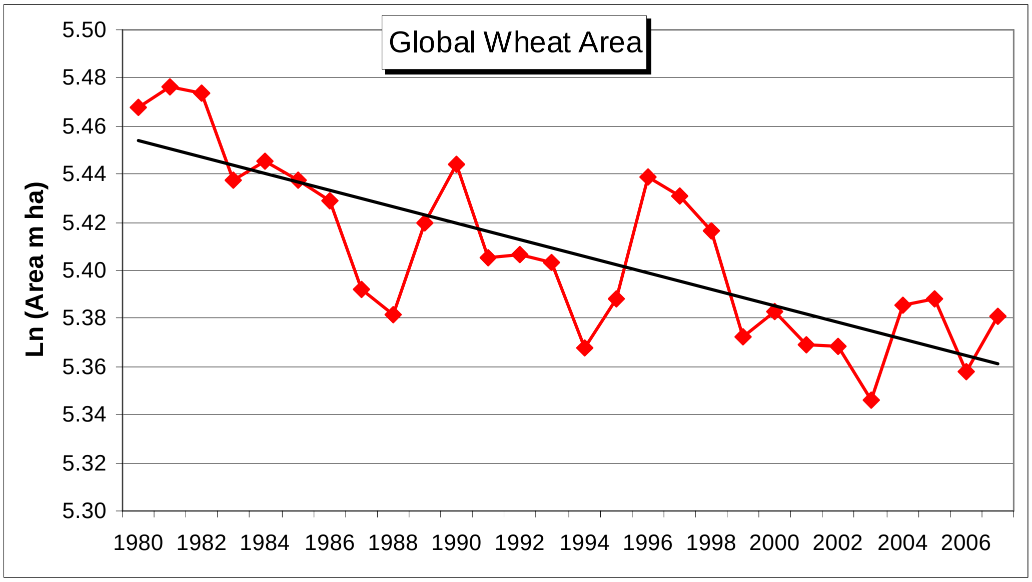


Table A 1.3
Source USDA

The rate of increase of global yield given by the linear regression fit is  - 0.35% p.a.

## Appendix 2 Biofuel co-product displacement of soy meal and cereals

The following data is use for animal feed balances

| Biofuel Process Yield Data - NW Europe | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Crop** | | **Feed Wheat** | **Feed Wheat** | **Maize** | **Maize** | **Sugar Beet** | **Rape Seed** | **Soy Bean** |
| **Use** | | **Feed** | **Biofuel** | **Feed** | **Biofuel** | **Biofuel** | **Biofuel** | **Biofuel** |
| **Yields** | | | | | | | | |
| Raw Grain (NW Europe) | te/ha | 7.67 | 7.67 | 8.6 | 8.6 | 67.8 | 3.6 | 2.5 |
| Traded Grain moisture | | 15% | 15% | 15% | 15% | | 9% | 13% |
| Biofuel from grain | te/te raw grain | | 0.322 | | 0.331 | 0.078 | 0.42 | 0.162 |
| Biofuel from grain | te/ha | | 2.47 | | 2.84 | 5.27 | 1.52 | 0.40 |
| Biofuel heat value | GJ/te | | 26.8 | | 26.8 | 26.8 | 37.2 | 37.2 |
| Biofuel energy yield | GJ/ha | | 66.2 | | 76.1 | 141 | 56.7 | 15.0 |
| Biofuel yield | te eq be/ha | | 2.47 | | 2.84 | 5.27 | 2.12 | 0.56 |
| Animal Feed moisture | | 14% | 10% | 12% | 10% | 9% | 10% | 10% |
| Animal Feed | te/te grain | 0.99 | 0.299 | 0.97 | 0.282 | 0.058 | 0.52 | 0.71 |
| Animal Feed | te/ha | 7.58 | 2.29 | 8.29 | 2.42 | 3.95 | 1.88 | 1.76 |
| Metabolisable energy (ruminants) | GJ/te DM | 13.6 | 13.5 | 13.8 | 14.0 | 12.3 | 12.0 | 13.4 |
| Metabolisable energy yield | GJ/ha | 89 | 27.9 | 101 | 30.5 | 44.1 | 20.3 | 21.3 |
| Protein | te/te DM | 12% | 43% | 10% | 37% | 8.2% | 40% | 54% |
| Protein | te/te feed | 10.4% | 39% | 8.4% | 34% | 7.5% | 36% | 49% |
| Protein Yield | te/ha | 0.79 | 0.90 | 0.69 | 0.81 | 0.30 | 0.68 | 0.86 |

Table A 2.1

### Sources & notes

- Crop yields for N W Europe are the average yields from 2003-5 for UK, Germany, France, Ireland and Netherlands and are taken from FAOSTAT.
- Biofuel yields are typical data
- Metabolisable energy data of animal feed is from: Farm Management Pocketbook, John Nix, 38th edition (2008)
- Protein content of wheat is from HGCA UK quality survey for Nabim group 3 & 4 wheats and equivalent France and Germany data for feed wheat.
- Protein content of other crops is from FAO data
- Protein content of animal feed from biofuel co-products is by mass balance
- The protein content of DDGS includes free nitrogen in the cereal that is converted into yeast protein during fermentation

| Mass Balance for Wheat Bioethanol | | | | | |
|---|---|---|---|---|---|
| **Protein effectiveness of DDGS** | 0.80 | | | | |
| | | **EU Animal Feed Supply** | | | |
| **Crop Use** | | **EU Wheat Biofuel** | **EU Wheat Feed** | **Soy Biofuel** | **TOTAL** |
| **1) Cereal used for bioethanol** | | | | | |
| Area | ha | 1.0 | | | 1.00 |
| Grain biofuel | tes eq be | 2.47 | | | 2.5 |
| Animal feed | tes | 2.29 | | | 2.29 |
| Metabolisable energy | GJ | 27.9 | | | 27.9 |
| Effective Protein | tes | 0.72 | | | 0.72 |
| **2) Cereal used as feed** | | | | | |
| Area | ha | | 0.15 | 0.69 | 0.842 |
| Biofuel | tes eq be | | | 0.39 | 0.4 |
| Animal feed | tes | | 1.12 | 1.22 | 2.34 |
| Metabolisable energy | GJ | | 13 | 14.8 | 27.9 |
| Protein | tes | | 0.12 | 0.60 | 0.72 |
| Net extra biofuel | tes eq be | | | | **2.08** |
| Net Area | ha | | | | **0.16** |
| **Effective Biofuel Yield** | tes be eq/ha | | | | **13.2** |

Table A 2.2
All input data from Table A 2.1

| Mass Balance for Biofuel Co-products | | Wheat | Maize | Rape Seed | Sugar Beet |
|---|---|---|---|---|---|
| Protein effectiveness = | | **0.80** | | | |
| % soymeal replaced by DDGS | | 0.74 | 0.62 | 0.66 | -0.08 |
| Area of soy displaced | ha soy/ha bf | 0.69 | 0.62 | 0.53 | -0.23 |
| Matabolisable energy from soy | GJ/ha bf | 14.8 | 13.1 | 11.4 | -4.9 |
| Area of cereal feed displaced | ha feed/ha bf | 0.15 | 0.17 | 0.10 | 0.55 |
| Biofuel from soy | te eq be/ha bf | 0.39 | 0.34 | 0.30 | -0.13 |
| Effective biofuel yield | | 13.2 | 11.8 | 5.0 | 8.0 |
| Wt soy meal per wt co-product | te/te C/P | 0.53 | 0.45 | 0.50 | -0.10 |
| Wt cereal feed per wt co-product | te/te C/P | 0.49 | 0.61 | 0.41 | 1.07 |

Table A 2.3
All input data from Table A 2.1

## Appendix 3 Effect of 2020 EU biofuel demand on land use change

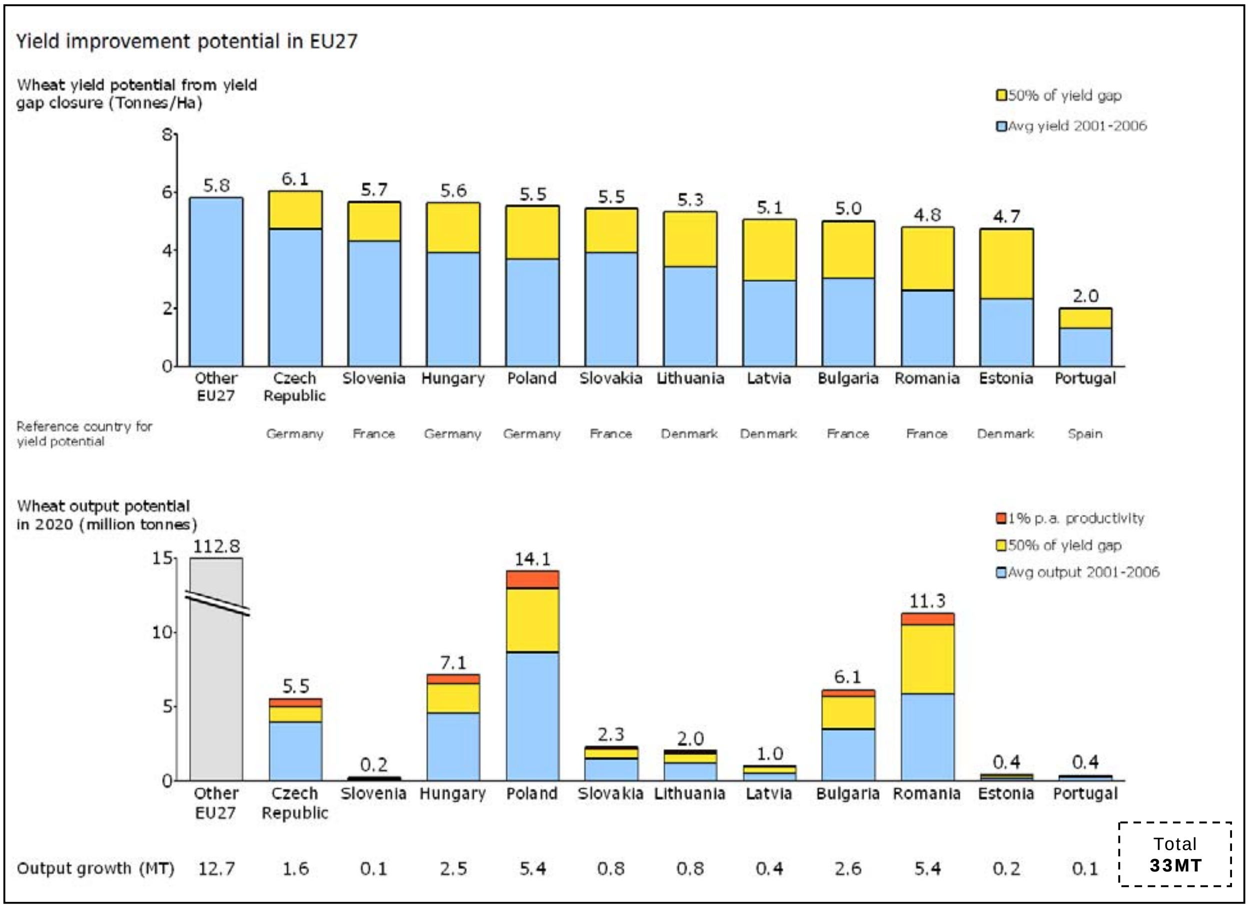


Figure A 3
Source: FAOSTAT production database, Ensus analysis

## Appendix 4 Impact of increased food crops on land with high carbon stocks

The analyses of the land use changes associated with different crops are shown below. For each crop, the three or four countries with the highest increase in crop area are considered. The change in land use of crops in each country is apportioned according to the land use change in the crop, forest and grassland areas. A weighted average land use change ratio for each crop is calculated from these data.

| Maize - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area m ha | | | Ratio of Historic Land Use Change | | |
| | Maize | Forest | Permanent Grassland | Forest | Grassland | Cropland |
| USA | 3.3 | 2.6 | 1.6 | 0 | 0 | 100% |
| China | 4.9 | 30.2 | 0.0 | 0 | 0 | 100% |
| India | 1.5 | 2.0 | -0.5 | 0 | 0 | 100% |
| **Average** | | | | **0%** | **0%** | **100%** |

| Rape - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area m ha | | | Ratio of Historic Land Use Change | | |
| | Rape | Forest | Permanent Grassland | Forest | Grassland | Cropland |
| EU | 1.8 | 6.5 | -3.6 | 0 | 0 | 100% |
| India | 1.1 | 2.0 | -0.5 | 0 | 0 | 100% |
| China | 2.0 | 30.2 | 0.0 | 0 | 0% | 100% |
| Canada | 1.2 | 0.0 | 0.0 | 0 | 0% | 100% |
| **Average** | | | | **0%** | **0%** | **100%** |

| Soy - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area m ha | | | Ratio of Historic Land Use Change | | |
| | Soy | Forest | Permanent Grassland | Forest | Grassland | Cropland |
| USA | 5.0 | 2.6 | 1.6 | 0 | 0% | 100% |
| Brazil | 11.3 | -28.9 | 4.0 | 100% | 0% | 0% |
| Argentina | 8.1 | -1.5 | -0.1 | 18% | 82% | 0% |
| **Average** | | | | **52%** | **27%** | **21%** |

| Sugar Cane - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area m ha | | | Ratio of Historic Land Use Change | | |
| | Sugar Cane | Forest | Permanent Grassland | Forest | Grassland | Cropland |
| Brazil | 1.2 | -28.9 | 4.0 | 100% | 0% | 0% |
| South Africa | 0.2 | 0.0 | 0.2 | 0% | 0% | 100% |
| China | 0.2 | 30.2 | 0.0 | 0% | 0% | 100% |
| **Average** | | | | **79%** | **0%** | **21%** |

| Palm - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area m ha | | | Ratio of Historic Land Use Change | | |
| | Palm | Forest | Permanent Grassland | Forest | Grassland | Cropland |
| Malaysia | 1.9 | -1.1 | 0.0 | 58% | 0% | 42% |
| Indonesia | 3.0 | -18.7 | -0.6 | 97% | 3% | 0 |
| Nigeria | 1.1 | -4.1 | -0.9 | 82% | 18% | 0 |
| **Average** | | | | **82%** | **5%** | **13%** |

Tables A 4

**Sources & notes**

- Crop areas from FAOSTAT production database, forest & grassland areas from FAOSTAT resource database
- Where increases in crop land area correspond to decreases in forested area, the crop has been grown on deforested land
- If the reduction in forest is less than the increase in the biofuel crop the biofuel crop can't all have come from forest.
- If the increase in forest area is greater than the reduction in grassland, then the reduction in grassland is due to the grassland being converting to forest, rather than being used for biofuel crops.

After adjustment of the sugar cane data for sugar cane in Brazil, the result is:

| Sugar Cane - Land Use Change 1995 - 2005 | | | | | | |
|---|---|---|---|---|---|---|
| | Change in Land Area Mha | | | Ratio of Historic Land Use Change | | |
| | **Sugar Cane** | **Forest** | **Permanent Grassland** | **Forest** | **Grassland** | **Cropland** |
| Brazil | 1.2 | -28.9 | 4.0 | 15% | 85% | 0% |
| South Africa | 0.2 | 0.0 | 0.2 | 0% | 0% | 100% |
| China | 0.2 | 30.2 | 0.0 | 0% | 0% | 100% |
| **Average** | | | | **12%** | **67%** | **21%** |

**Table A 4.1**

## Appendix 5 Indirect land use change GHG penalty

Input data is shown on yellow background

| Calculation of Indirect Land Use Change GHG Penalty | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Including "Change of Land Use" | | Feed Wheat | Maize | Rape | Sugar Beet | Sugar Cane | Soy | Palm |
| Country | | NW Eur. | NW Eur. | NW Eur. | NW Eur. | Brazil | Brazil | Indonesia |
| Biofuel yield | te/ha | 2.5 | 2.8 | 1.5 | 5.3 | 4.6 | 0.40 | 3.6 |
| Biofuel yield | GJ/ha | 66 | 76 | 57 | 141 | 123 | 15 | 135 |
| Proportion of demand growth from LUC | | 0% | 32% | 40% | 0% | 59% | 69% | 72% |
| **ILUC Penalty** | | | | | | | | |
| Carbon stock - Grassland | te CO2/ha | 7 | 7 | 7 | 7 | 9 | 10 | 18 |
| Carbon stock - Forest | te CO2/ha | | | | | 37 | 37 | 31 |
| Ratio historic LUC to grassland | | 0 | 0 | 0 | 0 | 67% | 27% | 5% |
| Ratio historic LUC to forest | | 0 | 0 | 0 | 0 | 12% | 52% | 82% |
| Average carbon stock | | 0 | 0 | 0 | 0 | 10 | 22 | 26 |
| Allocation of LUC to biofuel | | | | | | | 36% | 90% |
| Allocated LUC penalty | kg CO2/GJ NC\ | 0 | 0 | 0 | 0 | 50 | 364 | 126 |
| **Co-product Credit** | | | | | | | | |
| Area of soy displaced | ha/ha bf crop | 0.69 | 0.62 | 0.53 | 0.00 | 0.00 | 0.00 | 0.00 |
| Soy meal allocation | te CO2/ha bf cro | 11 | 10 | 9 | 0 | 0 | 0 | 0 |
| Average LUC credit | kg CO2/GJ NC\ | 102 | 78 | 91 | 0 | 0 | 0 | 0 |
| **Net Land use change penalty** | kg CO2/GJ NC\ | -102 | -78 | -91 | 0 | 50 | 364 | 126 |
| Mineral fuel GHG emissions | kg CO2eq/GJ | 85 | 85 | 86 | 85 | 85 | 86 | 86 |
| Land use change penalty | v mineral fuel | -120% | -92% | -106% | 0% | 59% | 422% | 146% |
| Country | | UK | France | UK | UK | Brazil | Brazil | Mal/Ind |
| GHG emissions - RTFO | kg CO2eq/te bf | 1623 | 1319 | 2048 | 1351 | 648 | 2891 | 1670 |
| GHG emissions - RED | kg CO2eq/MJ | 19 | 16 | 24 | 16 | 8 | 33 | 19 |
| GHG savings RTFO - no L.U.C | v mineral fuel | 29% | 42% | 36% | 41% | 71% | 10% | 48% |
| GHG savings - RED - no L.U.C | v mineral fuel | 54% | 56% | 44% | 48% | 74% | 44% | 57% |
| **Indicative GHG savings RTFO - inc L.U.C** | | | | | | | | |
| | v mineral fuel | **1.74** | **1.48** | **1.50** | **0.48** | **0.15** | **-3.78** | **-0.89** |

Table A 5.1

| Co-product Credit for displaced soy | | | | | |
|---|---|---|---|---|---|
| Soy meal Value/(Soy oil + soymeal value) 2005/6 | | 64% | | | |
| Proportion of soy demand growth from LUC | | 69% | | | |
| Soy displaces | | **Other Cropland** | **Grassland** | **Forest** | **Average** |
| Land source for soy growth | | 21% | 27% | 52% | |
| Carbon stock | te CO2/ha/yr | 0 | 10 | 37 | 22 |
| Soy LUC allocated to biofuel crop | te CO2/ha/yr | 0 | 4 | 16 | 10 |

Table A 5.2

### Sources & notes

- Biofuel yield is from table A 2.1
- Proportion of demand growth from land use change is from Figure 10
- Carbon stock data, Mineral fuel GHG emissions and GHG emissions RTFO are from Carbon & Sustainability Reporting within the RTFO, Technical Guidance, Part 2, RFA, Jan 2008
- Ratio of historic land use change is from table A 4
- Area of soy displaced is from table A 2.3

## Appendix 6 Processing cellulosic and lignocellulosic materials

Input data is shown on yellow background.

| Comparison of Options for Ligno-cellulosic Biomass | | | | | | | |
|---|---|---|---|---|---|---|---|
| **e.g. Corn Stover** | | | | | | | |
| Combustion Energy (LHV) | MJ/kg | | 17.0 | | | | |
| Technology | | **2nd Generation biofuels** | | | **Power Generation** | | |
| | | **Bioethanol** | | **FT Diesel** | **Coal** | **Replacing** | |
| | | **Current** | **Target** | **BTL** | **Co-firing** | **Coal** | **GTCC** |
| Dry Mass Yield | kg/kg | 18% | 22.7% | 14% | | | |
| Carbon Yield | kmole/kmole | 20% | 26.5% | 23% | | | |
| Energy Conversion Eff'y | LHV/LHV | 29% | 37.7% | 39% | | | |
| Power Generation Eff'y | MJe/MJ LHV | | | | 38% | 32% | 32% |
| Biofuel Yield | GJ/te | 4.9 | 6.4 | 6.7 | | | |
| Power | GJ/te | | | | 6.5 | 5.4 | 5.4 |
| GHG emissions | kg CO2eq/GJ | 12.8 | 12.8 | | 9.2 | 9.2 | 9.2 |
| Mineral Fuel GHG emissions | kg CO2eq/GJ | 84.8 | 84.8 | 86.4 | 112 | 112 | 62 |
| **GHG savings** | **kg CO2eq/te** | **356** | **462** | **581** | **665** | **560** | **288** |

Table A 6.1

### Sources & notes

- Bioethanol current technology: private communication with Imperial College, London
- Bioethanol target technology: Lignocellulosic Biomass to Ethanol Process Design and Economics ulilizing acid prehydrolysis and enzymatic hydrolysis of corn stover, Aden et al, NREL, June 2002
- FT Diesel technology: Well-to-Wheels Report Version 2b, CONCAWE, EUCAR & ECJRC, May 2006, Appendix 1, table 14
- It is assumed that if FT technology is used in the UK, it will include a pyrolysis step, which give a reduced efficiency: - The Feasibility of Second Generation Biodiesel Production in the UK, prepared for NNFCC, Nexant, July 2007
- Power generation efficiencies for biomass: Well-to-Wheels Report Version 2b, CONCAWE, EUCAR & ECJRC, May 2006, Appendix 1, table 15

| GHG Savings per unit Area | | | | | | |
|---|---|---|---|---|---|---|
| | | Wheat - Direct | Wheat - Inc' Straw | Wheat Using | Wheat Includin | Bioethanol from |
| Gasoline GHG emissions | kg CO2eq/MJ | 0.085 | 0.085 | 0.085 | 0.085 | 0.085 |
| Biofuel heat value (LHV) | GJ/te | 26.8 | 26.8 | 26.8 | 26.8 | 26.8 |
| Direct Grain biofuel Yield | te/ha | 2.47 | 2.47 | | | |
| Effective Grain biofuel Yield | te/ha | | | 13.2 | 13.2 | |
| Grain biofuel Yield | GJ/ha | 66 | 66 | 354 | 354 | |
| Default Grain GHG savings | per MJ | 54% | 54% | 54% | 54% | |
| Direct Grain GHG saving | te CO2eq/ha | **3.0** | **3.0** | **16.2** | **16.2** | |
| Ligno-cellulosic Yield | dry te/ha | | 3.5 | 3.5 | 3.5 | 10 |
| Biofuel Yield | GJ/te | | 6.4 | 6.4 | 6.4 | 6.4 |
| Default Grain GHG savings | per MJ | | 74% | 74% | 74% | 74% |
| Direct L/C GHG saving | te CO2eq/ha | | 1.4 | 1.4 | 1.4 | 4.0 |
| Total GHG Saving | te CO2eq/ha | **3.0** | **4.4** | **17.6** | **17.6** | **4.0** |
| Indirect land use change credit | kg CO2/GJ NCV | | | | 102 | |
| Indirect land use change credit | te CO2eq/ha | | | | **36** | |
| **Total GHG Saving** | te CO2eq/ha | **3.0** | **4.4** | **18** | **54** | **4.0** |

Table A 6.2

### Sources & notes

- Grain biofuel yields are from table A 2.1 and A 2.3
- Default GHG savings are default value from RED Annex VII, Feb 2008-04-12
- Bioethanol yield from ligno-cellulosic feeds is the target for 2$^{nd}$ genenarion technology from Table A 6.1
- Credit for indirect land use change for wheat is from Table A 5.2.

## Appendix 7 Nitrous oxide (N2O) abatement in nitric acid plants

| Ammonium Nitrate Fertiliser GHG Emissions | | | |
|---|---|---|---|
| Ammonium nitrate CO2 emissions | Kg CO2/kg N | 1.9 | |
| Ammonium nitrate N2O emissions | Kg CO2/kg N | 4.9 | |
| Ammonium nitrate total emissions | Kg CO2/kg N | 6.8 | |
| N2O emissions with 80% abatement | Kg CO2/kg N | 1.0 | |
| GHG emissions from abated plant | Kg CO2/kg N | 2.9 | |
| GHG emissions savings from abated plant | Kg CO2/kg N | 3.9 | |
| **Biofuel** | | **Bioethanol from wheat** | **Biodiesel from Rape** |
| Nirogen Fertiliser usage | kgN/ha/yr | 183 | 185 |
| Biofuel yield | GJ/ha/yr | 66.2 | 56.7 |
| Nirogen Fertiliser usage | kgN/GJ | 2.76 | 3.26 |
| GHG emissions savings from abatement | kg CO2/GJ | 10.8 | 12.8 |
| Mineral fuel emissions | kg CO2/GJ | 84.8 | 86.4 |
| **GHG savings from abatement cf mineral fuel** | | **13%** | **15%** |

Table A 7.1

### Sources & notes

- Ammonium nitrate emissions from: Energy Consumption and GHG emissions in Fertiliser Production, Jenssen & Kongshaug, IFS proceedings No 509.
- Nitrogen fertiliser usage “Carbon &Sustainability Reporting within the RTFO, Technical Guidance, Part 2, RFA, Jan 2008”
- Biofuel yield: Table A 2.1