ensus

TACKLING CLIMATE CHANGE

HOW BIO-REFINING CROPS CAN MAKE BETTER USE OF LAND TO MEET OUR NEEDS FOR FOOD AND LOW CARBON BIOFUELS

September 2008

CONTENTS

PEER REVIEW

This paper has been peer reviewed. The reviewer, Dr Frank Rosillo-Calle of the Imperial College Centre for Energy Policy and Technology (ICCEPT), provided the following statement:

"This paper provides an interesting and challenging approach to producing biofuels in the EU. I believe that the Ensus methodology and conclusions in this paper are robust and thorough and provide a good representation of the effective land use and environmental effects of biofuel production in Europe"

EXECUTIVE SUMMARY

As the manufacture of biofuels grows, questions are being asked as to whether such a strategy can be supported without putting unacceptable pressure on the food supply chain. This paper critically assesses the arguments and looks in particular at the impact of using wheat in Europe to support the growth of Bioethanol as a substitute for gasoline/petrol.

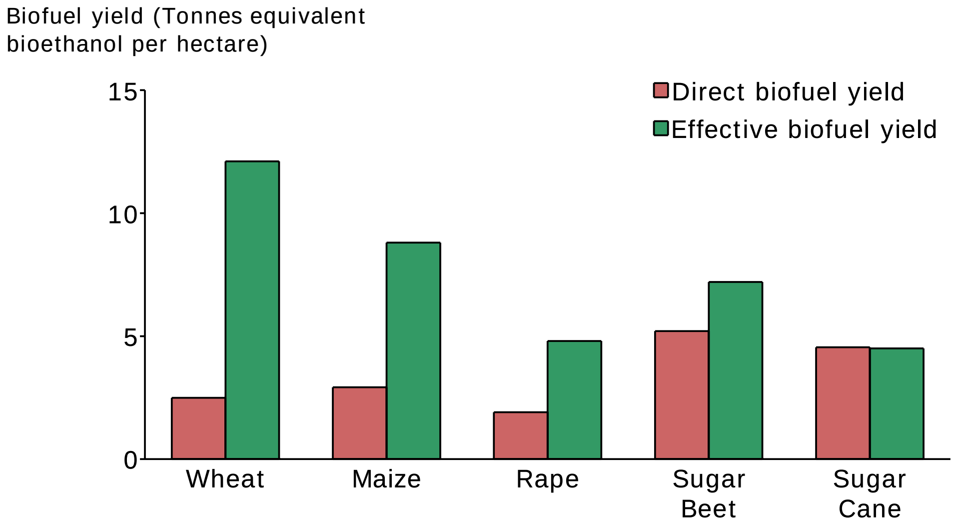
In order to respond to the challenge of global warming, transport fuels are a priority for action; they are the source of over 18% of Greenhouse Gas (GHG) emissions in the EU and are notable as the only significant source of GHG's which are increasing. Whilst more efficient cars and new technologies will inevitably contribute to meeting this challenge, the use of biofuels is an essential element of the strategy to decarbonise transport fuels. Biofuels vary in their contribution to saving carbon. Manufactured in the right way and using the right feedstock, biofuels can reduce GHG's by at least 50% compared to fossil fuels Refs 2 & 3. As shown in the Ensus paper to the Royal Society (Ref 1) as part of the evidence it submitted as part of the society's review of biofuels, Ensus' first plant in the UK, using wheat as a feedstock will achieve GHG savings in excess of 60%.

For years, land has been used to meet the world's food requirements, while other sources such as oil, coal and gas have been used to meet energy and transport fuel requirements. In other words, today's sun has been used to feed the world and yesterday's sun (over millions of years) has been used to meet the world's energy and fuel needs. The challenge is to use land and today's sun to meet not only the world's food needs but also its requirements for energy and transport fuel requirements. The critical question is whether this can be done without putting undue pressure on the planet's food supply chain and land use.

Bioethanol is manufactured through the fermentation of sugars. Today this is done by accessing sugars directly (sugar cane and beet) or by breaking down the starch in grains such as wheat to sugar. Biorefineries for the manufacture of bioethanol from cereals also produce a co-product of protein rich animal feed (DDGS) as well as carbon dioxide. Previous studies that have compared the biofuel yields from alternative crops have almost entirely ignored the credit for high protein co-products, such as DDGS from grain crops.

In meeting our food requirements, growing protein in sufficient quantities and concentrations is critical. Although cereal crops such as wheat and maize are very efficient at converting the sun's energy, the concentration of protein is too low for animal feed. Soy meal is widely used as a supplement to raise protein levels and Europe today imports about 35 million tonnes of soy meal to use as an animal feed supplement. However soy makes inefficient use of land and of the sun's energy producing only 2.5 tes/ha, compared to a yield of 7.7 tes/ha for wheat in NW Europe. When cereals are biorefined to make bioethanol, the protein in the co-product DDGS is at a much higher concentration than in the original cereal and can replace soy meal. This means that cereals produce high protein feedstocks as well as low carbon biofuel, thus creating the opportunity for much more effective use of land.

In the graph below, the effective yield of bioethanol, including credit for land saved from the co-product animal feed, is compared with the direct yield, which takes no land credit for the co-product.

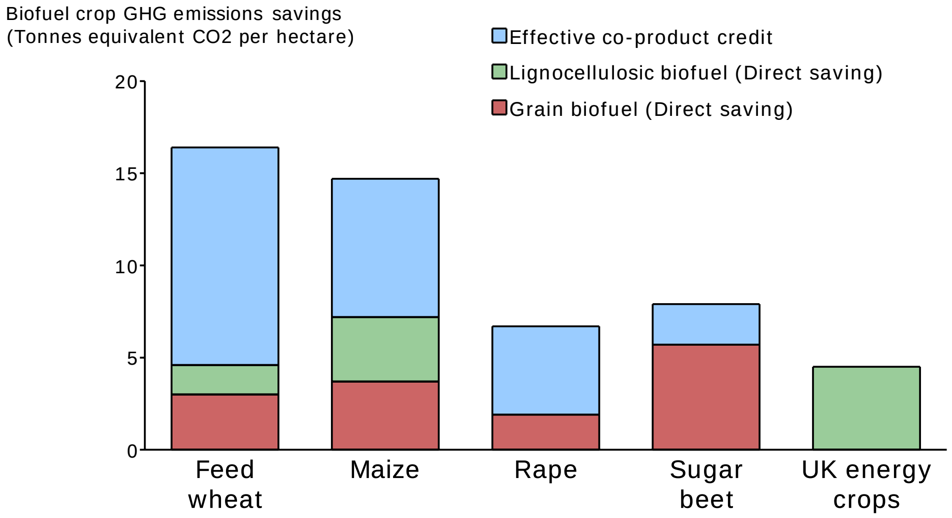


Thus at current yields, the use of cereals to produce bioethanol could enable more effective use of the land by growing a greater proportion of crops which are more efficient at converting the sun's energy to food and biofuel products. The use of bioethanol DDGS to replace soy meal could therefore enable large scale EU production of biofuel from wheat and maize of 35mt/yr with only a small net increase in the global arable land area. With continued increases in cereal yields, the bioethanol can be obtained with no increase or even a decrease in global cropland area.

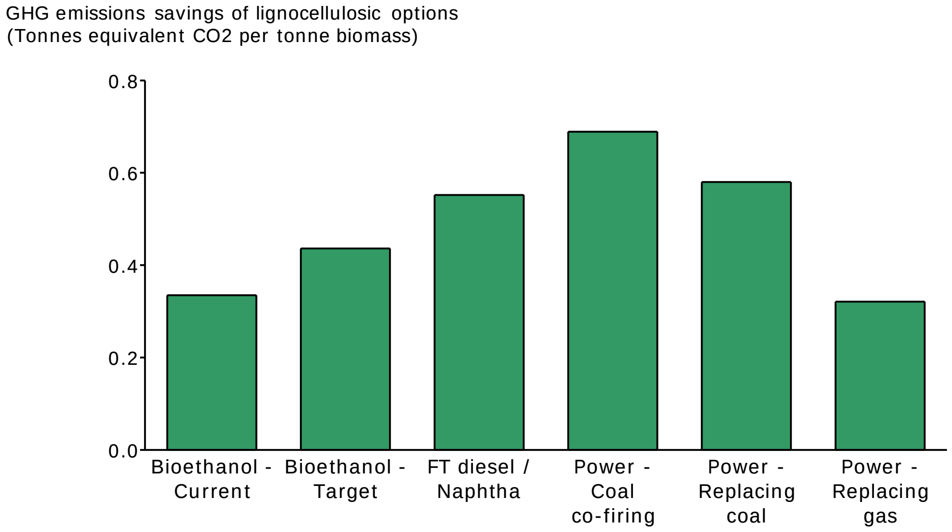
For example with sustainable higher cereals yields and an increased land use of 4 million ha, the supply of biofuel cereals in the EU could be increased by about 110 million tonnes per year (mtes/yr) by 2020. This would enable production of about 44 mtes/yr of bioethanol in the EU, which could replace more than 8% of the EU road transport fuels consumption. The increased protein production from the DDGS would reduce EU import of soy meal by 18 mtes/yr and would reduce the area required for growing soy in South America by 6 million ha. There would result in a net decrease in land area of 1.5 million ha.

This is not the whole story. The above analysis only considers wheat grain. When growing wheat a similar amount of straw and stalks are also produced, ca 8 tonnes/hectare, of which half is harvested and is available for use to generate energy, either for power generation, or biofuel. In fact when this is taken into account wheat has the potential to be a very effective way of meeting the world's food, fuel and energy requirements and is more effective than ligno-cellulosic energy crops on arable land.

Although the commercial generation of biofuels from ligno-cellulosic feedstocks is a few years away, the GHG savings per hectare for the production of biofuels are substantially greater from wheat than energy crops grown in the UK.



In considering what to do with the straw and stalks, they can be burnt for energy or they can be a source of ligno-cellulose feedstock for so called second generation biofuel manufacture. The analysis in this paper shows that waste dry biomass such as straw and stalks can be used more efficiently to replace coal fired power generation than for biofuels production.



SUMMARY OF KEY ARGUMENTS/CONSIDERATIONS

1) Climate Change:

A major element in the reduction of global warming is the de-carbonisation of power generation and transport fuels. Many options are available for decarbonisation of power generation, but options for decarbonisation of transport fuels are much more limited. Whilst efforts will continue to be made to use cars less and work will continue on making more efficient cars, a critical part of the strategy to decarbonise transport fuels must be biofuels. The only available technology in the foreseeable future is to produce these from agricultural crops. Therefore as we move to address global warming, we need to use global land area not only for food, but also for low carbon transport fuels and possibly for power generation.

2) Pressure on Land:

While the need for fuels as well as food will place substantial additional demands on land, there are several ways in which this increased demand can be, at least partially, accommodated.

- Land can be more fully utilised, by bringing unused land into food and fuel production and continuing to increase crop yields.
- A market and trade structure which encourages the developing world to develop a vibrant agricultural sector by creating a market for grains in the developed world which takes away the need for distorting subsidies.
- The growth of the production of bioethanol from cereals enables re-optimisation of crops for food and fuel, in order to better utilise existing agricultural land.

3) Food and Fuel Crop Yields:

Seed crops vary in their ability to convert sunlight to energy and protein and there is a trade off between the protein concentration and crop yield. High protein concentration crops, such as soy have a low total yield. Wheat and maize have a low protein concentration, but are very efficient at converting sunlight to energy and protein.

4) 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 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 35-50%. 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 25%-35%. 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.

5) Effective Bioethanol Yield:

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 tes/ha, the effective yield after taking into account the DDGS co-product can be much higher at 12 te/ha or more. The land that is currently used to grow soybean could be used at a higher overall efficiency to grow other crops, such as maize. 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.

6) Bioethanol Production in EU:

As a result of higher cereals yields, increased land use supported by the abandonment of set aside and higher productivity from land, particularly in Eastern Europe, the supply of wheat and maize in the EU could be substantially increased by 2020. This would enable production of bioethanol in the EU, which could replace more than 8% of the EU road transport fuel consumption. The increased protein production from the DDGS would reduce EU import of soy meal reduce the pressure on deforestation in South America.

7) Technology Development

Further developments will be needed to:

- develop higher yielding wheat varieties
- reduce energy requirements in bioethanol plants
- avoid degradation of protein in the fermentation and DDGS drying processes
- modify fermentation yeasts to produce essential amino acids (EAAs), to improve the EAA profile in DDGS.

8) Ligno-cellulosic Energy Crops:

There has been widespread promotion of the production of bioethanol from ligno-cellulosic energy crops, such as miscanthus and SRC willow (where biofuels are the only product), compared to grain crops, which produce both biofuel and food. The potential benefit of energy crops is stated to be that they won't compete with food crops and will give higher biofuel yields. However energy crops will still compete with food crops, unless they are grown on land that cannot be used for food. In actual fact the biomass yield of energy crops is no higher than for wheat and maize and since the bioethanol conversion from ligno-cellulosic energy crops is lower than from cereal grains, the biofuel yield per hectare from energy crops is significantly lower than for cereal crops. Also farmers are reluctant to tie up there land to grow perennial energy crops, rather than annual crops. Since cereal crops also give a co-product high protein animal feed, there is in fact be no case for growing ligno-cellulosic energy crops for biofuel generation on arable land.

9) GHG Savings:

Taking into account the use of co-products for animal feed, the effective GHG savings per ha from growing biofuel crops such as cereals and oilseeds are much higher than the direct savings. Although sugar beet and sugar cane have higher direct GHG savings per hectare than grain crops, the co-products are low protein or are not used for animal feed and do little to offset their land use. As a result, the effective biofuel yields from sugar cane and sugar beet are lower than for cereal crops. It is important when, as proposed in UK and Germany, biofuel incentives are related to GHG savings, that the GHG credit for co-products takes proper credit for the protein. This will encourage the most efficient use of land for growing high yield energy plus protein crops, such cereals and rapeseed, rather than sugar cane.

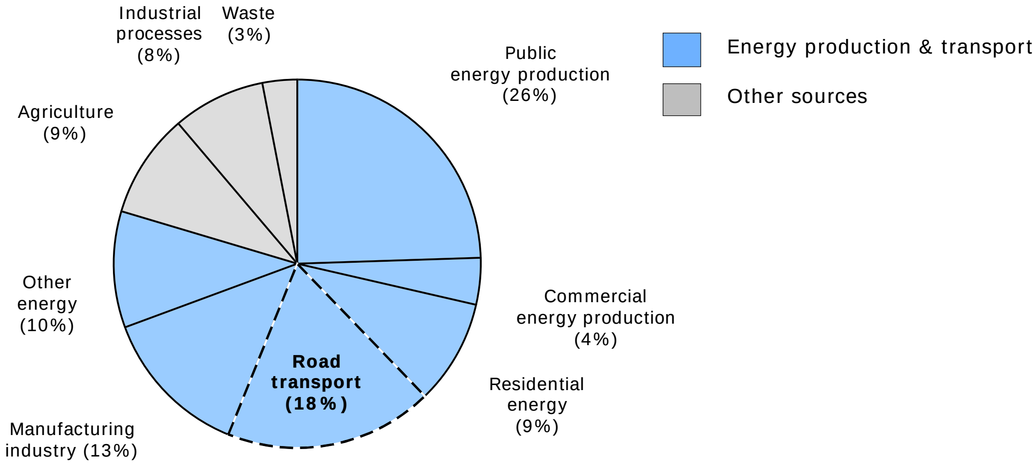
10) Alternative uses for Ligno-cellulosic Biomass:

While dry ligno-cellulosic biomass waste, can be used to produce biofuels, the GHG savings of the biomass are higher if they are burned for power generation and substantially higher if the power generation replaces coal powered generation.

1) CLIMATE CHANGE

The main cause of global warming is greenhouse gases (GHG) emissions. The breakdown of EU GHG emissions by sector (Ref. 4) is shown in diagram 1.1.

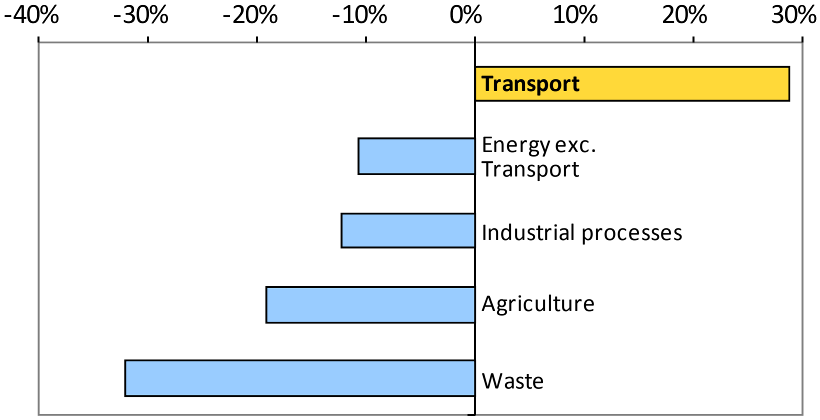
Diagram 1.1 - EU27 total GHG emissions by sector 2006



It can be seen that 80% of GHG emissions are related to energy production and transport fuels.

A major step in the reduction of global warming is therefore the de-carbonisation of power generation and transport fuels. Many options are available for decarbonisation of power generation, such as nuclear, wind, wave, tidal, solar, burning agricultural crops and residues and carbon sequestration from burning fossil fuels.

Diagram 1.2 - EU27 GHG emissions change 1990-2006



The growth of EU GHG emissions by sector (Ref 4) is shown in diagram 1.2. Since 1990, while all other sectors have seen a significant reduction in GHG emissions, those from transport have increased by more than 25%.

Decarbonisation of transport fuels is just one element in the reduction in the growth of GHG emissions from transport fuels and consumption of transport fuels will need to be reduced by the development of more efficient engines and encouraging the use of more efficient means of transport. Options for decarbonisation of transport fuels are much more limited than for power generation and the only technology in the foreseeable future is the production of transport biofuels from agricultural crops. There are other options for non carbon transport, based on hydrogen in fuel cells. However in order to give GHG savings, the hydrogen would need to be generated from decarbonised electric power. This will therefore give zero GHG savings until the base load power generation sector is completely decarbonised.

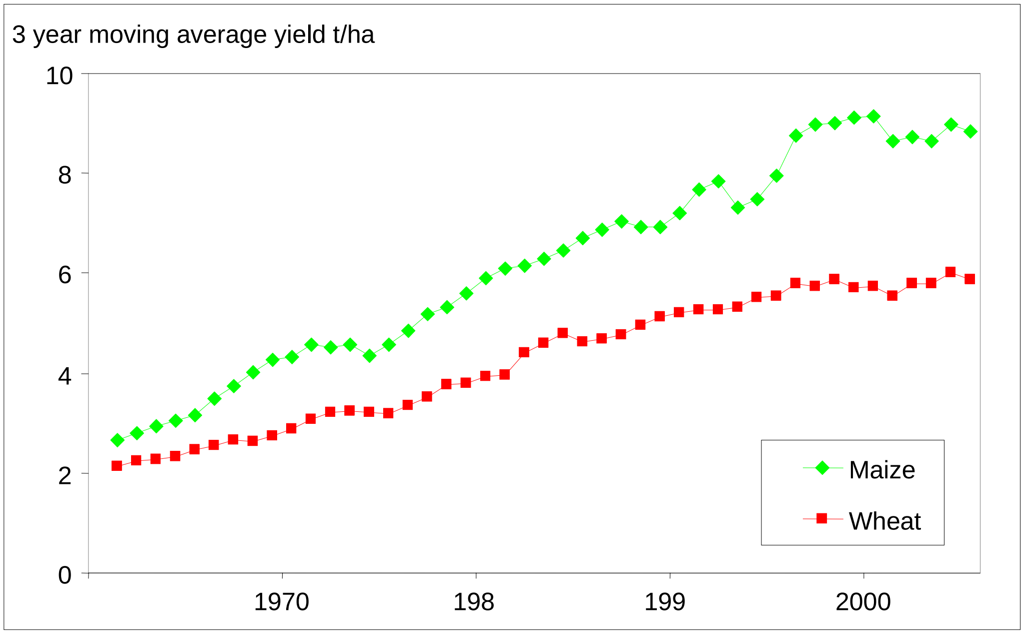
It is clear therefore, that as we move to address global warming, we need to use global land area not only for food, but also for transport fuels and possibly also for power generation.

2) PRESSURE ON LAND

While the need for fuels as well as food will place substantial additional demands on land, there are several ways in which this increased demand can be, at least partially, accommodated. These are:

- Vast tracts of land in Africa, South America and Asia can be brought into production if there is an increased demand for food and fuel.
- Continuation of the increase in crop yields, which have been increasing consistently for many years. This is particularly the case in the EU, where the Common Agricultural Policy encouraged higher agricultural output.

Diagram 2.1 - EU 15 cereal yields



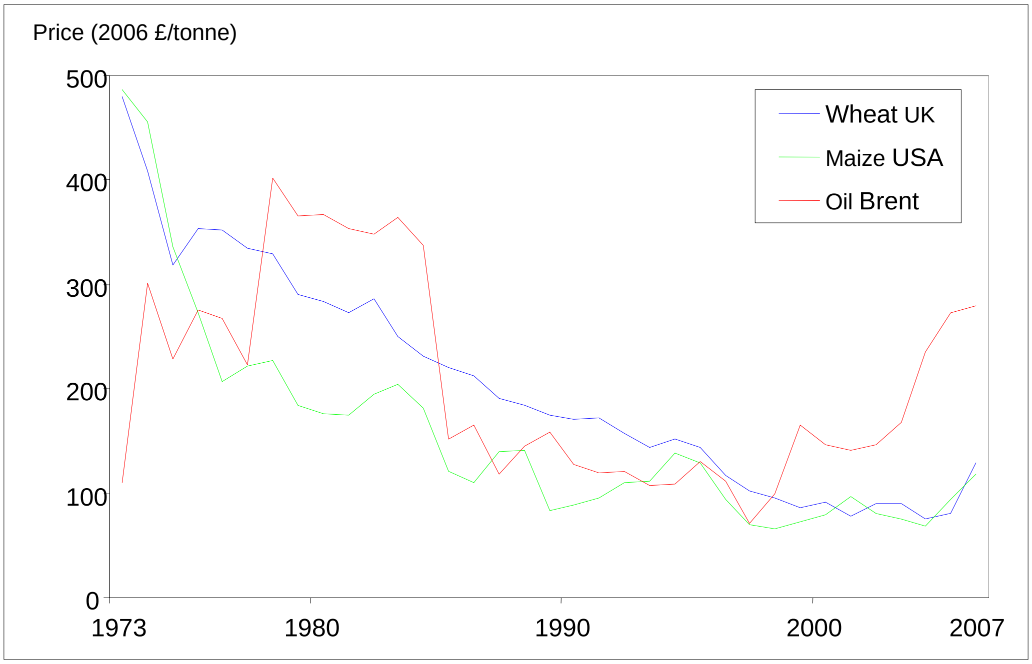
Source FAOStat

The EU wheat and maize yields have gone up by 2.5% and 2.8% per annum respectively between 1961 and 2006. This has given yield increases over this period of 2.8 times for wheat and 3.4 times for maize.

It is important to note that higher yields have not entailed higher GHG emissions. It is shown in Ref 2 that the GHG emissions from cultivation per tonne of wheat are lower for the high wheat yields obtained in UK and Germany, compared to those for lower yielding countries such as Canada and Ukraine.

The increase in cereals productivity has led to negative real price inflation. Price trends are shown below for wheat and maize, compared to crude oil.

Diagram 2.2 – Real price trends



Source: FAOStat, EIA

Various factors will enable substantial quantities of biofuel crops to be grown:

- Removal of set-aside mandates will encourage increased food output.
- Import duties and subsidies on particular crops have encouraged non-optimum use of land, for example growing sugar beet in EU and sugar cane in US. Removal of these subsidies will lead to more efficient use of land and resources.
- In developed countries, there is widespread destruction of food, which does not meet the most exacting supermarket standards.
- The growth of the production of bioethanol from cereals enables re-optimisation of crops for food and fuel, in order to better utilise existing agricultural land. This is explained in the following sections.

Eventually however, the need to use land to grow crops for food as well as fuel will put more pressure on the use of land than historically. Therefore, in considering optimum use of resources, costs and benefits need to be considered in terms of unit land area as well as in terms of per unit of product. For example alternatives options for biofuel production and associated GHG savings need to be considered per unit land area.

3) FOOD AND FUEL CROPS YIELDS

Table 3.1 Utilisation of Plant Components

	Monogastric animals inc' humans	Ruminant Animals	Transport Fuels	Heat & Power
Sugar	Yes	Yes	Yes	Yes
Starch	Yes	Yes	Yes	Yes
Cellulose	No	Yes	No	Yes
Oil	Yes	Yes	Yes	Yes
Proteins	Yes	Yes	No	Yes
Lignin	No	No	No	Yes

Food crops produce a range of commercially useful plant products including protein, carbohydrate and lipid (oil or fat). The different components of plants and their utility using current commercial technology is shown in table 3.1

Commercial technology in this case means that the technology is economic, without excessive subsidies. The utilisation of other plant components using second generation to produce transport fuels is discussed in section 8.

There are three stages that need to be considered to determine the relative effectiveness of crops for different applications:

- Capturing sunlight to generate primary plant energy in the form of glucose
- Efficiency in converting primary energy into crop products
- Efficiency in converting plant products into food and fuel.

The rate of sunlight capture to generate primary plant energy has a low efficiency and as long as water and some other critical resources are available, it is the limiting step in the growth of plants. The total plant yield is therefore dependent on the amount of sunlight available and because of this will vary from region to region. Comparisons of crop yields in this note are therefore average data for a group of countries in N W Europe with reasonably similar climates.

Table 3.2 Plant Energy Conversion

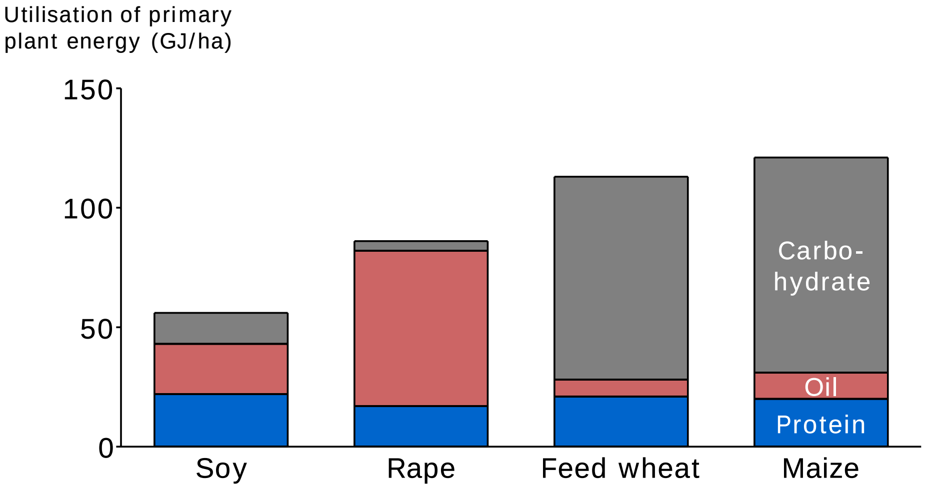
Component	**Plant Energy Conversion Efficiency MJ/MJ**
C6 sugar	100%
Sucrose e.g.beet	100%
Starch - cereals	97%
Oil - oilseeds	89%
Cellulose	96%
Lignin	83%
Proteins (available N)	82%

It has been shown (Ref 12) that the efficiency of converting primary plant energy into each plant component depends on the component, but is generally the same for all plants. The data from Ref 12 is worked up in Appendix 1 to give the results shown in table 3.2. It can be seen that the conversion efficiencies to carbohydrates are high at 96% or more, but for oil, lignin and protein, the conversion efficiencies are somewhat lower.

These efficiencies can be used to determine the amount of the primary energy input that goes into providing useful plant products to give a "primary energy utilisation" for each crop. Crops that are equally effective in using sunlight to make useful products will have a similar "primary energy utilisation". The average yield and compositions of various crops in NW European countries have been used to determine the plant primary energy and its utilisation in some alternative crops.

The results for the energy used in the harvested grain crops at average NW Europe yields are shown in Diagram 3.1. The base data and determination of these are shown in appendix 1.

Diagram 3.1 – Utilisation of primary plant energy



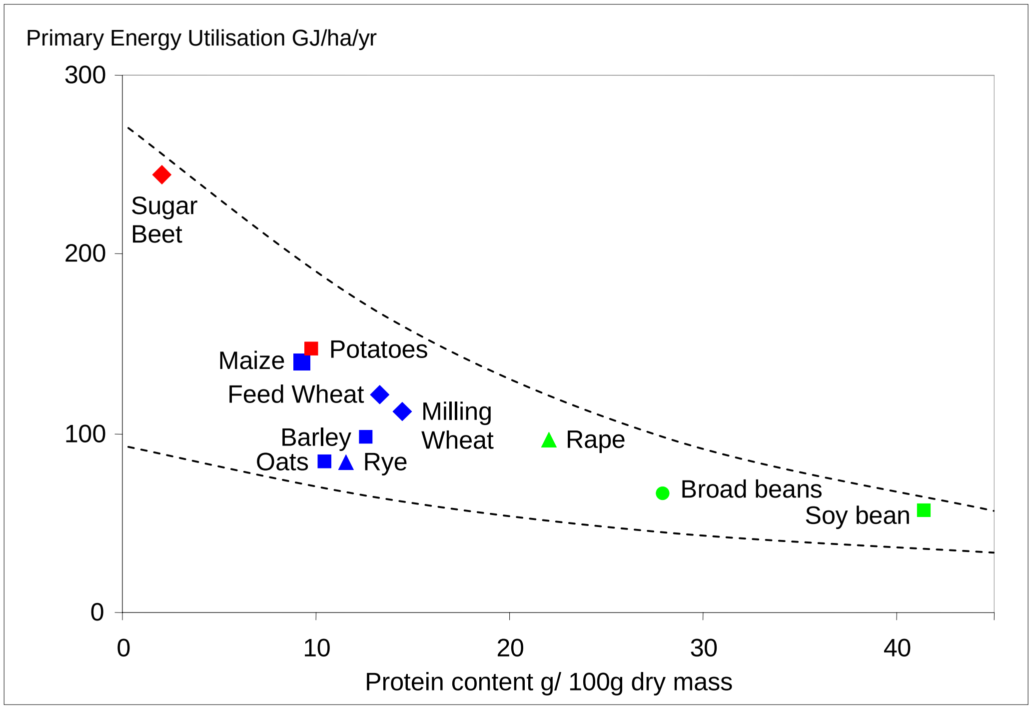
The amount of energy utilised into plant products by soy beans is substantially lower than for other crops and is half that of wheat and maize. This is mainly due to the primary energy used to by soy to fix nitrogen from the air. The inefficiencies in generating the nitrogen to make protein are shown in appendix 1

The plant energy needed to fix nitrogen from the air in leguminous crops is very high, so the efficiency of protein production, when nitrogen is fixed from the air is much lower at 34%, compared to the efficiency of 82% when using available nitrogen in the soil. The overall efficiency for making protein using synthetic nitrogen is 64% and includes the mineral energy for the nitrogen. It is clear that whether protein is made by fixing nitrogen, or by the use of synthetic nitrogen, the resource cost per MJ of protein is substantially higher than for other plant components and therefore the 'hard won' protein should be conserved for food, rather than being burnt.

Nitrogen fixation does give a reduction in GHG emissions, compared to using synthetic nitrogen, when considered on the basis of GHG emissions per unit output. However, in an environment where land is a limiting resource, the GHG savings must be considered per unit of land. It is shown in appendix 7.1 that the GHG savings per unit of nitrogen per unit land area are 1.7 times greater using synthetic nitrogen compared with nitrogen fixation.

The useful primary energy utilisation is calculated in appendix 1 and shown below for a wider range of harvested crops in NW Europe.

Diagram 3.2 - Crop primary energy utilisation - N W Europe



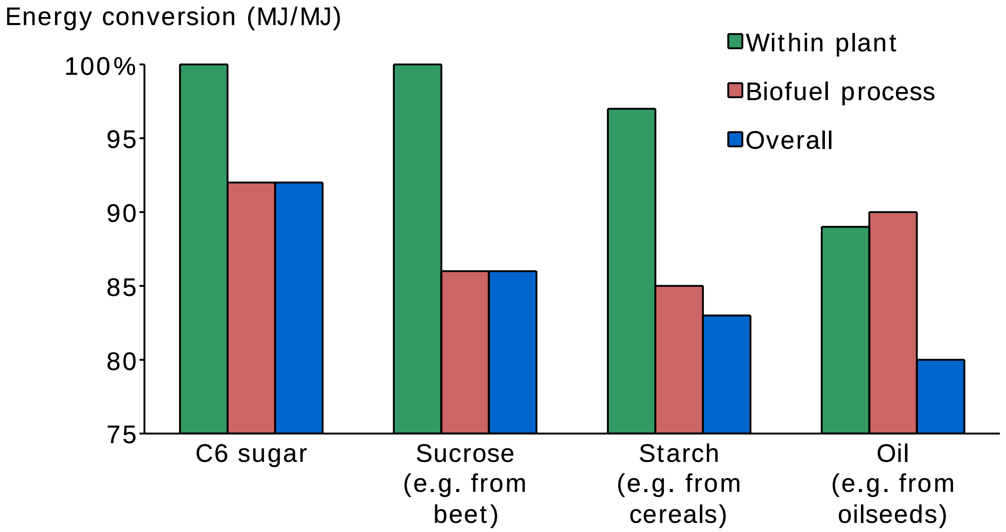
This shows a clear relationship where the higher the concentration of protein per dry mass of recovered crop, the less efficient the crop is at capturing energy to produce useful products. This is very important in considering the productivity of different crops. Low protein crops can achieve higher energy productivities than high protein crops, but the world needs protein for animal feed as well as energy, so the energy and protein outputs must be considered together.

BIOFUEL PRODUCTION EFFICIENCIES

Different plant products are used to make biofuels, using alternative technologies: Starch and sugar are converted to bioethanol using fermentation, while vegetable oils are converted to biodiesel using transesterification or hydrogenation. In both cases the remaining plant components are used as animal feed.

Due to large variations between heat contents of plant products and biofuels, the efficiencies of producing alternative biofuels, are best looked at on an energy basis (rather than mass basis) and are shown below. These data are explained in appendix 3.1.

Diagram 3.3 - Biofuel energy conversion efficiencies



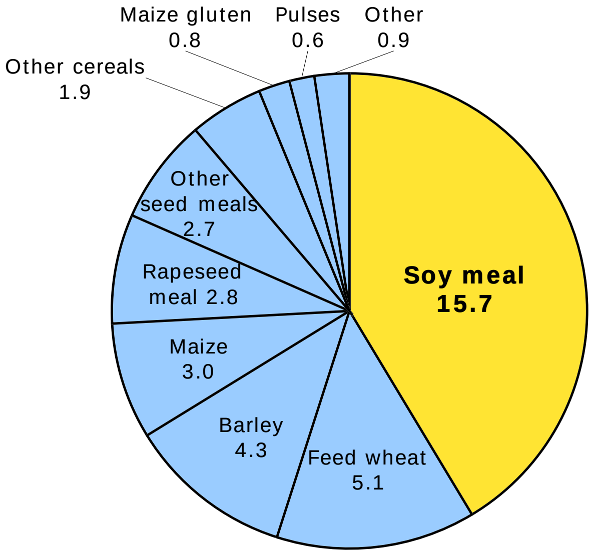
Taking all the conversion inefficiencies into account, the conversion from primary plant energy to biofuel energy are slightly higher for sucrose at 86% than starch at 83% and oil at 80%. This means that there is little intrinsic difference in biofuel energy efficiencies using the sun's energy to make sugar, starch or oil in plants.

4) ANIMAL FEED

In order to produce meat efficiently, animals are fed with a range of feeds to provide energy and protein. These animal feeds are mainly seed crops and include wheat, maize, rape meal soy meal and are blended to provide an optimum feed for different animals. The blending is operated, primarily to meet the optimum protein and energy levels for animal feed, but also to meet many other factors, such as the amino acid requirements. The energy content of different animal feeds is fairly similar, but the protein content varies widely.

The breakdown of the supply of protein in animal feed in the EU is tabulated in appendix 2 and is summarised in diagram 4.1.

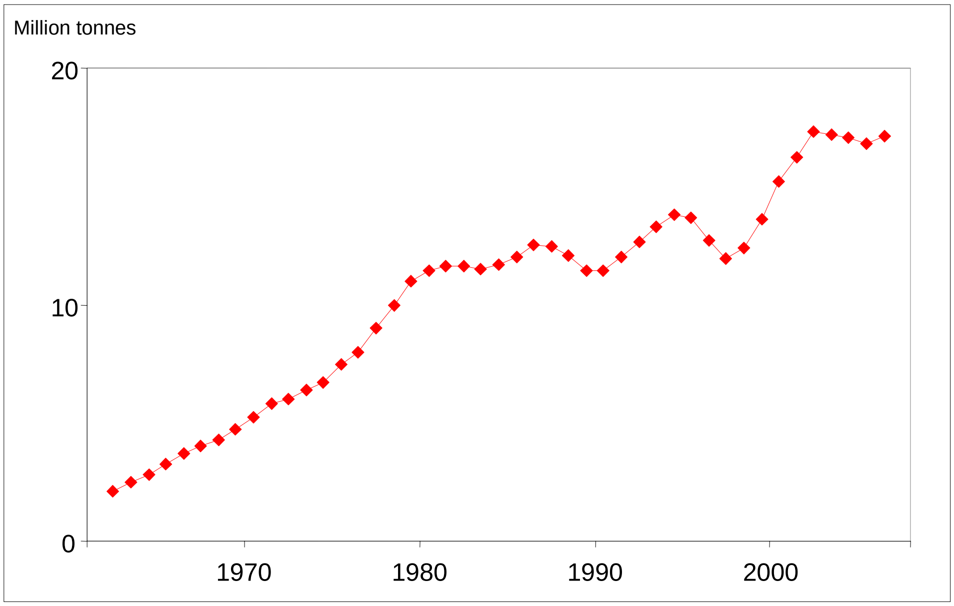
Diagram 4.1- EU Animal feed protein supply (Million tonnes, 2007)



Rapeseed and other seed meals are mainly supplied from within the EU, but nearly all the soy meal is imported to the EU. The trend in EU protein imports is shown in diagram 4.2.

Protein imports are rising steadily and the UK and EU each now import about 50% of their entire animal feed protein requirements. This is of serious concern (Ref. 11), due to concerns about imported soy and maize products, which come mainly from N and S America, being contaminated with unapproved genetically modified organisms (GMOs).

Diagram 4.2 - EU 27 Animal feed protein net imports

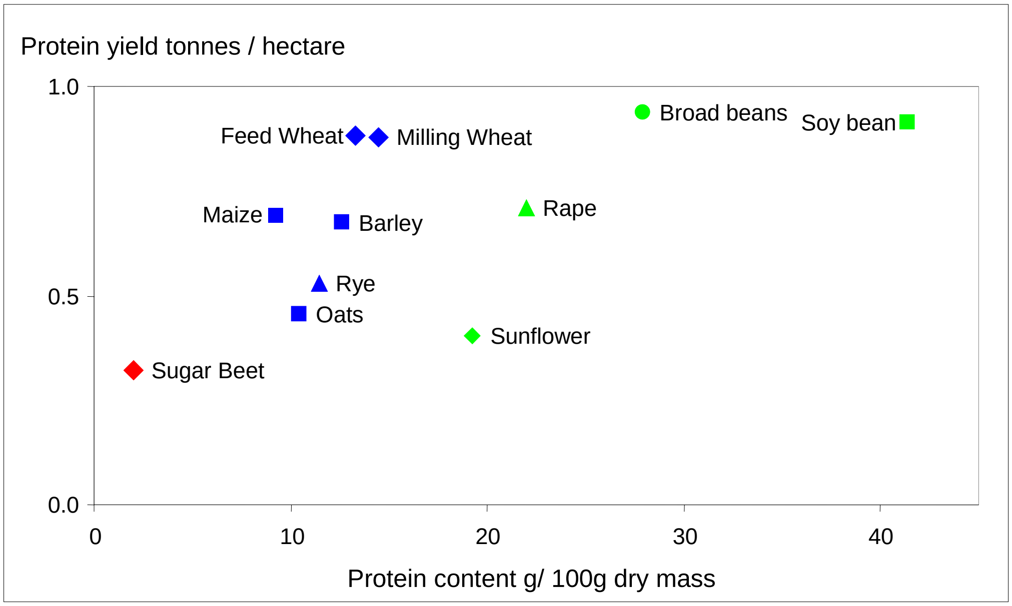


Source FAOSTAT (Ref 38)

It can be seen from the data in appendix 2, that the major animal feed import is of soy meal, which as shown in diagram 3.3 is the least efficient major crop at utilising sunlight and land to produce plant products.

The protein yield per hectare of different crops, versus the protein concentration, is shown in appendix 1 and summarised in diagram 4.3.

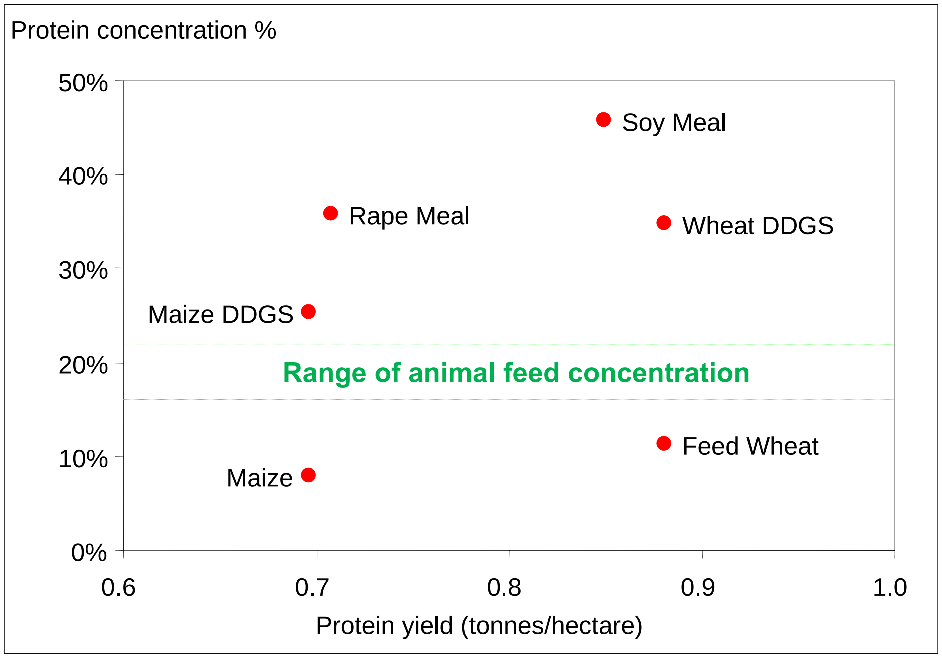
Diagram 4.3 - Protein content of crops - N W Europe



It may be seen that the protein yields of many crops are fairly similar, with yields around 0.65 – 0.9 tes/ha. Although soy is recognised as being a protein crop, due its high protein content, the protein yield is little higher than wheat and maize.

The protein levels of alternative animal feeds are calculated in appendix 3 and summarised in diagram 4.4. Bioethanol will be made from feed wheat.

Diagram 4.4 - Protein content of animal feed



DDGS is Distillers Dried Drains and Solubles and is the co-product of the production of ethanol from cereals. 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 35-50%. Low protein concentration cereals are therefore blended with high concentration oil seed meals to give the optimum animal feed concentration. The reason why soy meal is so widely used, despite its inefficiency, is because the high protein concentration enables it to be blended with widely available low protein animal feeds, in order to obtain the optimum protein concentration for compound animal feeds.

However, as can be seen in the diagram 4.4, high concentration protein animal feed components can also be obtained by growing lower protein concentration crops such as wheat and maize and concentrating the protein. The low protein concentrations in cereal crops are concentrated by removing the starch to make bioethanol. Additionally significant quantities of protein are produced during fermentation from non protein nitrogen and starch to grow the yeast. This not only increases the protein concentration, but also the protein yield. The fermentation process therefore produces a protein concentration in the DDGS that is high enough to replace soy meal for blending in animal feed.

5) EFFECTIVE YIELD OF BIOFUEL CROPS

The effective yield of biofuels, such as cereals and rape includes credit from the land area saved by using high protein co-product DDGS or seedcake to replace crops, such as feed cereals and soy as animal feed. This credit has either been ignored completely in previous work on the evaluation of grain crops for biofuel production, e.g. Pimentel Ref. 9, or credit is only taken for the for the displacement of cereals e.g. Searchinger, Ref 10.

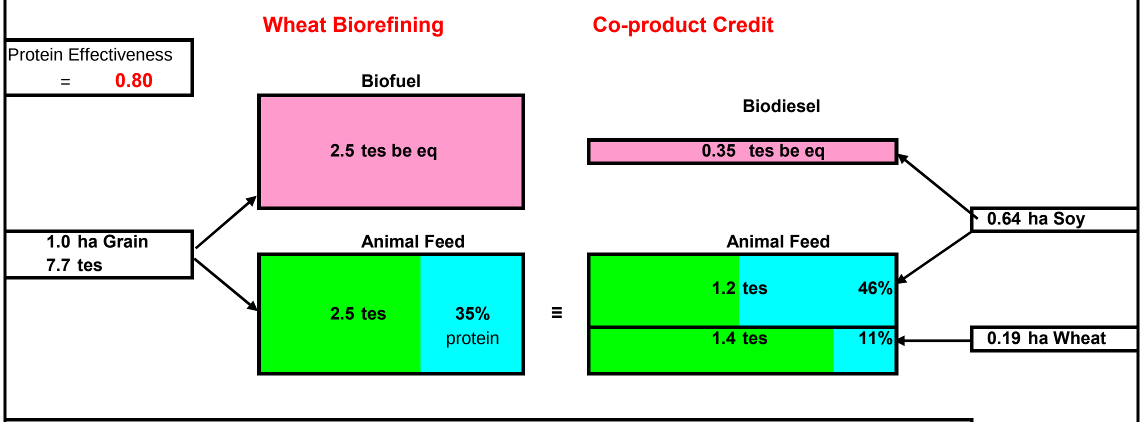
EFFECTIVE BIOETHANOL YIELD OF WHEAT

The credit for the DDGS from wheat and maize, can be determined in various ways, depending on assumptions around which animal feed components are replaced by DDGS, which species the DDGS is fed to and where the replaced animal feeds are grown. DDGS protein may have a lower value than soy meal protein, due to degradation in the bioethanol process and has a lower essential amino acid (EEA) level than some current animal feeds, such as soy. This makes little difference when DDGS is fed to ruminants, but limits the extent of DDGS use in feeds for monogastric animals, such as pigs and poultry. Analysis of data on feed trials for poultry using corn DDGS (Ref 27) shows a slightly lower protein effectiveness. In order to take account of this, a DDGS protein effectiveness of 80% compared to soy meal protein has been assumed.

In the EU, feed wheat that is in excess of demand is exported and as shown in appendix 2, soy meal imports are adjusted to meet the substantial EU demand for animal feed protein, that is excess to the internal EU supply. Feed wheat can therefore be regarded as the marginal animal energy feed and imported soy meal as the marginal high protein feed. It is assumed that DDGS will replace a mixture of feed wheat and soy meal imported from South America , to give the same metabolisable energy and effective amount of protein.

The simplest way of assessing the effective yield of bioethanol from wheat, is to compare two agricultural options, one which used wheat for biofuel and the other which uses feed wheat and soy meal to match the animal feed value of DDGS. The comparison is summarised in diagram 5.1 below and shown in detail in appendix 4.

Diag 5.1 Land Use & Effective Biofuel Yield



Summary

		Biorefining	Co-product Credit	Net
Land Area	ha	1.0	0.82	0.18
Biofuel production	tes be eq	2.49	0.35	2.1
Net Land/direct biofuel land				21%
Effective Bioethanol Yield	tes/ha			12.1

Scenario 1 – Using wheat for biofuel (left hand side)

- 1 ha of wheat is grown to produce bioethanol and DDGS for animal feed. This produces 2.5 tes of bioethanol plus 2.5 tes DDGS, with a protein content of 35%. The DDGS can replace a mixture of soy meal and feed wheat to give the same amounts of protein and metabolisable energy (ME) as the DDGS.

Scenario 2 – Use wheat and soy to achieve the same animal feed requirements (right hand side)

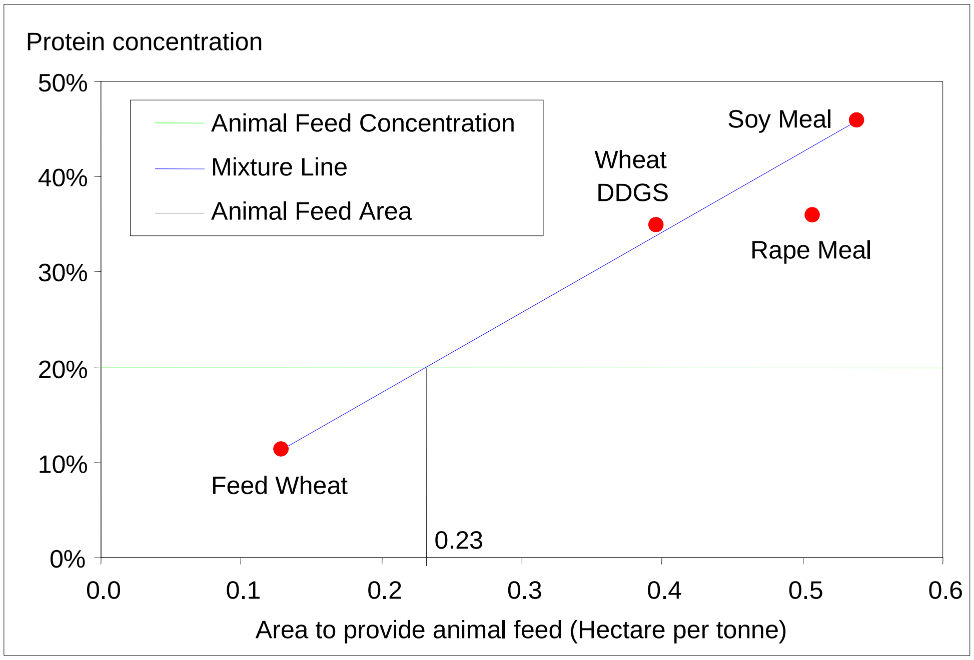
- To achieve the same energy and effective protein requirements, wheat needs to be mixed with soy meal in a ratio of 1.4 tes wheat to 1.2 tes soy. This requires 1.4 tes of wheat using 0.19 ha of land and 1.2 tes of soy meal using 0.64 hectares of land.

- The co-product soy oil is assumed to be made into biodiesel and after correcting for the higher energy of biodiesel, compared to bioethanol, it is credited as equivalent bioethanol.

In both cases, the animal feed product will be blended with more feed wheat to give the desired animal feed composition.

Comparing the two cases, the effective bioethanol yield is determined by dividing the net extra bioethanol by the net extra land area. The effective bioethanol yield from wheat in this case is 12.1 tes/ha, compared to the direct biofuel yield of 2.5 tes/ha. The reason for this result is explained further in diagram 5.2.

Diagram 5.2 - Area needed to provide animal feed



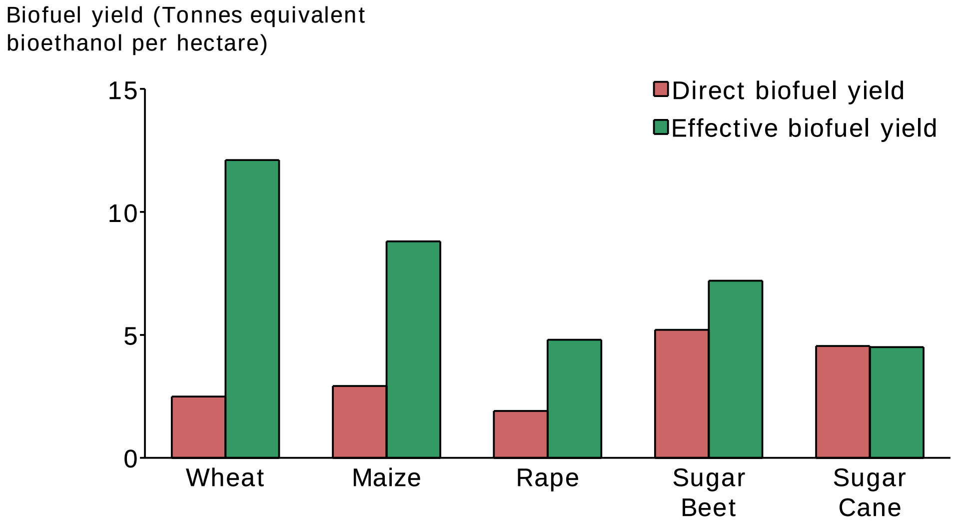
The blue mixture line between soy meal and feed wheat gives the land area needed to provide an animal feed at any concentration by blending these components. For example to supply animal feed at 20% protein (green line), the area is 0.23 ha/te feed. It happens that using these data, the point for DDGS lies very close to this mixture line. Therefore the area needed to supply a 20% protein animal feed from DDGS and feed wheat is the same as that of the blend of soy meal and feed wheat. Since the yield of biofuel from wheat is substantially higher than for soy bean, this extra fuel comes with no increase in land area.

It is claimed that some S American soy is grown on deforested land and therefore the reduced EU soy requirement may well lead to reduced deforestation.

EFFECTIVE YIELD OF OTHER BIOFUEL CROPS

A similar analysis has been done for other biofuel crops. The data are given in appendix 4 and summarised in diagram 5.3.

Diagram 5.3) Effective biofuel yield



This shows that it is vital to take into account the credit for the biofuel co-products when comparing yields of biofuel crops. Although sugar beet has a high direct biofuel yield, there is little protein co-product, so the relative co-product credit is small.

With most plants producing bioethanol from sugar cane the bagasse is burnt to provide power, so there is no co-product credit (Ref 23). While co-product molasses from the production of refined sugar is used as animal feed, the bioethanol yield assumes maximum sugar conversion. While other co-products can be produced from sugar cane, or bagasse, these do not provide a land use credit.

6) BIOETHANOL PRODUCTION IN EU

There are several ways in which the production of cereals can be increased within EU in order to provide feed for bioethanol production. These are:

- Increasing cereal crop yields. - As shown in diagram 2.1 above, cereal yields in EU have been increasing steadily for many years. A more detailed analysis of these data is shown in appendix 5.1. From these data it is reasonable to assume that yield increases in the original EU 15 countries will continue at the same rate of 1.5%/yr. The increased output in 2020, compared to current levels which will give approximately a further 48 million tonnes/yr
- Increasing Eastern EU productivity. - In the period 1975-1982 cereal yields in Eastern EU countries were about 83% of the EU 15 countries, whereas current yields of cereals in Eastern EU countries are only 60% of the levels in EU15 countries. These yields in Eastern EU countries therefore have the potential to be increased as more modern farming methods and science are applied. The nitrogen fertiliser usage per ha of arable crops in E Europe is less than half that in NW Europe (Ref. 37). It is assumed that yields in the new EU 12 countries can be increased at a rate of 3%/yr to 2020. This is lower than the rate that both EU 15 and EU12 countries averaged between 1965 and 1885 and will give a further 38 mtes/yr of cereals
- Increased cereal land. - The requirement for set aside land has been dropped in EU. It is assumed that cereal crops will be grown on half of this land. Together with a small amount of land being transferred from sugar beet, under the sugar reforms, this will provide 4 mhas of extra cereals land. Another 31 m tes/yr of cereals can be expected from this source.

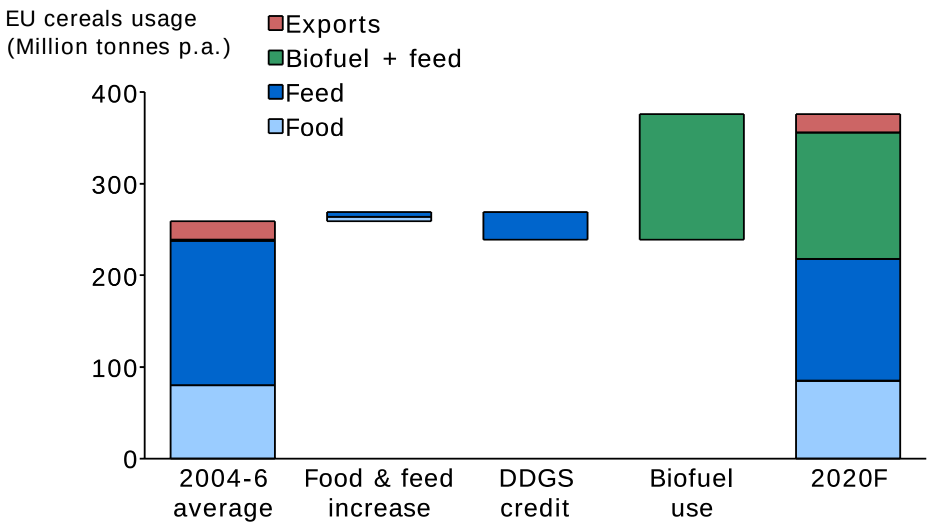
The results of these increases in EU cereals production are shown in appendix 5.2 and are summarised in Table 6.1 and Diagram 6.1

Table 6.1 Additional Bioethanol from Cereals in EU

		Wheat	**Maize**	**Barley**	**Total**
Increase in EU 15 production by 2020	Mt/yr	26.4	9.5	11.8	**48**
Increase in EU 12 production by 2020	Mt/yr	17.6	14.2	6.2	**38**
Additional crop from extra land	Mt/yr	13.3	17.3	0.0	**31**
Impact of non biofuel consumption	Mt/yr	-16.2	3.3	3.3	**-10**
Additional cereals crop available	Mt/yr	41.0	44.3	21.3	**107**
Cereal displaced by DDGS co-product	Mt/yr	9.3	13.5	7.5	**30**
Additional cereals bioethanol crop	Mt/yr	50.4	57.8	28.8	**137**
Bioethanol production in EU	Mt/yr	**16.2**	**19.4**	**8.2**	**44**
Reduction in soy meal Import	Mt/yr	**7.7**	**5.7**	**4.4**	**18**

Increase in demand for food and animal feed up to 2020 will give a small increase in cereal demand. However, this increase will be more than offset by the cereals that will be freed up by the DDGS co-product from cereal refining.

Diagram 6.1 - EU cereals balance for biofuels



The above analysis shows that there is considerable potential for extra cereal growing in the EU, which after accounting for increased cereal demand for food and animal feed, will give the potential for about 137 million tonnes of cereals for biofuel by 2020. This will allow a total production of 44 mtes/yr of bioethanol, within the EU, which will be equivalent to more than 8% of the energy demand for all EU transport fuels in 2020.

Assuming that increased EU rape and sunflower for biodiesel production can meet the remaining 2% EU energy target, the total target can be met by EU grown crops. The current trade position for cereals is not changed, so the EU could neither be accused of causing higher food prices in the rest of the world by importing biofuels, or of stifling food production in developing countries by increasing food exports. For a biofuels target above 10% in 2020, it is likely that the EU would need to import biofuels or include biofuels from waste materials.

The high protein co-product from the production of ethanol from cereals within the EU, will reduce the increase in imports of soy meal mainly from S America) by 18 mtes/yr by 2020. This will give a substantial improvement in the security of supply of non GM animal feed in the EU.

The reduced EU demand for soy meal will avoid the use of about 6 million ha of new land in S America, which would come from destruction of forest or from cerrado grassland. The avoidance of the destruction of these habitats should more than offset the environmental concerns of the re-use of 3.5 m ha of rotational set-aside land in the EU.

7) TECHNOLOGY DEVELOPMENTS

Technology development is required in several areas:

- Higher yielding strains of cereal
- Bioethanol plant technology
- Quality of DDGS
- Profile of essential amino acids

HIGHER YIELDING STRAINS OF CEREAL

New cereal strains continue to be developed to give higher yields and increased disease resistance. Further work needs to be done to find strains that are more suitable for more marginal land and to give high yields in Eastern Europe. While it is an advantage for wheat used for bioethanol to have higher starch content, this is not an overriding incentive as long as proper credit is given for the protein content in the DDGS

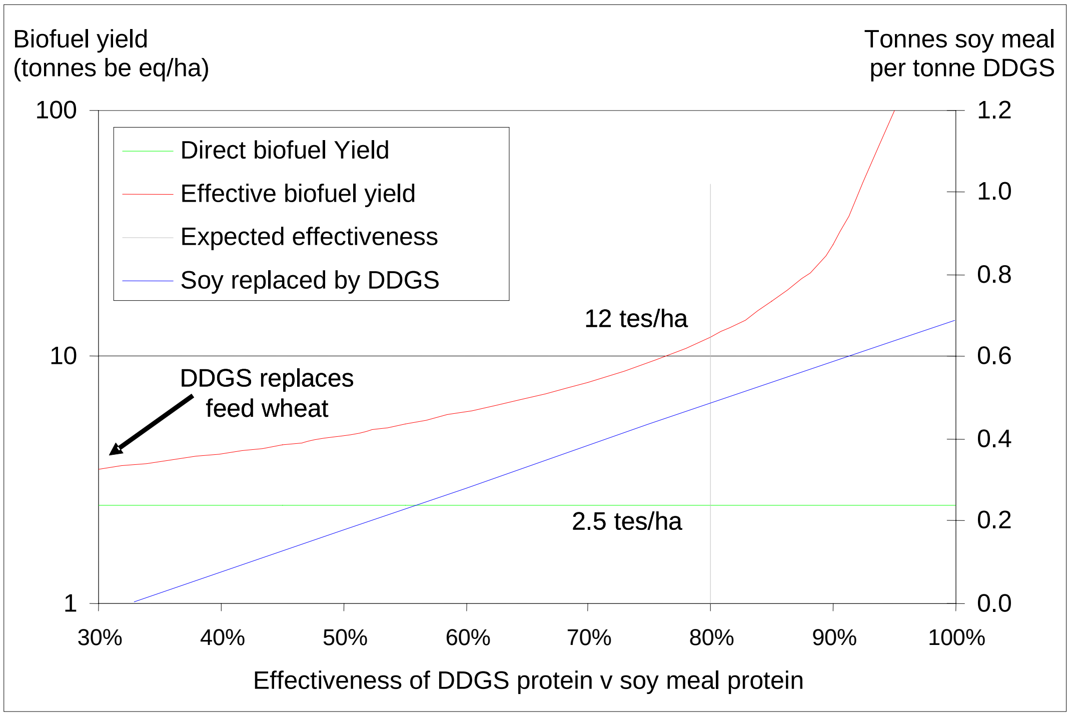
BIOETHANOL PLANT TECHNOLOGY

Starch utilisation from cereals in modern bioethanol plants is very good, but work needs to be done to develop yeasts, or staged fermentation to operate at high ethanol concentrations and hence reduce energy consumption.

QUALITY OF DDGS

The effective yield of bioethanol depends on the effectiveness of the protein in the DDGS, compared to that in soy meal and hence the ratio of feed wheat and soy meal replaced by the DDGS. In some bioethanol plants, protein can be degraded during the distillation and drying stages, such that some of the protein becomes degraded and is less effective. The relationship between the effective bioethanol yield from wheat in NW Europe and protein effectiveness is shown below.

Diagram 7.1 - Effective biofuel yield from wheat



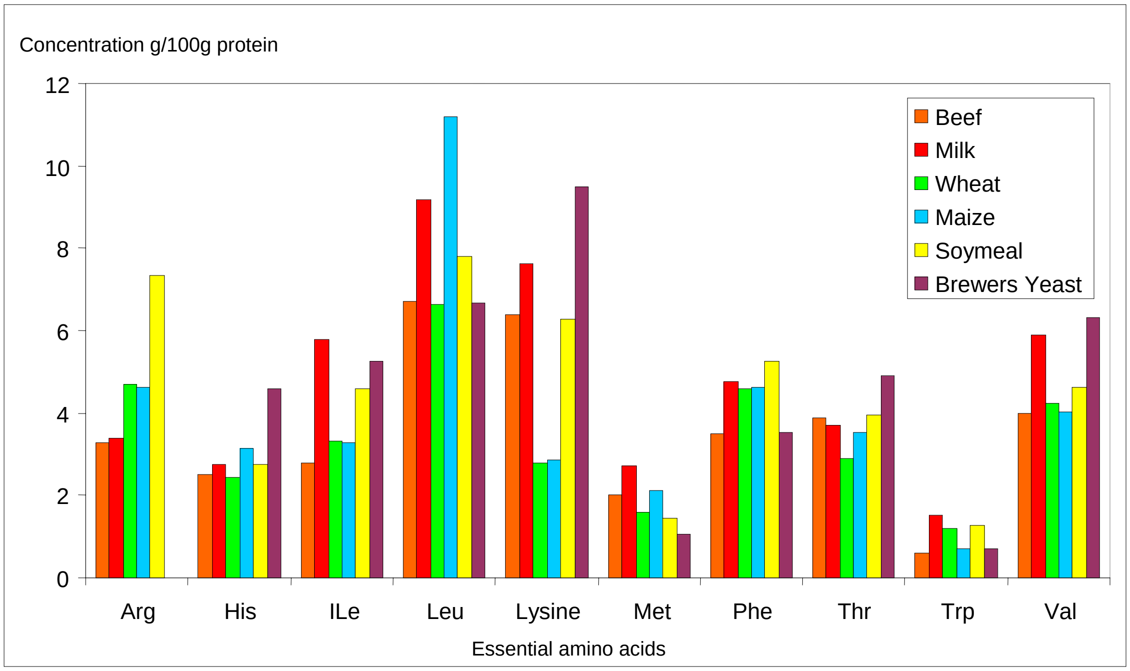
The direct bioethanol yield is 2.5 tes/ha. If DDGS co-product simply replaces feed wheat as animal feed, to give the same metabolisable energy, the net land usage for biofuel is lower and the effective yield is 50% higher at 3.7 tes/ha. Taking into account the higher protein value in the DDGS, compared to wheat, the DDGS actually replaces a mixture of wheat and soy meal as animal feed. Since soy has a much lower yield than wheat, the net land usage for biofuel reduces and effective yield increases. If the effective protein yield per hectare of DDGS is high enough that it can provide the same amount of animal feed per ha as soy meal, then the effective yield of bioethanol becomes infinite.

Further developments will be needed to avoid degradation of protein in the fermentation and DDGS drying process and to ensure consistency of the DDGS product.

PROFILE OF ESSENTIAL AMINO ACIDS

Animal feed must meet the required level of each essential amino acid (EAA) as well as the overall protein level. The comparison of EAA levels in various crops compared to the requirements for cattle are:

Diagram 7.2 - Essential amino acid profile



The orange and red bars represent the EAA profile in beef and milk (Ref. 22) and therefore give a good indication of the EAA demands for beef and dairy cattle. The other bars show the EAA content in alternative animal feed crops (Ref 22) and show how effectively the protein in different crops can be utilised by the animals. Where there is shortfall of EAA, it must either be made up by blending or addition of synthetic EAA, while if there is a surplus, the EAA is broken down and used to build up other proteins. It can be seen that the EAA levels in protein from cereals and oil seed meals match fairly closely the requirements for beef and dairy cattle. The exceptions are low levels of lysine and threonine in wheat and maize, tryptophan in maize and methionine in soy meal. There is also some degradation of the lysine or other EAAs during DDGS drying. Synthetic lysine and threonine are readily available and are widely used as additives to compound feeds.

About 10% of the protein in the DDGS is from the yeast and the DDGS will contain the EAAs from the yeast that is grown during fermentation as well as the EAAs from the wheat. It can be seen that brewers' yeast (Ref. 24) has significantly higher levels of lysine and yeast can be modified to produce higher amounts of the EAAs, such as lysine, where there is a shortage in the cereal.

8) LIGNO-CELLULOSIC ENERGY CROPS

There has been widespread promotion of the benefits of producing bioethanol from ligno-cellulosic energy crops, such as miscanthus and SRC willow (where the crop is used make only biofuel), compared to cereals using arguments such as:

- bioethanol from cereal crops competes with food, while bioethanol from energy crops does not
- cereal crops require high nitrogen inputs which lead to high GHG emissions for biofuel production
- the yields of biofuels from ligno-cellulosic feedstocks are significantly higher than from food crops, so energy crops should be used for biofuel
- the savings in GHG emissions are higher for biofuels from energy crops than for biofuels from grain crops

However, these proposed benefits fail to give any credit to the high protein co-product animal feeds from grain crops, despite the amount of co-product being similar to the amount of biofuel production. These issues are discussed below.

COMPETITION BETWEEN FOOD AND FUEL

Current biofuel crops grown in the EU, such as cereals for bioethanol and rapeseed and sunflower for biodiesel can be used for either food or biofuel production or a mixture of the two. Since energy crops produce cellulose that cannot be digested by humans, it has been argued that they do not compete with food. However, this argument misses the point. The important issue is whether or not 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.

While some energy crops **can** be grown on marginal land that is not currently being used to grow food crops, they only relieve pressure on land if they actually **are** grown on marginal land. Certainly energy crops are currently being grown in the UK on land that was previously used for growing food crops.

Although some marginal land may currently not be needed for growing food, 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.

NITROGEN INPUTS

There are substantial GHG emissions associated with nitrogen fertiliser for growing cereals, both in the CO2 and N2O emissions from N fertiliser manufacture and also in the N2O emissions from land.

In crops such as wheat, maize and rape, nitrogen from fertiliser is converted to nitrogen in the grain in the form of protein. All this protein goes into the DDGS or meal co-product. The nitrogen mass balance and conversions for the different crops, using the RTFO default figures (Ref 2), are shown in Table 8.1.

Table 8.1 Applied Nitrogen Utilisation in different Crops

		UK Wheat	French Corn	UK Rape
Raw Grain Yield	te/ha/yr	7.76	8.52	3.03
N Fertiliser Use	kgN/ha/yr	183	170	185
N Fertiliser Use	kgN/te grain	23.6	20.0	61.1
DDGS/Meal Yield	kg/kg grain	0.33	0.31	0.57
DDGS or Meal protein content		38%	29%	36%
Nitrogen in DDGS/meal	kgN/te grain	20.4	14.5	32.7
N2 in grain / N2 in applied fertiliser	kg/kg	87%	73%	54%

Input data is shown on a yellow background

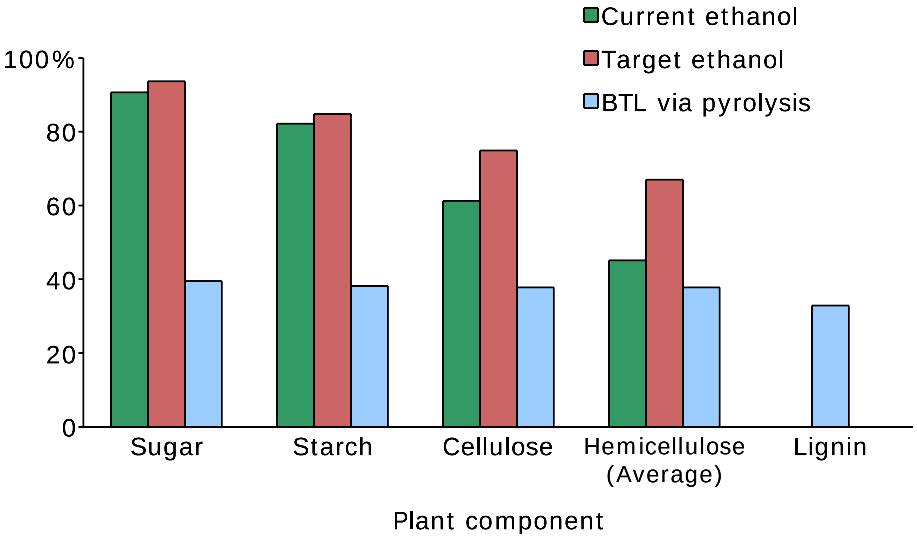
In the table, the applied nitrogen inputs are compared to the nitrogen output in protein per tonne of grain. The table shows that cereal crops, such as wheat and maize are very efficient in converting applied nitrogen into protein and that the amount of nitrogen in protein in wheat DDGS is equal to 87% of the nitrogen that is applied to these crops in fertiliser.

The high nitrogen inputs to cereal crops are therefore being used to produce protein in co-product animal feed, not to produce bioethanol. Since DDGS and meal are used as animal feed, these nitrogen inputs still go into the food chain.

COMPARISON OF PRODUCT YIELDS

The overall efficiency of conversion of plant primary energy to biofuel has been determined, using data in tables 3.2 and 3.4 and data from Refs 14-17 for the conversion of plant components to biofuels. The data is set out in appendix 6 and is summarised in diagram 8.1.

Diagram 8.1 – Biofuel energy efficiencies

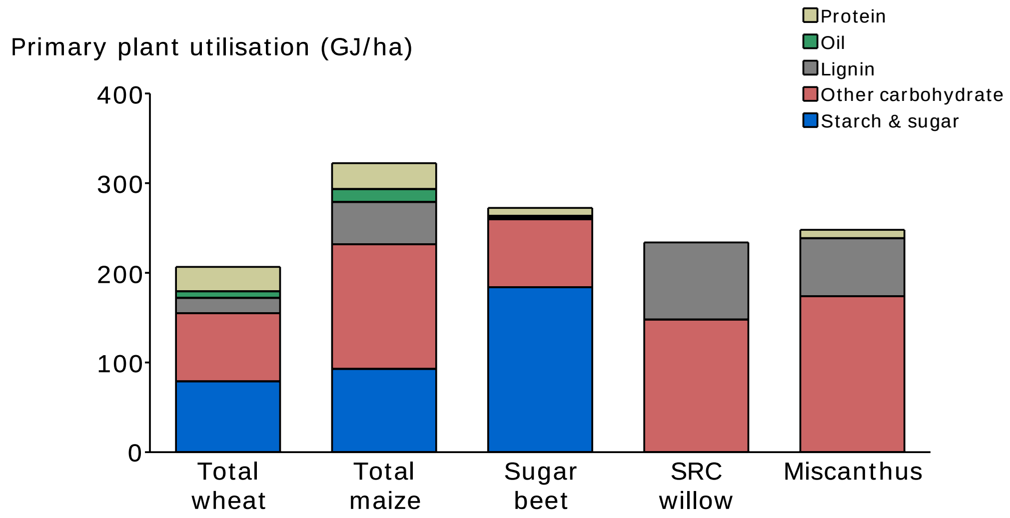


Cellulose and hemicellulose will be converted to bioethanol using so called "Second Generation" technology. The green bars show the likely current state of technology (Ref 16), while the red bars are for technology targets as per Ref. 15. The blue bars represent the Biomass to Liquids (BTL) route, which is the production of diesel and naphtha via pyrolysis, gasification, Fischer Tropsch synthesis and hydrocracking. Development work on second generation technology is progressing slowly because there are lots of problems and the technology is expensive. It is very difficult to obtain a true picture of current progress.

The graph shows that the energy conversion of sugar and starch, using first generation technology is very good. The conversion of cellulose and hemi-cellulose, using currently available second generation technology is poor. The target energy conversion efficiency of cellulose and hemi-cellulose is lower than can currently be achieved by cattle. Also, the timescale for achieving the targets that have been set for second generation technology are unclear, but these could be easily be 10 or 15 years away. This is discussed further in appendix 6. It is not envisaged that it will become possible to convert plant lignin to ethanol.

Cereal crops such as wheat and corn have straw or stover that can be recovered to produce bioethanol. It is assumed that 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. Using typical crop yield and composition data, the total primary energy utilisation of some crops is shown in appendix 6 and summarised in diagram 8.2.

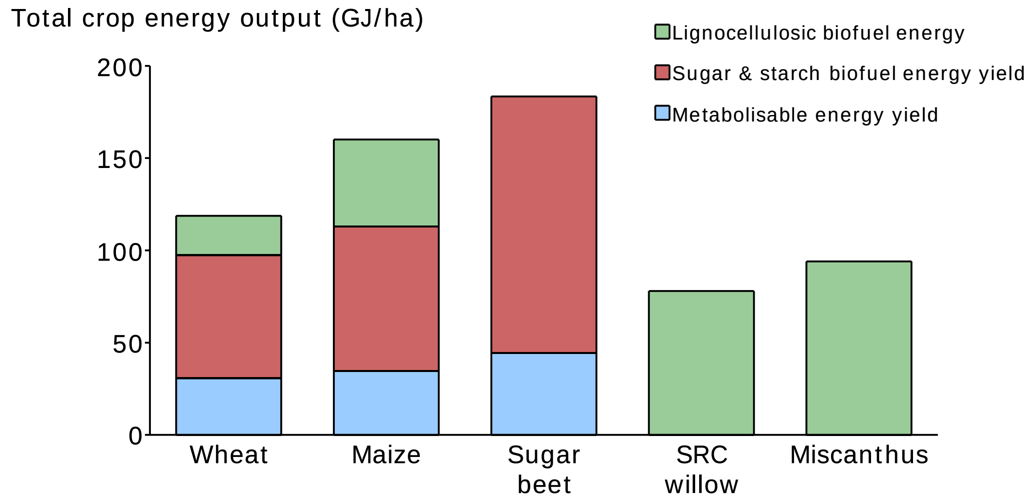
Diagram 8.2 – Utilisation of primary plant energy



The primary energy utilisation for short rotation coppice (SRC) willow and miscanthus grown in the UK is similar to sugar beet and wheat. This indicates that these crops are all utilising similar amounts of sunlight. The energy utilisation for maize is higher because it is grown in countries with a sunnier climate than UK. The split of crop components is different between food crops and energy crops, with food crops having a much higher level of sugar or starch, which give higher conversion to bioethanol. The effect of this is shown in appendix 6 and diagram 8.3.

No account has been taken in diagram 8.3 of the displacement of soy by wheat and maize.

Diagram 8.3 – Total crop energy output (technology target)



This shows that even using target technology performance for second generation technology, the energy output yield of energy crops, such as SRC willow, and miscanthus will be significantly lower than for current crops such as sugar beet, wheat and maize. This is because the efficiency of converting lignin, cellulose and hemicellulose to useful energy is significantly lower than for sugar and starch.

With improved crops, the yield from energy crops, such as short rotation coppice (SRC), poplar and miscanthus in the UK may rise significantly from the current 10-12 tes/ha. However yields of cereals are also increasing steadily and this is likely to continue.

Farmers are reluctant to tie up land to grow perennial energy crops, such as miscanthus and SRC rather than annual crops, because they may miss our on highly profitable years for annual crops. There are also problems that these perennial crops need investment and time to become established and it can be difficult to remove roots and return land to annual crops at the end of the energy crop life.

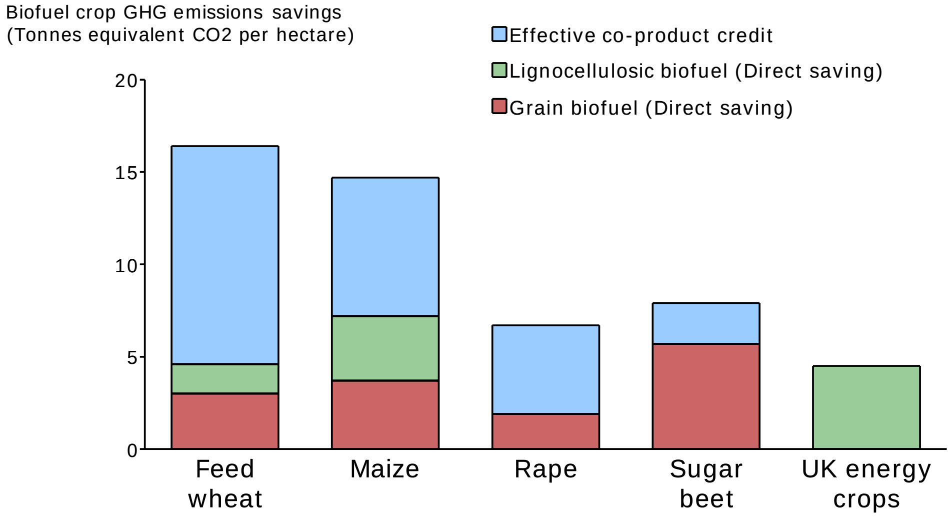
There is therefore no case for growing energy crops on arable land in order to obtain higher bioethanol yields. The comparison of the GHG emissions of bioethanol from SRC and miscanthus is considered below.

9) COMPARISON OF GHG EMISSION SAVINGS

Due to the concern that the drive for biofuels will lead to a shortage of land, it is important to ensure that the GHG savings from biofuels are achieved as efficiently as possible from the land area available. The metric that needs to be compared is therefore the GHG saving per unit land area.

This has been calculated for some biofuel crops. The data used is given in appendix 7.2 and the results are shown below.

Diagram 9.1) Biofuel crop GHG emissions savings



GHG saving figures for biofuels include credit for co-product DDGS and seed cake, which is used as animal feed. DDGS replaces a mixture of feed wheat and soy meal, so that more arable land is freed up to grow food more biofuel crops. The calculation of direct GHG savings (in the UK RTFO and JEC methodologies in Refs 2 and 10), use a substitution approach for the co-product. This gives a credit for the GHG emissions used to grow the soy bean and feed wheat replaced by the co-product. However, in a land limiting environment, the GHG credit for co-products should be calculated as the GHG savings from growing further biofuel crops, such as maize on the displaced land. When this is taken into account, the effective GHG emission savings from making biofuels from grain crops are much higher than the direct GHG savings. Although sugar beet and sugar cane have higher direct GHG savings per ha, than grain crops, they have little or no animal feed co-product to offset their land use. As a result, the effective biofuel yield from sugar cane and sugar beet are lower than for cereal crops.

It is important when, as proposed in UK and Germany, biofuel incentives are related to GHG savings, that the GHG credit for co-products takes proper credit for the protein. This will encourage the most efficient use of land for growing high yield energy plus protein crops, such cereals and rapeseed.

With improved technology for making bioethanol from ligno-cellulosic feeds, the GHG savings from using energy crops to make bioethanol will probably be increased to 100%, so the GHG savings per ha will increase. However the effective GHG savings of bioethanol from wheat (taking into account the DDGS co-product), will still be substantially higher than those of bioethanol from energy crops. There is therefore no case for growing energy crops on arable land in the UK in order to produce bioethanol.

This analysis has been based on mixed farming in a temperate climate and there may well be a case for using energy crops to produce biofuels, in other situations:

- other countries with warmer climates, giving higher energy crop yields
- areas where there is no market for co-product animal feed from cereal crops.

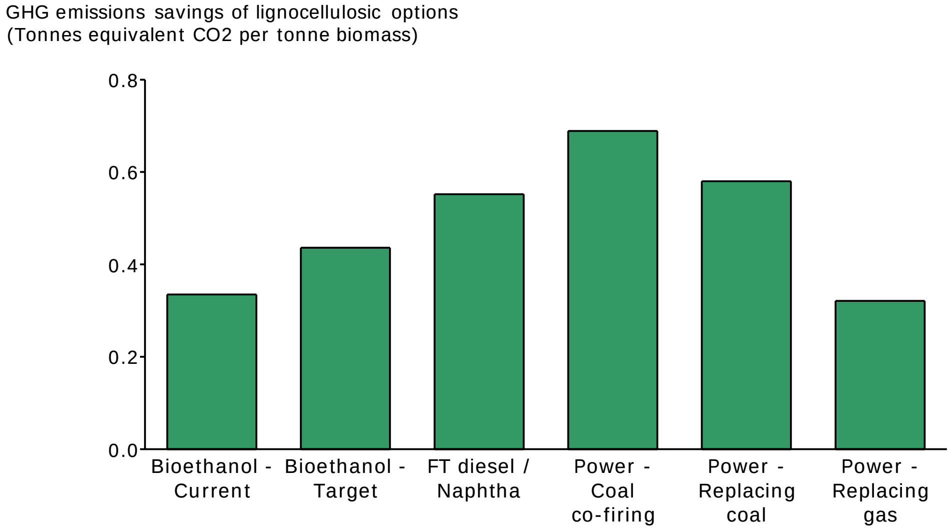
A similar analysis should also be done for grassland, comparing alternative grass crops and their use for forage, or bioethanol plus fodder, or bioethanol only.

Plants can convert sunlight more efficiently to form sugar, starch and oil than to form lignin and so higher biomass yields are not obtained by growing ligno-cellulosic crops, rather than food crops. Also since both first and second generation biofuel processes will convert sugar, starch and oil to biofuels more efficiently than cellulose and lignin, there is no point in growing ligno-cellulosic crops for biofuel production.

10) ALTERNATIVE USES FOR LIGNO-CELLULOSIC BIOMASS

It is shown above that there is no case for growing energy crops for biofuel production in NW Europe. The comparison of options for utilising dry waste biomass is shown below. The data and assumptions are given in appendix 7.3.

Diagram 10.1 - GHG savings of ligno-cellulosic options



The analysis shows the GHG savings from biomass waste from producing biofuels and from generating power. The benefit from the use of biomass power to replace coal fired generation is substantially higher than other options. Also, the use of biomass for power generation, although expensive, will be significantly lower than the cost of biofuels manufacture. However, as was stated in section 1, there are many alternative options for decarbonising power generation, whereas the decarbonisation of transport fuels is limited to biofuel generation.

The decision will depend ultimately on Government energy strategy. If nuclear power is used to replace coal for base load power generation, biomass can be used for the production of biofuels. However, if nuclear or other renewable power generation is delayed, then waste biomass should be used for power generation.

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APPENDIX 1 - CROP YIELD DATA

Plant Primary Energy Conversion

Component	Wt product/Wt glucose	Combustion energy (LHV)	Primary Energy for conversion	Plant Energy Conversion Efficiency
	wt/wt	MJ/kg product		MJ/MJ
Soluble C6 sugar	1.0	13.8	13.8	100%
Sucrose	0.826	14.9	16.7	100%
Starch	0.826	16.1	16.7	97%
Oil	0.33	37.2	41.7	89%
Cellulose	0.826	16.0	16.7	96%
Lignin	0.465	24.7	29.6	83%
Proteins (available N)	0.51	22.1	27.0	82%

Energy needed to Produce Protein

		Fixed N	Synthetic N
Plant Energy (Available	MJ/MJ protein	1.22	1.22
Primary Plant Energy to	MJ/MJ protein	1.70	
Mineral energy	MJ/MJ protein		0.34
Total Energy	**MJ/MJ protein**	**2.92**	**1.56**
Energy efficiency		**34%**	**64%**

Average NW Europe Crop Yields 2004-6

		Maize	Barley	Rye	Oats	Rape	Soy bean	Sunflower	Sugar Beet	Broad beans	Feed Wheat	Milling Wheat
Yield N.W.Europe	**tes/ha**	8.7	6.12	5.3	5.0	3.5	2.5	2.3	66.9	3.9	**7.75**	**7.1**
Percent Composition moist												
Source		Ref 33	Ref 33	Ref 33	Ref 33	Ref 33	Ref 33/34	Ref 33/34	Ref 28	Ref 33	Ref 5/35	Ref 5/35
Water		13.0%	13%	13%	13%	9%	13%	9%	76.0%	14%	14.6%	14.6%
Protein		8.0%	11%	10.0%	9.1%	20%	36%	18%	0.5%	24.0%	11.4%	12.4%
Lipid (B)		4.0%	3%	2.3%	6.8%	43%	19.5%	45%	0.1%	2.2%	2.3%	2.3%
Carbohydrate		73.9%	71.1%	72.9%	68.7%	24.4%	26.5%	25.1%	21.0%	56.8%	70.1%	69.1%
Ash		1.2%	2.20%	1.8%	2.4%	3.6%	5.0%	3.4%	0.3%	3.0%	1.7%	1.7%
Starch +Sugar		65%	55%	60.0%	38.3%			39.3%	16.2	39.3%	61.8%	
Total Check		**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**0.98**	**1.00**	**1.00**	**1.00**
Protein content Use	% Dry	9.2	12.6	11.5	10.5	22.0	41.4	19.2	2.0	27.9	13.3	14.5
Protein Yield	**tes/ha**	0.70	0.67	0.53	0.46	0.71	0.91	0.40	0.32	0.94	0.88	0.88
Primary Energy Usa	**MJ/kg**	16.1	15.9	15.8	16.7	27.4	22.3	27.7	3.7	16.9	15.7	15.8
Primary Energy Usa	**GJ/ha/yr**	**140**	**98**	**84**	**84**	**97**	**57**	**64**	**244**	**66**	**122**	**112**

Notes

- Data for primary plant energy requirements are taken from Refs. 12 and 13.
- Data for biofuel conversion efficiencies are taken from Ref. 2
- Crop yields for N W Europe are from Ref 32 and are the weighted average yields for UK, Germany, France, Ireland, Belgium, Denmark and Netherlands from 2004 -6.

Wheat

- The yield of feed wheat is 8.5% higher than that of milling wheat (9) and wheat grown in the EU is about 50:50 feed wheat : milling wheat (30), so the yield of feed wheat is taken as 4.25% higher and the yield of milling wheat 4.25% lower than average NW Europe wheat yields.
- The protein content for wheat is normally reported and quoted for the milling industry as N x 5.7.
- This has been converted to N x 6.25 which is the standard used for other crops and for the animal feed industry
- Feed wheat protein is average 2005 – 7 for Nabim groups 3 & 4 in the UK (13)

UK Wheat Protein	**Average 2005 -7**			
Avg Moisture content	14.6%			
	Protein = N x 5.7		**Protein = N x 6.25**	
	% DM	**% Moist**	**% DM**	**% Moist**
All Wheat	12.5	10.9	13.8	
Milling Wheat	12.9	11.3		12.4
Feed Wheat	11.9	10.4		11.4

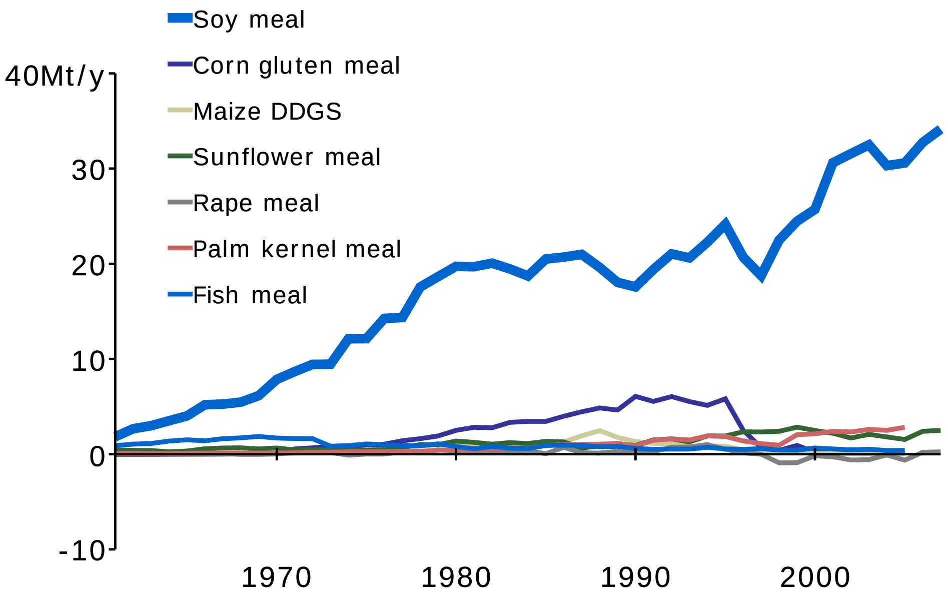
Useful Primary Energy Utilisation			**GJ/ha/yr**			
		Sugar Beet	**Wheat**	**Maize**	**Rape**	**Soy bean**
Protein	27.0	36.2	25.3	22.3	18.7	27.4
Oil	41.7	1.6	6.6	12.0	64.8	21.1
Carbohydrate	16.7	234	87.2	104.4	12.8	12.8
Total		**272**	**119**	**139**	**96**	**61**

APPENDIX 2 - ANIMAL FEED DATA

EU Animal Feed Supply

Animal Feed Component	Volume Used	Protein Concentration	Self Sufficiency	Total Protein Mtes/yr
	2006/7			
	Ref 19	Ref FAOStat	Ref 20	
Wheat	52.5	9.8%	100%	5.1
Maize	39.1	7.7%	90%	3.0
Barley	38.9	11.0%	100%	4.3
Other Cereals	17.3	11.0%	100%	1.9
Total cereals	**148**			
Maize gluten feed	3.5	23%	48%	0.8
Distillery by-products	0.5	32%	50%	0.2
Rape & sun seeds	1.4	22%	50%	0.3
Rapeseed meal	8.3	34%	72%	2.8
Soya cake and meal	32.7	48%	2%	15.7
Sunflower cake and meal	4.2	37.5%	31%	1.6
Other oilseed cake and meal	4.6	25%	57%	1.2
Pulses	2.4	27%	93%	0.6
Fish Meal	0.9	65%	57%	0.6
Tapioca	0.9	10%	0%	0.1
Other materials (6)	0.9	25%	23%	0.2
Total	**208**		**50%**	**38**

EU 27 Net imports of high protein animal feed



Source FAOSTAT (Ref 38)

APPENDIX 3 – BIOFUEL PROCESSING DATA

3.1 Biofuel Conversion and Energy Yields

Bioethanol Stoichiometry						**Efficiency**
	Glucose			**Ethanol**		
	C6H12O6		=	2 x C2H6O	+ 2*CO2	
Mass	180			92	88	**51.1%**
Energy MJ/kg	13.8			26.8		
Energy MJ	2478			2466		**99%**
	Sucrose					
	C12H22O11	+ H2O	=	4 x C2H6O	+ 4*CO2	
Mass	342			184	176	**53.8%**
Energy MJ/kg	14.9			26.8		
Energy MJ	5102			4931		**97%**
	Starch			**Ethanol**		
	C6H10O5	+ H2O	=	2 x C2H6O	+ 2*CO2	
Mass	162	18		92	88	**56.8%**
Energy MJ/kg	16.1	0.0		26.8		
Energy MJ	2615			2466		**94%**

Plant Primary Energy and Biofuel Conversion						
	Within Plant	**Biofuel Processes**				
Component	**Plant Energy Conversion Efficiency MJ/MJ**	**Extraction efficiency**	**Process conversion efficiency mol/mol**	**Stiochiometric conversion efficiency MJ/MJ**	**Biofuel energy conversion efficiency MJ/MJ**	**Overall energy efficiency MJ/MJ**
C6 sugar	100%	100%	92%	99%	92%	**92%**
Sucrose e.g.beet	100%	97%	92%	97%	86%	**86%**
Starch - cereals	97%	98.5%	92%	94%	85%	**83%**
Oil - oilseeds	89%	80%-96%	95%	100%	90%	**80%**

Notes

- Plant energy conversion is from appendix 1.
- Extraction efficiency is the amount of biofuel raw material that can be are extracted from the crop. Data for starch from cereals is from Refs 5 and 36.
- Data for sugar beet is from Ref 28.
- The oil extraction efficiency from oil seeds varies from 80% for expelling and 96% using solvent extraction. Data is from Refs 33 and 34.
- Process conversion inefficiencies are due to by-product formation: some sugar is converted to yeast and non bioethanol products and there are oil refining losses for vegetable oils. Data references are:

Vegetable oil:	Ref. 2.
Bioethanol from cereals:	Refs 5 and 36
Bioethanol from cane sugar:	Ref 23

- The stoichiometric process energy inefficiencies are due to exothems in the ethanol and trans-esterification reactions and are shown in the table above.

3.2 Biofuel Product and Co-product Yields

Biofuel Process Yield Data									**Source**
Theoretical bioethanol yield from starch	wt/wt			56.8%					5
Typical bioethanol yield / theoretical yield				91.5%					36
Biodiesel yield from vegetable oil	wt/wt			0.95					2
	Crop	**Feed Wheat**	**Maize**	**Barley**	**Rape Seed**	**Soy Bean**	**Sugar Beet**	**Sugar Cane**	
	Region	N W Eur	N W Eur	N W Eur	N W Eur	Lat Am	N W Eur	Brazil	
Crop Yields									
Crop Yield avg 2004-6)	te/ha	7.75	8.7	6.1	3.5	2.36	66.9	74.0	32
Moisture content	te/te grain	14.6%	13.0%	13.0%	9.0%	13%			33
Protein content (N x 6.25)	te/te grain	11.4%	8.0%	11.0%					33/35
Sugar + starch	te/te grain	61.8%	64.6%	55.1%					33
Metabolisable energy	GJ/te DM	13.6	13.8	13.2					21
Metabolisable energy yield	GJ/ha	90	104	70					calc'n
Biofuel Output									
Oil from grain	te/te grain				0.41	0.175			34
Biofuel from crop	te/te grain	0.321	0.336	0.286	0.39	0.166			calc'n
Biofuel from crop	te/te crop						0.078	0.064	2/17
Biofuel from crop	te/ha	2.49	2.92	1.75	1.37	0.39	5.20	4.70	calc'n
Biofuel heat value	GJ/te bf	26.8	26.8	26.8	37.2	37.2	26.8	26.8	2
Biofuel energy yield	GJ/ha	66.7	78.3	47.0	51.1	14.6	139	126	calc'n
Biofuel yield	te eq be/ha	2.49	2.92	1.75	1.91	0.54	5.20	4.70	calc'n
Animal Feed Output									
Animal Feed moisture	wt/wt	10%	10%	10%	10%	11.5%	9%	N/A	33
Animal Feed yield	te/te crop	0.326	0.316	0.412	0.557	0.786	0.058	0	calc'n, 17
Protein	te/te feed	35%	25%	27%	36%	46%	7.5%		calc'n, 33
Animal Feed Yield	te/ha	2.53	2.75	2.52	1.97	1.85	3.90		calc'n
Metabolisable energy	GJ/te DM	13.5	14.0	12.2	12.0	13.4	12.5		21
Metabolisable energy	GJ/ha	30.7	34.6	27.7	21.3	22.0	44.4		calc'n
Protein content	te/te crop				20%	36%	0.44%		calc'n
Protein Yield	te/ha	0.88	0.70	0.67	0.71	0.85	0.29		calc'n

Notes

- Input data is on a yellow background
- Bioethanol yields from cereals are typically 90% to 93% of theoretical (15). An average of 91.5% is used
- Soy bean yield for Latin America is a weighted average for Brazil & Argentina

APPENDIX 4 – EFFECTIVE BIOFUEL YIELDS FROM FOOD/FUEL CROPS

Effective yields use average NW Europe crop yields and a conservative estimate that DDGS protein is 80% as effective as soy protein.

All the data below is derived from the biofuel process yield data in appendix 3.
The balances are obtained solving simultaneous equations for energy and protein balances.

Effective Yield of Wheat Bioethanol							
Protein effectiveness of DDGS		0.80					
			Co-product Replacement				
Crop Use		**Wheat Refining**	**Wheat Feed**	**Soy Refining**	**Total**	**Net Biofuel**	**Net Area**
		EU	EU	Lat Am			
Land area	ha	**1.0**	**0.19**	**0.64**	**0.82**		**0.18**
Outputs							
Grain biofuel	t eq be	2.49		0.35		**2.1**	
Animal feed	t	2.53	1.44	1.18			
Metabolisable energy	GJ	30.7	17	14.0	**30.7**		
Effective Protein	t	0.70	0.16	0.54	**0.70**		
Effective Biofuel Yield	t eq be/ha					**12.1**	

Using similar balances for other crops:

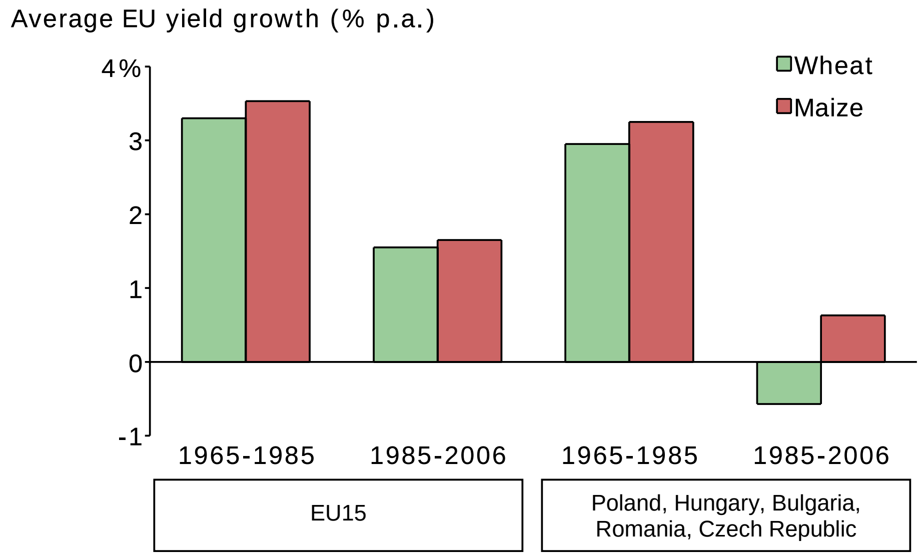
Effective Yield for Biofuels						
		Feed Wheat	**Maize**	**Rape Seed**	**Sugar Beet**	**Sugar Cane**
Protein effectiveness		**0.80**	**0.80**	**0.80**	**0.80**	
Direct biofuel Yield		2.49	2.92	1.91	5.20	4.55
Area of soy displaced	ha soy/ha bf	0.64	0.464	0.56	-0.32	0
Metabolisable energy from soy	GJ/ha bf	14.0	10.2	12.4	-6.9	
Area of cereal feed displaced	ha feed/ha bf	0.19	0.234	0.10	0.57	0
Biofuel from soy	te eq be/ha bf	0.35	0.25	0.31	-0.17	
Effective biofuel yield		**12.1**	**8.8**	**4.8**	**7.2**	**4.5**

APPENDIX 5 – EU CEREAL BALANCE FOR BIOFUELS

5.1 Cereal Yield Increases

Yields and historic rates of cereals yield increases in the EU are shown below, using data from FAOSTAT (Ref 32).

EU cereal yield comparisons



Yield increases of wheat and maize in Eastern European countries: Poland Hungary, Bulgaria, Romania and Czechoslovakia from 1965 to 1985 were similar to those of the EU 15 countries at levels higher than 3%/yr. This was a period of high real prices of cereals. However, in the period from 1985 to 2006, when real prices were substantially lower, the yield increases were lower at about 1.5%/yr in EU 15 and lower in E European countries, with a yield decrease for wheat.

EU Crop Yields		**Wheat**	**Maize**
Avg Grain Yield 2004-6			
NW Eur	t/ha	7.44	8.75
EU15	t/ha	6.00	8.98
EU27	t/ha	5.28	6.89
EU12	t/ha	3.78	5.15
Pol,Hun,Bul,Rom,Cz	t/ha	3.83	5.09
Ratio EU5/EU15		64%	57%
Avg Grain Yield 1975-82			
EU15	t/ha	3584	5.23
Pol,Hun,Bul,Rom,Cz	t/ha	3311	3.88
Ratio EU5/EU15		92%	74%

The average yields in E European countries in the period from 1975 to 1982, reasonably close to those in EU 15 countries – 92% in the case of wheat. However, due to the low rates of yield increase, since this period, relative yields have fallen to levels that are substantially lower than EU15 countries – 64% for wheat.

This illustrates that E European yield capabilities are substantially higher than at present, given the necessary development and investment.

On the basis of this historic information, it is assumed that with higher cereals prices giving a positive return to farmers, yield increases in EU 15 countries will continue at 1.5%/yr and the new EU 12 countries can attain yield increases of 3%/yr that were being attained in the period 1965 -85.

5.2 Additional Bioethanol from Cereals in the EU

The base data and derivation of the data for table 6.1 and diagram 6.1 are:

Additional Bioethanol from Cereals in EU in 2020						**Source**
EU transport fuel demand 2020	Mtoe/yr	330				Ref 30
EU set-aside land avg 2005-7	Mha	7.0				Ref 31
Re-use of set-aside land for bioethanol	Mha	3.5				see text
Land from reduced sugar beet targets	Mha	0.5				Ref 31
Extra land available for cereals	Mha	4.0				
		Wheat	**Maize**	**Barley**	**Total**	
Avg EU 27 cereals production 2004-6	Mt/yr	137	64	58.4	259	Ref 32
Avg EU 27 crop yield 2004-6	t/ha	5.3	6.9	4.2		Ref 32
EU crop area	Mha	25.8	9.2	13.9	49	
W Europe (E15) increase in Yield	per yr	1.5%	1.5%	1.5%		see text
New EU (E12) increase in Yield	per yr	3%	3%	3%		see text
Average output E15/EU27 2004 6		77%	60%	81%		Ref 32
Increase in EU 15 production by 2020	Mt/yr	26.4	9.5	11.8	48	
Increase in EU 12 production by 2020	Mt/yr	17.6	14.2	6.2	38	
Extra land available	Mha	2.0	2.0	0	4.0	
Additional crop from extra land	Mt/yr	13.3	17.3	0.0	30.5	
Increase in non biofuel consumption	%/yr	0.9%	-0.4%	-0.5%		Ref 31
Impact of non biofuel consumption	Mt/yr	-16.2	3.3	3.3	-10	Ref 31
Additional cereals crop available	Mt/yr	41.0	44.3	21.3	107	
Cereal displaced by DDGS co-product	Mt/yr	9.3	13.5	7.5	30	App 4
Additional cereals bioethanol crop	**Mt/yr**	**50.4**	**57.8**	**28.8**	137	
Bioethanol yield 2020	te/te	**0.32**	**0.34**	**0.29**	0.32	App 4
Bioethanol production in EU	Mt/yr	**16.2**	**19.4**	**8.2**	**44**	
Bioethanol production in EU	Mtoe/yr				**28**	
Bioethanol/Total transport fuel					8.5%	
Land Area Saving					**Land Area**	
Re-use of set aside land	Mha				3.5	
Reduction in soy meal Import	Mt/yr	7.7	5.7	4.4		18
Latin America Soy yield growth	%/yr					3.6%
Reduced land use from lower soy imports	Mha				5.6	
Latin America soy oil yield	tes/ha					0.39
Mal/Ind palm oil yield	tes/ha					3.3
Palm oil area to replace lost soy oil	Mha				0.7	
Net decrease in land use	Mha				**1.5**	

Note

- The area split between wheat, maize and barley is assumed to stay the same, but in fact the move from barley to higher yielding wheat and maize is likely to continue.

APPENDIX 6 - BIOFUELS FROM ENERGY CROPS AND LIGNOCELLULOSIC BIOMASS

Bioethanol Yield from Biomass

Conversion status	Current	Intemediate Conversion			Target Conversion		
Reference	**16**	**14**	**14**		**15**	**15**	
Component	**Net molar conversion to EtOH**	**Molar conversion to sugar**	**Molar sugar to EtOH yield**	**Net molar conversion to EtOH**	**Molar conversion to sugar**	**Molar sugar to EtOH yield**	**Net molar conversion to EtOH**
C6 Sugar	92%	100%	92%	92%	100%	95%	95%
Sucrose	89%	97%	92%	89.4%	97%	95%	95%
Starch	91%	98.8%	92%	90.9%	99%	95%	93.9%
Cellulose	70%	80%	92%	73.6%	90%	95%	85.5%
Hemicellulose							
Xylan	50%	75%	85%	63.8%	90%	85%	76.5%
Arabinan	50%	75%	0%	0%	90%	85%	76.5%
Mannan, Galac	70%	75%	0%	0%	90%	85%	76.5%
Lignin	0%	0%	0%	0%	0%	0%	0%

Conversions for ligno-cellulosic feedstocks to bioethanol are from Refs. 14 – 16 . Other data are from appendices 1 and 3.

BTL Energy Efficiency

Pyrolysis	77%
Gasification	89%
FT Synthesis	72%
Hydrocracking	80%
Overall	**39.5%**

Conversions for ligno-cellulosic feedstocks to FT biodiesel from Ref. 17

Bioethanol Yield from Plant Primary Energy

	Plant Energy Conversion	Process Molar Conversion Efficiency Current	Target	Process Energy efficiency	Contamination Loss Ref 15	Overall Bioethanol Energy Efficiency Current	Target	BTL via pyrolysis
Component	**MJ/MJ**	**mole/mole**		**MJ/MJ**		**MJ/MJ**	**MJ/MJ**	**MJ/MJ**
C6 Sugar	100%	92%	95%	99%	1%	90.6%	93.6%	39.5%
Sucrose	100%	89%	95%	97%	1%	85.5%	90.9%	39.5%
Starch	97%	91%	94%	94%	1%	82.2%	84.8%	38.2%
Cellulose	96%	70%	86%	94%	3%	61.3%	74.9%	37.8%
Hemicellulose avg	96%	51%	76.5%	94%	3%	45.1%	67.0%	37.8%
Lignin	83%	0%	0%	0%	0%	0.0%	0.0%	32.9%
Hemicellulose C5	96%	50%	76.5%	94%	3%	45.2%	69.1%	
Hemicellulose C6	96%	70%	76.5%	94%	3%	63.2%	69.1%	

No enzymes are commercially available for the fermentation of C5 sugars, so current conversions are uncertain. Current second generation technology for cellulose and hemicellulose must be run at low ethanol concentrations of 2-5% ethanol compared to 15-20% for conversion of starch. This needs a much higher cost and energy usage to evaporate excess water.

Utilisation of Primary Plant Energy

Plant Component	Primary Energy for conversion	Overall Biofuel Energy Efficiency		Wheat Grain	Wheat Straw	Maize	Corn Stover	Sugar Beet	Total Wheat	Total Maize	SRC Willow	Miscanthus
		Current	Target								2 Yr	
	MJ/kg	MJ/MJ	MJ/MJ	Dry Mass Plant Composition								
C6 Sugar	13.8	91%	94%	3%		2%			2%	1%		
Sucrose	16.7	85%	91%					68.9%	0%	0%		
Starch	16.7	82%	85%	69%		72%			45%	35%		
Cellulose	16.7	61%	75%	4%	38%	3%	38%	6%	16%	21%	41%	43%
Hemicellulose	16.7			8%	29%	6%	26%	8%	15%	16%	24%	24%
Xylan (C5)	16.7	45%	69%	5%	23%	4%	22%		11%	13%	20%	20%
Arabinan (C5)	16.7	45%	69%		3%		2.7%	8%	1%	1%	2.7%	2.7%
C6	16.7	63%	69%	2%	2%	2%	2.2%		2%	2%	1.6%	1.6%
Pectin	16.7	0% ?	0% ?					6%	0%	0%		
Lignin	29.6	0%	0%	1%	14.5%	1%	18.9%	0.4%	6%	10%	29%	19%
Oil	41.7			2.6%		5%		0.2%	2%	2%		
Protein	27.0			13.3%	3.8%	9.2%	4.7%	2.0%	10%	7%		3%
Recoverable Yield	**tes DM /ha**			**6.61**	**3.5**	**7.57**	**8**	**16.1**	**10.1**	**15.6**	**10**	**11.5**
Primary Energy Utilisation												
Starch & Sugar				79	0	93	0	184	79	93	0	0
Other CHO				21	56	19	120	76	76	139	148	174
Lignin				2.0	15.0	2.2	44.8	1.9	17.0	47.0	85.9	64.7
Oil				7.3	0.0	14.5	0.0	1.7	7.3	14.5	0.0	0.0
Protein				23.8	3.6	18.8	10.2	8.9	27.4	28.9	0.0	9.3
Total Primary Energy Utilisation		GJ/ha		**133**	**74**	**148**	**175**	**273**	**207**	**323**	**233**	**248**
Conversion to ethanol - current		GJ/ha		**72**	**21**	**83**	**47**	**177**	**93**	**130**	**60**	**72**
Conversion to ethanol - target		GJ/ha		**76**	**28**	**87**	**62**	**195**	**104**	**149**	**78**	**94**

Notes

- Wheat composition data is for low protein, high starch wheat for animal feed from Ref 5.
- Composition for ligno-cellulosic feed composition is from Refs. 6 and 7.
- Yield data for NE Europe grain crops is from Ref 32
- Yield data for UK energy crops is from Ref. 8.
- Higher yields can be achieved for all crops during controlled testing or trials. For example: wheat yields of 10tes/ha are widely achieved in UK and yields up to 15te/ha are possible, while yields of 17te/ha have been achieved for miscanthus. Higher yields of energy crops can be achieved in the US due to a warmer climate. The yields used are average UK yields for crops grown in the UK, or average NW Europe and US yields for crops grown elsewhere.
- Rape straw and soy straw is very friable and difficult to collect so have not been included in the data for these crops.

APPENDIX 7 - GHG SAVINGS DATA

7.1 COMPARISON OF SYNTHETIC NITROGEN WITH NITROGEN FIXATION

The nitrogen needed to provide protein in high yielding crops, can either be supplied via synthetic nitrogen or fixed nitrogen by the plant. When land is unlimited, the use of nitrogen fixation reduces N2O emissions.

However, in a land limited scenario, which is envisaged with the growth of biofuel production, the low efficiency of using primary plant energy for nitrogen fixation, reduces the total yield from the land. The calculation below compares the GHG emissions for obtaining nitrogen within the plant by using synthetic nitrogen and by nitrogen fixation.

Benefit from Using Synthetic Nitrogen		Synthetic N	Fixed N	Refs
GHG emissions from synthetic N e.g. wheat				
CO2 emissions from manufacture	kg CO2/kg N	1.90		25
N2O emission (no abatement)	kg CO2 eq/kg N	4.90		25
N2O emission (80% abatement)	kg CO2 eq/kg N	0.98		
Total GHG emissions from manufacture	**kg CO2 eq/kg N**	**2.88**		
		Wheat	**Soybean**	
Applied nitrogen - UK wheat	kg/ha/yr	197		18
Diesel for fertiliser spreading	kg CO2 eq/ha	17		2, 21
N2O emissions from land	kg CO2 eq/ha	660	500	10, 26
Total N related GHG emissions	**kg CO2 eq/ha**	**1246**	**500**	
Avg Protein yield NW Europe	te/ha	0.80	0.88	FAOStat
Nitrogen Yield	kg/ha	128	141	
GHG emissions to obtain plant N	**kg CO2 eq/kg N**	**9.7**	**3.5**	
GHG cost from lower biofuel yield				
Primary plant energy to fix N	MJ/kg N		234	13
Primary plant energy to make CHO	MJ/MJ CHO		1.21	Table 3.2
Increase in biofuel production	MJ bf/kg N		194	
Mineral fuel GHG emissions	kg CO2 eq/GJ		85	2
Increase in mineral fuel emission	kg CO2 eq/kg N		16	
Losses in biofuel processing			20%	
GHG cost from lower biofuel yield	**kg CO2 eq/kg N**		**13.2**	
Total GHG emissions	**kg CO2 eq/kg N**	**9.7**	**16.7**	
Benefit factor from synthetic nitrogen		**1.7**		

The quoted figures for the GHG emissions for synthetic nitrogen in ammonium nitrate production are high, due to N_2O emissions from associated nitric acid plants. Since the returns of N_2O abatement on nitric acid plants are very high compared to other means of reducing GHG emissions and it has been assumed that N_2O abatement will continue to progress rapidly in the EU.

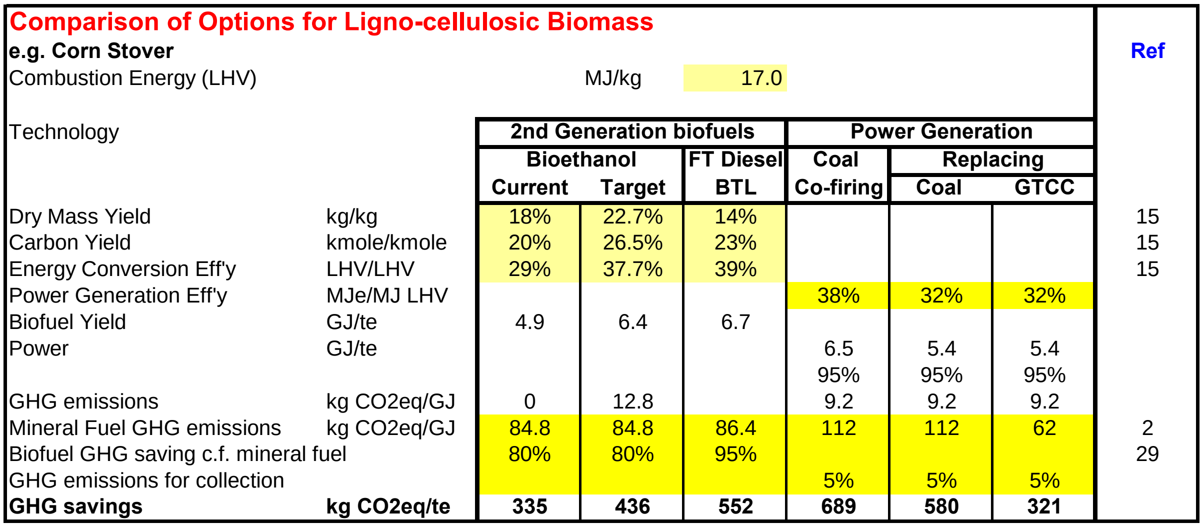
The GHG emissions needed to obtain plant nitrogen are determined by comparing the nitrogen related GHG inputs for wheat and soy. The total GHG emissions from producing N in wheat are 9.7 kg CO_2 eq/kg compared to 3.6 for soy. It is assumed that the primary plant energy that is used to fix nitrogen could otherwise be used to produce plant products such as starch or fat, which could be used to produce biofuels. The biofuels would be burnt instead of mineral fuels to reduce GHG emissions. The biofuel yield lost due to fixing N is 13.2 kg CO_2 eq/ kg of fixed N. Thus in a land limited scenario the total GHG emissions associated with fixing N are thus 1.7 times higher than those associated with the use of synthetic N.

7.2 COMPARISON OF BIOFUEL FROM GRAIN CROPS AND ENERGY CROPS

GHG emission Savings of Biofuels							
GHG emissions of mineral fuels							**Ref.**
Petrol	kg CO2eq/MJ	0.085					2
Diesel	kg CO2eq/MJ	0.086					2
Coal	kg CO2eq/MJ	0.112					2
Biofuel GHG emissions savings		**Feed Wheat**	**Maize**	**Rape**	**Sugar Beet**	**UK Energy Crops**	
Biofuel heat value (LHV)	GJ/te	26.8	26.8	37.20	26.8		
Grain biofuel saving c.f. mineral fuel		54%	56%	44%	48%		29
Direct Grain biofuel Yield	te/ha	2.49	2.92	1.37	5.20		
Direct Grain GHG saving	**te CO2eq/ha**	**3.1**	**3.7**	**1.9**	**5.7**		
Effective Biofuel yield	te/ha	12.1	8.8	4.8	7.2		App 3
Effective grain GHG saving	te CO2eq/ha	14.8	11.2	6.7	7.9		
Effective co-product credit	te CO2eq/ha	11.7	7.5	4.8	2.2		
Lignocellulosic biofuel saving c.f. mineral fuel		87%	87%			80%	29
Lignocellulosic biofuel yield	GJ/ha	21.3	47.2			66	App. 6
Lignocellulosic biofuel	**te CO2eq/ha**	**1.6**	**3.5**			**4.5**	
Direct GHG Saving	**te CO2eq/ha**	**4.6**	**7.2**	**1.9**	**5.7**	**4.5**	
Effective GHG saving	**te CO2eq/ha**	**16.4**	**14.7**	**6.7**	**7.9**	**4.5**	

Biofuel GHG savings w.r.t mineral fuels are typical values from the RED (Ref 29)

7.3 COMPARISON OF OPTIONS FOR LIGNO-CELLULOSIC CROPS



Comparison of Options for Ligno-cellulosic Biomass

e.g. Corn Stover

Combustion Energy (LHV) MJ/kg 17.0

Technology		2nd Generation biofuels			Power Generation			Ref
		Bioethanol		FT Diesel	Coal	Replacing		
		Current	Target	BTL	Co-firing	Coal	GTCC	
Dry Mass Yield	kg/kg	18%	22.7%	14%				15
Carbon Yield	kmole/kmole	20%	26.5%	23%				15
Energy Conversion Eff'y	LHV/LHV	29%	37.7%	39%				15
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	
					95%	95%	95%	
GHG emissions	kg CO2eq/GJ	0	12.8		9.2	9.2	9.2	
Mineral Fuel GHG emissions	kg CO2eq/GJ	84.8	84.8	86.4	112	112	62	2
Biofuel GHG saving c.f. mineral fuel		80%	80%	95%				29
GHG emissions for collection					5%	5%	5%	
GHG savings	**kg CO2eq/te**	**335**	**436**	**552**	**689**	**580**	**321**	

Notes

- Corn stover is used as the basis for this comparison, but the results will be similar for other ligno-cellulosic wastes.
- Data for second generation bioethanol is taken from Refs. 14 -16
- Data for Biomass to Liquids (BTL) via Fischer Tropsch is based on data from Ref. 17.
- The FT product includes naphtha and kerosene, which will replace other refined oil products.
- The mass conversion efficiency is lower, but the energy conversion efficiency is higher for BTL than for biothanol. This is because FT biodiesel has a substantially higher calorific value than bioethanol.
- Mineral fuel GHG emissions are from Ref. 2
- The GHG Savings efficiencies for second generation biofuels are from Ref. 3