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Opportunities and implications of using the co-products from biofuel production as feeds for livestock

by

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1 Abstract

Targets for biofuel use have been established in many countries, including the UK. Currently the main feedstocks in the UK are wheat for bioethanol and oilseed rape (OSR) for biodiesel. The main co-products of biofuel production from these feedstocks are dried distillers grains and solubles (DDGS), rapeseed meal (RSM) and glycerol, all of which can be used as livestock feeds. If all the UK target for biofuels are produced from home-grown crops, this could result in the production of up to 1.3 million tonnes of rapeseed meal (RSM), 1.0 million tonnes of wheat distillers dried grains with solubles (DDGS) and 210 kt of glycerol per annum by 2010. This represents about one quarter of current compound feed production. However, these quantities are unlikely to become available for use in livestock rations within the short-medium term. Limiting factors include OSR crush capacity, the use of imported feedstocks for oil production, the development of methods of producing ethanol from biomass (rather than wheat) and demand for use of these co-products in power generation.

DDGS and RSM are already widely used as feed materials in livestock rations. Published research suggests that there is scope for using more, although variability between production plants in the composition of co-products – particularly for bioethanol – may be a constraint. Considerable research has been undertaken in N America on the use of DDGS in livestock rations, but because maize – rather than wheat – is the main feedstock for bioethanol production caution is needed in interpreting N American results. If significant supplies of RSM and DDGS become available in the UK, protein sources used in compound feed formulations may change, and this will be reflected in changes in the total protein and amino acid profiles of rations. As a result, there could be increases in the amounts of nitrogen and phosphorus excreted by livestock.

The increasing global demand for biofuels will result in increased demand for the raw feedstocks (wheat, maize, soyabean and OSR). This in turn will result in an increase in livestock feed prices. This effect has already been observed in the UK, and the trend is likely to continue. In the longer term, the development of systems of bioethanol production from biomass, rather than food crops, is likely to have a major impact on both crop and livestock producers in the UK.

2 Executive Summary

- The objective of the current study was to consider a number of issues associated with crops grown for the production of biofuels in Great Britain, and the use of co-products resulting from their production as livestock feeds.

- At present the main plant-derived feedstocks for biofuel production are oilseed rape (OSR) for biodiesel and wheat and molasses (from sugar beet) for bioethanol.

- The UK Renewable Transport Fuels Obligation (RTFO) has set targets for biofuels use in the UK. If these were met from home-produced biodiesel and bioethanol, this would result in the production of up to 1.3 million tonnes of rapeseed meal (RSM), 1.0 million tonnes of wheat distillers dried grains with solubles (DDGS) and 210 kt of glycerol per annum by 2010.

- Information provided by the biofuel industry suggests that these quantities of RSM and DDGS are unlikely to become available for use in livestock rations within that timescale. Limiting factors include OSR crush capacity, the use of imported feedstocks for oil production, the development of methods of producing ethanol from biomass (rather than wheat) and demand for use of these co-products in power generation.

- On the basis of information currently available, it is estimated that by 2010 an additional 150 kt tonnes of RSM and 10 kt glycerol will be available from UK-crush oilseed rape. Predicting DDGS production from wheat is more difficult, because at present no bioethanol plants are operational in the UK. However, based on current planned production, up to 1.1 million tonnes of DDGS could be available annually, of which 940 kt may be available for use as animal feed.

- In the short term, co-products from biofuel production from OSR (and other oilseeds) and sugar beet are likely to have a similar nutritional value to existing co-products. DDGS resulting from bioethanol production could be very different nutritionally to that of DDGS produced from the current potable alcohol production, but this will depend on methods of production used.

- In the medium term, pressure to reduce green house gas emissions is likely to result in lower protein content feedstocks produced through lower fertiliser use and the development and use of new varieties. This will result in a lower protein content in the co-products. The effects of this on total or digestible amino acid content, or on rumen degradability, are unknown, but will need to be assessed in order to optimise the use of the co-products in livestock diets.

- One of the co-products of biodiesel production is glycerol. It is a high energy feed, which can be fed to both ruminants and monogastric animals, although there is relatively little experience of its use as an animal feed. Further research in the UK is recommended to assess maximum inclusion rates in livestock diets.

- Based on current estimates of production, it seems likely that the livestock industry could absorb all of the additional RSM and glycerol produced. Their use would displace other feed materials currently imported into the UK.

- Most of the recent information on maximum inclusion rates of DDGS in livestock diets has come from research carried out in the USA using maize-based DDGS. However, this has a very different composition from wheat-derived DDGS, and further research is recommended with this by-product to establish maximum limits for inclusion in diets, particularly for pigs and poultry.

- This variation in composition between maize and wheat-based DDGS should be borne in mind when reviewing published data; to avoid confusion it is considered essential that DDGS are always qualified in terms of their cereal base. The fact that both maize and wheat-based DDGS are available in the UK is further support for this qualification. Unless stated otherwise, DDGS in this report refers to that derived from wheat.

- Variability in the composition of co-products between different biofuel producers does occur, and can be a major issue for feed compounders. However, variability is likely to become less as technology develops and biofuel producers adopt the most efficient methods of production.

- Increasing global demand for biofuels will affect feed prices primarily as a result of the increase in demand for the raw feedstocks (wheat, maize, soyabean and OSR). In the UK it is anticipated that cereal prices will rise, and as a result overall feed prices will increase. If significant supplies of RSM and DDGS become available in the UK, protein sources used in compound feed formulations may change, and this will be reflected in changes in the total protein and amino acid profiles of rations. As a result, there could be increases in the amounts of N and P excreted by livestock. Concentrate feeds used in the UK are subject to world feed prices, and as a result, increasing supplies of RSM, DDGS or glycerol would be most likely to replace imported feeds.

- There is increasing concern that the use of cereals for the production of bioethanol is pricing low-income consumers out of the market for staple foods. As a result, the methods of energy generation from biomass are likely to change rapidly over the next few years. Lignocellulose sources are likely to become the major feedstocks for bioethanol plants, while there will be increasing attention on the development and use of alternative oilseeds for biodiesel production. These developments will have an impact both on crop and livestock producers in the UK, and they will need to react rapidly to changes in the supply of feed materials.

3 Introduction

In 2003 the European Commission published the Biofuels Directive (EU, 2003), which promoted the use of biofuels and other renewable fuels for transport as a means of reducing carbon emissions. This set indicative targets for Member States; in the UK these were incorporated into the Renewable Transport Fuels Obligation (RTFO), which requires that 2.5% of petrol and diesel used in the UK is from biofuels in 2008, increasing to 3.75% in 2009 and 5% in 2010. In his latest budget announcement (21 March, 2007), the Chancellor of the Exchequer announced that this level could rise to 10% by 2020, to match the European Council's agreement made March 9th. The RTFO is set to begin in April 2008, and the Government expect it to deliver net savings of around 1 million metric tonnes of carbon dioxide annually by 2010. As an incentive to biofuel production, a tax rebate of 20 p/litre has been granted to make biofuels more competitive with petroleum.

The production and use of biofuel is not new. In 1898, when Rudolph Diesel first demonstrated his compression ignition engine at the World's Exhibition in Paris, he used peanut oil. However, commercial production of biofuels remained of marginal interest until the latter part of the last century, when Brazil started mass production of bioethanol from sugar cane. By the end of 2006 over 2 million flex-fuel cars – capable of using a mix of bioethanol and fossil fuel - had been sold in that country, while in Sweden flex-fuel models are outselling ordinary petrol and diesel cars.

It has become apparent that the dependency of industrialised nations on fossil fuels is environmentally and economically unsustainable. The USA has been producing maize-derived alcohol since the late 1970's, but interest in biofuels has increased dramatically in recent years as the authorities in California and other states passed laws forcing car manufacturers to reduce pollution levels. President Bush's State of the Union Address in 2006 marked a gear-change, promoting the use of ethanol from starch fermentation and biodiesel made from soybeans as an alternative to petroleum, and stimulating research to develop second-generation fermentation technology using plant biomass[1].

In the UK, about 700,000 litres (around 600 tonnes) of biodiesel are currently sold each month, produced mainly from recycled cooking oils, and available as a 5% blend from around 100 filling stations in the UK[2]. However, in order to meet the RTFO targets the use of

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[1] e.g., Switchgrass (*Panicum virgatum*), a summer perennial grass that is native to North America.

[2] Defra statistics

biofuels will need to increase substantially. The NFU have estimated that 1.2 billion litres of bioethanol and 1.35 billion litres of biodiesel will be required to meet the 2010 biofuel target in the UK[3]. As discussed later in the current report, the extent to which these will be produced from home-grown feedstocks is currently unclear. A whole raft of factors, many of them outside the influence or control of the UK, will determine the development of biofuel production in this country, and subsequently the supply and availability of the co-products of biofuel production for use as livestock feeds.

As a starting point, the current report considers the likely implications of producing all of the biofuels from home-produced feedstocks.

- The biodiesel target would require 2.7 million tonnes of oilseed rape. This equates to an extra 840,000 ha of oilseed rape (OSR) to be grown – assuming that none of the oilseed rape (600,000 ha) currently produced is diverted into fuel.

  A by-product of oil extraction from oilseed rape is rapeseed meal (RSM). It is estimated that about 0.9 million tonnes of RSM are currently produced in the UK, of which 0.66 million tonnes is used in the manufacture of compound feeds for livestock. In addition, RSM is used by home mixers and in total mixed rations. Increasing the amount of oilseed rape production by 2.7 million tonnes and crushing this in the UK would provide an additional supply of 1.3 million tonnes of RSM.

- To achieve an additional 1.2 billion litres of bioethanol using current technologies would require 3 million tonnes of wheat[4]. UK exports of wheat vary year on year, but are approximately 2.9 million tonnes, so the majority of the requirements could potentially be supplied from home production.

  Distillers dried grains with solubles (DDGS) is the main by-product of ethanol production, and represents about 35% of the original wheat grain. Thus the three million tonnes of wheat used for biofuel production would yield about 1 million tonnes of DDGS, which is 3.5 times the current amount used by UK feed manufacturers.

- Bioethanol can also be produced from sugar beet. Because of its poor storage, the sugar would need to be extracted over the winter, but processing the sugar to ethanol could be

[3] NFU online – 10 August 2006

[4] NFU online – 10 August 2006

done throughout the year. With changes to world trade and cheaper imports, the amount of sugar beet grown is likely to decrease from its current level of 145,000 ha. Currently there are about 0.62 million tonnes of sugar beet co-products available after sugar extraction, which includes dried sugar beet pulp (0.515mt), pressed pulp (0.085mt) and molasses (0.02mt). About 45% of the pulp is fed to beef cattle and sheep, with the remainder being fed to dairy cows. Some is also fed to pigs, primarily to dry and pregnant sows.

It is clear that biofuel production in the UK will result in substantial quantities of co-products. One potential use for this material is as a fuel for energy generation. Alternatively, they may be used as a feed for livestock. The purpose of this current study is to consider a number of issues associated with crops grown for the production of biofuels in Great Britain, and the use of co-products resulting from their production. This has been achieved through the following sub-objectives:

1. To determine the predicted manufacturing capacity of biodiesel and bioethanol in Great Britain annually for the next 5 years.

2. To examine the potential impact of trade agreements, EC support policy and feedingstuffs legislation on crops grown for the production of biodiesel and bioethanol.

3. To assess whether the co-products of fuel production have similar nutritional attributes to current DDGS, OSR meal and sugar-beet co-products, and examine the impact that future changes in crop varieties, crop husbandry and manufacturing might have on the feed value of co-products of ethanol or biodiesel production.

4. To provide an indication of likely amounts of DDGS and OSR that could be used in diets for beef and sheep, pigs and poultry.

5. To examine the impact of an increase in the supply of co-products from biofuel production on the price and availability of other livestock feeds.

6. To undertake a strategic analysis of the impact of these changes on the economics of livestock production systems.

4 Policy drivers for biofuels and biofuel derived feedstuff production in the UK

4.1 Biofuel policy

As reported above, recent development in the biofuels industry in the European Union (EU) have been primarily driven by concerns over climate change and the need to reduce reliance on fossil fuels. Indicative targets for biofuel use in the EU are contained in the Biofuels Directive 2003/30/EC. The Renewable Transport Fuels Obligation (RTFO) was announced by the UK government as a way to ensure long term demand for renewable fuels in the UK, and will encourage oil suppliers to incorporate a renewable component into the transport fuel supply chain. The targets set as part of the RTFO stipulate that, on a volume basis, 2.5% transport fuel sales should be from a renewable source by 2008, 3.75% in 2009 and 5% from 2010/11. The 5 % target will require 2.5 million tonnes of biofuel by 2010. There are plans to increase the RTFO further to 10% by 2020, yet this would require substantial modification of European fuel standards since they are currently based on a 5% incorporation level.

The RTFO will include, from 2010, a level of carbon accreditation to ensure that the biofuel has a net energy gain compared to the fossil fuels that they replace, and a level of sustainability assurance to ensure that materials for biofuels are produced in a sustainable manner. The exact details of such schemes are currently being developed (HM Government, 2006).

At present, because of favourable prices, large amounts of bioethanol are imported from Brazil and palm oil is imported from a number of countries in Asia for biodiesel production. Yet concerns over the sustainability of these sources are growing, particularly where palm plantations are increasing at the expense of natural tropical habitats. These issues are being addressed by the Roundtable on Sustainable Palm Oil (RSPO), and other developing assurance groups for sugar and soya. UK derived feedstocks may be relatively more expensive, but depending upon the details of the sustainability aspect of the RTFO, may become more attractive in the longer term due to tighter safeguards on sustainability.

The EU standard for biodiesel, EN14214, was set to ensure the quality of biodiesel in the EU, since the physical properties of the oil can significantly affect engine performance. According to the FAO (2006), world-wide, rapeseed oil accounts for 84% of biodiesel production, 13% is derived from sunflower oil, 2% from soybean and other oils and 1% from palm oil. Since the EU accounts for over 80% of world biodiesel production (EurObserv'ER, 2006), these figures can be taken as indicative of EU production also. Oil from palm and soya beans alone do not meet the requirements for the European standard, and must therefore be blended with rape oil or additives such as cold-flow improvers must be included. According to the ASA (2006), Soya oil use is limited to a 20-25% blend in the production of biodiesel. Revision of the European standards could therefore potentially affect the proportion of rape compared to soya and palm oil used in biodiesel production, and hence the amount of rape used in biofuels production. Spain, for example, has adopted a higher iodine value for biodiesel feedstocks, which allows the use of pure soya oil as fuel. In future, biofuels will need to be from assured sustainable production and in sufficient amounts to meet the RTFO targets.

These targets may be met by imported or home produced biofuels. Many factors will determine the amount of biofuel that is imported, including the cost of the feedstock, the ability to meet standards, UK processing capacity and the amount of feedstock that may be produced in the UK. Trade agreements and agricultural policy will also have a significant effect.

4.2 Agricultural Policy

4.2.1 Common Agricultural Policy

The European Common Agricultural Policy (CAP) is arguably the single largest influence on agricultural production throughout the EU, and is the main route for providing support for farmers and the rural community at large. Directives and regulations seeking to support the production of biofuels must work within the policy framework of the CAP in so far as cropping and land use are concerned, and within Transport and Environment policy frameworks for fuel use and emission standards. In contrast, there is no specific UK wide legislation governing the production of crops for biofuels purposes. Farms growing crops for biofuels are eligible for the single farm payment as are food crops, so farmers can choose to grow crops for whichever market gives the greatest profit. Crop production in the UK is fully decoupled from the support payments. Elsewhere in the EU decoupling is partial for some production payments. In France, 25% of support payments for cereals are coupled to production, while in Spain 25% of support that is coupled to production applies to arable crops generally[5].

[5] http://ec.europa.eu/agriculture/markets/sfp/ms_en.pdf

4.2.2 Set Aside

In order to reduce the amount of food production in the EU before decoupled subsidies were introduced, farmers were required to set aside between 5 and 20% of their land in order to qualify for subsidies. Now the area set-aside is dependent on the area set-aside in 2005 and is determined using entitlements that can accommodate changes in farming circumstances. The set-aside land can be used for growing energy crops but is subject to legislation about how much can be used (c.f. Blair House Agreement section) and is not subject to the same aid incentives as non-set aside land (c.f. Energy Aid Payments). There is increasing political pressure and widespread support for the removal of set-aside; its original role was one of supply control, this having been largely replaced by the introduction of the single payment system (SPS) and direct decoupled support. Its removal is likely to be a central part of the CAP 'health check' which the Commission intends to launch during 2008.

4.2.3 Blair House Agreement

The Blair House Memorandum of Understanding (Blair House Agreement) of 1992, between the USA and EU, set limits on the amount of subsidised EU oilseed production on both non-set aside land for food uses, and on set-aside land for non-food uses. This limit is based on the amount of protein meal after crushing. Within the EU, annual output from oilseeds planted on set-aside land for industrial purposes is limited to 1 million tonnes soybean meal equivalent. If this ceiling is exceeded, the EU is required to fix a percentage reduction in oilseed contracts so that the total falls below 1 million tonnes equivalent. Until now, this has not been such an issue, but with the increasing growth of the biofuels industry throughout the EU, Blair House limits are now being reached. However the world markets are changing; according to the USDA, the EU considers the CAP changes in 2003 removed the subsidy advantage of oilseeds, and the US itself is now more concerned about total supplies and fuel security. Removal of set-aside would overcome the Blair House limitations on oilseed production for industrial uses.

However, the EC believes that, pursuant to CAP reforms undertaken in 2003, it is no longer subject to the Blair House limitations on oilseed production. In 2005, rapeseed production intended for use as biodiesel feedstock was grown on 1.8 million ha (MHA) including 0.9 MHA of set aside[6].

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[6] http://italy.usembassy.gov/pdf/other/RS22404.pdf

4.2.4 Energy Aid Payment

All crops grown for biofuels markets on non set-aside land are eligible for an Energy Aid Payment (or Carbon credit), which was introduced in the CAP reform of 2003, and is in addition to the SPS payment and is subject to evidence of a contract to supply a specific processor. The current payment of €45 per ha is subject to maximum guaranteed area of planting throughout the whole EU not being exceeded. Previously set at 1.5 MHA, this has recently been extended to 2 MHA to accommodate the eastward expansion of the EU[7]. If this ceiling is exceeded, the energy aid payment is adjusted *pro rata*. Farmers can qualify for this aid if the production of the energy crops is covered by a contract with a processor, or if the farmer can prove that he will process the crop on farm. The actual amount received by the farmer may be substantially lower than this. For example in the UK up to half is absorbed by the need to transfer the rights overseas. In other countries the subsidy is subject to modulation by individual member states, and the modulation impact on this aid in the UK is much higher than in other EU Member States. Due to the low level of this subsidy, few believe that it will make any real impact on biofuels production, although the EU are reportedly looking to increase the subsidy to €90 per ha to make it more attractive to growers.

4.2.5 Sugar Sector Reforms

Recent sugar reforms within the EU will significantly affect sugar production, utilisation and supply and may impinge on biofuel production. Several factors mean that sugar beet may be an important feedstock for biofuels. Sugar beet can now be grown on set-aside land as a non-food crop and on non-set-aside land, and qualify for the energy aid payment. Sugar used for bioethanol production is also excluded from quotas of production. For example, the British Sugar bioethanol facility in Wissington, Norfolk is using sugar beet, which would otherwise have been destined for export markets.

4.2.6 The Renewables Obligation

In the UK, electricity suppliers are required to produce a proportion of their energy from renewable sources. Under the Renewables Obligation (RO), which was introduced in 2002, all licensed electricity suppliers are required to produce evidence that they have sourced a

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7 http://www.rpa.gov.uk/rpa/index.nsf/vContentByTaxonomy/RPA%20Schemes**Energy%20Aid%20Payments**Grower's%20Guide**?OpenDocument

specified proportion of their electricity supplies from renewable energy sources. The proportion has increased annually, from 0.03 in 2002 to 0.104 in 2010. Qualified renewable generators receive a Renewable Energy Certificates (ROC) for each unit of energy produced, and electricity suppliers demonstrate their compliance with the RO. Co-firing of biomass with fossil fuel qualifies for ROCs.

If a supplier fails to meet its obligation, it must pay a so-called "buy-out" fine for every MWh it sold that was not "renewable". This therefore provides an alternative use – and value - for the co-products of biofuel production. The potential market value of biomass as a source of renewable energy is difficult to predict, being influenced by many factors but particularly the calorific value of the material and the market price of ROCs. This market might further be affected if changes were made in the requirements for obtaining ROCs – for instance, if it were to become a requirement that to obtain ROCs the plant material must come from a crop specifically grown for co-firing.

4.2.7 Biofuel trade agreements

Biofuels required to fulfil the EU and UK directives may be imported from abroad, which would mean that no co-products would be produced in the EU. Biodiesel imports are subject to an import duty of 6.5%. However, since the EU is currently the principle producer and user of biodiesel in the world, there is little international trade in biodiesel at present. Bioethanol already incorporated into petrol is currently subject to an import duty of 6%. However, It is estimated that during 2002-2004, approximately 70% of bioethanol imports entered the EU via preferential trade agreements, such as the Contonou Agreement, Everything but Arms Agreement, Generalised System of Preferences Plus system, and agreements with countries such as Egypt under the Euro-Mediterranean agreement and Norway, with 61% of imports being subject to no import duty, 9% subject to reduced import duty (EU, 2006). The remaining 30% of bioethanol imports came from most favoured nations, such as Brazil.

4.2.8 Feedingstuffs legislation

The use of materials as feeds for livestock is governed by legislation originating in Brussels and incorporated in the UK Feedingstuffs Regulations (2005), as amended. Legislation introduced in 1970[8] included a non-exclusive list of feed materials that could be used as feeds

[8] Directive 70/524/EEC

for livestock. This included rapeseed meal and dried distillers' grains. However, the status of co-products, and particularly co-products used as livestock feeds *but produced from the non-food industry*, has been the subject of discussion within regulatory authorities, including both Defra and the Environment Agency, for a number of years. Indeed, at the time of writing, the whole situation remains unclear and guidance, based on a number of cases that have been taken to the European Court of Justice, is awaited from Defra. If rapeseed meal and distillers grains, produced from biofuel production, were classified as waste under the Waste Framework Directive, then manufacturers and users would need to carry the appropriate licences to sell and use these products. Discussions are currently in progress between the feed industry and regulators. Clearly the outcome of these discussions will have major implications both for home-produced and imported biofuel co-products[9].

5 Biodiesel feedstock

5.1 Current situation

Oilseed rape is by far the most important UK crop used to produce biodiesel. In the UK in 2005/06, 500,000 ha of oilseed rape was grown on non-set-aside land producing 1674 kt of oilseed rape. A further 75,000 ha was grown on set-aside land, producing 196 kt of oilseed rape. Altogether the UK produced 1870 kt of oilseed rape[10]. About 92% of UK oilseed rape was produced in England with almost all of the remainder produced in Scotland. The amount of oilseed rape produced in the UK has increased gradually since 2002 (Figure 1). Relatively small amounts of oilseed rape are exported and imported which generally result in small changes to the overall balance (Table 1).

Table 1. Oilseed rape production, imports and exports (kt) (Source: Defra Statistics)

	2002	2003	2004	2005	2006
Total UK production	1,468	1,771	1,608	1,901	1,870
Imports	333	136	198	47	123
Exports	205	272	104	172	207
Total new supply	1,587	1,634	1,703	1,776	1,786

[9] It is estimated that in 2004 the EU imported 800,000 tonnes of feed from biofuel distilleries in North America (R Crawshaw, *personal communication*)

[10] http://statistics.defra.gov.uk/esg/statnot/osrsur.pdf)

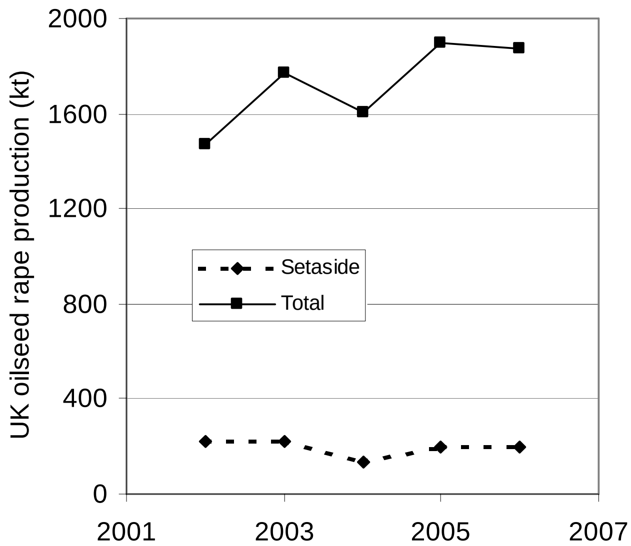

Figure 1. Oilseed rape production in the UK (*Source: Defra statistics*)

5.2 Current and planned biodiesel production

Several companies have existing or planned biodiesel production capacity in the UK. All UK producers will produce glycerine as a co-product of the biodiesel manufacturing process and thus the availability of glycerine will mirror the development of the industry. However, it is worth stressing that the amount of meal produced is dependent upon UK crush capacity as biodiesel producers use vegetable oils rather than oilseeds. The development of UK crush capacity is discussed later in this section. Current situation

Several biodiesel production facilities exist in the UK and use a variety of different feedstocks. Two biodiesel plants currently exist in the North East. One plant, with a capacity of 250 kt per annum uses a combination of rape oil, soya oil and palm oil in roughly equal amounts, but these proportions will be subject to crop prices at the time of production. It therefore seems reasonable to assume that about one third of the feedstock will be from oilseed rape. A second plant has a capacity of 32kt and whilst this plant currently uses soya oil, it will switch to using *Jatropha curcas* oil when plantations in Asia and Africa mature in 2008. In the North West there is a 200 kt capacity facility producing biodiesel from a range of feedstocks including rape, sunflower, peanut and maize oils. This company have also started producing biodiesel for the domestic heating sector with a capacity of 100 kt per year

(50% of capacity). It has not been possible to quantify the quantities of each feedstock used, so we have assumed a conservative estimate of 10% from oilseed rape. A biodiesel facility in Humberside, with a capacity of 50 kt, currently uses used vegetable oil (used cooking oil) as its sole feedstock and a biodiesel facility in Scotland, with a capacity of 45 kt currently uses used vegetable oil and tallow as its feedstocks. Current annual production of biodiesel is estimated to be 545 kt and 109 kt of glycerine per annum. Existing utilisation of rapeseed oil in biodiesel production is estimated to be approximately 100 kt.

2007

A biodiesel facility in Humberside with a capacity of 100 kt is due to come on line in 2007 and will utilise rape, sunflower, soya and used vegetable oil as its feedstock. The company have signed up 1,500 farmers for oilseed rape contracts and planned to secure 160 kt of UK oilseed rape from the 2006 harvest. This means that oilseed rape would produce over 60% of their oil requirements during 2007. There are plans for a plant in Merseyside with a capacity for 100 kt by the end of 2007. It is likely that soya will be the initial feedstock, to be replaced by Jatropha oil when the plantations begin to be harvested in 2008. If current plans are realised, there will be a capacity for 745 kt biodiesel production in the UK by the end of 2007 and 149 kt of glycerine will be produced. Oilseed rape oil will account for an additional 60kt of feedstocks, and together UK production is estimated to require 160 kt of oilseed rape by the end of 2007.

2008

Two 200 kt capacity plants are planned on the same site in the North East which would begin production in 2008. There are also plans for an oilseed crusher on this site with a capacity of 250 kt. It therefore seems likely that a significant proportion of the feedstock will be oilseed rape. A producer plans to increase its production capacity in Humberside from 100 kt to 200 kt. It is not known whether oilseed rape will provide the main feedstock for this plant also but they currently use a neighbouring crusher that has a capacity to process about 150 kt oilseed rape per annum. We do not know of any plans to increase crush capacity in the Humber region, so it is possible that the biodiesel producers are using as much UK oilseed rape as they are able to already. The plant to be built in 2007 in the North West intends to increase production to 320kt and will utilise Jatropha as a feedstock. If these plans are realised, total UK biodiesel production capacity will be approximately 1465 kt by the end of 2008, and a total of 293 kt glycerine will be produced. We have assumed that the requirement for UK oilseed rape oil will be around 700 kt by the end of 2008.

2009

A biodiesel facility using used vegetable oil as a feedstock with a capacity of 150kt and located in the North West is due to come on line in 2009. A 500 kt biodiesel plant is planned for Scotland; however, it is not known what the feedstock will be for this plant. The port location means that it will be easy to import feedstock. However there are also plans for an oilseed crusher nearby with a capacity of 250 kt. This would have the potential to supply 20% of the plant's oil requirement. If current plans are realised the UK will have the capacity to produce a total of 2,115 kt of biodiesel by the end of 2009 and this will produce a total of 423 kt glycerine. We have assumed that the requirement for UK oilseed rape meal will be around 950 kt by the end of 2009.

If all of these planned biodiesel plants are built, then the UK will have the capacity to produce just over 2,100 kt of biodiesel by the end of 2009 (Figure 2). This would represent close to 10% by volume of the diesel used for road transport in the UK. It is estimated that this level of biodiesel capacity would use 950 kt of oilseed rape (Figure 3). UK oilseed rape production would need to increase by 50% to meet this demand, assuming the biodiesel market did not displace the food market.

In the UK there are three main oilseed crushers, down from five in 1992. Companies often withhold exact crushing capacities, so the following figures are estimates. ADM Ltd operates a crusher at Tilbury with a capacity of between 800 kt and 1,000 kt per year. Cargills have crushers at Liverpool and Hull with combined crushing capacities of about 750 kt per year. The total crush capacity in 2006 is estimated at around 1800 kt per year. Of course these crushers also process other oilseeds, such as soya. It is estimated that about 900 kt of RSM is produced from UK crushing. Of this, 660 kt is used in the manufacture of compound feeds for livestock. Additionally RSM is used as a livestock feed by home mixers. There are two crushers planned for the UK in the next five years; one in Scotland with a projected capacity of 250 kt due to begin operation in 2009, and one for the North East with a projected capacity of 250 kt. Current plans suggest that the meal produced from the North East crusher will be burned to provide energy, but we do not know at present whether the meal produced in Scotland will be burned or used for animal feed. Whilst we estimate from current plans that an additional 950kt of rape will be required for the biodiesel industry, the additional planned crush capacity is only 500 kt. It is therefore clear that unless more crushing capacity is built, either the biodiesel plants will use less UK grown oilseed rape, or oilseed rape for fuel will displace some of the oilseed rape currently used for food.

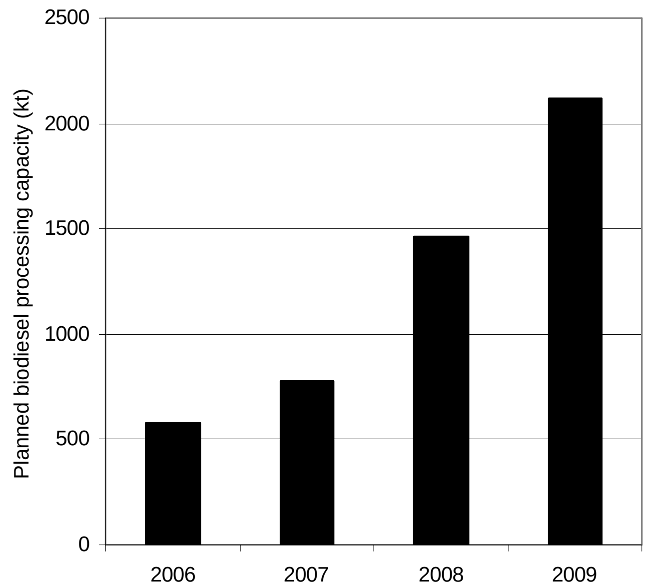

Figure 2. Current and planned biodiesel production in the UK per annum

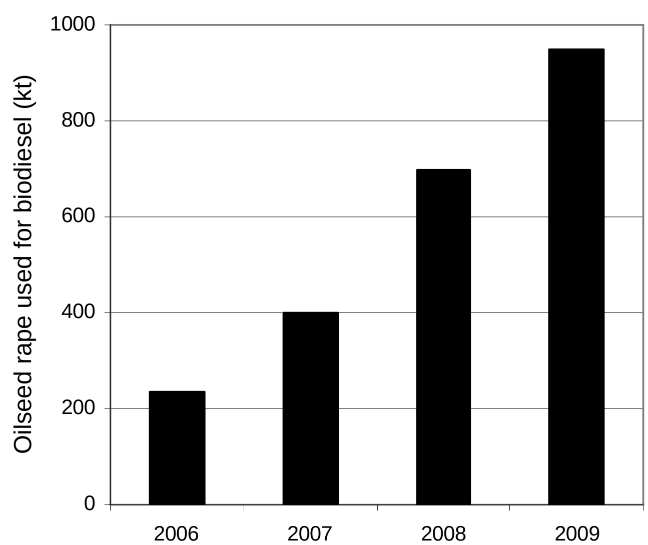

Figure 3. Oilseed rape that may be used for biodiesel production in the UK per annum

5.3 Effects of processing on rapeseed meal quality

The rate of nitrogen fertiliser applied to biofuel crops is very important because this accounts for the majority of green house gas (GHG) emissions that are associated with producing the crops. It is therefore possible that oilseed rape for biodiesel will eventually be produced using less nitrogen (N) fertiliser than is currently used. This will only occur if assurance schemes that are currently being drawn up for biofuel crops incentivise a lower rate of fertiliser use or premiums are paid for crops with lower associated GHGs per litre of oil. At the time of writing this report, it is impossible to estimate how much the N fertiliser may be reduced by, or if it will be reduced at all.

If N fertiliser is reduced then this will reduce the protein content of the meal. The results of nine N response experiments carried out on several varieties in 1990 show the effect of N rate on the oil content and protein content of the seed (Figure 4). These data have then been used to estimate the effect on the protein content of the meal (Figure 4). This indicates that reducing N rate from 180 kg N/ha to 120 kg/ha will reduce protein content of the meal from 401 to 383 g/kg (Figure 4).

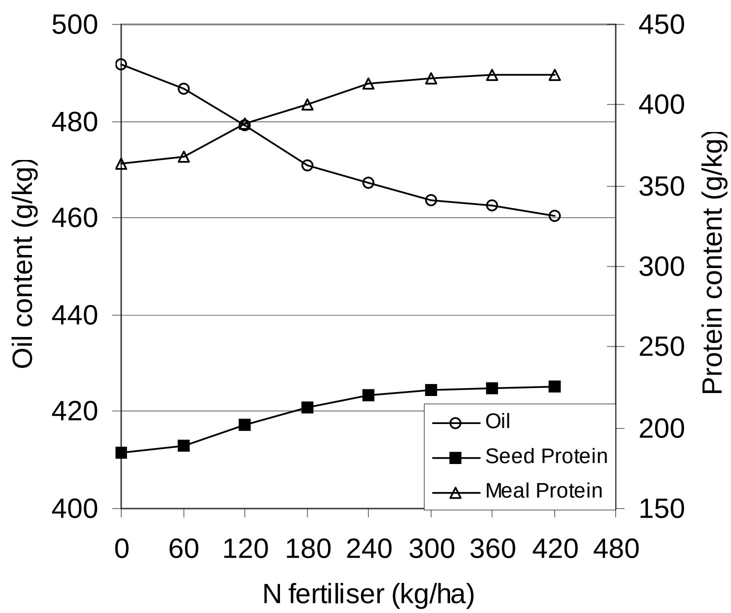

Figure 4. The effect of N fertiliser on the protein content of rapeseed meal. Data from nine N response experiments carried out on several varieties in 1990.

For the next several years it is likely that the same varieties that are used for food will also be used for biodiesel. This is because food varieties produce oil quality that is well suited for the internal combustion engine and meets the European standard for biodiesel (EN14214). Plant breeders select varieties that will perform well in the HGCA Recommended List testing system, and at the time of writing there are no plans to include new requirements into the testing system that are specific for biodiesel production. It should also be noted that breeding varieties with novel traits usually takes several years. A Defra LINK project (LK0979) which began in 2006 aims to help plant breeders select varieties that have a lower requirement for N fertiliser. One of the candidate breeding targets that may facilitate this is reduced seed protein content. If research shows that lower seed protein can reduce the requirement for N fertiliser then it is likely that there will be pressure to develop varieties with this trait. It is estimated that a reduction in seed protein content of 30 g/kg (e.g. 230 to 200 g/kg) is possible given the genetic range of protein content that has been observed. A reduction of this size would reduce the protein content of the meal from 420 to 390 g/kg.

It has been suggested that biodiesel could be produced from high glucosinolate varieties because these may have a greater oil yield potential. Breeding for low glucosinolates occurred in the mid 1980s and was a difficult challenge for breeders because the low glucosinolate breeding material included several traits that reduced agronomic performance. This was illustrated by a drop in oil content at the time of breeding for low glucosinolates (Figure 5). However, this was soon overcome and the yields achieved by low glucosinolate varieties in the Recommended List testing system are about 1 t/ha greater than the high glucosinolate varieties in the 1980s. The use of high glucosinolate varieties will also create volunteer problems that will restrict the potential for growing oilseed rape for food in the same rotation. It therefore seems unlikely that breeders will begin breeding varieties with high glucosinolates for the biodiesel market. Growing high glucosinolate varieties will also have major implications for the use of co-products – high glucosinolate levels are toxic to livestock and it would therefore require feed compounders/home mixers to test for glucosinolate levels to ensure that they are buying low glucosinolate co-products.

There may be scope for improving the cold filter plugging point and oxidation stability through breeding by altering the fatty acid profile. It has been shown that reducing the level of stearic acid and palmitic acid improves the cold flow properties. However at the time of writing the current report there appears to be no pressure to make these types of improvements.

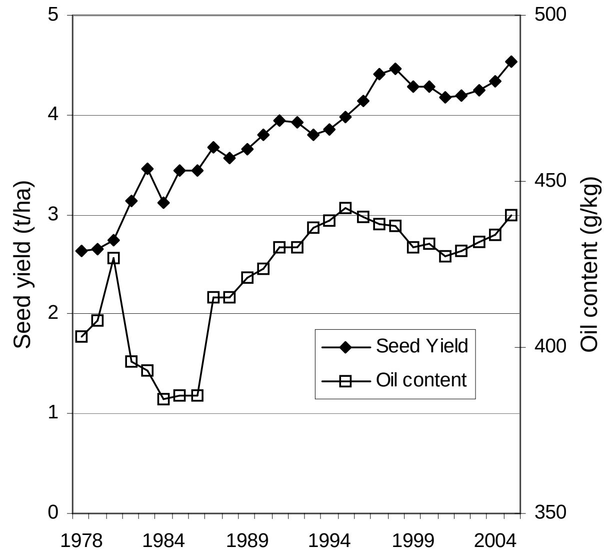

Figure 5. Seed yield and oil content from the HGCA Recommend List variety testing system.

5.4 Conclusions

If all of the planned biodiesel plants are realised then the UK will have the capacity to produce 2,100 kt of biodiesel by 2010. This is about double the requirement set by the RTFO. Plans to double the RTFO to 10% by 2020 are being discussed. It is difficult to estimate how much UK produced oilseed rape will be used in these biodiesel plants because this will depend on the prices of the various feedstocks and which feedstocks satisfy the assurance schemes currently being developed. Oilseed rape currently costs more than most other feedstocks, but is likely to satisfy the assurance standards more easily.

It is estimated that up to 380 kt of biodiesel could be produced from oilseed rape. This would require 950 kt of oilseed rape. It is likely that the remainder of the biodiesel would be produced from UVO, palm, soya, sunflower and Jatropha. Current crush capacity matches the oilseed rape supply from home production and imports. Therefore additional crush capacity would be required to process any additional oilseed rape that is grown to meet the demand for biodiesel. However, at the time of writing this report only 500 kt of additional crush capacity is planned for the UK. This means that either more crushing capacity is required, or less oilseed rape will be used, or oilseed rape for biodiesel will displace some of the oilseed rape currently processed for food use.

An additional 500 kt of crushing capacity would produce about 300 kt of RSM. It is proposed that half of this would be burned in a power station. This leaves 150 kt of additional RSM being produced at the proposed crusher in Fife, which is planned for 2009.

Crushing capacity is likely to be the key factor which influences the amount of RSM produced in the UK. On the basis of the information available at the time of writing, it appears that an additional 950 kt of RSM will be available from biodiesel production in the UK for use as livestock feed.

There is little evidence that rape-meal from oilseed rape used for biodiesel will have very different nutritional composition. It is possible that less N fertiliser will be used, and looking further ahead new varieties may be developed with a lower seed protein and a lower requirement for N fertiliser. It is difficult to estimate the extent to which N fertiliser may be reduced by (if at all). The reductions in the protein content of rape-meal are unlikely to be greater than 30 g/kg (e.g. 420 to 390 g/kg). Several factors mean that it is unlikely that there will be a switch to using high glucosinolate varieties.

6 Bioethanol feedstocks

6.1 Current situation

In the short term, wheat will be the primary cereal feedstock for bioethanol production in the UK. In 2005 it was grown on 1,868 kha out of 4,427 kha (or 42%) of land sown to arable crops. The amount of wheat produced in the UK has remained stable at approximately 14-15 million tonnes per annum over the past four years with an average on farm yield of 8 t/ha (Defra Statistics, 2007). Wheat export and import varies substantially according to the year, but exports generally exceed imports, occasionally by twice as much. Based on data from 2001-2005, the UK has an export surplus of wheat of between 1.6 to 3.8 million tonnes of wheat grain per annum as shown in Table 2.

Table 2. Wheat production, imports and exports (kt) (Source: Defra Statistics)

	2001	2002	2003	2004	2005
Production	11,580	15,973	14,288	15,473	14,863
Imports	1,305	1,368	985	784	1,175
Exports	1,626	1,624	3,778	2,293	2,466
Total new supply	11,259	15,717	11,495	13,964	1,352

6.2 Current and planned bioethanol production

At the time of writing, no bioethanol is produced in the UK, with the majority of the ethanol sold in the UK imported from outside the EU or from facilities in Sweden and Spain. However, several plants are planned for the next five years and the locations of the plants, cumulative feedstock requirement, production of ethanol and co-products are given in.

2007

It is likely that the first bioethanol plant to be built in the UK will utilise sugar beet as a feedstock for alcohol production. Recent changes in the sugar trading in EU have prevented surplus sugar from EU being exported onto world markets. However, British Sugar plans to utilise the previously exportable sugar in alcohol production to produce bioethanol. Current plans are to utilise 700 kt of sugar beet to produce 55 kt of bioethanol per annum. Approximately 180 kt of dried beet pulp will be produced, but because the amount of sugar beet processed in Wissington will not change, this will not lead to any increase in the amount of sugar beet pulp availability to livestock markets over previous years.

2008

The first wheat to bioethanol facilities are planned for 2008, yet, given the difficulties by some producers in obtaining finance for plants, it is difficult to give any reliable estimate of exactly when they will go ahead.

The largest requirement for wheat in 2008 for bioethanol production is likely to be on Teeside, where two bioethanol facilities are planned. Together, these plants will process 1,500 kt of wheat to 475 kt of bioethanol with 515 kt DDGS produced. In Somerset, one plant is proposed in which an estimated 350 kt wheat will be processed to 110 kt bioethanol and 120 kt DDGS. On Humberside, one plant is proposed where 325 kt wheat will be processed to 100 kt bioethanol and 100 kt DDGS. In Northamptonshire, 300 kt wheat will produce 100 kt bioethanol and 100 kt DDGS. In total, throughout the UK, there will be an estimated 2,425 kt wheat required to produce 835 kt bioethanol and 835 kt of DDGS by the end of 2008 if all plants come to fruition.

2009

In 2009, a wheat-to-alcohol facility processing 600-700 kt wheat per annum is planned on Humberside, which will produce an estimated 210 kt bioethanol per annum. This will increase the amount of DDGS produced on Humberside to 460 kt per annum. However, the plant plans to use the DDGS as a biomass feedstock for power, steam and gas generation, therefore this will not impact upon the feed market. Another facility at Teeside is planned to begin operation in 2009, utilising 360 kt of wheat feedstock to produce 110 kt bioethanol per annum. Assuming the DDGS is sold as a livestock feed, this would be estimated to produce approximately 110 kt DDGS. In total, this would result in 625 kt DDGS from plants on Teeside each year by the end of 2009.

If all of the planned bioethanol plants are built, the UK will have the capacity to produce approximately 1.25 million tonnes of bioethanol by the end of 2009 (as shown in Figure 6). Based on a projected requirement for 25 million tonnes of petrol in 2010 and the RTFO inclusion of 5%, this would provide all the required bioethanol demand from home production. It is estimated that this demand for bioethanol would utilise an estimated 700 kt of sugar beet and 4,035 kt wheat (Figure 7), approximately half of which could come from the export surplus in the case of wheat based on current export data. **Based on current plans for production, this will result in an estimated 1,095 kt of additional DDGS per annum being available for animal feeds** (as shown in Figure 8). This will be in addition to the 3 kt already produced each year by the potable alcohol industry in the UK (mainly from distillers in northern Britain).

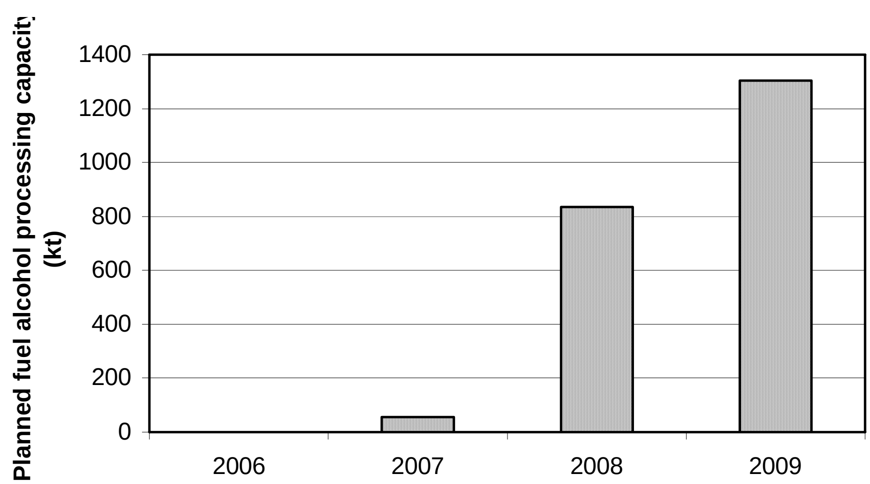

Figure 6. Planned bioethanol production in the UK

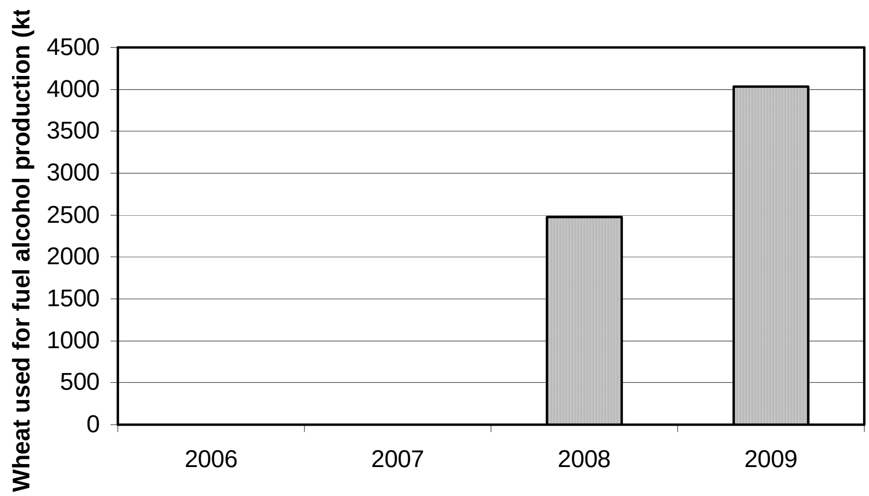

Figure 7. Likely quantities of wheat used for bioethanol production in the UK.

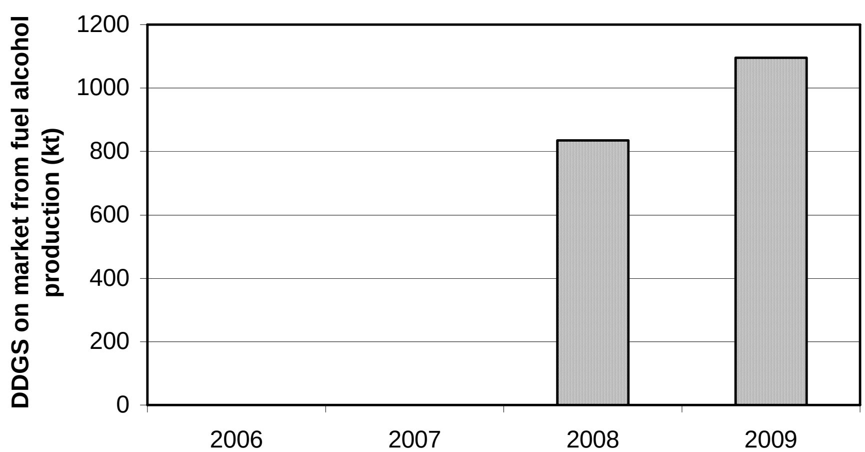

Figure 8. Projected DDGS production from bioethanol production on the market.

6.3 Effect on animal feed quality

Using current fermentation technology, wheat is the most suitable feedstock for bioethanol production in the UK and, with the exception of the British Sugar plant in Wissington, all planned bioethanol plants in the UK plan to use wheat as their primary feedstock.

Sugars from the breakdown of storage carbohydrates (principally starch) and free sugars are fermented by yeast to form alcohol and carbon dioxide. The remaining constituents – the spent grains together with some soluble residues – are combined to produce a product known as draff. Although this is used as a feed for livestock, its high moisture content makes handling and storage difficult, and so the material is usually dried to produce dried distillers grains with solubles (DDGS). DDGS have been produced as a co-product of the potable alcohol industry for centuries and have been traditionally fed to livestock as a protein-rich foodstuff. A typical benchmark for wheat composition is given in Figure 9 below.

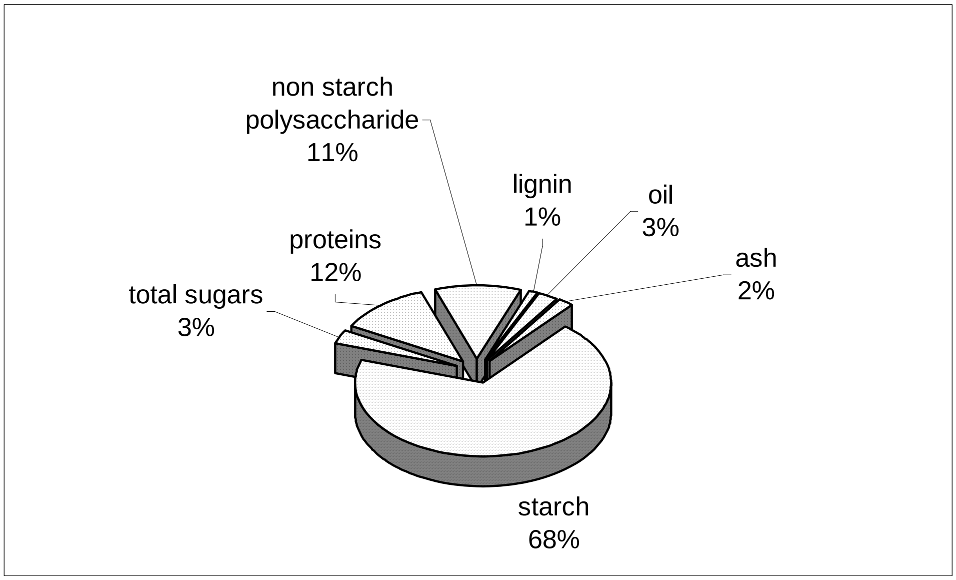

Figure 9. Benchmark composition of wheat grain (from Smith *et al.*, 2006).

Removal of the starch and sugars concentrates the remaining contents approximately three fold as shown in Figure 10 and Table 3. DDGS contains higher crude protein and fibre contents than grain but similar gross energy to wheat grain. Furthermore, DDGS has increased available phosphorous levels compared to wheat grain; this is particularly relevant for pigs, poultry and other non-ruminant animals, since they lack the enzyme phytase that releases phosphorous from phytin (Jaques, 2003).

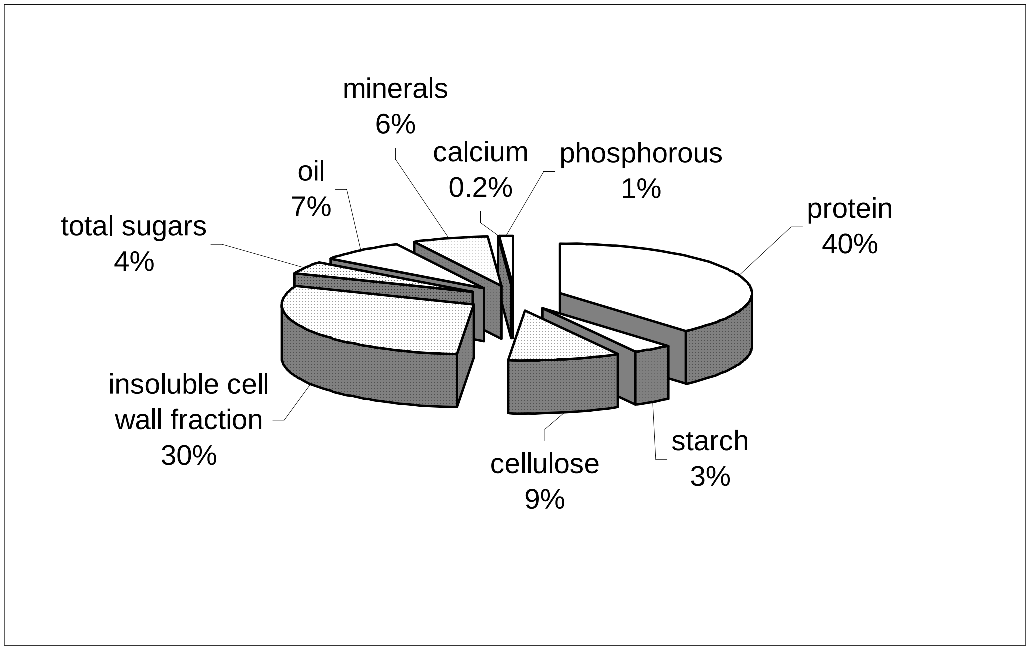

Figure 10. Benchmark composition of DDGS based on a modern bioethanol facility with a 99% conversion efficiency of starch and sugars to alcohol.

The majority of planned bioethanol plants in the UK aim to produce DDGS for the livestock feed market. Whilst the overall process of potable alcohol production and fuel alcohol production are broadly similar, variations in the raw materials, processing aids and processing conditions have the potential to significantly affect the nutritive value of the DDGS, and is the focus of this section.

Table 3. Nutritional composition of wheat grain and wheat DDGS from a modern fuel alcohol facility (based on Nyachoti *et al.*, 2005). Data is normalised to 100% dry matter and based on values for Canadian wheat. Chemical and amino acid composition is given in terms of g per kg, and energy composition is given in terms of MJ per kg. Figures do not include available carbohydrates since these are fermented in the bioethanol production process.

	Wheat	Wheat DDGS	Concentration of the nutrient after processing
Dry matter	1000	1000	1.0
Nitrogen	23.1	67.5	2.9
Gross energy	18.3	21.4	1.2
Acid detergent fibre	52.2	137.5	2.6
Neutral detergent fibre	127.9	320.5	2.5
Ether extract	16.2	38.5	2.4
Ash	17.5	46.3	2.6
Total Phosphorous	4.0	8.9	2.2
Phytate P	3.2	1.9	0.6
Calcium	0.6	1.7	2.6
Essential amino acids:			
Arginine	6.0	15.8	2.6
Histidine	3.2	8.0	2.5
Isoleucine	5.6	13.4	2.4
Leucine	10.2	28.6	2.8
Lysine	3.7	7.1	1.9
Phenylalanine	6.3	19.6	3.1
Threonine	4.7	14.0	2.9
Valine	6.6	18.0	2.7

7 Bioethanol Production

In order to understand how DDGS from fuel alcohol production may differ from potable alcohol industries, it is first necessary to understand the differences in processing between the two industries. In all cases, cereal is first ground and the starch is broken down using enzymes. The sugars produced as a result of starch breakdown are then fermented by yeast to ethanol. The grain solid components (thick stillage) are separated from the liquid by centrifugation or by pressing, before the alcohol is removed from the liquid component by distillation. The remaining liquid can be mixed with the thick stillage and dried to form distillers dried grains with solubles. Alternatively, the grains may be sold dried without the soluble component as wheat dried distillers' grains (DDG) or the solubles dried without the grains (DDS).

The process for Scotch whisky production is protected by the Scotch Whisky Order of 1990 and the Scotch Whisky Act of 1988, which state that only grains, water and yeast may be used in this process. Exogenous enzymes or chemicals are prohibited. For grain whisky production, the enzymes required for starch breakdown are supplied from a small amount of germinated barley that is added to the slurry. In contrast, the fuel alcohol industry can make full use of a suite of enzymes and chemicals to enhance both the yield and rate of ethanol production.

Key differences in the DDGS from whisky production and fuel alcohol industries may arise at several steps in the process and are highlighted below. However it is important to note that significant variation in DDGS composition occurs between different distilleries and between different fuel alcohol plants, as shown in Table 4 below. Therefore, DDGS composition is dependent not only on the type of alcohol facility (potable versus fuel), but also on the specific processes at each facility.

Table 4. Composition of DDGS from two fuel alcohol plants in Northern France using wheat as a feedstock for alcohol production. (From Arvalis, 2006). Data are normalised to 100% dry matter and based on values for Canadian wheat. Energy composition is given in MJ per kg and chemical and amino acid composition is given in terms of g per kg.

Composition	Site A	Site B
Dry Matter	93.3	95.3
Crude Protein	32.1	35.1
Starch	11.7	3.0
Crude cellulose	6.1	8.5
Insoluble cell wall fraction	26.7	26.9
Total sugars	6.5	3.9
Oil	5.7	6.4
Minerals	4.7	5.8
Calcium	0.1	0.2

Phosphorous	0.8	0.9
Amino Acids:		
Lysine	0.7	0.6
Threonine	1.0	1.1
Methionine	0.5	0.5
Cystine	0.6	0.7
Methionine+Cystine	1.1	1.2
Tryptophan	0.4	0.4
Isoleucine	1.1	1.2
Leucine	2.1	2.3
Valine	1.4	1.5
Arginine	1.4	1.5
Histidine	0.7	0.7
Phenylalanine	1.4	1.5
Tyrosine	0.9	1.0
Serine	1.5	1.6
Alanine	1.2	1.3
Aspartic Acid	1.6	1.7
Glutamic Acid	8.2	9.0
Glycine	1.3	1.4

Between the two French plants in Table 4, there is large variation in both the residual starch and total sugars remaining in the DDGS, suggesting different conversion efficiencies to alcohol. The protein and fibre components vary less. As residual starch content increases there is a concomitant reduction in the amount of cellulose, oil, minerals and protein in the DDGS and this could have significant nutritional effects on the nutritive value of the co-products produced.

7.1 Variation in the composition of co-products of bioethanol production

(Note: DDGS is not categorised in this section according to cereal base, although where US data are reported it is likely that maize is the source.)

Despite progress in the developing industry, it should be remembered that DDGS are essentially a by-product of a process that is designed for ethanol production. As such, factors inherent to the production process (type of fermentation, enzymes used, drying temperature and duration) combined with the fact that fermentation relies on a 'live' product (yeast) means that several variables can substantially influence the physical and nutritional properties of the resultant DDGS. Although this variability in quality has traditionally been associated with 'old' processing plants, the fact remains that there may still be a considerable amount of variability in terms of chemical, physical and nutritional characteristics of DDGS produced from 'newer' processing plants. In assessing the published scientific literature examining the digestibility of DDGS in pig and poultry diets, particular discrepancies appear to exist between calculated values for metabolisable energy (ME), lysine and phosphorous. The variation in co-products as a consequence of processing is discussed below.

7.1.1 Metabolisable energy (ME)

The official ME value of DDGS as listed in the pig NRC nutrient tables is 3032 kcal (12.69 MJ) per kg DM (NRC, 1998). However, this figure is noticeably lower than measured values in recent scientific literature. Spiehs *et al.* (2002) examined 118 samples of DDGS from 10 'new generation' (less than 5 years old) bioethanol plants in Minnesota and South Dakota and reported an average ME value of 3749 kcal (15.69 MJ) per kg DM. In a separate trial, Stein *et al.* (2005) found the average ME value of four sources of DDGS to be 3378 kcal (14.13 MJ) per kg DM. A recent comparison of proximate analysis of 34 DDGS samples by the University of Minnesota[11] revealed an average ME content of 3814 kcal (15.96 MJ) per kg DM. It would appear from these data that the ME content of DDGS from modern ethanol plants is both higher than in traditionally listed feed ingredient tables and varies between production plants.

7.1.2 Lysine

As a result of the bioethanol production process, DDGS may be extremely variable in colour. Heat damage and/or overheating can lead to the formation of Maillard reaction products, whereby sugars and carbohydrates react with proteins (primarily the lysine) to form less digestible complexes. There are several scientific studies reporting a strong association between cereal grain colours and both the content and digestibility of lysine. Cromwell *et al.* (1993) examined the physical, chemical and nutritional characteristics of 9 sources of DDGS, varying in grain colour in trials with both chicks and growing pigs. It was found that lysine content and digestibility were correlated ($P = <0.05$) with grain colour. Dark coloured grains were associated with the lowest lysine values (content and digestibility), leading the author to

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[11] University of Minnesota website www.ddgs.umn.edu/profiles.htm

conclude that lysine was more sensitive to overheating than the other amino acids analysed (no pattern was established between DDGS colour and digestibility of any other amino acids measured in the study).

A similar conclusion linking a light DDGS grain colour with enhanced lysine content and digestibility has been reached by other authors working with chickens (Dale and Batal, 2005; Fastinger *et al*., 2006) and pigs (Fastinger and Mahan, 2006). In terms of growing pig performance, Cromwell *et al.* (1993) found that grain lightness (measured on the Hunter L scale) was highly correlated with both growth rate and feed conversion ratio (FCR) with lighter coloured grains yielding the most beneficial performance results.

NRC have reported that the lysine content of DDGS is 6.7 g/kg (NRC, 1998). However, recent scientific trials appear to show that this single value may not be suitably accurate in stating lysine content: Fastinger *et al.* (2006) reported a value of 6.4 g/kg but a study by Spiehs *et al,* (2002) examining 118 samples of DDGS calculated an average value of 8.5 g/kg. Similarly, other studies have reported discrepancies in DDGS lysine content; Fastinger and Mahan, (2006) and Stein *et al.* (2006) have recorded average lysine values of 6.4 and 7.9 g/kg respectively.

Of more significance is the *range* of lysine values obtained. Stein *et al.* (2006) analysed 10 DDGS sources and found lysine content varied between 6.8 and 8.8 g/kg. Recorded values as high as 10.2 g/kg (Spiehs *et al.,* 2000) indicate that some revision of the official listed value may be needed, as it appears that the true lysine content of DDGS may be somewhat higher and more variable than is currently stated in nutrition tables. Similarly, the coefficient of digestibility of lysine is given in the NRC tables as 0.47 (NRC, 1998). Again, this single value does not appear adequate as animal trials show considerable variation: A recent study with caecectomised roosters (Parsons *et al.,* 2006) examining 20 samples of DDGS calculated average lysine digestibility to be 0.72 (range 0.59-0.84). Another study with chickens by Lumpkins and Batal (2005) calculated lysine digestibility to be between 0.75 and 0.80. Trials with grower-finisher pigs have recorded apparent ileal digestibility values for lysine ranging from 0.25 to 0.52 (Fastinger and Mahan, 2006) and between 0.35 and 0.56 (Stein *et al.,* 2006). The results from these animal trials suggest that lysine digestibility may also be higher and more variable than the current listed book values.

7.1.3 Phosphorous

Phosphorous content of DDGS is listed as 7.7 g/kg (NRC, 1998). The results from several recent studies suggest that this figure is fairly accurate, with reported values ranging from 7.2 to 8.9 g/kg (Spiehs *et al.,* 2002; Martinez-Amezcua *et al.,* 2004; Parsons *et al.,* 2006; Stein *et al.,* 2006). It has been suggested that during the bioethanol fermentation process, small quantities of phytase are produced by the yeast, converting the phosphorous into more available forms (Martinez Amezcua *et al.,* 2004; Dale and Batal, 2005). Indeed, Xu *et al.* (2006) reported a high figure for the coefficient bioavailability of phosphorous (0.90) for weaner pigs fed diets containing either 100 or 200 g DDGS/kg.

A similarly high value (0.85) was found by Fent *et al.* (2004) using a slope ratio bioavailability assay, with mono-sodium phosphate as a control comparison. In this trial, piglet fibula bone ash and fibula breaking load were the variables measured. Work with older pigs (20 kg initial weight) by Whitney and Shurson (2001) also calculated bioavailability in pigs to be between 0.875 and 0.922. Although feeding a diet formulated to contain 200 g/kg DDGS/kg also appears to improve phosphorous utilisation in late finisher pigs, a trend for nitrogen excretion to increase has also been observed (Spiehs *et al,* 2000).

In calculating the bioavailability of phosphorous in DDGS when fed to poultry, Dale and Batal (2005) estimated a value of 0.65. Studies with chicks have typically reported average values of around 0.75-0.79 (Martinez Amezcua *et al.,* 2006; Parsons *et al.,* 2006) although it appears from the literature that bioavailability can be noticeably variable; Parsons *et al.* (2006) calculated values ranging from 0.62-1.00. The general consensus from the literature is that although the combination of heat processing and fermentation may increase the availability of phosphorous in the resulting DDGS, it should be noted that excessive heating is known to have detrimental effects on amino acid content and digestibility (particularly that of lysine).

7.1.4 Key processing issues

The presence of soluble non-starch polysaccharides (NSP) increases the intrinsic viscosity of liquids while the insoluble non-starch polysaccharides also increase viscosity through their high water binding capacity. This can lead to numerous problems: Liquids with increased viscosity are difficult to mix and heat evenly, due to high heat transfer coefficients, leading to localised over-heating. Sugars (particularly pentose sugars such as xylose) present in the DDGS can react with amino acids and theoretically render them inaccessible to subsequent digestion, as a result of browning (or Maillard reactions) during drying. This is particularly a problem for essential limiting amino acids such as lysine. Indeed, heating may also result in the destruction of phytic acid, subsequently reducing phosphorous. Browning can have a detrimental effect on the smell, appearance and palatability of the DDGS product and hence reduce voluntary intake by the livestock.

The temperature and duration over which the DDGS are dried at the end of the bioethanol production process can have significant effects on the nutritional status of the DDGS as a result of the Maillard reaction. Modern bioethanol plants have much gentler drying temperatures than old style bioethanol plants and distilleries, and this fact is expected to reduce the potential for Maillard reactions, and theoretically may increase the nutritional benefits over traditional DDGS through less browning and hence improved digestibility of product. Non-cooking processes, where starch is broken down without first undergoing a liquefaction step, are available, and are reported to have beneficial effects on the DDGS by reducing the extent of heat damage to proteins. However, apart from the amount of insoluble crude protein, which is a measure of heat damage to the proteins, and slightly higher sulphur and less zinc, chemically they are similar with moderate crude protein levels, high fat content and high NDF digestibility (Robinson, 2007).

In a typical modern bioethanol plant utilising wheat as a feedstock, the amount of starch in the DDGS is typically 10-30 g/kg whereas in a less efficient plant, DDGS may have a higher starch content (*ca*. 100 g/kg) as in Table 4.

In traditional distilleries, distillation is performed in copper stills, which may result in high levels of copper in the DDGS - although this is subject to wide variation between distilleries. Copper is an essential trace element that may be advantageous to a number of livestock species, although some breeds of sheep are highly susceptible to copper toxicity (Pass and Lambart, 2003).

7.2 Effects of processing aids on DDGS composition and nutrition

A major, and probably the most important difference between bioethanol plants and distilling plants is the ability to use enzyme aids to increase efficiency in the former. Such enzymes are forbidden in whisky production except when added to residues after distillation. The technology available for bioethanol (and co-product) processing is developing rapidly, and, as Gibson and Karges (2006) note, any alteration in the ethanol production process will lead to changes in the DDGS. The following sections illustrate some of the modifications to the manufacturing process to produce bioethanol, and the effects that these may have on the co-products produced.

7.2.1 Hemicellulases

Scenario 1 (Figure 11) shows the potential effects of using hemicellulase enzyme mixes on the quality of the DDGS co-product. Enzyme mixes have been used for many years in monogastric animal food to enhance digestibility. Specific enzyme mixes are commercially available for rye; wheat and barley based on the different nature of their NSP so viscosity problems can be overcome, at a cost, in bioethanol plants.

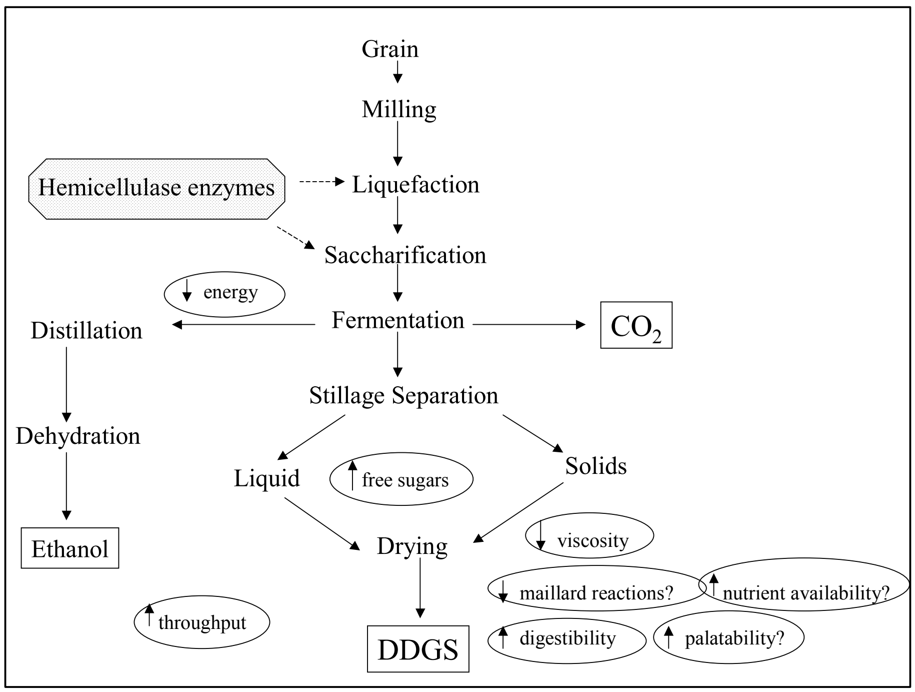

Figure 11. Overview of the effect of using hemicellulose enzyme mixes on DDGS composition (Scenario 1).

Reduction of NSP levels enzymatically would again reduce the viscosity problems inherent in wheat processing from certain cultivars and therefore reduce the energy costs of the process, and provide improvements in throughput. Since the NSP will be partially hydrolysed, viscosity would be reduced, and digestibility of the DDGS would be expected to increase. It is more contentious whether reduction in viscosity by enzymatic breakdown would reduce Maillard reactions; although viscosity would be reduced and the potential for localised heating decreased, degradation of NSP would increase free sugar levels. Since free sugars complex with amino acids during the Maillard reaction, it is unclear whether browning would be increased or decreased with increased pentose sugars, and this would have knock-on effects on the availability of amino acids and palatability of the DDGS.

7.2.2 Nitrogen or Protease use

Scenario 2 (Figure 12) shows how addition of fermentation aids, specifically the addition of a nitrogenous source or addition of protease enzymes to break down the proteins within the wheat grain. Increasing nitrogen supply would increase free amino nitrogen that would have a beneficial effect on yeast health and enhance fermentation.

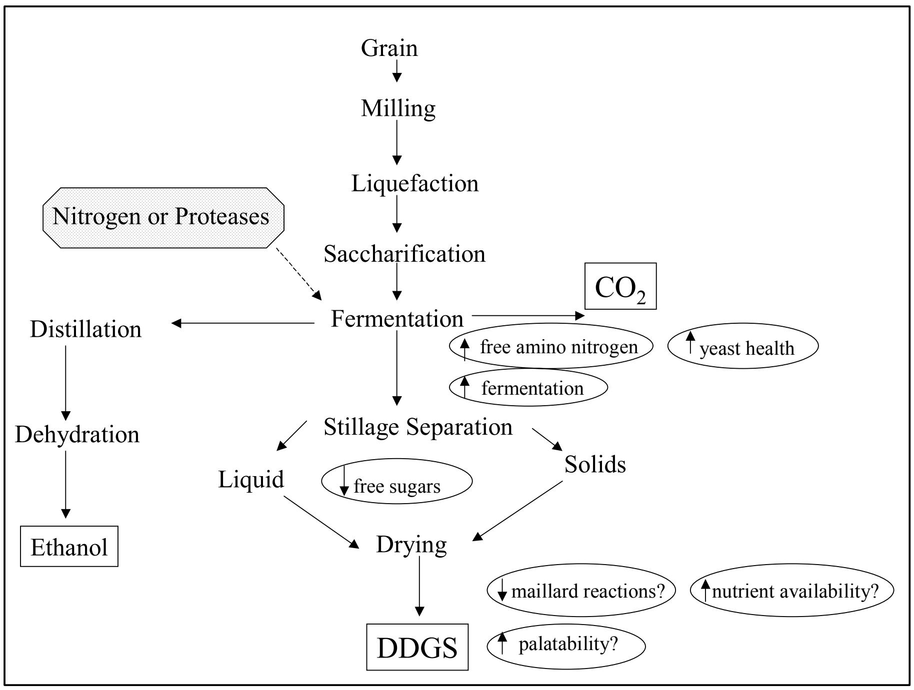

Figure 12. Overview of the effect of using exogenous nitrogen source or proteases on DDGS composition.

With increased fermentation, the amount of free sugars would be expected to be lower in the DDGS, since fermentation should change them to alcohol. The reduction in sugars may not however reduce the potential for Maillard reactions, since free amino acids would be increased and therefore effects on diet digestibility and palatability are uncertain. However, reduction of viscosity from hydrolysis of gluten proteins using a protease may give benefits in processing efficiency and throughput in the plant.

7.2.3 Debranning

NSP such as arabinoxylans (pentosans), and mixed linkage β-glucans can have significant detrimental effects on processing efficiency. Removal of the bran prior to the liquefaction and gelatinisation steps (e.g. by abrasive or roller milling) would provide benefits to the efficiency of ethanol production, and may also improve the efficiency and nutritional quality of the DDGS co-product depending on how the bran is used. In Scenario 3 (Figure 13), the bran is burnt which provides some heat to the energy intensive steps later in the process. Alternatively, the bran may be added back to the DDGS after drying as in Scenario 4 (Figure 14).

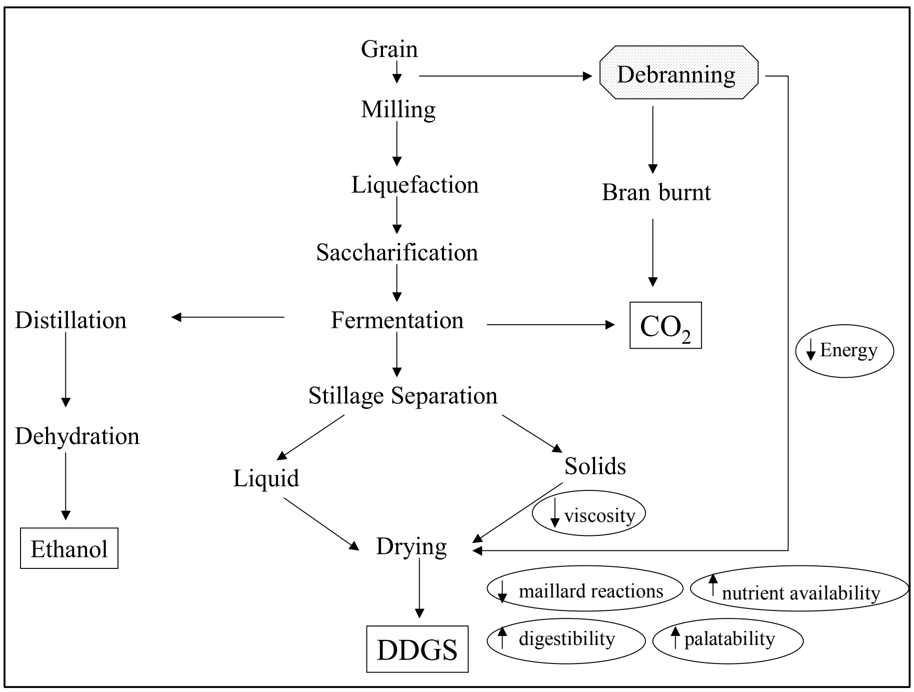

Figure 13. Overview of how debranning and burning the bran for energy could potentially affect DDGS composition (Scenario 3).

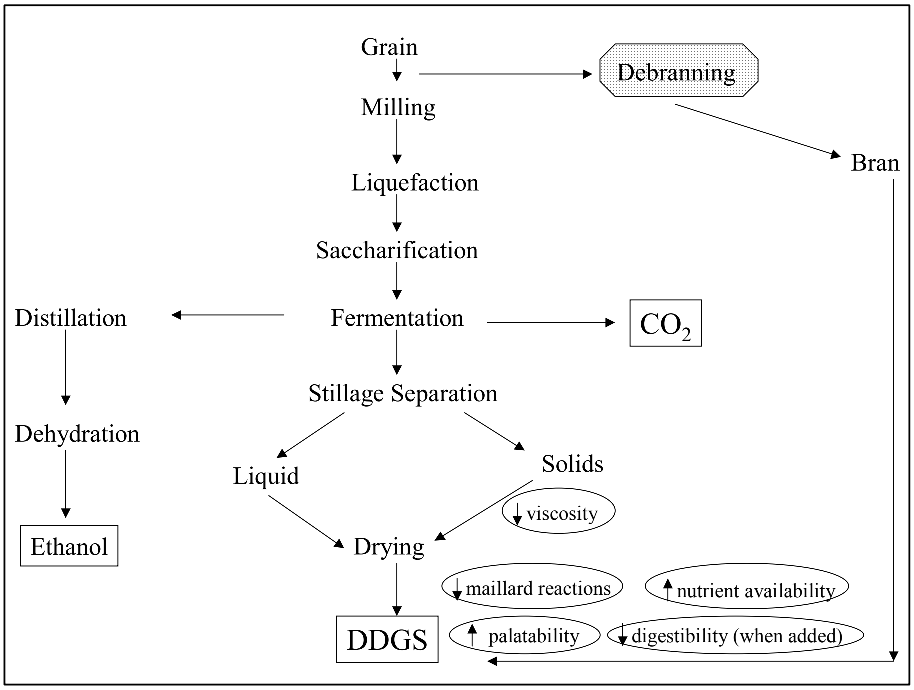

Figure 14. Overview of how DDGS could be potentially affected by debranning and adding back the bran component after DDGS drying (Scenario 4).

Debranning is a potential way in which both fuel and potable alcohol facilities could reduce potential viscosity problems during processing and potentially enhance the nutritional value of the co-products produced. However, there is an increased cost in investing in debranning equipment and it remains to be seen whether any of the planned bioethanol facilities will employ debranning in their processes.

7.2.4 Fractionation

Several bioethanol plants in the USA dry-mill maize feedstock into several fractions, which are then utilised in several end products in a "biorefining" operation. "Biorefining" allows the production of several high value products from the process for markets as diverse as the nutraceutical and cosmetic industries and can contribute significantly to the profitability of the plant (Tibelius and Trenholm, 1996).

Biorefining has the potential to significantly alter the composition of the resulting DDGS and is highly dependent upon the fractionating system employed and end use of the products. In the Broin Bfrac system for example, three fractions are obtained from the whole maize grain;

an endosperm fraction (which is used for alcohol production), a bran fraction and a germ fraction, and three animal feed co-products are obtained. Removal of the bran and some of the germ prior to fermentation results in a DDGS with very high levels of protein, reduced oil and phosphorous contents, and with a high energy level (Gibson and Karges, 2006). Because the bran is removed, this will reduces the NSP content (and the NDF) so allowing better digestibility (Robinson, 2007). The dehydrated germ-enriched fraction has higher oil and phosphorous contents, and although the germ fraction has a lower overall crude protein content, the amino acid composition is favourable and the soluble crude protein fraction is substantially increased (Gibson and Karges, 2006; Robinson, 2007). The remaining bran and syrup are then mixed to form another animal feed product. Whether similar processes will be used in UK bioethanol facilities remains to be seen.

7.2.5 Varietal and agronomic effects

The nutrient composition of the grain prior to processing has a dramatic effect on the variability of the resulting DDGS. Since sugars and starch together account for approximately two-thirds of the grain, removal of the starch and sugars concentrates the remaining constituents by approximately three-fold, as shown in Table 3 below. This magnifies any variations in the nutritional profile so, for example, wheat containing 115 g protein/kg would generate DDGS with 40o g protein/kg, whereas wheat containing only 70 g protein/kg might produce DDGS containing only 280 g protein/kg, with a corresponding increase in the proportion of NSP as shown in Table 5. Protein content can be manipulated through variety choice and N fertiliser application rates. Similarly, one can also predict variation in starch content of DDGS from various scenarios as being in the range 24 to 129 g/kg (i.e. a similar range to that reported from the French factories above), based on a predicted starch conversion efficiency varying between 0.95 and 0.99, and a range of starch contents in the wheat feedstock between 690 and 725 g/kg (as shown in Table 5). With respect to the protein fraction, Spiehs *et al.* (2002) reported that in maize DDGS, variations in lysine content could be partially attributed to the variation in lysine in the raw material delivered to the ethanol plants.

Since DDGS is a co-product of the industry it is hard to envisage any real drivers at the present time for selecting varieties based on a favourable nutrient profile, after removal of the starch and sugar components. A focus on standardising composition (e.g. on protein content) will depend on feedback from the animal feed industry.

Table 5. Four scenarios showing how the total protein content of the wheat grain and the efficiency of conversion of starch in the bioethanol process, can affect the resultant composition of DDGS.

		Composition (g/100g DM)	
Starting feedstock (Wheat)		DDGS (@99% digestion of starch*)	DDGS (@95% digestion of starch*)
Benchmark wheat			
Sugars	3.0	0.0	0.0
Starch	69.0	2.4	11.0
Protein	11.5	40.1	36.6
NSP	11.0	38.3	35.0
Lignin	1.0	3.5	3.2
Oil	2.5	8.7	7.9
Ash	2.0	7.0	6.4
Concentration factor for protein:		*3.49 X*	*3.18 X*
Low protein (or high alcohol yield) wheat			
Sugars	3.0	0.0	0.0
Starch	72.5	2.9	12.9
Protein	7.0	27.8	24.9
NSP	12.0	47.6	42.7
Lignin	1.0	4.0	3.6
Oil	2.5	9.9	8.9
Ash	2.0	7.9	7.1
Concentration factor for protein:		*3.96 X*	*3.56 X*

* Efficiency of digestion of starch in the biofuel plant or distillery

Initially, the varieties used in both potable and bioethanol markets are likely to be the same; using varieties which give a good alcohol yield and few processing problems, as described in HGCA research review no. 61 "Wheat as a feedstock for alcohol production". Varieties are tested for distilling suitability as part of the HGCA Recommended List testing system. Whilst varieties currently suitable for distilling are likely to be easy to process, the use of chemicals and enzymes in bioethanol facilities may widen the range of wheat varieties used, so that hard wheat and varieties with the 1BL/1RS translocation may be acceptable. At present, there are no plans to include a specific requirement for bioethanol production in the Recommended List (RL) for wheat, but currently the RL gives an indication of which wheat varieties are preferred for distilling (i.e. potable alcohol production), and in the short term, this specification is equally useful to biofuels producers. As with the potable alcohol industry, wheat may ultimately be displaced, either wholly or partially, in favour of other feedstocks (such as triticale or maize) depending on economics, and this would again have large effects on the nutritional composition of the DDGS co-product.

Introduction of carbon assurance schemes as part of the RTFO will ensure that the GHG and energy balance of the biofuel exceeds that put into its manufacture. Agricultural practices have been estimated to account for almost half of the energy and GHG emissions in the production of the biofuel crop. Within this, N fertiliser is the single major factor because of the energy involved in producing it, and because it increases emissions of GHG from the soil. Reduction of fertiliser N would therefore increase the potential energy and GHG balance of the biofuel and, since fertiliser N increases grain protein content at the expense of starch, reducing N fertiliser inputs would also have beneficial effects on alcohol yield. Fertiliser N is however a major influence on grain yield, so major reductions in this nutrient would reduce yields to uneconomic levels. The optimal fertiliser N rate to maximise alcohol yield is currently being investigated in an HGCA project “Optimising nitrogen application for biofuels”. A major Defra LINK project “Genetic Reduction in Energy and Emissions of Nitrogen through cereal production” (GREEN grain), is investigating whether there is sufficient genetic diversity in cereal crops to maintain yield whilst reducing N applications.

8 Bioethanol production from sugar beet

The British Sugar bioethanol plant in Wissington, Norfolk will use sugar from sugar beet as a feedstock for bioethanol production. This adds to the current capability at Wissington based on granulated sugar production. Sugar beet is harvested over a five-six month season in winter, and is processed at this time to extract a syrup which is stored for use over the rest of the year. Fermentation of the sugars in the syrup by yeast produces ethanol, which is subsequently distilled. Approximately 75% of the syrup produced at Wissington will be utilised for sugar production, while the remaining 25% will be used for ethanol production.

Since the beet is grown and processed in the same way to extract the syrup for both markets, the beet pulp composition will be the same for both products.

8.1 Bioethanol production - Conclusion

If all of the planned bioethanol plants are realised the UK will have the capacity to produce 1.25 million tonnes of bioethanol by 2010 which is, based on projected estimates of petrol usage in 2010, enough to satisfy the 5% biofuel requirement of the RTFO. With the exception of the British Sugar bioethanol plant in Norfolk, all plants intend to use wheat as their feedstock and this will produce just over 1 million tonnes of DDGS as a co-product. This will add to the 300 kt of DDGS currently produced as a result of potable alcohol production in the UK. The UK is currently an importer of DDGS, yet the magnitude of planned production is almost 20 times that imported (66 kt) in 2005 (Shurson, 2006). Although the majority of plants intend to sell the DDGS as an animal feed, at least one producer is planning to burn the DDGS as a fuel to provide some of the power for the process. If prices for DDGS drop significantly, more manufacturers (both from the bioethanol and potable alcohol industries) may follow suit.

As described above, the residues of wheat-derived DDGS may differ dependent upon whether they have been produced in a traditional whisky distillery, neutral alcohol distillery or in a bioethanol facility. It is important to note that there can be significant variation in the composition of DDGS both between traditional distilleries and bioethanol production as a result of differences in processing efficiencies and in the composition of the original feedstock. Theoretically at least, the DDGS from modern bioethanol plants will be nutritionally superior to that of older plants. The uniformity of ingredients and continuity of supply are important to feed compounders. Uniformity of co-products from biofuel production has tended to improve as technology has developed – with increasing competitiveness, plants will tend to adopt the most efficient processes. Continuity of supply and consistency are likely to improve as production plants increase in size. For this reason, after availability and flexibility of the main feedstock supply, which usually favours location at ports, proximity to animal populations, which can make use of the co-products, is a factor in locating bioethanol plants.

9 Overall Conclusion

Current plans for biofuel production in the UK include the use of three main home-grown feedstocks, namely sugar beet and wheat for bioethanol production and oilseed rape for biodiesel production. Rapeseed meal from biodiesel production and sugar beet pulp from bioethanol production are unlikely to differ substantially from those currently produced because; 1) varieties and agronomic practices maximising sugar and oil yield are desirable for both industries, and 2) extraction of sugar and oils is similar for both industries and is potentially carried out as part of the same process. The efficiency by which the sugars and oils are removed will have effects on the nutritional profile of the resulting co-products, yet this is as likely to vary between different plants and crushers as between different processes.

The residues of wheat grain, DDGS, may differ dependent upon whether the DDGS has been produced in a traditional whisky distillery, neutral alcohol distillery or in a fuel alcohol facility. The extent of the variation in the composition of DDGS from traditional distilleries is already well known, and accommodated by the end users. For DDGS produced for bioethanol production, the variability is difficult to predict because none are currently being produced in the UK. The best that can be done is to examine the situation in north America, where there is a history – albeit a relatively short one – of bioethanol production. There is evidence that considerable variability may occur between manufacturing plants, although within plants the composition of DDGS is more consistent – reflecting perhaps differences in manufacturing processes. It is important to note that bioethanol production in the USA is based principally on maize, while that in the UK will primarily use wheat, at least in the short term. Moreover, considerable research efforts are being directed at developing new enzymes and manufacturing processes to improve both the efficiency of ethanol production and the composition of the co-products. As a result, the variability that might have been observed in recent years may not occur to the same extent in coming years.

Changes to the varieties used, and agronomic practices employed in the production of biofuel crops may have a significant effect on the quality (and quantity) of the feedstock and hence the nutritional quality of the co-products obtained. Reduction of fertiliser N inputs to the crop in particular, will become increasingly desirable in the future for both feedstock quality and environmental reasons. In the short term, reduction of fertiliser N will be driven by the desire to increase the oil and starch content of the feedstock. In the longer term, introduction of carbon assurance schemes as part of the RTFO will potentially result in the need to optimise fertiliser N application because of its large effect on the GHG and energy balance of the crop. Reduction of fertiliser N inputs into the crop will potentially result in a lower protein content in the resulting co-product, which in turn may have significant effects on the value of co-products as a feed for livestock.

10 The use of biofuel co-products in livestock rations

Appendix Table 1 lists the feedstocks that are likely to be used in the production of biodiesel. These include oil from oilseed rape, soya bean, palm kernel, sunflower and Jatropha. However, it is assumed that only rapeseed will be crushed in the UK, and therefore only oilseed rape and glycerol will be produced as co-products of biodiesel production. For bioethanol production, wheat will be the primary feedstock, producing DDGS as a co-product, although the British Sugar plant at Wissington (Norfolk) will use sugar beet as a feedstock, producing sugar beet pulp as a by-product.

This section examines the current and potential use of the co-products of biofuel production, namely rapeseed meal (RSM), wheat-derived distillers dried grains with solubles (DDGS), sugar beet pulp and glycerol

11 The use of rapeseed meal in livestock feed.

11.1 The chemical composition and nutritive value of rapeseed meal

Rapeseed meal (RSM) is a black and yellowish meal that is slightly oily to the touch. Since the advent of varieties of oilseed rape with low levels of anti-nutritive factors[12] in the 1970's, it has been increasingly used as a cost effective source of protein for farm livestock and poultry. It is available all year round, and its price is typically lowest during August/September.

Fed alone, RSM is less palatable than proteins such as soya, but this is overcome when fed in conjunction with other feeds - either in loose mixes, compound feeds or in total mixed rations. Typical values for its composition are given in Table 6, and because it is often considered as an alternative to soyabean meal, indicative values for this are also given.

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[12] Erucic acid and glucosinolates

Table 6. Typical composition of rapeseed meal and soya bean meal (MAFF, 1990)

Constituent [13]	RSM		Soyabean meal [14]	
	Mean	Range	Mean	Range
Dry matter (g/kg)	898	991-929	886	874-902
Crude protein (g/kg DM)	401	351-432	493	400-531
ME Ruminants (MJ/kg DM)*	12.1		13.6	
ME Pigs (MJ/kg DM)*	10.5		12.0	
Oil (g/kg DM)	535	25-83	27	23-32
Ash (g/kg DM)	76	67-97	68	64-79
Calcium (g/kg DM)	8.4	5.1-15.6	3.9	2.8-8.7
Total Phosphorus (g/kg DM)	11.3	7.5-13.2	7.4	6.8-8.5
Available phosphorus (g/kg DM)*	3.8		6.1	
Total lysine (g/kg DM)	21.9	20.5-23.3	33.4	27.0-36.5
Methionine (g/kg DM)	7.2	6.3-8.6	6.9	6.5-7.3

* Derived from Ewing (1998)

Rapeseed meal is primarily viewed as a protein feed, although it also contributes to energy in the ration. The main nutritional differences between RSM and soyabean meal are in the higher energy and protein contents in the latter. Higher levels of essential amino acids also give soyabean meal a higher nutritional value, particularly for non-ruminants. RSM has a higher fibre content, which also tends to limit its inclusion in non-ruminant rations. These differences tend to be reflected in the prices of the two feeds (see Figure 15). RSM has a higher level of total phosphorus, but its bioavailability to non-ruminants is lower than in soyabean meal. As a result, this may have implications where attempts are in place to reduce levels of P in livestock manures.

Although UK-derived rapeseed meals are produced to very high standards, some variation does exist between samples of the meal. MAFF (1990) reported the results of analyses on a range of samples analysed between 1985 and 1989 (Table 6). It is accepted that these are relatively old data, and that current processing methods are likely to result in a more consistent quality. Nevertheless, natural variability will occur, reflecting differences between crop varieties, agronomic factors (soil type, climate, fertilizer application, etc.) and the effects

[13] % dry matter unless otherwise stated

[14] Hipro Soya

of different processing, and for this reason, users should regularly test consignments of the meal for chemical composition.

11.2 Feeding rapeseed meal to livestock

The development of cultivars of oilseed rape with greatly reduced glucosinolate contents (termed double-low or double-zero varieties) has enabled greater inclusion of RSM in livestock diets, particularly for pigs and poultry, although anti-nutritional factors such as tannins may still be present, leading to reduced digestibility when incorporated at significant levels in the diet. The extent to which RSM is used in livestock rations, and the scope for further use, is considered below.

11.3 Ruminants

Rapeseed meal has been widely used in rations for ruminant livestock. Although authorities differ in what they consider to be the maximum recommended levels, Ewing (1998) has suggested maximum levels of inclusion of 250-300 g/kg for RSM in concentrates for a range of livestock categories. This section reviews some of the studies that have been undertaken to establish these recommendations. However, in many of the studies, particularly with beef cattle, diets have not been iso-nitrogenous and as a result growth responses have been attributed to the amount of protein supplied, rather than the source of the protein.

An important characteristic of the nutritive value of RSM for ruminant livestock is the extent to which it is degraded in the rumen. This affects both the supply of nitrogen to the rumen micro-organisms – for conversion into microbial protein – and the supply of undegraded amino acids, which are used directly by the animal for protein synthesis. Rumen protein degradability is not easily measured, and as a result varying estimates may be found. Ha and Kennelly (1984) reported that the effective degradability of RSM protein was 0.658. Kendall *et al.* (1991) suggested that the effective degradability of RSM averaged 0.515, compared to 0.591 for soybean meal. Hvelplund and Madsen (1990) suggested that the protein in RSM has a degradability of 0.68, compared to 0.60 for soyabean meal[15]. Using the values proposed by Hvelplund and Madsen (1990), every 100 g RSM consumed provides 11 g bypass protein, compared to 20 g for a similar quantity of SBM in cattle (8% outflow rate). What is clear from these and other studies is that degradability is not fixed. These differences are likely to

[15] At a rumen outflow rate 8% hour^{-1}

reflect differences both in the feed – as a result of growing and processing - and in the methods used to measure degradability.

The degradability of dietary protein is of particular importance when formulating rations for highly productive ruminant livestock, and in particular pregnant and lactating ewes, and cattle and sheep rations where high rates of gain are required.

For many ruminant livestock, however, the protein degradability in the rumen is less critical than it may be for highly productive animals. Indeed, for a number of ruminant production systems, the higher levels of rumen degraded protein make it a particularly useful addition to diets containing low protein forages, including those based on maize and whole-crop silages, and those containing a high proportion of straw.

11.3.1 Calves

In the USA, satisfactory growth rates in recently weaned calves of between 0.6 and 0.9 kg/day have been reported when RSM has been the sole protein supplement, and were similar when cottonseed or soyabean meal were the protein supplements (Claypool *et al.,* 1985). In the UK, no adverse effects of RSM were observed in feed intake by 160 kg calves receiving diets containing 250 g RSM/kg compared to those fed soyabean meal supplemented diets providing the same amount of protein (Hill, 1991).

11.3.2 Growing and finishing cattle

RSM has gained widespread acceptance as a source of protein for growing and finishing cattle, in both extensive and intensive production systems. A number of studies have been published that indicate that 250 g RSM/kg in the concentrate mix produced similar levels of intake and liveweight gain diets as containing soybean meal. However, since the protein is degraded relatively rapidly in the rumen, a lower rumen degradable protein source should be used in combination.

For many beef systems, RSM can be used as the only protein inclusion in beef diets, with levels of up to 250 – 300 g/kg of the concentrate fraction of the ration. For store cattle, protein quality is less important, and a barley-based mix containing approximately 170 g crude protein/kg DM, with 330 g RSM/kg and minerals and vitamins, would be suitable to feed with grass silage. High-energy feeds are generally more suitable for finishing cattle given silage than lower energy feeds, and a 200 g/kg inclusion of RSM in a rolled barley plus

RSM mix, together with appropriate mineral/vitamin supplementation, will generally provide sufficient protein to finish cattle off a grass silage-based ration.

11.3.3 Suckler Cows and calves

Trials have shown that RSM can be used as the sole concentrate for dry suckler cows fed on *ad lib* cereal straw. Up to 2 – 3 kg per head per day, depending on cow condition, have been successfully fed. A suitable concentrates for suckled calves and weanlings, which are being stored over the winter for grazing the following summer, would be a 20:80 RSM:rolled barley mix, providing a mix containing 140 g CP/kg DM[16].

11.3.4 Sheep

RSM is widely fed to all types of sheep, and there are no adverse effects on feed intakes or other performance parameters, provided the diets are balanced for energy and essential nutrients (Hill, 1991). It has been suggested that because of its poor palatability, use of RSM should generally be restricted to ewe diets, with a maximum inclusion rate of 100 g/kg. However, when Vincent *et al.* (1988) fed ewes a diet containing 200 g RSM/kg no negative effects on feed intake, milk production, number of lambs born per ewe or lamb birth weight were observed. Hill *et al.* (1990) also fed diets containing 210 g RSM/kg to lambs with no negative effects on feed consumption or growth rate. More recently, Mandiki *et al.* (1999) fed lamb diets containing up to 300 g RSM/kg with no apparent adverse effects on weight gain or feed intake.

11.3.5 Other species – horses

Only relative few studies appear to have been undertaken to examine maximum inclusion rates in diets of horses. Sutton (1988) investigated potential concerns about RSM palatability by horses, and concluded that up to 150 g RSM/kg in recreational horse diets could be fed without any adverse effects on feed intake.

11.4 Non-ruminants

A significant amount of trial work has been carried out over the years regarding the inclusion of RSM in pig and poultry diets. However, considerable variation in the levels of

[16] Source: Department of Agriculture and Rural Development, Northern Ireland

glucosinolates, along with lack of consensus regarding tolerance levels (both across and within species) makes an overall comparison of the literature somewhat difficult. A recent review of glucosinolates in animal nutrition (Tripathi and Mishra, 2007) is a useful addition to the literature because it attempts to draw together many of the trials from the last 30 years. The following discussion draws on the relevant sections of Tripathi and Mishra (2007) and also refers to the original published literature cited, along with other reported trial data.

11.4.1 Piglets

In assessing the inclusion of RSM in pig and poultry diets and any associated effects on animal performance, a dose-response effect appears to be evident (i.e. as glucosinolates content in the diet increases, the more progressive/severe are the detrimental effects on animal health and performance). Two trials with piglets (Baidoo *et al*., 1987), weaned at either 3 or 5 weeks, examined the replacement of soyabean meal with canola meal (containing 9.8-10.0 μmol/g glucosinolates) at between 88 g/kg to 353 g/kg. Regression analysis revealed that for each percentage increment addition of canola meal in the diets, a significant linear decrease in both daily fed intake and liveweight gain was evident. More recent work feeding weaned piglets for 6 weeks with canola meal containing considerably lower glucosinolate levels (4 μmol/g) concluded that solvent-extracted canola meal can be included up to 250 g/kg without affecting performance (King *et al.,* 2001).

11.4.2 Grower-Finishers pigs

In determining the rate of inclusion of RSM in older pig diets, it appears from the literature that, in line with pigs of other age ranges, tolerance levels are inversely related to dietary glucosinolate content. Mullan *et al.* (2000) fed RSM with a glucosinolate content of 10.5 μmol/g to grower-finisher pigs and found that dietary inclusion above 150g/kg resulted in negative performance effects and thyroid hypertrophy. In contrast, King *et al.* (2001) reported up to 300g of a low glucosinolate content (4.0 μmol/g) per kg could be fed without a significant effect on growth performance or carcass weight.

Interestingly, there is evidence to suggest that finisher pigs appear to be more sensitive (less tolerant) to glucosinolate levels in the diet than growers; Roth-Maier *et al.* (2004) reported that growing pigs (30-60 kg) were able to tolerate a glucosinolate level of up to 2.2 μmol/g feed, whereas finishers (60-120 kg) were only able to tolerate up to 0.9 μmol/g. These dietary glucosinolate levels were derived from RSM inclusion rates of 260 and 108 g/kg respectively.

The implication from this study is that sensitivity to glucosinolate levels may be increased over time, suggesting some re-evaluation of RSM content in finisher pig diets may be needed.

11.4.3 Adult breeding pigs

A study with gilts by Opalka *et al.* (2001) looked at long term feeding with graded levels of low glucosinolate (6.6 µmol/g) RSM, compared against a control (soyabean) diet. The results found no significant reproductive performance differences when RSM diets were fed during growth, gestation and lactation phases at inclusion levels of 120, 50 and 120 g/kg respectively. In addition, serum hormone concentrations measured in the resulting piglets did not differ between control and RSM groups. Further literature suggests that a RSM containing lower levels of glucosinolates (4 µmol/g) can be incorporated at even higher amounts in lactating sow diets (up to 202 g/kg) without negatively affecting fed intake, weaning-to-oestrus interval or piglet survival rate (King *et al.,* 2001).

11.4.4 Broilers

Regarding the effects of RSM in poultry diets, problems associated with intake of glucosinolates appear to be more severe in layer hens than in broilers. It has been suggested that this could be because broilers are typically reared for only 6 to 8 weeks, and as such, this short period of feeding may not be sufficient for the negative effects of glucosinolates to become fully expressed (Tripathi and Mishra, 2007).

A recent HGCA-funded study confirmed that feeding rapeseed meal to broilers up to 60kg/tonne inclusion rate did not influence feed intake, growth or feed conversion in male or female birds. Comparing diets containing double-zero RSM at levels of 100 and 200 g/kg against a control wheat/soyabean diet for broilers, McNeill *et al.* (2004) found feed intake was reduced in chickens consuming either of the RSM diets compared to the control. Weight gain was similarly depressed, with growth rate directly linked to feed intake. FCR calculations over the entire 42-day trial period were not statistically different between dietary treatments. The diets were pelleted to prevent selection of individual ingredient particles by the birds and intake levels were found to be equal across diets. At slaughter, a consumer sensory panel was unable to identify any difference in taste between breast meat of birds fed 100 g/kg RSM and the control diet. Breast meat from the birds given 200 g/kg RSM was identified by the panel as being different to the control but no strong aversion was expressed. The results of the taste panel and the reduced growth rates recorded from the animal trial at the higher inclusion level lead the authors of the paper to conclude that broiler producers should limit RSM dietary inclusion rate to 100 g/kg. This level is in agreement with general recommendations of between 100 and 150 g/kg dietary inclusion in broiler diets made by other authors (Fasina and Campbell, 1997; Roth-Maier, 1999; Khan *et al.,* 2006).

11.4.5 Layers

The occurrence of a 'fishy' taint in eggs has restricted the commercial use of RSM as a protein supplement in the diet of laying hens producing brown-shelled eggs in the UK. The taint arises due to a genetic defect impeding the oxidation of trimethylamine, released from sinapine and other dietary choline sources. As a result of this defect, large amounts are able to pass into the yolk of the egg, producing the taint. Because of this, dietary inclusion of RSM in layer diets has traditionally been recommended at low levels, typically below 100 g/kg (Mawson *et al.,* 1995) and often, only in the diets of layers that produce white-shelled eggs. Although a study by Roth-Maier (1999) concluded that canola meal could be included in layer diets up to 150 g/kg, again, the recommendation was only for layers of white-shelled eggs, in order to avoid the risk of developing taint. However, a breeding development to remove the defective gene means there now exists a greater opportunity to include RSM in layer diets in the future.

The following table (Table 8) summarises the recommended rates of inclusion of RSM in pig and poultry diets from published scientific literature.

Table 8 Recommended rates of inclusion of RSM in pig and poultry diets from published scientific literature.

Species	Glucosinolate content (µmol/g)	Rate of inclusion (g/kg)	Reference
Pigs			
Weaner	4.0	250	King *et al.,* 2001
	10.5	150	Mullan *et al.,* 2000
Grower	2.2	260	Roth-Maier *et al.,* 2004
Finisher	0.9	108	Roth-Maier *et al.,* 2004
Grower/Finisher	4.0	300	King *et al.,* 2001
Gilts	6.6	120	Opalka *et al.,* 2001

Lactating Sows	4.0	202	King *et al.,* 2001
Poultry			
Broilers	NR	100	McNeill *et al.,* 2004
	14.3-16.4	100	Fasina & Campbell, 1997
	15.4	150	Roth-Maier, 1999
Layers	NR	<100	Mawson *et al*., 1995
	15.4	150*	Roth-Maier, 1999

NR = not reported in the study * For layers producing white-shelled eggs

12 The scope for increasing the use of rapeseed meal in livestock diets

It is estimated that 900 kt of oilseed rape meal is produced from UK crushing in 2006. According to Defra statistics, 670 kt of RSM were fed to livestock in that year, an increase of 11.7% over the preceding year. This represented 28% of the oilseed cakes and meals used, and 7.1% of all feed materials used in Great Britain in that year. In addition, RSM is used as a livestock feed by home mixers, e.g. in total mixed rations for ruminants, and by integrated producers.

While data are available for the *total* amount of RSM used, a breakdown by species is not available. Until recently, feed companies were not obliged to disclose their feed formulations, and while they were usually willing to provide this information to individual customers, no overall statistics are available on the extent to which RSM is used for different classes of livestock[17]. Therefore, it is difficult to estimate the scope for increasing the amount of RSM for a particular livestock category.

In the absence of these data, an attempt has been made to estimate the potential total use of RSM, at a national level, using data on the production of compound feeds and the maximum recommended levels for each of the livestock types. In Appendix Table 1 and Table 9 below, maximum recommended inclusion rates (Ewing, 1998) have been applied to current levels of compound feed production (Defra statistics) to estimate the potential maximum utilisation of RSM in livestock diets.

[17] Directive 2002/2/EC on ingredient declaration of compound feeds came into force on 17 November 2006 - this obliges manufacturers to declare the formulations of compound feeds

Table 9. The production of compound feeds and blends in Great Britain in 2005, potential inclusion rates (Ewing, 1998) and potential utilisation of RSM in compounds for livestock.

	Current production ('000 tonnes)	Incorporation rate (g/kg)	Potential RSM use
Cattle: Dairy compounds and blends	2,445.7	250	611
Other cattle: compounds and blends	841.7	400	337
Cattle: Protein concentrates	76.1	600	46
Sheep: Breeding compound and blends	369	250	92
Sheep: Grower/finisher compounds and blends	238	150	36
Pig grower	324	30	10
Pig finisher	590.5	30	18
Pig breeder	405.1	50	20
Poultry layer feeds	869.8	50	43
Poultry broiler feeds	889.5	30	27
Total			**1,240**

This approach suggests that in excess of 1.2 million tonnes of RSM could potentially be used, if it was available and the price justified it. The production of compound feeds is not static, and has been declining in a number of sectors in response to reductions in livestock numbers. Adjusting for changes in compound feed production, particularly in the ruminant sector, suggests that the maximum potential utilisation of RSM is approximately 980 kt per annum. In other words, even allowing for a reduction in compound feed use, feed manufacturers and livestock farmers compounders could utilise a further 300 kt of RSM than they currently do. It should be noted that inclusion rates for some classes of pigs and poultry recommended by Ewing (1998) are lower than suggested in this report (Table 8) and so potential utilisation of RSM is higher than indicated above.

As discussed in this report, predicting the amount of additional RSM from biodiesel production is difficult at this stage, but it seems unlikely that it will exceed 300 kt, at least in the short to medium term. It appears, therefore, that there is capacity to absorb all of the additional RSM from biodiesel production at current predicted levels of production.

13 The use of dried distillers grains in livestock feed.

A number of different forms of distillers' grains are available for use in livestock diets, depending on the grain used and the method of fermentation, and as a result they vary in their composition and feed value. Historically, distillers dried grains with solubles (DDGS), produced as a result of fermentation with wheat, have been the principle by-product of grain whisky and grain neutral spirit production, and the sole feed material available from five of the eight grain distilleries in Scotland (Crawshaw, 2001). Because wheat is likely to be the main feedstock for ethanol production in the UK in the short term, wheat-derived DDGS is likely to be the main by-product available for livestock feeding.

Defra statistics indicate that 251 kt of distillery co-products were used in the production of compound feedingstuffs in 2006. This includes co-products from fermentation of barley, wheat and maize. In addition to this, some distillery co-products are fed in their fresh (i.e. undried) state and would therefore not be included in the Defra statistics. Converting these to an equivalent weight of dry feed, the total amount of distillery co-products used in animal feedingstuffs is likely to be in the order of 400 kt. Crawshaw (2001) reported that 165 kt DM per annum of wheat-DDGS was used in livestock feeds in 1999, but that this declined to 124 kt tonnes in 2001. In addition, imported DDGS is also available; in 2004 the EU imported 800 kt tonnes of DDGS from biofuel distilleries in the USA, of which 66 kt were used in the UK (Shurson, 2006).

The composition of DDGS from grain whisky production can be variable. Although the crude protein content is high, UK tables of feed composition (MAFF, 1990) report a range of 260-350 g/kg DM (with a mean of 300). Not surprisingly, the amino acid composition also varied, with lysine and methionine ranging from 5.0 to 7.7 and 3.6 to 4.9 g/kg DM, respectively, based on 5 samples. The digestible fibre (NDF) content of 10 samples ranged from 230 to 460 g/kg DM. Carvalhoa *et al.* (2005) measured the nutritive value of a number of protein supplements commonly used for ruminants[18]. Maize distillers grains (268 g CP/kg

[18] Solvent extract palm kernel meal, expeller palm kernel meal, copra meal, maize distillers dried grains and maize gluten feed.

DM) had higher *in vivo* digestible energy content than any of the other supplements. Rumen N degradability of DDGS (54% at 16 hours of incubation) was lower than for the other maize product (maize gluten feed) but higher than for the other supplements. The intestinal digestibility of the rumen-undegraded protein (50.1%) was lower than for any of the other supplements examined, confirming the results of other studies (e.g. Moss and Givens, 1994). The authors attributed this to the extensive heat treatment of DDGS during processing. Crawshaw (2001) estimated that wheat-DDGS has a DE value in the range of 15.3-16.5 MJ/kg DM, and that for ruminants the expected metabolisable energy (ME) content will be 12.7-13.9 MJ/kg DM. This is somewhat higher than the value quoted by MAFF (1990) of 12.2 to 12.8 MJ/kg DM.

DDGS contains high concentrations of digestible fibre, which make it an ideal feed for ruminants. Ewing (1998) has suggested maximum inclusion rates of wheat distiller's dark grains for ruminants of up to 400 g/kg for cattle and 200 g/kg for ewes. Because of its' high fibre content, it is generally considered to be less suitable for non-ruminants, and maximum levels of 50 g/kg have been proposed for broilers, layers, finishing pigs and sows (Ewing, 1998).

13.1 Feeding dried distillers' grains with solubles to livestock.

There is a long history of feeding co-products of the distilling industry to livestock, particularly ruminants. These co-products have included distillers' grains in their fresh form – also known as draff - and the dried form.

As a result of the rapid increase in bioethanol production in the USA, there has been considerable interest in the use of DDGS in livestock rations, and this has prompted considerable research to identify optimum/maximum inclusion rates in diets. Some of this research is reviewed below. However, most bioethanol production in north America currently uses maize as the feedstock, while that produced in the UK will be derived from wheat. MAFF (1990) provide limited data on the composition of wheat and maize-based DDGS; the latter had slightly higher protein (317 vs. 302 g/kg DM) and digestible fibre (343 vs. 335 g/kg DM), respectively, although *in vitro* digestibility was similar (621 g/kg DM). A major difference between the two forms of DDGS is the level of oil, with maize-derived DDGS having almost twice the level (109 g/kg DM) than wheat-derived DDGS (55 g/kg DM; MAFF 1990). A number of reports from the USA refer to the fact that high oil content of maize-derived DDGS has the potential to affect fibre digestibility, milk quality, immune function, end-product quality (carcass composition, fatty acid profile, fat firmness, shelf life), reproductive function (ovarian activity, embryo survival), and human health by changing the end-product fatty acid profile.

DDGS from maize would contain high levels of carotenoids, which would risk colouring carcass fat; the UK consumer prefers ‘white’ pig and poultry fat. The use of wheat-DDGS is likely to have less of an effect in this context. This emphasise the importance of specifying the cereal origin for DDGS; if this is not done, then there is a danger that a commodity named simply DDGS may be of maize and not wheat origin; although the colour of the product would be a good indicator of origin, it would not be a perfect test.

13.2 Ruminants

13.2.1 Beef cattle

In the United States, beef cattle have been successfully fed up to 400 g/kg of the ration DM as wet or dried DGS (Al-Suwaiegh *et al.,* 2002; Ham *et al.,* 1994; Larson *et al.,* 1993). Roeber *et al.* (2005) fed up to 500 g/kg of the DM as wet or dry DGS with no adverse effect on beef tenderness or palatability. These studies used DDGS primarily as an energy feed, and therefore contained more protein and phosphorus than required for growing cattle. Lancaster *et al.* (2004) reported a study which was conducted to evaluate the effect of DDGS compared to soyabean meal fed to suckler calves (as part of a creep feed) and weaned calves. Average daily gain was not affected by the protein source. Benson *et al.* (2005) fed DDGS to feedlot beef in which maize and urea were replaced by increments of DDGS up to an inclusion rate of 350 g/kg in the DM; there were no differences in the final weights of cattle as a result of feeding DDGS, although cattle on the highest level of substitution tended to have a higher dressing percentage and carcass weights ($P<0.10$). No differences were detected between treatments in daily liveweight gain, food conversion efficiency or carcass composition.

Knowledge regarding quality and sensory traits of beef fed DDGS is limited. In one study designed to evaluate effects of feeding DDGS on colour, tenderness, and sensory traits of Holstein steers, Roeber *et al.* (2005) fed maize silage-based diets containing 0, 250 and 500 g DDGS/kg in the diet DM. Feeding DDGS at up to 500 g/kg of the diet DM did not affect tenderness or palatability.

13.2.2 Sheep

Historically, DDGS has not been recommended as a feed for sheep because of the high levels of copper usually found in this feed, as a result of distillation taking place in copper stills. In bioethanol production, distillation takes place in stainless steel stills, and so high levels of copper are not an issue. Nevertheless, there have been relatively few studies reported in which DDGS has been fed to sheep. A lactation study using DDGS to replace 0.66 of the grain (maize), equating to 250 g/kg of the diet, improved triplet-reared lamb growth performance by 12%; there was no difference in single and twin-reared lambs (Held, 2006).

Few studies using DDGS in lamb growing-finishing diets appear to have been undertaken. In one study from North Dakota, dried distillers grains - replacing up to one third of the maize portion of a maize and alfalfa based finishing ration - increased lamb performance and had no negative effect on lamb carcass traits. Cautiously, the US National Corn Growers Association has recommended maximum inclusion rates in lamb finishing rations of 100 g/kg[19]. Higher inclusion levels, they suggest, may be economical but generally reduce intake and potential performance, although this recommendation may be specific to maize-based DDGS with its higher oil content. One precaution with lamb finishing rations is that calcium:phosphorous ratios need to be closely monitored to prevent the development of urinary calculi, since distillers' grains are high in phosphorous and low in calcium.

In reviewing US data, summary, Erickson and Klopfenstein (2005) concluded that DDGS could be fed at up to 400 g/kg of the diet DM of ruminants without adverse effects. This is broadly in line with the recommendation of Ewing (1998) (Appendix Table 1).

One of the challenges associated with feeding large quantities of DDGS in the future will be managing the higher levels of phosphorus (P) in DDGS. Wheat-derived DDGS is reported to have P concentrations of approximately 9 g/kg in the DM, which is more than twice the level in wheat grain. Where DDGS is used, attention needs to be paid in order to minimise any oversupply of P, with associated potential environmental effects. Even when the economics favour the use of DDGS, high inclusion rates will add considerably more phosphorus to the diet, creating greater diet formulation challenges. Rations containing DDGS can also easily exceed the animal's requirement for protein (nitrogen), largely because of amino acid imbalance and availability. If not carefully managed, this can result in increased nutrient

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[19] http://www.ncga.com/livestock/PDFs/DistillersGrainsBooklet.pdf

(nitrogen and phosphorus) excretion and environmental implications, especially for producers with a restricted land base for manure application.

13.3 Non-ruminants

A number of studies have examined the effects of DDGS at a variety of inclusion rates in pig and poultry rations.

13.3.1 Piglets

Whitney and Shurson (2004) reported that DDGS could be fed at levels of up to 250 g/kg in the diet of weaned piglets, without negatively affecting growth performance after a 14-day period of acclimatisation. However, the authors issued a note of caution with regard to feeding DDGS at this level to weaned piglets weighing less than 7 kg. They warn against the possibility of reduced feed intake and growth in such small piglets. A similar study (Gaines *et al.,* 2006) confirmed that dietary inclusion of up to 300 g DDGS/kg from modern ethanol plants could be fed to young pigs without limiting feed intake or liveweight gain.

13.3.2 Grower-Finisher pigs

Although an identical rate of inclusion (300 g/kg) has been shown to be tolerated by older pigs, the problem of nutritional variability of DDGS sources, and its effect on animal performance, has been effectively demonstrated by Cromwell *et al.* (1993). In this study, growing pigs were fed one of two dietary blends of DDGS. The first blend contained light coloured DDGS, the second diet was composed of smoky, dark coloured grains (excessively heated during the fermentation process). The blends were fed at three inclusion levels (100, 200 or 300 g/kg) and clear differences ($P < 0.05$) were observed in growth rate, feed intake and FCRs, with pigs fed the diet composed of light grains performing clearly better than those animals fed the dark/smoky DDGS dietary blend.

A study by Whitney *et al.* (2001) with grower-finisher pigs, reared up to 115 kg, concluded that for optimum carcass composition, no more than 200 g DDGS/kg should be fed when the diet is formulated on a total amino acid basis. It was argued that for dietary inclusion above this level, the diet should be formulated on a digestible amino acid basis in order to provide satisfactory performance and carcass composition. This inclusion level was supported in a later study by the same authors (Whitney *et al.,* 2006). They also reported that the incorporation of 200 g DDGS/kg in grower-finisher diets had no detrimental effects on pork muscle quality (assessed by colour, firmness and marbling scores).

One particularly interesting finding in the reviewed literature is that DDGS may possibly help to reduce the severity of ileitis in grower pigs. An enteric disease of the lower small intestine (and occasionally large intestine), caused by a gram negative bacteria *Lawsonia intracellularis,* the disease infects the epithelial cells in the crypts of the small intestine resulting in cellular proliferation, necrosis, ulceration and haemorrhaging of the epithelial surface. Whitney *et al.* (2006b) discovered that dietary inclusion of 100 g/kg DDGS appears to provide some benefit to growing pigs, infected with a moderate challenge of *Lawsonia.* The inclusion of DDGS reduced severity of lesions in both the ileum ($P < 0.05$) and colon ($P < 0.1$) in challenged pigs. However, previous work by the same authors showed that under a severe *Lawsonia* challenge, lesion incidence and severity were not reduced by dietary inclusion of DDGS at either 100 or 200 g/kg (Whitney *et al.,* 2006a).

13.3.3 Sows

It appears that sows are able to tolerate inclusion levels of up to 500 g/kg during gestation and around 200 g/kg during lactation, although there may be a period of reduced feed intake following adaptation when initially fed (Shurson *et al.,* 2004). A similar inclusion level in a study by Hill *et al.* (2006) found no detrimental effects in terms of sow weight loss or litter weight when DDGS was replaced in the diet at 150 g/kg.

13.3.4 Broilers

It has been reported that DDGS can be included in broiler diets at levels of 60 g/kg in the starter period and increased to 120-150 g/kg during the grower/finisher periods, without adverse effects to weight gain or FCR (Lumpkins *et al.,* 2004). However, the authors cautioned that feeding at a higher level during the initial 16 days of age may result in a depression in weight gain. It appears that broilers may be able to tolerate significantly higher levels of DDGS in the diet, although this depends upon the quality of the cereal grain after the fermentation process. As in their associated trial examining DDGS grain colour and the performance of growing pigs, Cromwell *et al.* (1993) were also able to clearly demonstrate a link between DDGS grain colour and animal performance in a 21-day study with day-old chicks. Animal growth rates were significantly different between those on a diet composed of light coloured DDGS grains, composed to those fed a diet of dark grains (489 g/d vs. 364 g/d:

P <0.01). In addition, a general increase in animal performance parameters (feed intake, weight gain and FCR) paralleled increasing dietary inclusion of DDGS up to 300 g/kg.

13.3.5 Layers

DDGS would appear to be an acceptable ingredient for layer diets. Recent trials studying inclusion in layer rations reveal that 150 g/kg can be tolerated without negatively affecting egg production (Lumpkins *et al.,* 2005; Roberson *et al.,* 2005). However, a significant reduction in egg production has been reported with hens fed a low energy density diet with 150 g DDGS/kg (Roberson et al., 2005). This had led to the recommendation that a maximum level of 100-120 g DDGS/kg should be used in commercial layer diets, with a lower level of DDGS inclusion in low energy rations.

An interesting effect reported in the scientific literature is the apparent link between egg yolk colour and dietary DDGS level; in a study feeding DDGS at levels of 50, 100 and 150 g/kg to layers, Roberson *et al.* (2005) was able to demonstrate that egg yolk colour was significantly (P = 0.005) darker within one month of feeding a light coloured DDGS source at 100 g/kg or higher in the diet. Furthermore, when DDGS in the diet was reduced to 50 g/kg, a darkening in yolk colour was still evident, although the colour change was only observable after 2 months.

The following table (Table 10) summarises the recommended rates of DDGS inclusion in pig and poultry diets from published scientific literature.

Table 10. Recommended rates of inclusion of DDGS into non-ruminant diets.

Animal	Rate of inclusion (g/kg)	Reference
Pigs		
Piglet	250	Whitney and Shurson, 2004
	300	Gaines *et al.,* 2006
Growers	300	Cromwell *et al.,* 1993
Finishers	200	Whitney *et al.,* 2001;Whitney *et al.,* 2006
Sows - gestation	500	Shurson *et al.,* 2004
- lactation	200	Shurson *et al.,* 2004
	150	Hill *et al.,* 2006
Poultry		
Broilers	60-150	Lumpkins *et al.,* 2004
	300	Cromwell *et al.,* 1993
Layers	150	Lumpkins *et al.,* 2005
	150 (100-120*)	Roberson *et al.,* 2005

* in low energy diets

13.4 The scope for increasing use of DDGS

As for RSM, the potential use of DDGS varies according to species, but no data are available for the actual use of DDGS by species. Given the high fibre content most of it will be used in ruminant rations, although as indicated above, inclusion levels of up to 300 g/kg have been successfully used in rations for pigs.

In an attempt to estimate the potential maximum utilisation in livestock diets, maximum recommended inclusion rates in compound feeds for each of the livestock categories (from Ewing, 1998) have been applied to data on compound feed production (Table 11), and using maximum recommended inclusion rates proposed by Ewing (1998), it is possible to estimate the potential amount of DDGS that could be used in Great Britain.

Table 11: The production of compound feeds and blends in Great Britain in 2005, recommended maximum inclusion rates (Ewing, 1998) and potential maximum utilisation of DDGS.

	2005 Production (kt)	Incorporation rate (g/kg)	Potential DDGS utilisation (kt)
Cattle: Dairy compounds and blends	2445.7	400	978
Other cattle: compounds and blends	841.7	400	337
Cattle: Protein concentrates	76.1	400	30
Sheep: Breeding compound and blends	369	150	55
Sheep: Grower/finisher compounds and blends	238	100	23
Pig grower	324	25	8
Pig finisher	590.5	50	29
Pig breeder	405.1	50	20
Poultry layer feeds	869.8	50	43
Poultry broiler feeds	889.5	50	44
Total			**1,567**

These figures only include the main livestock categories, and do not include other categories such as feeds for turkeys, integrated poultry production, horses or pets. If these are included, then it may not be unreasonable to assume that, based on 2005 production figures, there is a potential market for DDGS in excess of 1.6 million tonnes of DDGS.

It has been estimated that 1.2 billion litres of bioethanol and 1.35 billion litres of biodiesel will be required to meet the 2010 biofuel target in the UK[20]. To achieve an additional 1.2 billion litres of bioethanol using current technologies would require 3 million tonnes of

[20] NFU online – 10 August 2006

wheat, producing about 1 million tonnes of DDGS. Section 5 of this report reviewed the planned ethanol production in the UK. If this level of production is achieved, it will result in the production of 1,095 kt DDGS (Figure 8). Of this, 240 kt has been earmarked for use as feedstock for power, steam and gas generation, leaving a potential supply of 855 kt for use in other ways.

On the basis of these calculations, it appears that the UK livestock industry has the potential to utilise the additional supplies of DDGS produced from bioethanol production, in addition to that currently produced from whiskey distillation.

It is difficult to predict, however, with any degree of accuracy, the quantity of DDGS that will be available to the feed industry in the future. If all the proposed plants listed in Appendix Table 2 are built, and if all of the co-products go for animal feed, this will produce an additional 945 kt of DDGS – which is less than the predicted maximum potential utilisation in livestock rations. However, as discussed elsewhere in this report, there is some scepticism surrounding the number of plants that will be built, the feedstocks that will be used and the supply of co-products as animal feeds. Indeed, it would not be surprising to see improved and new products available. For instance, improvements in fermentation technology already provide DDGS from biofuel production that contain more protein and energy than DDGS from the brewing and distilling industries provided (Schingoethe, 2006). It is also becoming feasible to fractionate DGS into products that are higher in protein, other products that are higher in fat or in fibre, and products that are higher or lower in phosphorus. With the technology to do so available, it will be the demands of the market place that will largely determine the composition of feeds available from biofuel production (Rausch and Belyea, 2006).

14 Glycerol

Glycerol, also known as glycerin or glycerine, is a co-product of biodiesel production. It is a slightly viscous, yellow/brown liquid with a sweet taste. Glycerol is a trihydric alcohol that complexes with fatty acids to form a triglyceride. When the fatty acids are split from triglycerides, glycerol remains as a co-product. It is currently used primarily in medical, pharmaceutical and personal care preparations and in industrial processes, mainly in the production of flexible foams and paints.

In 2006, biodiesel production became the primary source of glycerol supply in the world, accounting for 41 percent of total production, and it is expected to grow to 65 percent by

2010[21]. While glycerol production grew by approximately 4 percent per year to 2005, it is expected to grow by 10 to 25 percent annually from 2006 to 2010 as a result of increasing biodiesel production. Annual growth in consumption of glycerol (mainly by the cosmetic and pharmaceutical industries) is estimated at 3-4 percent, which is significantly below the expected growth trend in future production.

In response, world glycerin prices have declined sharply. According to SOFIPROTEOL[22], spot prices for bulk glycerin have declined from 1700 € per metric tonne (MT) in 1995 to 450 € per MT in 2006. Glycerol producers are therefore exploring new markets for this material, including its use as an animal feed.

Glycerol is approved as a feed additive under EU legislation[23], with no restrictions as related to animal species or quantity that may be fed. Therefore, glycerol could become attractive as a feed for livestock if the amount from biodiesel production exceeds the needs of the pharmaceutical and chemical industries. For every 1000 kg of biodiesel produced, approximately 100 kg of crude glycerol is produced. As mentioned elsewhere in this report, if all the planned biodiesel plants are realised then the UK will have the capacity to produce 2100 kt of biodiesel by 2010. A by-product of this will be 210 kt of glycerol.

14.1 The composition of glycerol

While pure glycerol has a well-defined chemical composition[24], the composition of glycerol from biofuel production plants varies according to manufacturing process, and different grades may be available, reflecting the presence of impurities. Considerable amounts of contaminants (in particular methanol, sodium chloride and potassium chloride) may be present as a result of current biodiesel processing techniques (Lammers *et al.*, 2007a).

Schröder and Südekum (1999) reported the composition of three grades of glycerol of different purities (low, medium, high) reflecting different stages of the same process of rapeseed oil methyl ester production.

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[21] According to the financial branch of the French oilseed grower organization (SOFIPROTEOL)

[22] A French organisation for the promotion of oilseeds and protein crops

[23] EC Number E422: Community Register of Feed Additives pursuant to Regulation (EC) No 1831/2003 Appendixes 3 & 4. Annex: List of Additives

[24] $C_3H_5(OH)_3$

Table 12. Chemical composition (g/kg) of glycerol as related to purity (Schröder and Südekum, 1999)

	Purity of glycerol		
	Low	Medium	High
Water	268	11	25
Composition of the dry matter[25], g/kg			
Glycerol	633	853	998
Ether extract	7.1	4.4	n.a.[26]
P	10.5	23.6	n.a.
K	22.0	23.3	n.a.
Na	1.1	0.9	n.a.
Pb (mg/kg)	3	2	n.a.
Methanol	267	0.4	n.a.

The most pronounced variations among purities were the concentrations of water, glycerol, phosphorus and methanol.

14.2 The scope for glycerol use as an animal feed

14.2.1 Ruminants

Glycerol is a natural co-product of digestion in ruminants when dietary fats are fermented in the rumen. Hydrolysis of fats yields fatty acids and glycerol, with the latter being fermented by rumen micro-organisms into propionic acid. It is reasonable to assume that glycerol provided in feeds is digested in the same way as that arising from the fermentation of dietary fatty acids, and indeed studies by Khalili *et al.* (1997), Schröder and Südekum (1999) and Defrain *et al.*, (2004) have confirmed that ruminal acetate to propionate ratio is reduced as a result of feeding glycerol. Glycerol – from dietary fats – is therefore an important source of energy for ruminants, and they are well adapted to metabolising it.

Glycerol has a gross energy content of 18.1 MJ/kg. Lebzien and Aulrich (1993) proposed a net energy for lactation (NEL) content of 9.5 MJ/kg, or approximately 15.3 MJ metabolisable energy (ME). Schröder and Südekum (1999) reported *in vivo* net energy values 9.7 and 8.3

[25] Concentrations of cadmium, mercury and arsenic were below the detection limit.

[26] Not analysed.

MJ NEL/kg of glycerol (15.4 and 13.4 MJ ME) measured in sheep fed low or high-starch concentrates, respectively. When fed to steers with a low-starch concentrate, pure glycerol at dietary inclusion levels up to 200 g/kg had no effects on nutrient digestibilities. When included in diets containing higher levels of starch, glycerol reduced cell-wall digestibility but had no obvious effect on whole-tract organic matter digestibilities (Schröder and Südekum, 1999).

Because glycerol is a source of rapidly available energy, it has been used for many years as a supplement to alleviate ketosis[27] in dairy cows at or just after calving (Johnson, 1955; Bobe *et al.,* 2004). It is normally given as an oral drench, at up to 2 kg/day, and has been shown to be an effective means of increasing the energy intake of cows at this critical period when administered in this way. It appears that glycerol increases plasma glucose in the absence of propionate derived from rumen fermentation at time of decreased feed intake. Although most of the research has been undertaken with lactating dairy cows, there is no reason to believe that it would act in the same way in beef cattle and sheep.

A number of studies have examined the effect of providing the glycerol *in* feed rather than orally. Fisher *et al.* (1971) concluded that the mode of action behind feeding glycerol could be attributed to an increase in feed intake and subsequent supply of more glucogenic substrate. Additional work by Fisher *et al.* (1973) found that cows fed glycerol at 374 g/d lost less body weight and remained in a more positive energy balance than those fed glycerol at 174 g/d. From these data, they concluded that feeding glycerol as a top-dressing - rather than as a drench - could potentially improve the health and milk yield of dairy cows. More recently, Defrain *et al.* (2004) studied the efficacy of glycerol when fed to dairy cows just prior to and after calving, as part of a total mixed ration. They reported that when given in feed it depressed feed intake in the period immediately before calving, and as a result cows were more disposed to ketosis. Although not statistically significant, these authors also reported that feeding glycerol (either at 0.43 or 0.86 kg/day in a Total Mixed Ration; TMR) tended to reduce yields of energy-corrected milk relative to cows fed the control (35.2 and 35.0 vs. 38.7 kg/d, respectively) over the first 21 days in milk. It was suggested that the difference in response to providing glycerol in feed (rather than orally) could be attributed – in part at least - to differences in the diets, and in particular the amount and quality of the forage.

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[27] Ketosis is a condition that occurs when the intake of energy in feed is insufficient to meet the demands of the cow, and is particularly prevalent just after calving.

Other than as a means of alleviating ketosis, relatively few long-term studies have been published which have examined the potential use of glycerol as a feed ingredient. The studies that have been done with dairy cows (Khalili *et al.,* 1997; Defrain *et al.,* 2004; Bodarski *et al.*, 2005) have produced diverging results regarding the effects of glycerol when included in the diet.

Recently, Bodarski *et al.* (2005) reported the results of a study in which glycerol was fed to high yielding dairy cows in maize silage-based TMR rations from 2 weeks before calving to 10 weeks after calving. As illustrated in Table 13, the inclusion of up to 500 ml/day resulted in an increase in dry matter intake, milk production and protein content in milk. In addition, there were reductions in body weight losses and fat tissue lipolysis associated with the addition of glycerol in the diet.

Table 13. The effects on feed intake, milk yield and milk composition of including glycerol in Total Mixed Rations of high yielding dairy cows (Bodarski *et al.,* 2005)

	Without glycerol (control)	+ 300ml/head⁻of glycerol	+ 500ml/head of glycerol
Mean daily milk yield during 10 weeks of lactation (kg)	32.11[a]	36.81[b]	36.14[b]± 6.80
Mean total milk production from 0 to 70 days per cow (kg)	2248 [a]	2577 [b]	2530 [b]
Percentage different to control group	100.0	114.6	112.5
Milk composition:			
Mean protein content (%)	3.13 [a]	3.23 [ab]	3.48 [b]
Average DMI for first 10 weeks of lactation (kg DM/day)	19.86[a]	21.51[b]	21.78[b]

Means with different superscripts are significantly different, P>0.05

No significant effects on any other milk constituents were observed. These authors concluded that the inclusion of glycerol in rations of high yielding dairy cows at up to 10% of the ration DM resulted in positive effects on milk yield, milk composition and liveweight gain.

14.2.2 Methane production

Methane (CH_4) is produced in the rumen as a product of the fermentation of organic matter, and principally carbohydrates. This fermentation produces volatile fatty aids (principally acetic, propionic and butyric in the molar proportions of approximately 65:25:10) and these are the main source of energy for ruminants. It is generally accepted that manipulating rumen fermentation to produce more propionate and less acetate would lead to a reduction in hydrogen synthesis and consequently CH_4 production. Glycerol, either derived from hydrolysis of dietary triglyceride by rumen micro-organisms or fed directly in the diet is also fermented principally into propionic acid. Therefore, increasing the proportion of energy in the diet by glycerol – particularly at the expense of forages – may be expected to result in a reduction in methane production.

14.2.3 Non-ruminants

A review of the scientific literature reveals relatively few pig and poultry trials where the dietary inclusion of crude glycerol has been examined.

Piglets

The digestible energy (DE) value of feeding crude glycerol to young piglets (around 11 kg live weight) has been calculated as 3386 (± 149) kcal (14.17 ± 0.62 MJ) per kg (Lammers *et al.,* 2007a). It appears from the literature that crude glycerol can be included in the diet of weaned piglets at the rate of 100 g/kg without any adverse effects on animal performance; Lammers *et al,* (2007b) conducted a trial with 3-week-weaned piglets (initial weight 7.9 ± 1.2 kg) for 33 days and reported no significant differences in daily liveweight gain (DLWG) or FCR values between animals fed a diet containing either 0, 50 or 100 g/kg crude glycerol.

Grower-Finishing pigs

The DE content of crude glycerol when fed to grower-finisher pigs has been calculated in a study by Lammers *et al.* (2007a) as 3772 (± 108) kcal (15.78 ± 0.45 MJ) per kg. In this trial, crude glycerol was fed at dietary inclusion rates of up to 200 g/kg. As the DE value reported was not significantly different to the gross energy (GE) value of 3625 ± 26 kcal (15.17 ± 0.11 MJ)/kg, it was concluded that crude glycerol could be added as a source of energy for growing pigs.

A recent metabolism study in the USA has been reported[28] which examined the effects of including glycerol in the diets of fattening pigs; results showed that at levels of up to 200 g glycerol/kg, it had an energy content similar to maize. In a related study, 5% and 10% glycerin was fed to pigs from weaning to market weight. Results showed equal growth performance between the glycerin-supplemented diet and a more conventional maize-soyabean meal diet. This study includes carcass data collection and meat quality evaluations, but those results are not yet available.

Broilers

Studies examining the inclusion of glycerol in broiler diets appear to be in agreement in recommending a dietary level of around 100 g/kg. A study incorporating 0, 50, 100, 150, 200 or 250 g/kg of crude glycerol in a high protein (230 g/kg) diet by Simon *et al.* (1996) reported that after 31 days, FCR values of broilers were not negatively affected by inclusion of up to fed up to 100 g/kg. In addition, the highest weight gains in the trial were observable in the 50 and 100 g/kg groups. Inclusion of crude glycerol at 250 g/kg resulted in the poorest bird performance, accompanied by pathological changes to the crop epithelium, liver and kidneys.

A subsequent study by the same authors feeding low protein (150 or 180 g/kg) diets to day-old broilers for 23 days concluded that parameters including weight gain, FCR and nitrogen balance/utilisation were unaffected by the addition of crude glycerol in the diet at 100 g/kg (Simon *et al.,* 1997). This inclusion level is consistent with the conclusion of a previous study examining crude glycerol in broiler rations (Barteczko and Kaminski, 1999).

The results of a metabolism study with laying hens have recently been reported from the USA. Rations contained maize, soybean meal, meat and bone meal, and four levels of crude glycerol – 0, 50, 100, or 150 g/kg. Crude glycerol was used with high efficiency, and there were no adverse effects on egg production, egg weight, egg mass or feed consumption in this short experiment[29].

The following table (Table 14) shows recommended rates of inclusion of crude glycerol in pig and poultry diets from published scientific literature. Recommended rates of inclusion of crude glycerol in pig and poultry diets from published scientific literature.

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[28] http://www.wallacesfarmer.com/index.aspx?ascxid=fpStory&fpsid=27921&fpstid=2

[29] http://www.wallacesfarmer.com/index.aspx?ascxid=fpStory&fpsid=27921&fpstid=2

Species	Rate of inclusion (g/kg)	Reference
Pig Weaners	100	Lammers et al., 2007b
Poultry Broilers	100	Barteczko and Kaminski, 1999; Simon *et al*., 1996; Simon *et al.,* 1997

14.3 The use of glycerol in compound feed manufacture

In addition to its use as a feed ingredient, glycerol may also be used in compound feed manufacture to improve pellet quality and dust control. Schröder and Südekum (1999) investigated the effects on physical, chemical and hygienic variables of concentrate pellets containing glycerol as related to different purities and concentrations of glycerol in the feeds and stored for different durations and under varying environmental conditions. Glycerol was included at up to 150 g/kg (of the dry matter). These authors reported that pellet quality, in particular hygienic quality, was positively influenced by the inclusion of glycerol. In studies recently reported from the USA with pigs and laying hens, it was reported that inclusion of glycerol at 100 or 150 g/kg resulted in compounds that were "rather sticky" and did not flow well in dry self-feeders. This led the researchers to conclude that under these feeding conditions an inclusion rate of 100 g/kg may be the upper limit.

14.4 Conclusions

Relatively few studies have been undertaken on feeding glycerol to beef cattle or sheep. However, extrapolating the result of research with dairy cows, it is likely that glycerol will undergo fermentation in the rumen to propionate, similar to a fermentable carbohydrate source. Schröder and Südekum (1999) suggested that glycerol of different purities can be included in mixed diets for ruminants up to 100 g/kg of the dry matter as a substitute for rapidly fermentable starch sources, e.g. wheat or barley, without negatively affecting ruminal environment, ruminal nutrient turnover and whole-tract digestibilities of organic matter constituents. This recommendation clearly needs to be validated across a range of diets and for different species and methods of feeding for glycerol of different purity. Nevertheless, there does appear to be potential for glycerol to be used as a feed for ruminant livestock. There may also be environmental benefits associated with feeding glycerol; Defrain et al.

(2004) reported a decrease in NH_3N for cows fed glycerol, and as discussed above, its inclusion in diets may also be associated with reductions in methane emission by ruminants.

From the small number of studies examining crude glycerol in pig and poultry diets, it appears that inclusion up to 100 g/kg can be successfully fed to young piglets as an effective energy source, without affecting animal performance. A similar level can be recommended for broilers without incurring detrimental effects. Given the relative lack of trial data on this co-product, in comparison to DDGS and RSM, further research would be useful.

15 The economics of co-products usage

15.1 Likely supply of co-products in the UK

As reported elsewhere in this report, it has been estimated that an additional 2.7 million tonnes of oilseed rape and 3.0 million tonnes of wheat would need to be processed to meet 2010 RTFO targets for biodiesel and bioethanol, respectively. If all this were processed in the UK, it would produce 1.3 million tonnes of RSM and 1.0 million tonnes of DDGS. However, we believe that these figures for potential production of DDGS and RSM are at the top end of the plausible scenarios. The reasons for this include:

1. There is uncertainty over the extent to which biofuels may be imported into the UK rather than produced here, if oil companies find imported supplies cheaper than UK produced biofuels;
2. Imported vegetable oil, e.g. palm and sunflower oils, may be used rather than OSR, particularly where they are required to blend with home-produced biodiesel in order to meet EU standards;
3. The only OSR crusher being built in the UK in 2007 is committed to sell its RSM for co-firing in an electricity generating power station. No RSM is likely to be added to potential feed supplies from this particular source;
4. There is currently no plant being built in the UK to produce bioethanol from wheat;
5. A starch plant built in Manchester by Cerestar requires approximately 1 million tonnes of wheat, most if not all of which will be UK produced reducing the exportable surplus.
6. Current wheat exports are unlikely to disappear completely since profitable opportunities to supply some high value markets, which the UK currently supplies, will continue.

There is some scepticism about the extent to which the UK could expand OSR production. According to Defra the area of OSR in the December 2006 Survey of Agriculture was 17 per cent higher than at December 2005, primarily in response to prices which had risen from about £135 per tonne in 2005 to £160 per tonne in 2006. Growing OSR in place of set aside (if policy changes), sugar beet, some cereals and/or pulses is certainly feasible. In the case of sugar beet, factory closures are already encouraging this. For set-aside to become available for OSR grown as a dual use crop (food or biodiesel), a decision of the EU to remove set-aside obligations from the CAP will be required. Defra is actively pursuing this in negotiations with the EU, and the Commission have indicated their desire to remove set-aside. Most potential increase in the amount of rape grown would come from existing growers changing to grow OSR more frequently in their rotation, at the expense of other break crops or the lower gross margin cereals. There is a general consensus that the area of OSR grown in the UK could go from 0.5 to 1 million ha without tightening the rotation so much that yields are reduced. The area of OSR is about 18% of the area of cereals in the UK (in 2005, 2.9 million hectares of cereals and 519,000 hectares of OSR) so on average OSR is not grown very frequently but among OSR growers, OSR grown once in four years is common. Very tight rotations (OSR every 2 or every 3 years) would be likely to result in an increase in problems, such as club root, sclerotinia and volunteer weeds. Table 15 below suggests that OSR Gross Margins would have to rise significantly for OSR to become more attractive to farmers than winter wheat. An increase from about £150 per tonne to £185 per tonne (based on the prices underlying Table 15 of £75 per tonne for wheat and £150 per tonne for OSR and with no change in the price of wheat) would be required to make the Gross Margins equal. A more likely scenario is that strong demand for biofuel is likely to increase the price of both wheat and OSR.

The relative gross margins of arable crops in the UK (Table 15) suggests, at current prices, that more OSR would be grown at the expense of the area of other combinable crops and especially break crops, but not winter wheat. The Defra December 2006 survey confirms this, since the increased plantings of OSR were accompanied by a 5% increase in winter wheat area.

Table 15. Forecast Combinable Crop Gross Margins for 2007 (Nix, 2007)

Crop	**Average GM £/ha**
Winter wheat	359
Spring wheat	264
Winter barley	248
Spring barley	235
Winter oats	274
Winter OSR	248
Spring OSR	130
Field beans	254
Dried peas	166

In addition to differences in GM, OSR is a more risky crop to grow than wheat. For example, dry weather at harvest is very important for OSR.

Given these facts, it seems unlikely that 1.3 million tonnes of RSM and 1 million tonnes of DDGS will become available for animal feed in the UK by 2010. Although the probability is difficult to establish, industry sources tentatively suggest that the likelihood of achieving 1 million tonnes of DDGS is no more than about 70%. The chances of an additional 1.3 kt/year of RSM are put no higher than 25%, according to industry sources. The most likely range for availability of RSM from biodiesel production in the UK by 2010 is assessed at between zero and 0.5 kt/year. The former figure would be if all additional RSM were used for co-firing.

It should also be noted that biofuel production is increasing in many countries that are in close proximity to the UK, and it is possible that those co-products might find their way into the UK market. For example, the bioethanol plant being built in France at Lillebonne, near Le Havre, could easily supply into southern England as cheaply as a plant in Northern England, adding to the UK supply of DDGS. The plant is anticipated to have an annual capacity to process 840,000 tonnes of wheat.

15.2 The global market for livestock feeds

If there is an increase in the availability of RSM and DDGS, what will be the impact on the price and availability of these and other feed materials? Many of the ingredients used in the manufacture of compound feeds are part of a global industry, and are traded on world markets in large quantities. As a result, the livestock feed market is very dynamic, and changes in volumes or prices in one location can have a rapid impact on prices and availability elsewhere. This also applies to the feedstocks for potential biofuel production (primarily maize and wheat for bioethanol and OSR and soybeans for biodiesel). The link between the markets for bioethanol and biodiesel production is that both their feedstocks need land for their production.

As a result, prices of the main commodities tend to shadow each other. For example, the price of soya beans in the USA adjusts to maintain relative profitability with the maize crop, while in UK the price of OSR adjusts to maintain its relative profitability with other break crops in the arable rotation.

15.3 The price of feeds for livestock

All co-products used in feed formulations tend to be priced in relation to the price of the main source of energy and the main source of protein. In Europe these are respectively wheat for energy and extracted soybean meal for protein. (In the USA and many other parts of the world the main source of energy is maize, but Europe is different because trade policy under the CAP has restricted supplies of maize, which cannot be widely grown as a grain crop in most of Europe.)

Fluctuations in feed prices will affect the use of co-products in animal feeds. Until the MacSharry reforms of the CAP in 1992 - which led to the reduction in EU cereal prices in the late 1990's - wheat was an expensive source of feed for rations, and co-products were imported from around the world for use in livestock diets. Examples of this were rice bran from India, cassava meal from Africa, etc. Since the price of cereals in the EU fell dramatically in the late 1990's, the use of co-products in Europe has greatly decreased and wheat has become much more commonly incorporated in livestock rations as a main energy supplier.

However, if DDGS and RSM become much more plentiful in the UK they will be absorbed into rations, and the reduction in by-product use will be reversed.

Compounders use least-cost ration formulation software to establish the break-even prices of raw materials available for use in compound feeds. These take account both of a range of nutritional parameters in the feed and the nutritional requirements of the livestock to which the feeds are to be fed. As a result, prices of similar feed materials tend to move in parallel relative to the main energy and protein sources. For example, if the price of soyabean meal increases, the price of other protein-rich co-products will rise together according to their relative value in common mixes. This is illustrated in Figure 15, in which changes in the price of soyabean meal are reflected in prices of rapeseed meal and distillers grains. In compound feed manufacture, DDGS is frequently considered as an alternative energy feed to wheat, particularly in ruminant rations. However, because of its higher protein it has a higher nutritional value, and this is reflected in its price relative to that of wheat. Over the period April 2000 - April 2006 fluctuations in the price of DDGS tended to mirror those of wheat (Figure 16). On average they were 30% higher, but ranged from no difference (April 2000) to 69% higher (January 2001).

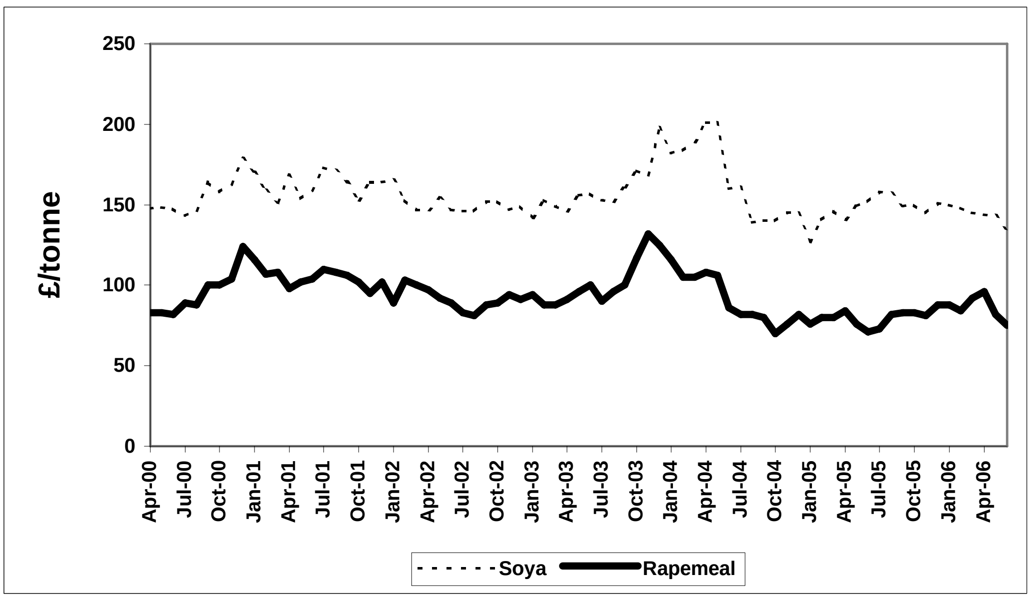

Figure 15. Market prices for soyabean meal and rapeseed meal between 2000 and 2006 (Tim Wilson, AB Agri, personal communication).

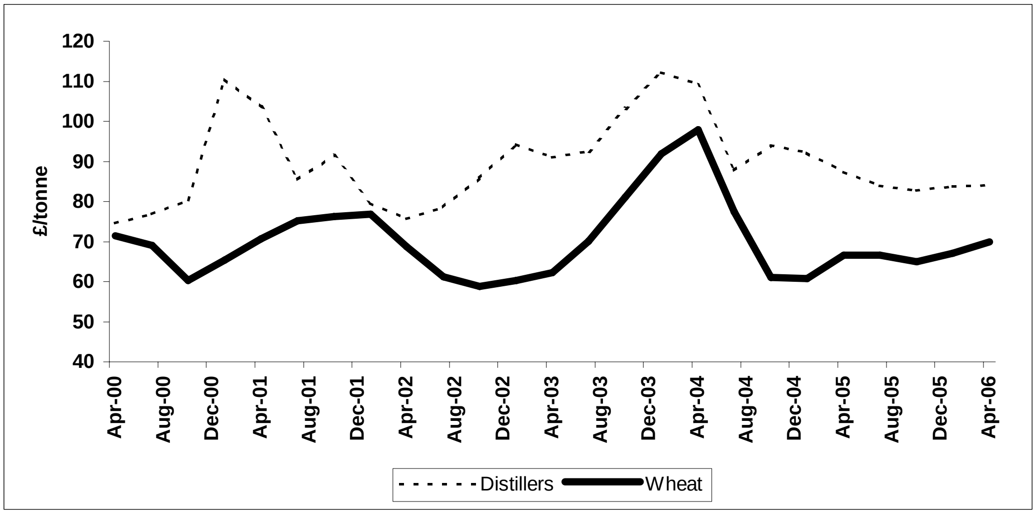

Figure 16. Market prices of wheat and DDGS between 2000 and 2006 (Tim Wilson, AB Agri, *personal communication*)

Any large increase in the supply of RSM and DDGS in the UK is therefore unlikely to have a major impact either on their price, or of that of other feeds used to formulate rations, since they would have to compete with prices of feed ingredients on the world market. As discussed elsewhere, RSM and DDGS are also feedstocks for energy production, and their value will also be influence by the market price of ROCs.

From this it may be concluded that an increase in the supply of DDGS or RSM will have less of an effect on the price of livestock concentrate feeds than the increase in demand for wheat and oilseed rape as feedstocks for bioethanol and biodiesel production. In future, as at present, one can expect the price of DDGS and RSM to be driven by world prices of wheat and soyabean meal.

15.4 The impact of increased feed prices on the economics of livestock production systems

The price of feeds used in livestock rations are principally determined by the prices of the main energy and protein feeds, and the prices of other feed materials tend to follow changes in the prices of these key feeds. In North America, these are maize and soyabean meal; in the UK – and most of northern Europe – these are wheat and soyabean meal. As a result of the increased demand for maize for bioethanol production in the USA, maize prices have increased by more than 50% since September 2006, and hit a 10-year high of US$3.77 per bushel. By 2006, around 60 percent of the total rapeseed oil produced in the EU was used in making biodiesel, and the increase in the price paid for oilseed rape has been attributed to increasing demand for biofuel production.

The main conclusion of this report therefore is that biofuel production will result in an increase in the price of concentrate feeds, largely because of increasing demand for wheat as a feedstock for bioethanol production and oilseed rape for biodiesel production. Increases in feed prices will have different impacts on the main livestock production systems as illustrated in Table 16. The table shows the impact of an increase in concentrate feed prices of between 10 and 40% on the gross margins of livestock systems (the gross margin before forage costs in the case of grazing livestock).

In the pig and poultry industries, concentrate feeds represent a very high proportion of their costs, and the reduction in gross margin would be greatest in these sectors. In practice the market would react, with all producers' costs of production increasing, and the prices of pig meat, eggs and chicken would rise. This has already occurred in the USA, where maize prices have increased substantially as a result of the increased demand for maize for biofuel production. This has been followed by increases in the price of wheat and barley. Before long, this will have to be reflected in higher meat and egg prices, although this effect has not yet been seen. For UK pig and poultry producers, there are few opportunities to reduce concentrate feed costs through extensification.

Only if the price of DDGS and RSM fall relative to that of wheat and soyabean meal (and other feed ingredients) would these co-products offer a cost saving opportunity for intensive livestock producers. Increased supplies of DDGS and RSM could have a temporary effect of this sort, but ration formulators rarely fail to observe and utilise more good-value ingredients. This usually restores the relationship between the prices of different ingredients.

For the grazing livestock enterprises of dairy, beef and sheep, the cost of concentrates is a much lower proportion of enterprise output. The impact on the gross margins of an increase in feed costs is therefore much lower than for pigs and poultry. These livestock sectors have a large number of variants that use more or less concentrate with varying proportions of forage in the diet. More expensive concentrates push the balance of profitability slightly in favour of the more extensive systems.

Table 16. Impact of Increased Concentrate Prices on a Range of Livestock Production Systems

	Dairy	Suckler cow Lowland (1)	Cereal Beef	Grazing & yard finish	18 m beef	Sheep	Sows	Pork	Layers	Broilers
Total variable costs (£/head)	393.0	78.0	323.0	95.0	193	18.4	358	18.8	6.81	84
Concentrate Cost (£/head)	254.0	28	253	53	119	7.5	289	15.3	5.31	68.9
Other Variable Costs (£/head)	139.0	50	70	42	74	10.9	69	3.5	1.5	15.1
Gross Margin (ex. Forage) (£)	800	151	118	144	286	30.6	316	6.6	0.72	8.1
Effect of changed concentrate price:	**Per Cent Change in Gross Margin (excl. forage)**									
+10%	-3%	-2%	-21%	-4%	-4%	-2%	-9%	-23%	-74%	-85%
+20%	-6%	-4%	-43%	-7%	-8%	-5%	-18%	-46%	-148%	-170%
+30%	-10%	-6%	-64%	-11%	-12%	-7%	-27%	-70%	-221%	-255%
+40%	-13%	-7%	-86%	-15%	-17%	-10%	-37%	-93%	-295%	-340%

Source: J. Nix Farm Management Pocketbook 2007.

Note: Sheep system is lowland ewes, sows are indoors. Lowland suckler cows are spring calving. For all systems performance is average.

The main economic conclusion is that the development of a biofuel industry will affect feed prices primarily through their impact on the price of their raw feedstocks (wheat, maize, soyabean & OSR) rather than through the availability of co-products. **In the short to medium term, increasing demand for feedstocks (wheat, oilseed rape) is likely to result in higher feed costs in the UK.** Because of uncertainties over the amount of biofuel production in the UK, it is not possible to estimate the extent to which prices will rise, but experience from the USA suggests that this could be considerable.

An increase in the availability of RSM and DDGS in the UK is not expected to have a significant impact on overall concentrate feed costs, because prices for these – as for other feed materials – are determined by world feed prices, which are ultimately linked to prices for the major energy and protein feeds.

Increasing prices of concentrate feed will have most impact on pigs and poultry. Because dairy, beef and lamb production in the UK is more grass-based than grain-based and higher grain prices will increase its relative competitiveness. For forage-based systems, increasing concentrate prices will slightly favour extensive livestock systems over those that use less land and more concentrate feed.

In the longer term, the development of alternative feedstocks for biofuel production may reduce demand for wheat and oilseed rape. The longer-term developments of biofuel production may also be influenced by the impact of biofuels on availability of food for human consumption. Current policy trends, particularly in the USA, could price low-income consumers out of the market for staple foods, leading to a revision of policy on biofuels. It is too soon to speculate whether these trends will result in a reduction in concentrate feed costs to pre-biofuel levels.

16 Discussion and conclusions

Total greenhouse gas (GHG) from all forms of road transport constitute about 18% of all GHG emissions in the UK, and this has increased from 14% in 1990. In an attempt to reduce GHG emissions from transport, the government have set targets for the use of bioethanol and biodiesel. While these targets have been clearly specified, the means by which they may be achieved is less clear. There is uncertainty over the extent to which the biodiesel and bioethanol required to meet the RTFO targets will be produced in the UK or imported, and if produced in the UK, the feedstocks that will be used to produce them.

A number of biodiesel plants currently use – or plan to use - imported vegetable oils. For biodiesel production from UK-grown oilseed rape, crush capacity is clearly the key limitation for the amount of meal that can be processed. However, information on the building of new processing plants is commercially sensitive, and it is therefore difficult to predict the amount of new crush capacity – and RSM production - over the next five years. If the planned crushers at Teeside and Rosyth are built, these will have a crushing capacity of 500 kt. It is anticipated that the RSM produced on Teeside will be burned in a power station, while the co-products from the Rosyth plant - 150 kt of rapeseed meal - may be used for animal feed.

With the exception of the British Sugar plant, which will use sugar from sugar beet as a feedstock, no bioethanol plants have yet been built in the UK. Estimates of the quantities of bioethanol and DDGS produced are therefore speculative, but if all the planned plants are realised they will have the capacity to process in excess of 3.4 million tonnes of wheat, producing 1.1 million tonnes of bioethanol and approximately 1.2 million tonnes of DDGS. Of this, at least 240 kt is destined for use in power generation, leaving a potential supply of just under one million tonnes of DDGS per annum for use as livestock feed. As for RSM, some of this may also be used for power generation where renewable fuels are required for electricity generation.

An objective of the current study was to examine the impact of additional supplies of RSM and DDGS on livestock feed use. Currently some 670 kt of RSM is used annually in the manufacture of compound feeds, with more used directly on farms. We conclude that there is capacity to increase this by a further 150 kt - to utilise the potential additional production from biodiesel production – without compromising livestock production. However, the obligation on power generators to produce a proportion of their energy from renewable sources provides a potential alternative use, and value, for the co-products of biofuel production.

For DDGS, the *potential* increase in supply - If all the planned bioethanol plants are realised - represents about 3 times the amount of distillery co-products currently used as livestock feed[30]. If DDGS were included in all livestock rations up to the maximum recommended level for each livestock category, this would utilise in excess of 1.5 million tonnes. At present, this level of utilisation is unlikely to be achieved, largely because of caution over maximum inclusion rates, particularly in pig and poultry diets. Appendix Table 1 shows typical recommend inclusion rates in non-ruminant diets of up to 50 g/kg; recent research however suggests that three or four times that amount may be fed to pigs and poultry (Table 10). Much of the recent research supporting the higher inclusion levels in pig and poultry diets has been undertaken in the USA, where bioethanol production uses maize, rather than wheat, as the feedstock. This results in a product that is markedly different to wheat-based DDGS, particularly in respect to the oil content. It is likely that further research would be required, using the wheat-based DDGS from bioethanol production, before pig and poultry producers accept higher inclusion rates of DDGS in their feed formulations.

Glycerol is a by-product of biodiesel production, but is currently not widely used as a livestock feed, largely because of demand in other markets. This situation could change with the increasing production of biodiesel. Glycerol has a very high energy concentration, and the energy is readily utilised by both ruminant and non-ruminant livestock. The main constraint on its utilisation in compound feeds appears to be its effect on the physical characteristics of the compound. For pigs on a liquid feed system, or ruminants on complete diet feeding systems, inclusion rates of 100 kg/tonne may be feasible. An additional benefit to its use in ruminant diets may be a reduction in methane production, although this requires verification. Whether it is fed to ruminants or non-ruminants, users will need to be aware of the levels of potential contaminants.

An understandable concern of potential users of the co-products of biofuel production is the effect of the processing on the composition of the feed. For oilseed rape, the process of oil extraction is currently the same whether it is destined for use as a food or biofuel. However, there will be pressure on those growing oilseed rape for biofuel production to reduce the amount of nitrogen fertiliser applied to the crop – since nitrogen fertiliser applied to the crop accounts for the majority of GHG emissions associated with growing the crop. Research programmes are already in place to identify varieties that have a lower requirement for fertiliser N. This would result in a reduction in the seed protein content, and in the resulting meal. What is not clear at

[30] 245 kt used in the manufacture of compound feeds (*Source: Defra statistics)* plus 200 kt used directly on farm

present is what effect this might have on the amino acid profile or – for ruminants – on rumen degradability of the protein.

For the future, it is the UK RTFO will change, from solely a volume basis to one which accounts for greenhouse gas savings, at some point. Carbon assurance and reporting will increase pressure to reduce N fertiliser inputs, which in turn will reduce protein content of the co-products. Further research should focus on how the development of new varieties and crop nutrition to reduce greenhouse gases may impact on the nutritional quality of co-products.

For bioethanol production, current research is focussed on improving the efficiency of ethanol production through better enzymes to release the sugars in starch-rich feedstocks, and yeasts to convert the starch into alcohol. Different processes have the potential to modify the composition of the resulting co-product. As with oilseed rape, there will also be pressure to reduce levels of N fertiliser applied to crops destined for bioethanol production, and again this will result in the production of grains with lower N contents. Current research is investigating wheat varieties that maintain yield but require less nitrogen fertiliser. Evidence from the USA would suggest that there has been considerable variation in nutrient composition of DDGS *between* plants, as a result in differences in the processes adopted, but that variability within plants – i.e. from batch to batch – tends to be low. It is hypothesised that over time the most efficient processes will be adopted, thereby reducing the amount of variation between manufacturing plants.

Considerable research effort is being devoted to the development of lignocellulosic plant material, as an alternative to the agricultural crops that are currently used for bioethanol production. A number of major challenges remain to be overcome, but progress to date is promising. What is clear is that the co-products of the processes will be very different from those of current bioethanol production, although what their nutritional vale to livestock will be – if any – is not currently known.

The current study set out to examine the effect of the biofuel industry on the availability of RSM and DDGS from biofuel production, and on the use and prices of these and other feeds for livestock. To understand the impact of the biofuel industry on feed prices, it may be useful to observe developments in the USA – which has a longer history of biofuel production. As a result of the increased demand for maize for bioethanol production in the USA, maize prices have increased substantially in recent years. Soyabean meal prices have also increased, partly because they tend to be pegged to maize prices but also in response to a predicted drop in the area planted to soya beans[31]. As prices of these key feeds increases, the prices of other feed materials have tended to follow, partly in response to extra demand – because of the higher costs of maize and soyabean meal. The situation in the UK is likely to be similar; demand for wheat as a feedstock for bioethanol production will result in higher prices for wheat as a feed for livestock, and this will result in an increase in the prices of other concentrate feed materials. Since most of the concentrate feeds used in livestock rations are globally traded commodities, they are subject to world market supply and demand. The UK livestock feed market is not immune to changes in global feed prices as a result of increasing demand for biofuels in other countries. The main conclusion of this report therefore is that biofuel production will – in the short term at least - result in an increase in the price of concentrate feeds, largely because of increasing demand for wheat as a feedstock for bioethanol production and oilseed rape for biodiesel production. The development of commercial production of bioethanol from cellulosic biomass may ease demand for maize and wheat, and result in lower cereal prices. This would, in turn, be expected to result in reductions in other feed costs.

Globally, there seems to be no doubt that the demand for biofuels will increase. The USA has set a target of 35 billion gallons of non-fossil fuel production by 2017, and this has to be set alongside targets already agreed for the Brazil, Canada, Australia and many other industrialised countries. China is now the third-largest fuel ethanol producer. Its ethanol and maize alcohol production consumed 8.9 million tons of maize last year, accounting for 44.5 percent of maize consumption, and China will become a net importer of maize within the next few years[32], with purchases of maize to use in feeds, biofuels and other industrial processes outstripping production nationally. In the EU, The European Council has agreed to a target of 10% biofuels in all road transport fuel by 2020. This would create additional demand for 45 million tonnes of grains and 38 million tonnes of oilseeds, using first generation processes. This would mean that the EU would become a net importer of grain – it currently exports about 20 million tonnes - and oilseed at a time when other major exporters are also pursuing aggressive biofuel policies.

Not surprisingly, there is considerable uncertainty over the effects of these developments in the short-term, and developments in biofuel production in the medium and long term. Much of this uncertainty centres on the ethical and economic concerns surrounding the use of a food material for fuel production.

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[31] Because more land is being used for maize production

[32] According to an official at the Chinese ministry of commerce

Maize is currently the predominant feedstock for ethanol production in the USA, and as a result of the rapid increase in the number of ethanol plants – currently three new plants are being commissioned each week – the price of cereals has risen sharply. In 2006-07 approximately 54.6 million tonnes of maize was used for bioethanol production, but with more than 80 ethanol distilleries under construction demand for grain for ethanol production is expected to increase to 81.3 million tonnes in 2007-08[33]. This continuing diversion of grain to the production of fuel ethanol has resulted in higher grain prices in the USA; livestock feed prices have increased as a result, and although this has yet to be reflected in increased food prices, it is expected to be very soon. Since the USA is a leading exporter of grain, this diversion of grain to fuel production is having a major impact on world food prices. For example, the overall food price index in India in January 2007 was 10% higher than a year earlier, while the price of wheat – a staple food in northern India - increased by 11% over the same period, largely as a result of reduced US maize exports. Increases in food prices as a result of higher world wheat prices have also been reported in China, while in Mexico there have been widespread public protests over the higher maize prices.

The biofuel industry is a relatively young one, and its ultimate direction is uncertain. There have been a number of recent developments that, if fulfilled, could have an impact on the feedstocks used for biofuel production, and the supply of RSM and DDGS as feeds for livestock.

- Many life cycle analyses have been undertaken to examine the environmental benefits of producing and using biofuels, with varying results. Hill *et al.* (2006) reviewed a number of studies that suggested that ethanol produced from maize produces only 25% more energy than is consumed, which is not considered to be very efficient. Other studies estimate more favourable energy balances, for some of the main environmental impact factors, particularly if the co-products are used to generate electricity. Clearly, the fate of co-products can significantly affect the energy and GHG balance of the resulting biofuel, and this will become increasingly important with the introduction of carbon assurance as part of the RTFO. However, there needs to be more research on the relative GHG and energy benefits of using co-products for specific uses since recent work[34] has suggested that feeding DDGS to animals can increase ammonia emissions (and possible N_20 emissions)

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[33] US Department of Agriculture

[34] Presented at the 1st International Ammonia conference, Ede, The Netherlands, 19-21st March 2007.

- The use of ethanol is further complicated by its water miscibility, which imposes an energy cost for distillation, and creates problems in transporting the fuel via pipelines[35]. A senior US politician has recently forecast "the future of bioethanol is not based on corn"[36]. Ethanol made from plant celluloses, which have no agricultural value, but which has the same properties as ethanol produced from wheat or maize, could play a key role in reducing the demand for cereals as feedstocks. It is predicted that the technology to do this will be developed and available within the next six or seven years[37]; in support of this the US Department of Energy has recently awarded grants in excess of $385 million to fund the development of new cellulosic ethanol plants over the next four years. The world's first commercially operational cellulosic bioethanol plant has recently been commissioned in Osaka, Japan. The plant takes wood-based waste materials (construction industry waste, waste from industrial wood product maufacturing, agricultural plant waste, tree cuttings, etc.) and extracts the polysaccharide content which is (eventually) fermented into ethanol. The rest of the biomass (mainly lignin) is used to generate energy (heat and electricity co-generation to maximise energy efficiency). In Europe, research is also well advanced in the production of biofuels from lignocelluloses. If the predictions for these technology are realised, alternative feedstocks – alternative to wheat in the UK – could be the basis of bioethanol production within the next decade, thereby reducing the supply of DDGS available as livestock feed from bioethanol production.

- One of the principal constraints on to the development of a biodiesel industry is the cost of growing the oilseed rape crop. As a result, there is considerable interest in the use of alternative oilseed crops with lower production costs for biodiesel production, and a number are currently being investigated. These include oilseed crops such as Sunflower, Crambe and *Camelina sativa*[38]. Commercially produced biodiesel from sunflower and Camelina is now available in parts of Europe, particularly France and Germany, and the use of this feedstock is expected to continue.

  The cost of biodiesel may be reduced substantially if energy crops are produced overseas, and a number of companies are exploiting this. For example, D1 Oils are investing in the development of huge plantations of Jatropha trees (*Jatropha Curcas*) in various countries,

[35] Butanol is a more user-friendly biofuel in this respect, but production of biobutanol on a commercial scale for biofuels is still unproven and under development.

[36] Clay Sell, US Deputy Secretary for Energy – Reuters, 29th March 2007

[37] Alex Farrell, Professor of Energy and Resources, UC Berkley

[38] Other potential crops include Crambe, Raphanus, Sinapis, Lepidium and Barbarea.

producing non-edible oil for the production of biodiesel. BP is funding a $9.4 m project in India to produce biodiesel from Jatropha, producing 9 million litres of biodiesel per annum.

- Although many factors will influence the level of biofuel production, primary drivers will be the price and availability of the feedstock, and tax incentives and tax exemption on the fuel that establish the price relative to oil. Germany is the EU's largest biodiesel producer, with production capacity of just over four million tonnes - increasing from two million tonnes in 2005. However, as a result of the recent changes in taxation[39], coupled with reductions in world oil prices, sales of biodiesel are currently down 30-40% compared to December 2006. In Spain, it is reported that the bioethanol plant in Salamanca, which has the capacity to process 50,000 tonnes of grain a month, is likely to stop production because high wheat prices make the ethanol uncompetitive compared with gasoline. In Britain, the two largest biofuel producers, have recently announced that their plants are working below capacity due to "difficult market conditions"; many in the biofuels industry were surprised that the Chancellor of the Exchequer did not boost incentives in his latest budget.

Whatever the future of biofuel production, it is clear that developments of the biofuel industry in the UK - and the supply of co-products from it – should not be considered in isolation from the rest of the world. The demand for feedstocks for biofuel production globally will determine overall prices of livestock feeds, and because RSM and DDGS are internationally traded commodities, world market prices for these and other feedstuffs will determine what feed materials are used in livestock rations in the UK, and their price.

17 Priorities for future research

Although targets for biofuel use in the UK have been established, there is currently some uncertainty over how these will be met. Factors such as lower costs of production of bioethanol in South America, increasing availability of alternative oilseeds from Asia, and changes in taxation of biofuels make it difficult to predict the extent of biofuel production in the UK, and the amounts of co-products arising from their manufacture. These co-products may also be used as fuel for electricity generation, although the extent to which this will happen in the UK is unclear. In the light of this uncertainty, it is difficult to identify clear areas of research. This study has, however, identified a number of areas where further information is needed if UK agriculture is to make best use of the co-products of biofuel production when they become available. Some of the priorities for further research are listed below:

[39] Removal of the 45-euro-cent petroleum tax breaks on biodiesel

1. Demands for increasing efficiency of biofuel production is likely to lead to the development of new varieties of crops specifically for use by the biofuel industry. An investigation on how the development of new varieties and crop nutrition may impact on the nutritional quality of by-products should be undertaken as and when these are commercially available.
2. In the medium term, pressure to reduce green house gas emissions is likely to result in lower protein content feedstocks produced through lower fertiliser use and the development and use of new varieties. This will result in a lower protein content in the co-products. The effects of this on total or digestible amino acid content, or on rumen degradability, are unknown, but will need to be assessed in order to optimise the use of the co-products in livestock
3. Glycerol is a natural co-product from the production of biodiesel, but has not been widely used as a livestock feed. There is need for further information on the potential use of glycerol, to include an investigation of whether glycerol contains significant levels of potential contaminants.
4. There is a suggestion that the inclusion of glycerol in ruminant diets may lead to a reduction in methane production. This requires verification.
5. Evidence from the USA suggests that there can be significant variation in nutrient composition of DDGS between and within bioethanol-producing plants. The extent of this variation between and within UK plants should be examined.
6. Much of the data on maximum use of DDGS in livestock rations originates from the USA, in which maize-derived DDGS has been fed. This has a very different composition to wheat-derived DDGS, and further research is recommended with this by-product to establish maximum limits for inclusion in diets, particularly for pigs and poultry.
7. DDGS and RSM could substitute for soyabean meal in many livestock rations. However, the amino acids in DDGS and RSM may not be utilised with the same efficiency. The higher phosphorus content in DDGS and RSM – compared to soyabean meal – may also result in additional phosphorus excretion. Research on the environmental impact – particularly in respect of N and P – as a result of increasing use of RSM and/or DDGS in livestock diets should be undertaken.

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Appendix Table 1. Recommended inclusion rates (kg/tonne) for rapeseed meal (RSM) and wheat distillers dried grains with solubles (DDGS) in livestock diets (from Ewing, 1998)

Species	**Inclusion rate (kg/tonne)**	
	RSM	DDGS
Ruminants		
Calf	50	100
Dairy	250	400
Beef	250	400
Lamb	50	0
Ewe	200	0
Pigs		
Creep	0	0
Weaner	0	0
Grower	25	25
Finisher	50	50
Sow	25	50
Poultry		
Chick	0	0
Broiler	25	50
Breeder	0	50
Layer	50	50