JOURNAL OF FARM MANAGEMENT VOL.13. No. 10. PAGES 1 - 20

REFEREED PAPER

SIGNIFICANCE OF WHEAT GRAIN QUALITY IN THE ECONOMICS OF THE UK BIOETHANOL INDUSTRY

K. D. Awole, P. S. Kettlewell, S. T. Parsons, M. C. Hare

The purpose of this paper is to quantify the economic impact of variation in alcohol yield from wheat grain used as the feedstock in the emerging UK bioethanol industry. Analysis of alcohol yield of 84 Recommended List samples shows that the annual cost saving from high alcohol yield wheat compared with low alcohol yield wheat could exceed £3 million per annum or £34 per tonne of wheat processed in a plant with a capacity of 100k tonnes of wheat per year.

Key words: bioethanol, wheat grain, feedstock quality, cost of production

Introduction

Bioethanol production is not new technology: it has been used when the world oil price has been high and when there has been restricted oil supply; for example, during the first and second world wars (Batchelor *et al*., 1994). In recent decades Brazil has become a model in producing biofuel. At least from the early 1970s until the mid 1990s, Brazil was the only country known for production of bioethanol (Mol, 2007). The recent escalation of oil price and increased interest in environmental issues has caused a resurgence of ethanol production. More and more countries are considering biofuel as a means of attaining greater energy security in addition to addressing environmental problems (Peters and Thielmann, 2008). Although the UK is less reliant on imported fuel than countries such as the USA, the environmental benefits of biofuels should not be overlooked (Robinson, 2002). The UK is committed to the Kyoto agreement to reduce greenhouse gas emissions, and in the UK an energy White Paper seeks reduction of carbon dioxide emissions by 60% before 2050 (Dti, 2003). The transport sector is responsible for about 30% of the UK's CO_2 emissions (Smith *et al*., 2006).

Biofuel production in the UK had been exclusively biodiesel until the start of bioethanol production in 2007 by British Sugar (GCC, 2007). A new bioethanol plant is also under construction by Ensus (at the time of writing, March, 2009) with a processing capacity of about 315 kilo tonnes of bioethanol per year. Another eight wheat grain bioethanol plants are planned with a total production capacity of about 1.6 million tonnes of bioethanol per year (NNFCC, 2008). The current bioethanol production in the UK has been promoted by government policy (blending quota), tax incentives and relatively high crude oil prices.

The economic feasibility of bioethanol in the UK has been investigated by several authors (e.g. Batchelor *et al*., 1994; Bullard *et al*., 2003; Turley *et al*., 2004). The results indicated that the production cost of bioethanol is generally higher than that of petrol. Studies conducted in China on cassava bioethanol and in the US on maize bioethanol suggested that the two most important factors in the economics of bioethanol production are petrol price and feedstock costs (Keim and Venkatasubramanian, 1989; Hu *et al*., 2004). When petrol is expensive and/or feedstock cost is cheap, bioethanol would be more viable (Anon, 1988). However, the relationship between these two is not very clear: while some suggest there is a strong correlation, others claim the relationship is only by chance.

The bioethanol market is global and highly competitive; so end-product price is exogenous to firms and encouraging the success of bioethanol production in the UK should focus on minimizing the cost of production (Smith *et al*., 2006). Bullard *et al*. (2003) suggested that the cost of production of bioethanol can be reduced, given significant investment in R&D. R&D is required to increase the alcohol yield (AY) of wheat and to improve the processing efficiency. It is important to note that increases in AY could result from purchases of the wheat feedstock. The UK potable alcohol distilleries have a Recommended List of varieties of wheat for distilling quality. Studies have shown that there is still high variation between and within these varieties in alcohol yielding potential (Kindred *et al*., 2008; Swanston *et al*., 2005; 2007). Several grain characteristics such as starch and protein concentration, thousand grain weight (TGW), grain length to width ratio have an association with alcohol yield and can be used as indicators of high alcohol yielding wheat (Awole *et al.,* 2008). Although grain starch content is the main raw material of the grain which will be converted to alcohol, it is difficult to measure starch content (Smith *et al.,* 2006). So far, among all grain characteristics, protein concentration and TGW are the best indicators of grain alcohol yielding potential (Awole *et al.,* 2008; Swanston *et al.,* 2007). More research is being conducted to identify the best quality criteria for alcohol yielding potential.

Poor quality wheat results in lower strength alcohol, and as a result it not only yields less alcohol but takes more energy to do so (Bringhurst *et al*., 2003). Moreover, poor quality wheat gives a larger proportion of residual material which again takes more energy for cooling and drying.

The main purpose of this analysis is to examine significance of the feedstock quality variability in the overall economics of wheat grain bioethanol production, so as to determine the need for clear feedstock quality criteria. Although the quality of wheat has an impact on the amount of alcohol produced and on energy-cost-saving, this analysis is limited to the effect on variability in alcohol yield. It is difficult to demonstrate the variation in energy consumption, since the energy data obtained from laboratory analysis is not representative of the larger scale industrial production of bioethanol.

Cost of production

Economic analysis requires detailed understanding of the ways in which costs are built, starting from production and proceeding through to marketing. The overall cost of bioethanol production and transportation, including the blending cost, should be comparable not only with petrol prices but also with the ‘free on board’ (fob) price of bioethanol imported from other countries. The major costs of bioethanol production can be categorized into three main parts as indicated below.

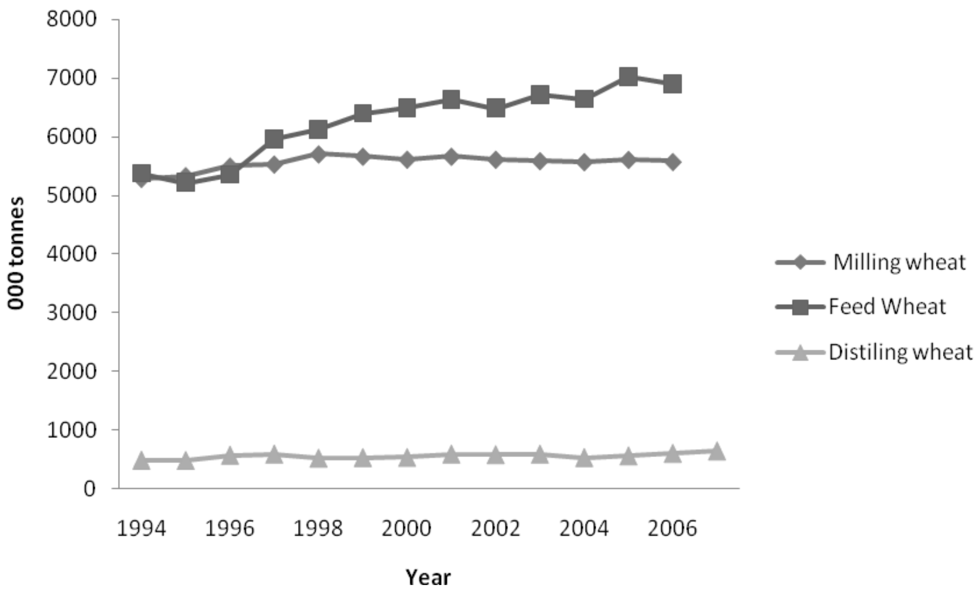
Feedstock cost

Feedstock is any biomass resource destined for conversion to energy or biofuel. Apart from the British sugar plant at Wissington which produces bioethanol from Sugar beet, all the other planned bioethanol plants in the UK use wheat as a feedstock. Therefore feedstock in this paper refers to wheat. Feedstock cost is the price that bioethanol producers must pay for the wheat delivered to their factory gate. Feedstock accounts for between 55-70% of the total cost of bioethanol production (Anon, 1983; Schultze *et al*., 2005), and therefore feedstock cost is an important factor in the economics of the industry.

The traditional markets for UK wheat are for animal feed and for milling - of which the majority is for bread and biscuit making (Hollins *et al*., 2006) - and also for brewing and distilling (Smith *et al*., 2006). Milling wheat and feed wheat have distinct properties: the main distinctions being grain protein concentration and potential grain yield per hectare. Feed wheat has been preferred by the potable alcohol industry and this will be the same for the biofuel industry because of its lower protein concentration and lower market price than that of milling wheat.

The price of feedstock is highly volatile depending on market conditions, expectations concerning future harvests and world stocks. In recent years the primary commodity price has been rising tremendously. World prices of wheat and maize increased by 136 and 31 percent respectively between March 2007 and April 2008 (Pfuderer and Castillo, 2008). There has, however, been a substantial decrease lately. Bioethanol production is very sensitive to wheat price (Batchelor *et al*., 1994). The price of feedstock (feed wheat) can be

Figure 1 The trend in UK feed wheat, milling wheat and distilling wheat consumption from 1994 to 2007. [Data source: HGCA)]



affected by the supply and demand for human consumption (milling wheat), supply and demand for livestock feed (feed wheat and other cereal feeds) and the supply and demand for alcoholic beverages, but it is more sensitive to supply than demand. Moreover the feedstock costs of bioethanol producers depend on the size of the order they are able to place and the contractual agreements made (DfT, 2006a). The historical data show that the demand for milling, feed and distilling wheat has been increasing during the past 15 years. The most notable one in the UK is feed wheat consumption (Figure 1). This indicates the potential competition for wheat in the near future which could raise the feedstock price.

Energy Cost

Energy used in the production process accounts for the second largest cost, next to feedstock cost, in the economics of bioethanol production. Schulze *et al*. (2005) studied the economics of bioethanol production from four feedstocks: sugar cane; wheat; maize and sugar beet (in Brazil, central Europe, US and Germany respectively). They concluded that the energy costs account for 10-16 percent of the total cost of bioethanol production depending on location and feedstock type. According to their study, the energy costs of bioethanol production from wheat in central Europe are approximately 10 percent of the total cost.

Table 1. Thermal and electrical energy required at different stages of bioethanol production

Process	Thermal energy use % of total Meridith (2003)	Electrical energy use % of total Meridith (2003)	Thermal energy use % of total Schulze (2006)
Grain recovery and milling	0	1	Not included
Cooking and Liquefaction	4-6	0	10
Fermentation	1	0	30
Distillation and dehydration	43-48	0	20
Evaporation and drying of DDGS	31-36	3-4	40
Utilities	4-6	4-5	Not included
Building	1	0	Not included
Totals	91	9	100

The major processes of bioethanol production from wheat are milling, cooking, fermentation and distillation. The energy requirement of each sub-process of wheat-based bioethanol production is indicated in Table 1 using estimates from two sources.

The most intensive energy-demanding steps are those which involve heating; these are cooking, distilling and drying the residue to produce dried distillers grain with solubles (DDGS). Reducing thermal energy required at these stages will have a significant effect on reducing the cost of energy and reducing greenhouse gases. Good plant design involving integration of heat-consuming steps such as distillation and dehydration could reduce the energy cost (Schulze *et al*., 2005). A number of commercial simulators such as Aspen Plus (Brien and Craig, 1996: Wooley *et al*., 1999; Krishnan *et al*., 2000) and Super Pro Designer (Kwiatkowski, 2006) have been used to optimize the processing efficiency and associated costs.

In addition to the processing efficiency, the quality of feedstock used has a substantial impact on energy saving. Both good quality and poor quality wheat require the same amount of energy during cooking, but poor quality wheat yields lower strength alcohol and high residual matter. Consequently, poor quality wheat requires more energy for each litre of alcohol produced during dehydration of the alcohol and drying of DDGS (Bringhurst *et al*., 2003). Smith *et al*. (2006) estimated that the value of high quality grain in UK bioethanol production could be millions of pounds a year. Therefore, both quality of the feedstock used and processing efficiency are very important in the economics of bioethanol production through energy saving.

Investment cost

The third most important cost in the economics of bioethanol production is the capital cost, accounting for 9-14% of the total cost of production (Schulze *et al*., 2005). When taking this cost into consideration, it is important to note that there are economies of scale. Batchelor *et al.* (1994) demonstrated that capital cost per litre is sensitive to scale of production as larger scales could significantly reduce the capital cost per litre of ethanol produced. It has been suggested that grants or soft loans could potentially reduce the production costs of bioethanol. Batchelor *et al*. (1994) suggested that a grant funding of about 40% of the capital cost can reduce the production cost by 3.7 p/litre making it cost only 35.1 p/litre for a plant size of 78 kt wheat *per annum*. The experience of Brazil and USA is worth mentioning in respect to government support towards development of biofuel production. In both countries the boost in bioethanol production has only been achieved after billions of dollars of subsidies. USA alone invested about US$11 billion to subsidise bioethanol production prior to 2001 (WorldWatch Institute, 2007).

The capital cost depends on the asset life of the production plant and the rate of return expected by the investors. Most of the economic analyses of wheat-based bioethanol production consider a 15% return rate on capital costs (Batchelor *et al*., 1994; Bullard *et al*., 2003). This figure is higher than normal energy investment analysis but reflects the rate of financial and technical risks involved in the establishment of such huge plants for a new product (Turley and Ceddia, 2003). Owing to the uncertainty of the life expectancy of any duty concession for bioethanol, it is difficult to account for the long-term depreciation of capital asset. It is unlikely that the government could guarantee a duty concession over a period of 5 years (Turley and Ceddia, 2003). Thus investors would require a higher rate of return and this makes the cost of production of bioethanol more expensive.

Revenue

Although bioethanol is the main product of the process and expected to yield returns, other co-products can be used to offset the production costs. The potential sources of revenue are discussed below.

Bioethanol

Bioethanol can be used as a petrol additive or it can also substitute for petrol (Walker, 2005). Bioethanol acts as an oxygenate, increasing the oxygen content of the fuel which enhances combustion, consequently resulting in increased efficiency and reduced emissions (Turley *et al*., 2004). Bioethanol represented a negligible amount (0.39%) of the total petrol usage in the UK up to 2006 (BERR, 2007). Tesco has been selling petrol of up to 5% blend at over 185 forecourts in the UK when it has been profitable to do so (Tesco, 2006). Eighty-five percent ethanol blends (E85) for flexible fuel cars have also been sold in the UK by Morrisons (Morrisons, 2006). In total, eight million litres of bioethanol, imported predominantly from Brazil, were sold in March 2006 in the UK (DfT, 2006b). Predictions show that the UK road transport demand will increase by 60% from 1990 to 2025 (NNFCC, 2008). This, together with renewable transport fuel obligation (RTFO) demands of 5% biofuel blending quota by 2010 imposes a very high demand for bioethanol in the UK.

Although the price of bioethanol has to follow that of petrol, the current production costs of bioethanol are generally more expensive than its counterpart. Consequently most countries have supporting policies in the form of blending quota and tax exemption or reductions to encourage use of bioethanol. The UK government has had a 20 p/litre of duty reduction for bioethanol since 2005.

Distillers dried grains with solubles

DDGS is an essential by-product of cereal bioethanol production. Taking out the starch from the grain through fermentation concentrates all the remaining nutrients of the grain by a factor of three, making DDGS rich in the three most expensive nutrients added to livestock diets: fat, protein and minerals (Jacques, 2003). Thus DDGS is a high value feedstuff for dairy cattle, beef cattle, pigs, poultry and aquaculture (EUBIA, undated).

Although DDGS can be used for other purposes as well, the current market for DDGS is in the feed sector. In addition to supplementing the local livestock cereal feed, DDGS will also play a considerable role in reducing or avoiding soyabean meal import to the UK. As the exact inclusion rate of DDGS in the animal feedstuff is not known, it is difficult to assess the market size of DDGS (Smith *et al*., 2006). The UK imported about 1.8 million tonnes of soybean meal in 2007. DDGS would compete with soya-bean meal in the feedstuff market if it contained high quality digestible protein. Currently the common use of DDGS in the feed is a substitute for alternative protein sources like soya-bean meal but DDGS can also replace energy sources in livestock feeding stuffs such as cereals (Jacques, 2003).

Even though DDGS is merely a by-product of bioethanol production it makes a substantial contribution to the economic viability of the industry (Tucker *et al*., 2004). According to Batchelor *et al.* (1994) the cost of production of bioethanol is sensitive to DDGS price. A study conducted in the USA showed that an income obtained from maize DDGS returns 40-45% of the cost of maize from which it is produced (Keim and Venkatasubramanian, 1989).

The simultaneous co-production of DDGS in millions of tonnes each year will affect the supply and consequently the price. In addition to the supply and demand there are many factors which could possibly affect the market price of DDGS and hence bioethanol production. Among these factors, the nutrient content of the DDGS is very important (Copper, 2007). Therefore, producing high quality DDGS is vital for commercially successful bioethanol production. The other factor which could determine the DDGS price is the price of the other feeds which DDGS is expected to replace. Soya-bean meal price as a protein source or cereal feed price such as maize, wheat and barley as an energy source, could compete with DDGS prices. Historically the price of maize DDGS in the United States generally follows that of maize grain (Cooper, 2007).

Carbon dioxide

Carbon dioxide (CO_2) is one of the major by-products of bioethanol production. Approximately 280 kg CO_2 per tonne of wheat is produced through yeast respiration (Smith *et al*., 2006). CO_2 can be collected and sold as an additional income source. The possible markets for CO_2 are: in the carbonated drinks industry; for greenhouses to enhance productivity; in refrigeration and packaging industries; or in fire extinguishers (Senn and Pieper, 2000). However the collection of CO_2 is very expensive, therefore it may not be economical to collect CO_2 with the current limited market (Smith *et al*., 2006). Although the North British Distillery is the only distillery in the country which collects, purifies and sells CO_2, the CO_2 market in the UK is currently saturated (Watts, 2008). All recent economic studies exclude CO_2 income due to lack of markets. However it is possible that in the future markets could be created for CO_2.

Others

In order to reduce the cost of production of bioethanol and obtain a higher economic benefit, the alcohol industry should generate value added co-products. The co-products could establish markets in the feed, food and fertilizer industry (Pass and Lambart, 2003). Home Grown Cereals Authority (HGCA) (2007) has been looking into one of the possible co-products, extraction of arabinoxylans (AX) from wheat bran. Arabinoxylan can be used in food and pharmaceutical industries. The research revealed that arabinoxylan could be produced economically in an integrated biorefinery and can enhance the economics of bioethanol production if there is a market for arabinoxylans.

A novel wheat-based biorefinery which could replace the current dry-milling process of wheat has been proposed by Arifeen *et al*. (2007a&b). This process allows the extraction of different components of the grain (bran, gluten, and starch) for different end-uses (Arifeen *et al*., 2007a&b). Such processing could produce value added co-products such as gluten (Arifeen *et al*., 2007a&b). Despite much research to diversify the co-products of bioethanol production, currently there is no commercially viable co-product apart from DDGS.

Economic analysis

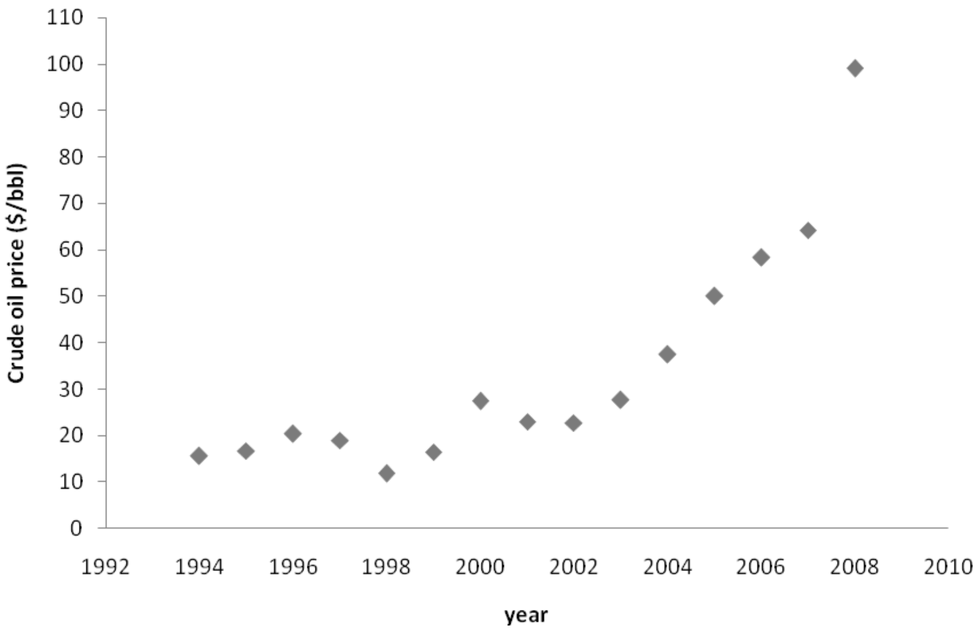
Supply and demand and price relationship between fuel energy sources

The historical crude oil price data has shown very high escalation in recent years (Figure 2). Such a huge rise in crude oil prices has created a good opportunity for bioethanol, as demonstrated by the tremendous increase in world bioethanol production. Biofuels in general have seen a threefold increase in the past two decades (Pfuderer and Castillo, 2008). A high crude oil price has a dual impact on bioethanol production. While high oil price makes bioethanol more competitive in the market, it also increases the cost of production of bioethanol due to high energy costs for feedstock production and processing.

In theory, the supply of petrol will affect demand for bioethanol in the market. However, for the time being this relationship is set to be relatively constant as bioethanol has constant demand created by a mandatory blending quota in the UK. The demand for biofuels is likely to remain the compulsory blending quota unless bioethanol becomes cheaper than petrol in the market.

The price of feedstock is the major determining factor for the economics of bioethanol production. As wheat has many other established uses, the price of wheat for bioethanol will be affected by demand and supply for these other uses. The most common way of studying such demand and supply interaction is through historical data. However, wheat bioethanol production and the market are relatively new phenomena, and therefore the market for both the feedstock as well as the bioethanol itself is not well developed and the information needed to obtain a clear understanding of the scenario is not currently available.

Figure 2. The annual average crude oil price in U.S. Dollars per barrel from 1994-2007 [Data source: EIA (05 Dec 2008)]



Cost of production

Several authors have looked into the economics of bioethanol production and estimated the cost of production p/litre of ethanol (Table 2). The studies were conducted in different years and conditions, thus showing considerable variation. The study by Batchelor *et al*. (1994) is based on a pilot plant which produces bioethanol from wheat in Sweden. All the expenses and revenues were determined from the operating company's actual data. This figure could be more reliable than other estimates as it is based on real operations rather than assumptions. Turley *et al*. (2004) and Walker *et al*. (2005) determined the cost of production based on the 1994 data of Batchelor *et al*., but adjusted to the current price of wheat and DDGS of the study year. Bullard *et al*., (2003) followed a different approach for determining the cost of production. The feedstock cost was determined as the cost required to grow wheat instead of the market price of wheat. The capital cost was considered based on different published sources of EU and North America together with consultations with several UK bioethanol project developers. The study by BTG (2004) is less relevant to UK conditions as it is entirely based on other countries' situations.

Despite the slight variation in the estimated cost of production by different authors, all concluded that bioethanol production is much more expensive than its counterpart, petrol production. The Department for Transport (DfT, 2006a) has studied the size of government concessions required to make bioethanol competitive with petrol using different scenarios of bioethanol production. It was suggested that a duty cut of 26-29 p/litre is required to incentivise bioethanol production from wheat (DfT, 2006a).

The cost of producing ethanol from wheat, updated from Bullard *et al.* (2003) for the 2008 average feed wheat price (£136) and recent DDGS price (£170) is about 48 p/litre. This is by replacing £65/t and £60/t of wheat and DDGS prices respectively. In this calculation the possible change in energy cost and capital cost over time is not considered. It is likely that energy efficiency has improved through time but the energy cost has increased, so the change in cost may not be significant. With the current duty reduction of 20 p/litre, wheat bioethanol costs appear cheaper than petrol prices (90 p/litre including tax at the time of writing). However, the energy content of bioethanol is not the same as petrol, therefore a litre of petrol can only be replaced by 1.49 litres of bioethanol (Peters and Thielmann, 2008). This will still make bioethanol expensive when compared with petrol, and a 20 p duty concession is not enough to compensate.

Table 2. Estimated cost of production of wheat grain bioethanol from different literature

Authors	Estimated cost of production p/litre	Country	Condition of the study
Batchelor *et al.* (1994)	38.8	United Kingdom	The costings are based on a quote from Chematur engineering AB of Karlskoga, Sweden 78 000 t of wheat/annum. Wheat price £115/t DDGS price £110/t AY = 384.6 litre/t
Bullard *et al.* (2003)	31.94	United Kingdom	AY = 355 litre/t 100 kt/year £66/t of wheat
Turley *et al.* (2004)	28.6	United Kingdom	Based on Batchelor *et al* (1994) and Warren *et al* (1994) and adjusted to current feed wheat and DDGS (soya meal price)
BTG (2004) as published on EUBIA website	41	EU-25	Bioethanol production costs in the EU-25, Bulgaria and Romania Wheat price €140/t = £97.4 (currency rate at: 1/12/04)
Walker *et al.* (2005)	30	United Kingdom	Adapted from Batchelor *et al* 1994 study for 2005 feed wheat and DDGS prices

US maize ethanol can be competitive with petrol, while Brazilian sugar cane ethanol is sometimes even cheaper than petrol (Mastny, 2006). Availability of cheap bioethanol on the international market could be a constraint for the UK bioethanol industry (Walker *et al.*, 2005). Brazilian bioethanol can be produced for as low as 10p/litre (Turley and Ceddia, 2003). Mastny (2006) reported that international trade in biofuels is currently limited because many countries have set tariffs on biofuels in order to protect domestic industries and also to ensure domestic subsidies are not spent to support other countries' industries. This is likely to change because of mandatory blending quotas, as domestic industries cannot supply full demand. Countries such as Brazil which produce ethanol in excess of local demand have the potential to influence the international market significantly.

One of the main reasons to encourage bioethanol or biofuels in general is to reduce greenhouse gas emissions. Although there has been a considerable debate on whether biofuels can reduce greenhouse gas (GHG) emissions, there is a majority consensus that biofuels do reduce GHG compared with petrol, but the quantity of emission saving depends on location, type of feedstock, how the crop is grown, and the fate of byproducts (Smith *et al*., 2006). Therefore, the cost effectiveness of biofuels as a means to reduce greenhouse gas emissions must also be considered. A number of authors have investigated the cost benefit analysis of bioethanol especially in regard to emission savings. IEA (2004) reported that bioethanol does save greenhouse gas emissions, but it may not be a cost-effective way of reducing emissions. The CO_2 abatement costs (CO_2 abatement cost is the additional cost of production of biofuels than fossil fuels which should be compensated by reduction in CO_2 emission) of bioethanol from different feedstocks in different countries were compared (Deconti, 2008). The result indicated that apart from the Brazilian sugar cane bioethanol, the CO_2 abatement costs of all bioethanols are significantly higher than the shadow price of CO_2 (shadow price of CO_2 is an estimate of the damage costs of one additional tonne of carbon emitted into the atmosphere). Among the bioethanol feedstocks compared, wheat has the highest CO_2 abatement cost. In addition to many other reasons such as high biomass production and favourable climate, the lowest cost of production as well as the lowest CO_2 abatement cost of the Brazilian sugar cane bioethanol can be explained by long term experience and the R&D invested to improve the efficiency and productivity of the overall process. More research is justified in order to reduce the cost of production and greenhouse gas emissions, so as to make bioethanol comparable with petrol.

Effect of feedstock quality

For the purpose of demonstrating the economic benefit of feedstock quality, the estimation made by Bullard *et al.* (2003) was used. This study estimated the cost of production of bioethanol in the UK and showed the total annual fixed cost for producing bioethanol from a plant with a processing capacity of 100 kt, of wheat per year (Table 3). According to Bullard *et al.* (2003) the fixed costs include: the capital cost and processing costs required assuming a discount rate of 15% and an economic plant lifetime of 15 years. The total income obtained from DDGS sales is also considered as fixed income and deducted from the total cost of production (i.e. as by-product credit). In their study the feedstock price was considered as the variable cost.

Batchelor *et al.* (1994) demonstrated the responsiveness of the cost of bioethanol production to changes in wheat price, DDGS price and capital cost while every other cost is held constant. This present paper followed the same procedure to show the effect of variability in AY on the production cost of bioethanol.

Table 3. Breakdown of bioethanol production costs adapted from Bullard et al. (2003)

	Annual cost (£)		
Processing capacity	100 kt	200 kt	300 kt
Feedstock cost	13,600,000	27,200,000	40,800,000
Conversion cost (Capital)	3,017,500	4,529,800	5,793,600
Conversion cost (processing)			
Energy	1,898,020	3,497,277	5,087,748
Staff	715,824	1,318,973	1,918,808
Maintenance	271,146	499,611	726,821
Admin. & general over heads	271,146	499,611	726,821
Working capital interest	677,864	1,249,028	1,817,053
Total annual cost	20,451,500	38794301	56870581
By product income	5,185,000	10,370,000	15,555,000
Net cost	15,266,500	28,424,300	41,315,850

The cost of production was calculated by leaving every other cost constant and by allowing the AY to vary. Instead of the constant AY data (355 litre/t) used in the Bullard *et al.* (2003) study, laboratory AY data of 84 samples from 14 varieties grown at 11 sites were used. These samples were part of HGCA Recommended List samples collected from two successive harvest years (2003 and 2004). The alcohol yield data of these samples were assessed in a laboratory by reflecting commercial practice of alcohol processing as described by Brosnan *et al*. (1999) and was obtained from the Scotch Whisky Research Institute (SWRI). The samples showed variation in AY up to 50 litre/t of wheat.

The cost of production of a litre of bioethanol is calculated using: the alcohol yield data from these 84 samples, capital and processing costs obtained from Bullard *et al.* (2003) study and the current feed wheat and DDGS price £136/t and £170/t respectively (average price of year 2008).

Cost of production = total annual cost / bioethanol produced per year
Total annual cost = feedstock cost + conversion cost – by product credit

Data sources

- Feedstock cost = average feed wheat price of 2008 (from HGCA) Although so far there is no bioethanol production from wheat grain in the UK, we know from the experience of the potable alcohol industry that there is no price differential being applied for distilling quality.

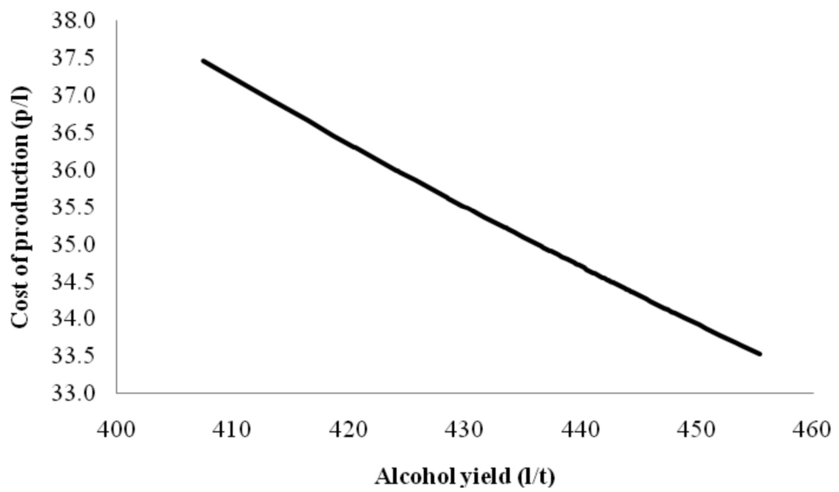
- Conversion cost = capital, operation & maintenance cost from Bullard *et al*. (2003)

- By product credit = DDGS sale income (average price of 2008, Farmers Weekly)

- Bioethanol yield = variable for this analysis (laboratory measured AY)

The range of cost of production p/litre obtained from this calculation is indicated in Figure 3. The best quality wheat and the poorest quality wheat shows great difference in the amount of alcohol produced per year and cost of production in pence per litre. Only 89,460 tonne of best wheat produces as much alcohol as 100 kt of poor quality wheat therefore it saves £1,433,465 from feedstock price (10540 t * £136/t). The amount saved from reduced cost of production of quality wheat is about £1,609,117 per year (40740 kl * 3.9 p/l). This implies, in total, if the plant uses the best quality wheat to produce 40740 klitres of alcohol per year it would save about £3 million a year. This means it earns £34 saving for each tonne of wheat processed.

Figure 3. The relationship of the cost of bioethanol production in p/litre with bioethanol yield litre/t of wheat



At higher plant capacity the saving would reduce slightly. For example a plant with a processing capacity of 200 kt and 300 kt wheat will save £5.8 million and £8.6 million per year or £32.8 and £32.2 per tonne of wheat processed respectively. For plants such as Ensus, with a capacity of 1 million tonnes of wheat, the benefit would be very large although, the exact figure cannot be shown here as the authors could not find cost estimation data on literature for such a large plant size.

This analysis did not include the possible energy saving due to quality of feedstock. A consideration of the cost reduction from energy saving is expected to boost this result substantially. This implies that a quality criterion such as described in the introduction, or a tool which predicts the potential alcohol yielding capacity of wheat and discriminates poor alcohol yielding and good alcohol yielding wheat, will save the company millions of pounds per year.

The sensitivity of cost of production to wheat price and DDGS price was also calculated using the relatively recent estimate of cost of production (Table 3) in order to check if the relationship described by Batchelor *et al*. (1994) remained the same. For example a £20 increase in price of DDGS reduces the cost of bioethanol production by 1.5 p/litre. This result closely agrees with the 2 p suggested by Batchelor *et al.* (1994) for the same DDGS price change (Figure 4). Similarly, £20 increases in wheat price increases the cost of production by 5 p/litre (Figure 5), which is the same as suggested by Batchelor *et al*. (1994). The data confirms the conclusion of Batchelor *et al.* (1994) that bioethanol cost of production is very sensitive to the wheat price. Although the DDGS price also plays a significant role in the bioethanol cost of production, its effect is not comparable with wheat price.

Figure 4. The relationship between the cost of bioethanol production in p/l and DDGS price £/t

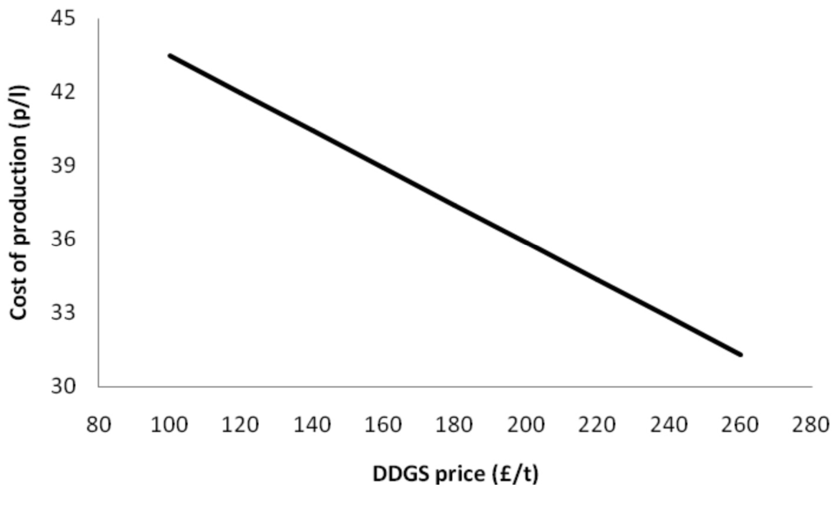


Figure 5. The relationship between the cost of bioethanol production in p/l and wheat price £/t

Conclusions

In current circumstances, bioethanol is not competitive with petrol even allowing for government concessions. To improve this situation, every possible measure will have to be taken in order to make bioethanol perform better. Emphasis should be on the two major costs of the process: feedstock cost and energy cost. A better quality wheat being purchased for intake at the distillery will play a vital role in reducing the overall cost of bioethanol production, hence improving profitability and business sustainability. The potential AY can be maximised by producing good distilling wheat together with efficient processing to extract the available AY from the grain. More fundamental research will be needed to enhance the potential AY of wheat.

About the authors

Kedija Demsis Awole (kawole@harper-adams.ac.uk) is a post graduate research student at Harper Adams University College (HAUC), Shropshire, United Kingdom. Peter Kettlewell is Reader in Crop Physiology at HAUC. Stephen Parsons is National Care Farm Initiative Advisor at HAUC. Martin Hare is Principal Lecturer in Crop Protection at HAUC.

Acknowledgment

We would like to thank Harper Adams University College for funding this research studentship and Scotch Whisky Research Institute for providing us with the alcohol yield data of Recommended List samples

References

Anon, 1983. *Alcohol Fuels. Options for developing countries*. Wachington, D.C.: National academy of sciences.

Anon, 1998. *Gasoline – monthly energy review* (August 1998). Bonneville:US Department of Energy.

Arifeen, N., Wang, R., Kooks, I.K., Webb, C. and Koutinas, A.A. 2007a. Process design and optimization of novel wheat-based continuous bioethanol production system. *Biotechnology Progress* **23**: 1394-1403.

Arifeen, N., Wang, R., Kooks, I.K., Webb, C. and Koutinas, A.A. 2007b. Optimization and cost estimation of novel wheat biorefining for continuous production of fermentation feedstock. *Biotechnology Progress* **23**: 872-880.

Awole, K.D., Kettlewell, P.S., Hare, M.C., Agu, R.C., Brosnan, J.M., and Bringhurst, T.A. 2008. Prediction of alcohol yield from wheat grain. *Aspects of Applied Biology **90**, Biomass and Energy Crops III*, pp. 161-164

Batchelor, S., Booth, E.J., Walker, K.C. and Cook, P. 1994. The potential for bioethanol production from wheat in the UK. *Research review No.* **29**. London: Home Grown Cereals Authority (HGCA).

Biomass Technology Group (BTG). 2004. Bioethanol production costs in the EU-25 + Bulgaria, Romania. As published on EUBIA website http://www.eubia.org/212.0.html [Date accessed 02 May 2008].

Brien, D.J.O. and Craig, J.C. 1996. Ethanol production in a continuous fermentation/membrane pervaporation system. *Applied Microbiology and Biotechnology* **44**: 699-704.

Bringhurst, T. A., Fotheringham , A. L. and Brosnan, J. 2003. Grain whisky: raw materials and processing. In: Russell, I *ed., Whisky: Technology, Production and Marketing*. London: Academic press. pp 77-115.

Brosnan, J.M., Makari, S., Paterson, L. and Cochrane, P. 1999. What makes a good grain distillery wheat? In: Campbell I. ed. Proceedings 5th Aviemore Conference on Malting, Brewing and Distilling, London: Institute of Brewing. pp. 225–228.

Bullard, M., Martin, D., Van den Broek, R., Tijmensen, M., Bradshaw, C., Garstang, J., Boeke, J., Blake, J. and Vertooren, M. 2003. *The Impacts of creating a domestic UK bioethanol industry*. A report for East of England Development Agency, EEDA o2/77 . Prepared by ADAS and ECOFYS. Available from: http://www.eastofenglandobservatory.org.uk/observatory/reports/environment/BioethanolFinalReportJune2003.pdf [Accessed 15 May 2008].

Business, Enterprise and Regulatory Reform. 2007. *The UK road transport biofuels market* [Online]. BERR . Available from: http://www.berr.gov.uk/files/file43824.pdf [Date accessed 02 April 2008].

Copper, G. 2007. Outlook for U.S. ethanol and DDGS production and disposition. In: Doppenberg, J. and Van der Aar, P. *eds*. *Biofuels implications for the feed industry*. The Netherlands: Wageningen Academic

Deconti, M., 2008. *Estimating the cost-effectiveness of biofuels* [Online]. Available from: http://www.defra.gov.uk/environment/climatechange/uk/energy/renewablefuel/pdf/biofuels-080414-2.pdf [Date accessed: 13 May 2008].

Department of the Environment, Transport and the Regions. 1998. National Road Traffic Forecasts (Great Britain). London: Department of the Environment, Transport and the Regions (DETR).

Department of Trade and Industry. 2003. *Energy white paper: Our energy future – creating a low carbon economy.* [online]. Available from: http://www.berr.gov.uk/files/file10719.pdf [Date accessed 9 June 2008]

Department for Transport (DfT). 2006a. *International resource costs of biodiesel and bioethanol*. Department for Transport [Online]. Available from: http://www.dft.gov.uk/pgr/roads/environment/research/cqvcf/internationalresourcecostsof3833 [Date accessed 18 May 2008].

Department for Transport (DfT). 2006b. Notes on biodiesel, bioethanol, and biogas [Online]. Available from: http://www.dft.gov.uk/pgr/roads/environment/rtfo/notesbiodiesel?version=1 [Date accessed 10 May 2008].

Department for transport.(Undated). *About the RTFO programme.* Available from: http://www.dft.gov.uk/pgr/roads/environment/rtfo/aboutrtfo [Date accessed 10 May 2008].

Enguídanos, M., Soria, A., Kavalov, B. and Jensen, P. 2002. Techno-economic analysis of Bio-alcohol production in the EU: a short summary for decision-makers. Institute for Prospective Technological Studies (IPTS). Available from http://ipts.jrc.ec.europa.eu/publications/pub.cfm?id=991 [Date accessed 2 Dec 2008].

European Biomass Industry Association (EUBIA) (Undated). *Creating markets for renewable energy technology EU RES technology marketing campaign* [online]. Available from: http://www.eubia.org/fileadmin/template/main/res/pics/projects/RESTMAC_-_Bioethanol_Production___Use.pdf [Date accessed 10 May 2008].

Green Car Congress (GCC) 2007. First UK Bioethanol Plant Officially Opens.

Available from: http://www.greencarcongress.com/2007/11/first-uk-bioeth.html [Date accessed 02 April, 2008].

Hollins, P.D., Kettlewell, P.S., Parsons, S.T. and Atkinson, M.D. 2006. The impact of supply, demand and grain quality on the UK bread and feed wheat price differential in the UK. *Journal of Agricultural Science* **144**: 411-419.

Home Grown Cereals Authority (HGCA) 2007. *Integrated exploitation of wheat for non-food products: An integration and assessment framework.* Project number 3186. London: Home Grown Cereals Authority.

Hu, Z. , Pu, G. , Fang, F. and Wang, C. 2004. Economics, environment, and energy life cycle assessment of automobiles fuelled by bio-ethanol blends in China. *Renewable Energy* **29**: 2183-2192.

International Energy Agency (IEA). 2004. *Biofuels for transport: an international perspective* [Online] Available from: http://www.iea.org/textbase/nppdf/free/2004/biofuels2004.pdf [Date accessed: 13 May 2008].

Jacques, K.A. 2003. Ethanol production and the modern livestock feed industry: a relationship continuing to grow. In: *The text book of alcohol*. England: Bath Press.

Keim, C.R. and Venkastasubramanian, K. 1989. Economics of current biotechnological methods of producing ethanol. *TIBTECH* . UK: Elsevier Science Publishers. vol **7**: 22-29.

Kindred, D.R., Verhoeven, T.M.O., Weightman, R.M., Swanston, J. S., Agu, R. C., Brosnan, J. M. and Sylvester-Bradley, R. 2008. Effects of variety and fertilizer nitrogen on alcohol yield, grain yield, starch and protein content, and protein composition of winter wheat. *Journal of Cereal Science* **48**: 46-57.

Krishnan, M.S., Taylor, F., Davison, B. H. and Nghiem, N. P. 2000. Economic analysis of fuel ethanol production from corn starch using fluidized-bed bioreactors. *Bioresource Technology* **75**: 99-105.

Kwiatkowski, J.R., McAloon, A.J., Taylor, F. and Johnston, D.B. 2006. Modelling the process and costs of fuel ethanol production by the corn dry-grind process. *Industrial Crops Production* **23**: 288-296.

Mastny, L. 2006. Biofuels for transportation – Global potential and implications for sustainable agriculture and energy in the 21st century. Germany: Worldwatch Institute.

Meredith, J. 2003. Understanding energy use and energy users in contemporary ethanol plants. In: *The alcohol text book*. Nottingham: Nottingham University Press.

Mol, A.P.J. 2007. Boundless biofuels? Between environmental sustainability and vulnerability. *Sociologia Ruralis.* **47**(4): 297 – 315.

Morrisons 2006. *Morrisons opens the UK's first bioethanol E85 fuel pump- as SAAB GB launches its 9-5 biopower for consumers that care.* Available from: http://www.morrisons.co.uk/1424.asp [Date accessed: 15 January 2008].
National Non Food Crops Centre (NNFCC). 2008. Biofuels update: The UK biofuel supply chain in 2008. Newsletter Issue 10 – spring 2008.

Pass, B. and Lambart, L. 2003. Co-Products In: Russell, I., Bamforth, C.W. and Stewart, G. *eds. Whisky: Technology, Production and Marketing.* London: Academic press.

Peters, J. and Thielmann, S. 2008. Promoting biofuels: Implications for developing countries. *Energy Policy* **36**: 1538-1544.

Pfuderer S. and Castillo, M. del 2008. *The impact of biofuels on commodity prices. Economics group Defra. Department for Environment and Rural Affairs.* Available online: http://www.defra.gov.uk/environment/climatechange/uk/energy/renewablefuel/pdf/biofuels-080414-4.pdf [date accessed 18 May 2008].

Robinson, M. 2002. *Alternative uses of wheat*. Leicestershire: Nuffield Farming Scholarships Trust.

Schulze T., Krenn, W. and Potschacher, P. 2005. Basic considerations and concepts in the planning and construction of grain-based bioethanol plants. *Zuckerindustrie* **130**:707-711.

Senn, T. and Pieper, H.J. 2000. Classical Methods. In: Roehr, M. *ed, The Biotechnology of Ethanol.* Weinheim: Wiley-VCH.

Smith, T. C., Kindred, D. R., Brosnan, J. M., Weightman, R. M., Shepherd, M. and Sylvester-Bradley, R. 2006. Wheat as a feedstock for alcohol production. *Research Review No. 61.* London: Home Grown Cereals Authority (HGCA).

Swanston, J.S., Newton, A. C., Brosnan, J.M., Fotheringham, A. and Glasgow, E. 2005. Determining the spirit yield of wheat varieties and variety mixtures. *Journal of Cereal Science* **42**:127-134.

Swanston J.S., Smith, P.L., Gillespie, T.L., Brosnan, J. M., Bringhurst, T. A. and Agu, R. C. 2007. Association between grain characters and alcohol yield among soft wheat varieties. *Journal of the Science of Food and Agriculture* **87**: 676-683.

Tesco plc. 2006. Biofuels. Available from: http://www.tescocorporate.com/biofuels.htm [Date accessed: 04 April 2008].

Tucker, M.P., Nagle, N. J., Jennings, E. W., Ibsen, K. N., Aden, A., Nguyen, Q. A., Kim, K. H. and Noll, S. L. 2004. Conversion of Distiller's Grain into fuel alcohol and a higher value animal feed by dilute acid pretreatment. *Applied Biochemistry and Biotechnology* **115**: 1139-1159.

Turley, D. and Ceddia, G. 2003. *Liquid biofuels – industry support, cost of carbon savings and agricultural implications.* Prepared for Defra Organic Farming and Industrial Crops Division [online] Available from: http://www.defra.gov.uk/farm/crops/industrial/research/reports/biofuels_industry.pdf [Date accessed: 13 May, 2008].

Turley, D.B., Boatman, N.D., Ceddia, G., Barker D. and Watola, G. 2004. *Liquid biofuels –Prospects and potential impacts on UK agriculture, the farmed environment, landscape and rural economy.* Report prepared for Defra, Organics, Forestry and Industrial Crops Division. Central Science Laboratory, Sand Hutton, York. Available from: http://www.defra.gov.uk/farm/crops/industrial/research/reports/biofuels_prospects.pdf [Date accessed: 03 March 2008].

Walker, K.C., Booth, E.J., Ross, D., Entwistle, G., Walker, R. L., Thomson, J., Askew, M. F., Holmes, C., Ceddia, G., Hugo, S. and Garrod R. 2005. *Opportunities for sustainable substitution of non-renewable materials with materials derived from agricultural crops*. A report for Defra Project NF 0516 [Online]. Available from: http://www.defra.gov.uk/defrasearch/index.jsp?query=opportunities+for+sustainable+ [Date accessed 23 May 2008].

Wareen R.K., MacDonald D.G. and Hill G.A. 1994. The design and costing of continuous ethanol processing using wheat and cell recycle fermentation. *Bioresource Technology* **40**: 263-273.

Watts, B. 2008 Manager of the North British Distillery Company Ltd, *personal communication*

Wooley, R., Ruth, M., Glassner, D. and Sheehan, J. 1999. Process design and costing of bioethanol technology. A tool for determining the status and direction of research and development. *Biotechnology Progress* **15**: 794-803.

Worldwatch Institute. 2007. *Biofuels for transport – global potential and implications for sustainable energy and agriculture.* London: Earthscan. pp, 110