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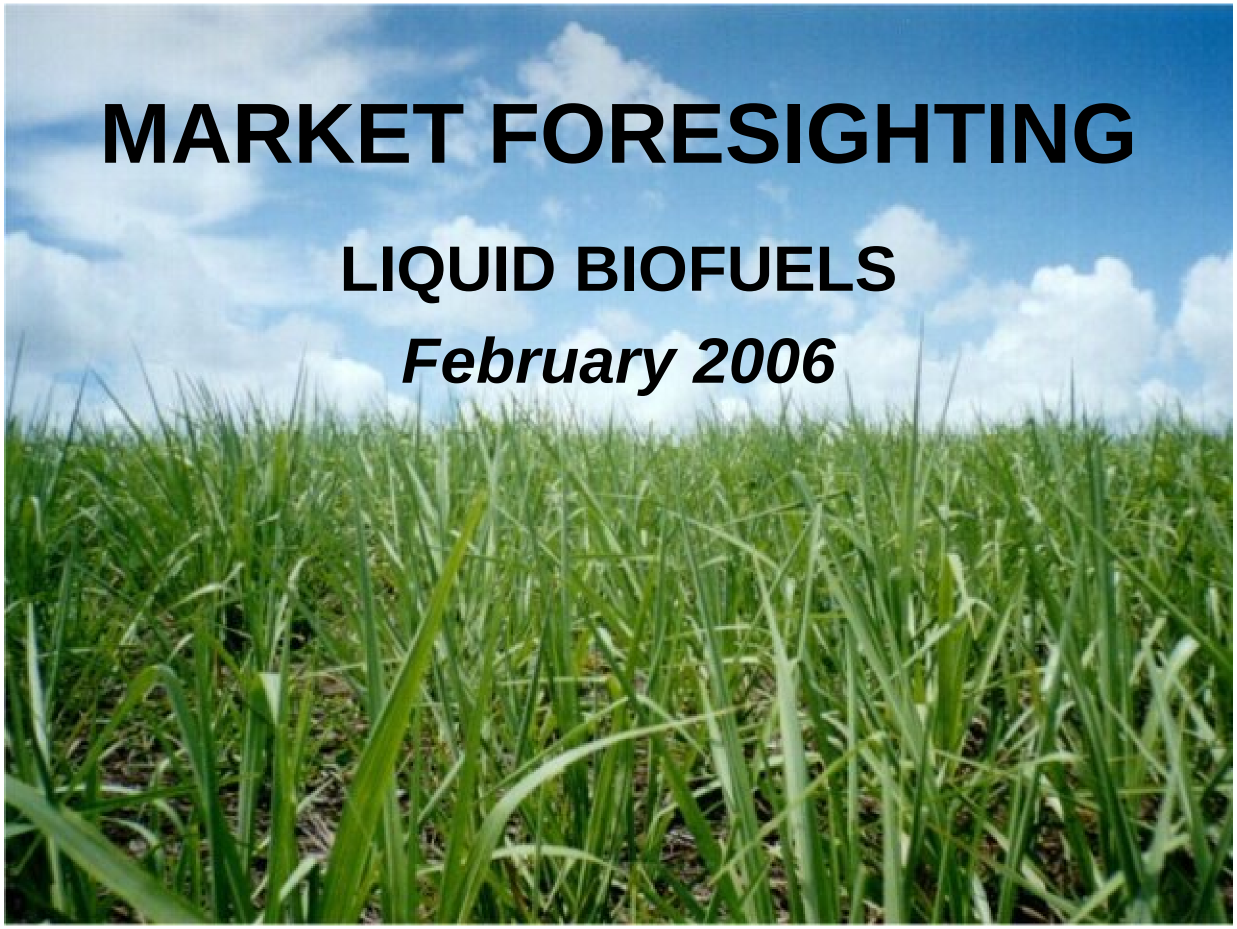
MARKET FORESIGHTING

LIQUID BIOFUELS

February 2006



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Why is ITI Life Sciences interested in liquid biofuels?

- Liquid biofuels are an extremely hot topic reflecting the rising global awareness of climate change.
- ITI Life Sciences is keen to assess the scope for innovations within the **life sciences industry** which could add value in liquid biofuels.
- While attention on biofuels intensifies, it is critical to assess the **real** market opportunities for Scotland under a commercially viable framework, targeting Global markets.
- A number of technical challenges along the value chain remain, presenting the ITIs with potential opportunities to invest.
- Liquid Biofuels are potentially an opportunity for Scotland's crop base to diversify and for Scottish academia and industry to add value via collaboration.
- ITI Energy are currently exploring alternative high value added uses for biodiesel by-products.

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Scope of this foresighting report

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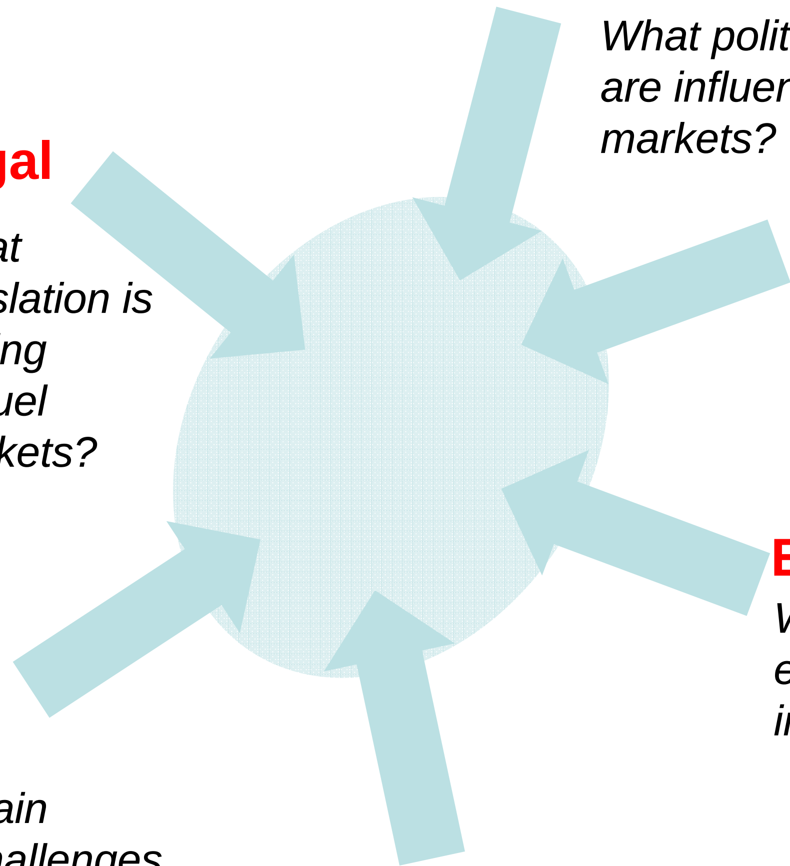
In order to assess biofuel opportunities in Scotland, ITI Life Sciences has broadened its focus, based in part on the framework opposite:

While we consider biofuels as a whole, each market segment is impacted by these forces to differing extents



Political

What political dynamics are influencing biofuel markets?

Legal

What legislation is driving biofuel markets?

Economical

Does domestic production of biofuels make economic sense?

Environmental

What is the actual environmental impact of biofuels?

Technology

What are the main technological challenges the ITIs can help address?

Sociocultural

Will social or cultural issues impact on biofuel adoption?

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The key forces include:

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Political/ legal forces

- Kyoto agreement driving EU member states to cut CO_2 emissions.
- Reform of the Common Agricultural Policy in 1992/2004.
- Political need to align with environmental concerns of voters.
- Effect of tax on oil revenues in the long term.
- Impact of Brazilian exports on global biofuel markets going forward.
- Competition between other value chains and biofuels for feedstock.
- Security of fuel supply and domestic capacity.

Socio-cultural forces

- Consumer awareness and acceptance.
- Sustainable development.
- Longer term view on next generation fuels.
- Lifestyle impact of car performance.
- Fuel efficiency-miles per gallon/litre.

Economic forces

- The net energy balance must be understood in greater context, but its impact is less assertive.
- Economic impact if feedstock is diverted to biofuel use.
- The need for sufficient infrastructure to process feedstock.
- Readiness of vehicle manufacturers and uneducated buyers.
- Risk of oil price change on biofuel competitiveness.
- Demand for biofuels.
- Markets for by-products.

Technological forces

Bioethanol

- Improving bioethanol yields from lignocellulose.
- Minimising energy losses during distilling and fermenting.
- Optimise enzymes to drive down energy cost.

Biodiesel

- Improving the oil yield from existing crops.
- Possible introduction of new crop varieties.

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The key findings (1)

There is a significant market opportunity

The introduction of a UK Road Transport Fuels Obligation (RTFO), requiring that 5% of the UK's transport fuel comes from a renewable source by 2010, creates a tangible UK demand that must be met by domestic production or imports. Despite a ramping-up of biodiesel production in the UK and the introduction of domestically produced bioethanol during 2006 (several bioethanol plants will come on-line in 2006), the overall output is expected to fall well short of that required to meet the RTFO. It may be more economically viable to supplement a limited domestic level of production with imports. Critically, the UK will also need substantial investment in infrastructure and to address supply chain hurdles if it is to create a viable biofuels market.

Scotland lacks an ideal feedstock and infrastructure to make bioethanol production in Scotland globally competitive

ITI Life Sciences' cost analysis suggests that bioethanol produced from a wheat feedstock would be able to compete with mineral oil. However, while Scotland does grow wheat, it is a net importer, and thus England has a better competitive position. Scotland does have a surplus of barley; however, barley is not an ideal bioethanol feedstock and we believe that further analysis is required to assess whether it is a viable alternative to wheat. To iron out fluctuations in feedstock supply, a bioethanol plant would ideally be able to process several feedstocks. Once again the variety of crops available in Scotland for bioethanol production is limited compared to other geographies.

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The key findings (2)

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Bioethanol is competitive with fossil petrol providing that the bioethanol production costs are no greater that c.18p/l of the refining cost of petrol

Based on projections using a 70 million litre plant, which was considered the most relevant scale for Scotland, bioethanol could be produced from wheat within the range of 30 to 40p/l compared to 20 to 25p/l for gasoline. This emphasises the important role of the 20p/l tax rebate in closing the price gap. Cost of production via barley was found to be only 8% greater than wheat. A number of factors could significantly influence costs, such as the cost of feedstock, value of by-products, changes to the Common Agricultural Policy and the EU sugar beet reforms. Clearly the current high price of oil improves the case for biofuels.

The environmental case is not as robust as it seems

Liquid transport biofuels have the potential to help meet the climate change targets in the Kyoto agreement, but while CO2 emissions from transport fuels could be reduced by the use of biofuels, a 5% blend in the UK will only reduce greenhouse gas emissions to a minor extent. The environmental effects of other emissions through combustion of biofuels are less certain.

The jury remains out on whether bioethanol releases more energy than is used to produce it

Despite conflicting studies it would appear that on a commercial scale it requires at least as much energy to produce bioethanol as it creates. However, more recent studies suggest a trend towards a positive net energy balance which will continue to improve with technical advances.

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The key findings (3)

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Bioethanol production is sub-optimal and there is significant scope for improving the process through the application of life science technologies and know-how

Bioethanol production is currently inefficient due to a large number of energy intensive steps in the production process. It is therefore important to examine any technologies that could improve bioethanol production. Significant work has been conducted in certain areas such as enzyme technology, with world class players such as Novozymes dominating. There is also scope to create feedstocks specifically optimised for producing liquid transportation fuels. Perhaps most importantly, yields of bioethanol from lignocellulose or whole-crop cereals and other forms of biomass such as forestry products remain a major area for innovation and an area Scotland may be well placed to serve.

There is relatively limited scope for improving biodiesel production through the application of core life science technologies and know-how

The main focus of innovation in biodiesel production revolves around improving the yield of oil from existing crops and exploring new crop varieties. Addressing the market demand will largely be solved through development of infrastructure and processing plants, which are not core areas of ITI Life Sciences.

ITI Energy is actively exploring alternative high value added uses for biodiesel by-products.

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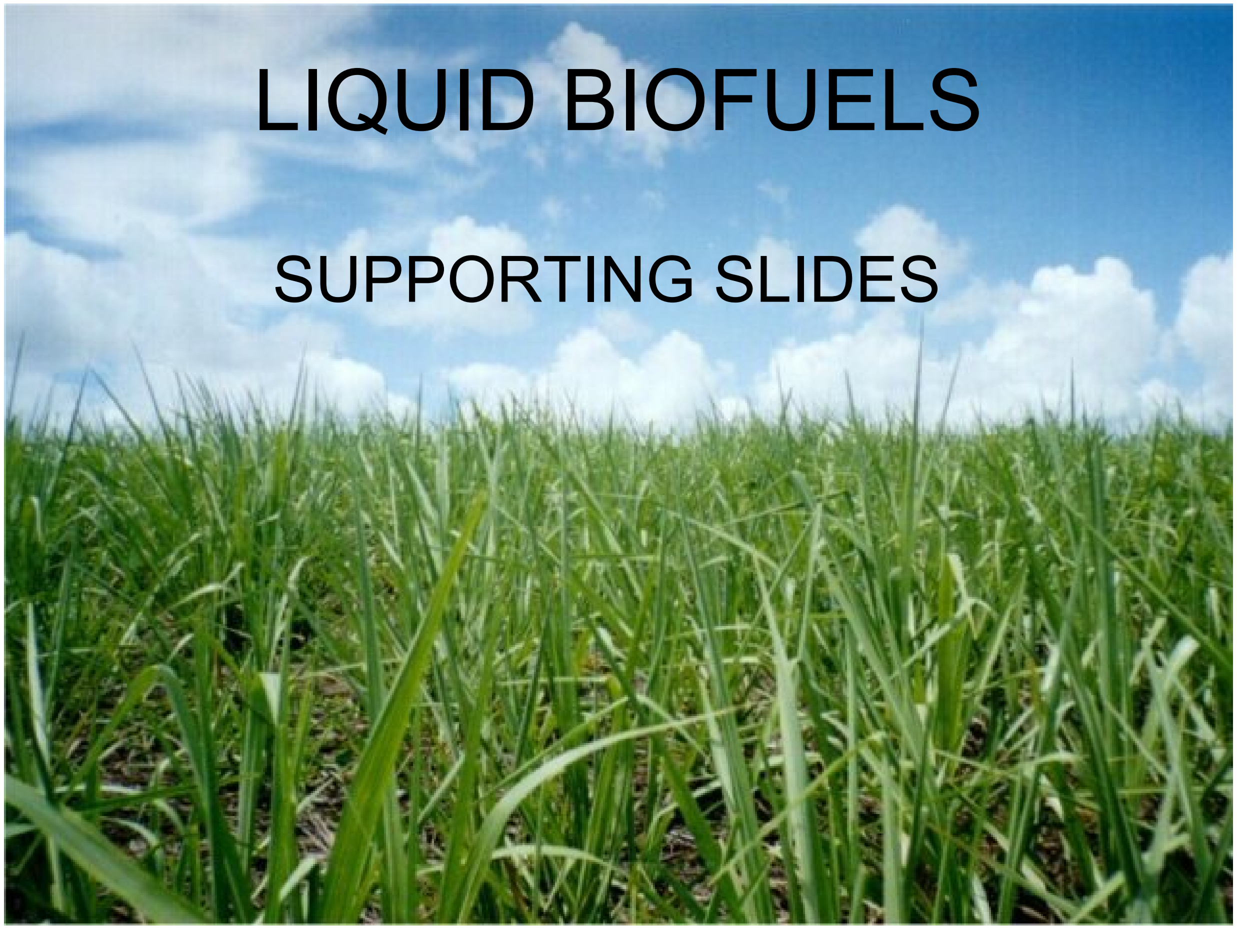

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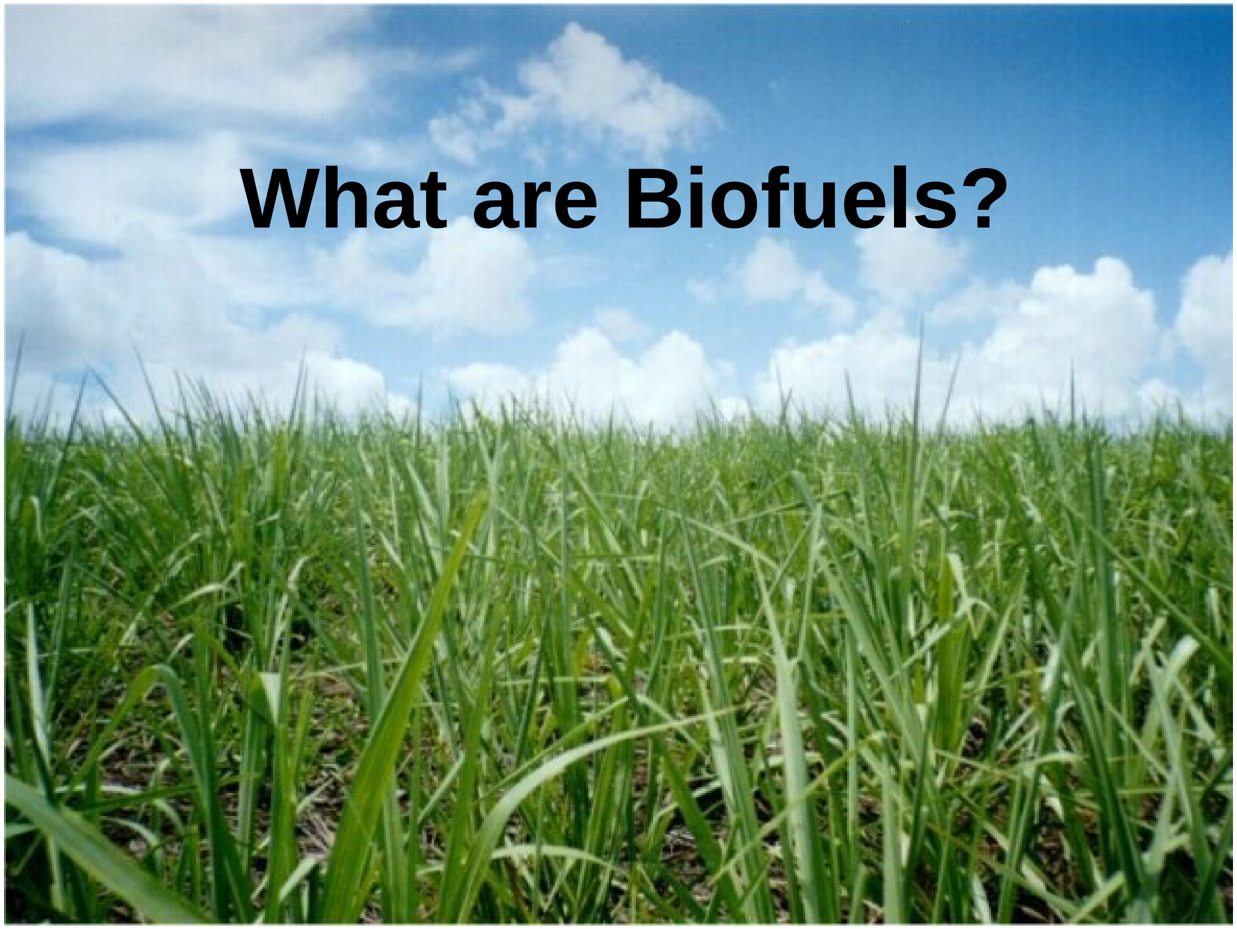

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Biofuels are a renewable natural fuel source which have the potential to serve as an alternative to fossil based fuels. In our analysis, we will be focusing on liquid biofuels, which depend on feedstocks from agricultural sources, primarily for use in transportation.

Biofuels have the potential to:

- Meet climate change commitments

  Climate change is one of the greatest environmental threats facing mankind. Under the Kyoto agreement, the EU is committed to reducing CO_2 emissions by 8% between 2008 and 2012. Biofuels can produce up to 50% less CO_2 than conventional fossil mineral fuels.

- Reduce reliance on fossil fuels and dependence on foreign oil imports

  The UK Government is concerned at the decline of indigenous energy supplies. Biofuels can reduce a nation's reliance on imported oil, improve fuel security and diversity of supply while significantly improving the economies in rural areas.

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Conventional biofuels can be processed from a range of natural sources by a number of long established methods including those below. At present, biodiesel and bioethanol are the principal commercially viable biofuels available.

To make biofuel production economically viable, the industry is faced with the dual challenge of procuring large quantities of biomass feedstock at an affordable price and making production processes simple and efficient.

Biofuel	Conventional name	Production process
Biodiesel from seeds	Biodiesel	Transesterification
Biodiesel from co-products (used oils/fats)		Refining, transesterification
Ethanol from sugar crops	Bioethanol	Fermentation, distillation
Ethanol from starch crops		Hydrolysis, fermentation, distillation
Ethanol from celluloses		Advanced hydrolysis, fermentation, distillation
ETBE	Bio-ETBE	Synthesis from bio-ethanol and isobutene
Diesel from bio-mass	Synthetic biofuel	Gasification and synthesis
SNG from biogas	Biogas	Digestion, CO_2/H_20 removal

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ETBE: Ethyl tertiary butyl ether SNG: Substitute natural gas

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It's all in the blend

In Europe, only a maximum of 5% by volume of bioethanol or biodiesel can be blended into transport fuels without invalidating vehicle warranties. However, biodiesel produced to EU Quality standard EN14214 can be used in specified engines at 100%.

Additionally, the EU Fuels Directive 2003/17/EC and the UK Motor Fuels (Composition and Content) Regulations place limits on compatibility of materials and effects of trace by-products and other matters. It is likely that blend volumes in Europe will increase in coming years placing greater demand on producers and the industry as a whole.

Some regional limits for biofuel content are higher as summarised below*:

Territory	Blend	Comments
Europe	B5	Mostly from rape seed oil
	B100	Available in Germany and Austria
	E5	A shift to E85 is possible
USA	E10	10% ethanol to standard gasoline is common
	E70-E85	Blend varies with region and season
	B20	Some use in Canada and USA
	B100	Californians use neat biodiesel
Brazil	E25-E75	Possible via "flex-fuel" engines

*The biofuel constituent is indicated with a capital "E" for ethanol or "B" for biodiesel followed by the percentage blend.

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The biofuel market continues to be driven by regional legislation

Under the Kyoto agreement, the EU committed to reducing CO_2 emissions by 8% between 2008 and 2012.

The main incentive for Governments and the European Commission to support biofuels is the fact that biofuels produce around 50% less CO_2 than mineral fuels.

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There is a significant market opportunity…

- Approximately 789,000 m^3 of bioethanol was consumed in Europe in 2004, generating revenues of €374m. Over €4bn of revenues are forecast for 2011. As bioethanol is blended with gasoline the consumption also depends to a large extent on the policies the oil majors adopt and the political or social pressures put on them.
- While a number of European countries have developed significant biofuel capabilities thanks to fuel tax rebates and economies of scale, the UK has lagged behind but is starting to address this, but mainly in terms of biodiesel production.
- The recent Renewable Transport Fuel Obligation (RTFO) announcement by the UK government creates a clear market need and is a major driver for the UK biofuel market going forward since biofuels must be sourced, though not necessarily in the UK.
- Significant market growth is expected in 2005 and 2006 as all previous MTBE sites convert to ETBE and consume ethanol as feedstock. However bioethanol production in the UK is only just starting.
- Biodiesel currently has a European market size of €1.5bn and double digit growth.
- Since 2004, UK capacity for biodiesel production has ramped up with further major capacity increases proposed by Greenenergy in partnership with Novaol, and Argent Energy for 2006, but scarcity of domestic source material remains an issue.

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…but a number of challenges remain including:

- Making the production processes **cost-effective**
- Balancing multiple agendas and stakeholders
- Reallocating sufficient crop base and feedstock
- Ensuring environmental impact is not negative/disruptive
- Meeting the **change in supply/demand** over time

The solutions include:

- Technological innovation to circumvent bottlenecks
- National/EU legislation on tax/subsidies
- Realistic balance between imports and UK production?

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Understanding the complex array of dynamics influencing the future of biofuels requires focus

In this report, we have focused on bioethanol and biodiesel rather than more speculative solutions further from commercial reality.

It is important to understand that while bioethanol and biodiesel are influenced similarly by legislation and market forces, they must be considered independently due to the different scope of challenges they present to markets, innovators and investors.

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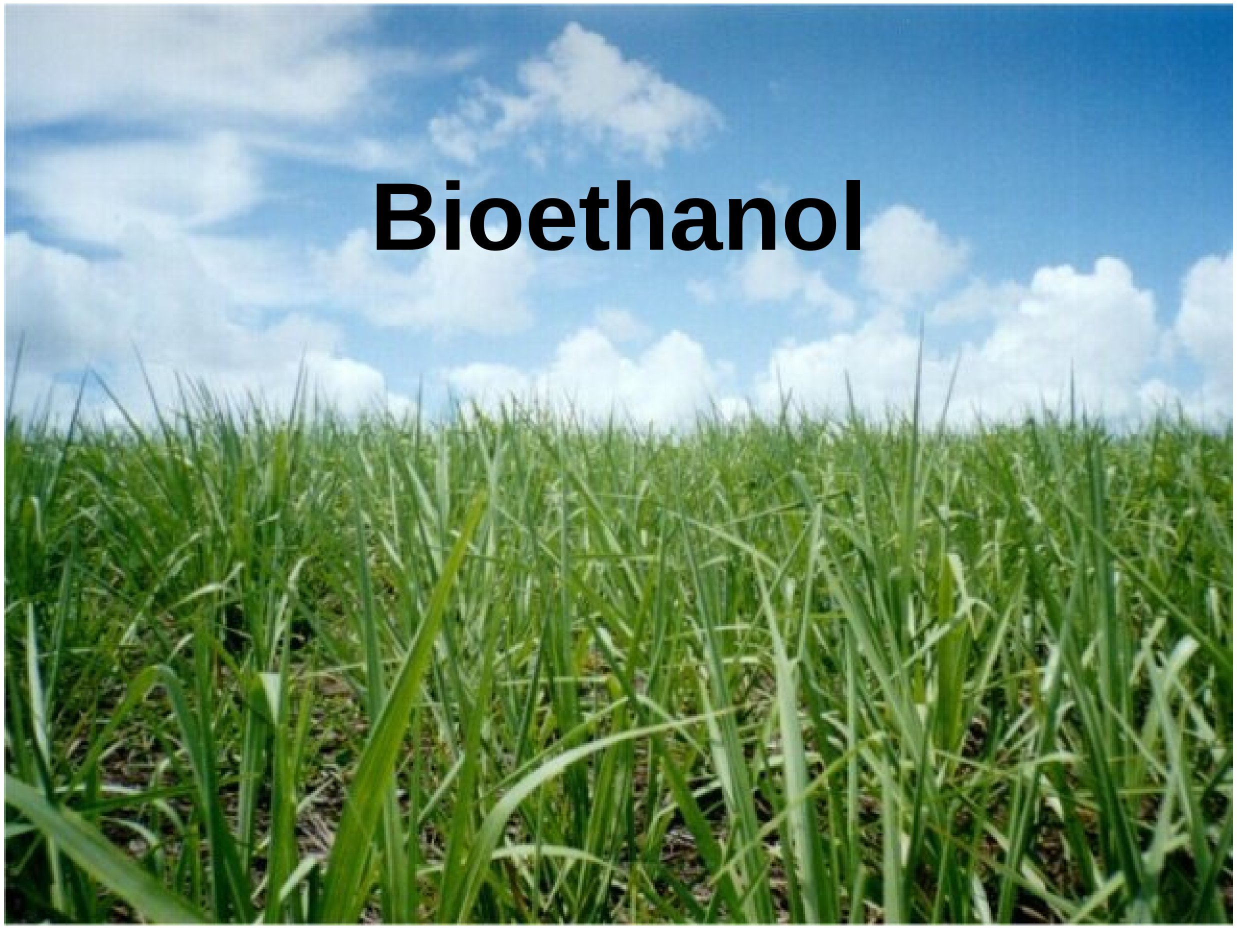

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Bioethanol

Bioethanol mainly originates from the biological fermentation of sugars or carbohydrates derived from plant sources.

Use of ethanol as transport fuel is not a new concept: Henry Ford's model T was designed in the 1920s to run on ethanol, or an ethanol petrol mix.

The large scale market for bioethanol emerged in 1975 from Brazil's National Fuel Ethanol Programme aimed at producing bioethanol from their abundant sugar cane feedstock. Now one third of all cars in Brazil run on bioethanol using "flex fuel" engines able to use various blends of bioethanol with gasoline. In total Brazil produces around 13 bn/l/yr of bio-ethanol.

The USA are a major producer of bio-ethanol from grain, with around 6 bn/l/yr currently being blended to produce various grades of motor-fuels.

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Bioethanol has a number of advantages over petrol

- A higher octane rating increases resistance to knocking and boosts efficiency. As an additive, ethanol in the form of ETBE can increase fuel economy by 2% in terms of distance travelled per unit volume of fuel, 5% in distance per unit of energy and up to 10% in specific power output.
- Has lower emissions of some pollutants, carbon monoxide, nitrogen oxide and negligible sulphur dioxide and aromatics.
- It can be extinguished with water if on fire.

But..

- Bioethanol produces higher emissions of formaldehyde and acetaldehyde, the effects of which are not clear.
- Less volatility compared with petrol makes engines more difficult to start in winter.
- Petrol alcohol blends will absorb water necessitating care to ensure water does not enter the fuel distribution system.

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Look to Brazil for evidence of success

- Thanks to a 29 year old ethanol programme, Brazil is now the world's low cost producer.
- The Brazilian ethanol program provided nearly 700,000 jobs in 2003.
- Oil imports between 1975-2002 were cut by a cumulative undiscounted total of $50 bn.
- This was more than ten times its total undiscounted real investment between 1975 and 1989 and around 50 times its cumulative 1978-1988 start up subsidy.
- Ethanol has replaced 25% of Brazil's gasoline, using only 5% of the land in agricultural production.

Key drivers of Brazil's success

- The government guaranteed purchases by the state owned oil company Petrobras.
- Low interest loans were available for agro-industrial ethanol firms.
- Fixed gasoline and ethanol prices where hydrous ethanol sold for 59% of government set gasoline prices at the pump.
- These factors have made ethanol production competitive without subsidy.
- Brazilian "total flex" cars introduced by VW and GM can use any pure or blended fuel from 100% gasoline to 100% ethanol.

It is important to note however, that the Brazilian model is not particularly relevant in the UK largely for reasons of scale, feedstock and land availability. A number of bioethanol initiatives of note are highlighted in the appendices.

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Production of bioethanol

A number of agricultural sources may be used for conversion into bioethanol, each of which presents technologically unique challenges for commercial scale production.

The main sources are:

Sugars

Starches

Lignocellulose

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Main sources of bioethanol

Sugars

When extracted from sugar-rich plants such as sugar cane and sugar beet, direct fermentation by yeast yields bioethanol after pre-treatment and enzymatic hydrolysis.

- The 3 main sugar crops are sugar cane, sweet sorghum and sugar beets. Sugar beet has the most potential for use in the UK for ethanol production with the advantages of producing high yields per hectare and high yields of beet pulp and beet top co-products.
- Sugar beet has not however, been grown in Scotland since the late 1960s.

Starches

Upon conversion of starch-containing grains such as wheat, maize and barley to sugar by hydrolysis, fermentation produces bioethanol. One advantage of using starchy feedstocks is that storage is easier than for sugar juice, but starch must be broken down into sugar before fermentation, although this process is relatively small.

- Maize has been used on a large scale in the USA. Potential home grown feedstocks in Scotland include wheat, barley and potatoes.
- An important factor in the choice of starchy feedstock is the starch content, with wheat and potatoes containing relatively high starch levels compared with maize which is in turn better than barley.
- Potatoes are generally cultivated for high quality seed potato production in Scotland, reducing the attractions of the lower value bioethanol market.
- A further disadvantage of using potatoes is that the costs of conversion are considered to be higher than for cereals.

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The production process

Sugar & starch crops are expensive and in demand for food use

Sugars → **FERMENTATION**

Starches → **Pretreatment** → **Enzymatic hydrolysis** → **FERMENTATION**

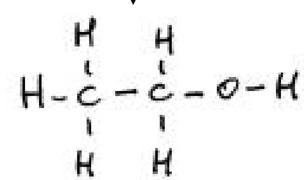
Cellulosic materials → **Pretreatment** → **Acidic/enzymatic hydrolysis** → **FERMENTATION**

Cellulosic methods currently at developmental batch stage with 40-55% efficiency

FERMENTATION

DISTILLATION

Heat recovery is a key area of focus for improved efficiency



ETHANOL → **Further distillation** → **ANHYDROUS ETHANOL**

energy intensive step

The whole process consumes 30- 40% of the energy produced

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Inefficiencies in the production process provides significant scope for innovation

- Plant science genetics offers the potential to generate crops with increased yield and utility tailored for producing biofuels.
- In optimising the feedstock, the challenge is developing crops with desirable physical and chemical traits while increasing biomass yields. Although many crops benefit from centuries of domestication, perennial species that could provide a renewable source of feedstock for conversion to fuels have not had such attention to date.
- Increasing the productivity of energy crops may depend on addressing those constraints with modern genomic tools. An obvious target is manipulation of photosynthesis to increase the initial capture of light energy, which at present is less than 2%.
- Since the efficiency of the bioethanol process depends on hydrolyzing agents gaining access to plant polysaccharides, alteration of plant cell wall structure could yield important advantages. For example, research suggests that when the percentage of lignin in poplar is reduced, the cellulose component of the plant cell wall is more easily digested by a bacteria and twice as much sugar is released. The intensive genetic engineering used to alter lignin structure and content to improve wood and papermaking quality has demonstrated the potential of these approaches.
- Exogenous depolymerization enzymes used in the bioethanol process could be replaced with plants capable of synthesizing these enzymes *in situ*. Enzymes, such as cellulase (converts cellulose to glucose), could be triggered for plant biosynthesis when an inducer is applied to the plant.
- Although biological protocols for converting polysaccharides to bioethanol are among the most developed process technologies available for biofuels, other promising chemical technologies are emerging driven by rapid advances in catalysis. This could lead to a suite of catalytic systems that will facilitate the conversion of biomass polysaccharides to liquid alkanes and oxyalkanes for fuel applications.

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Production of bioethanol from lignocellulose remains a hotly contested area

- Lignocellulose differs from conventional feedstock by its composition, namely cellulose, hemicellulose and lignin, which can vary depending on the source.
- Sources can be divided into waste products (such as agricultural residues, forestry residues and municipal solid waste), and materials grown for fuel production (such as woody or herbaceaous energy crops or trees produced by conventional forestry).
- **The production from lignocellulosic sources is more technically challenging for a range of reasons including:**
  - **Pre-treatment of the feedstock** and liberation of glucose and xylose from the biomass. The feedstock is subjected to physical, chemical and enzymatic processes to hydrolyse the sugar polymers to monomers. Generation of a large amount of inorganic waste such as gypsum and high production costs, particularly in enzymatic cellulose hydrolysis (c.50% of production costs), have hampered technological progress.
  - **Xylose fermentation** to ethanol. The Xylose in the feedstock is not converted to ethanol with ordinary strains of baker's yeast. An economically viable solution to Xylose fermentation is one of the holy grails in bioethanol production from lignocellulose.

- Further reductions in production costs are still possible through process optimisation, efficient use of waste residue (lignin and other non fermentable components) to heat and power generation and production of more cost effective enzymes.

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Lignocellulose remains a key area for innovation..

- All critical areas of technological weakness are under rigorous scrutiny by companies, universities and research institutes, particularly where regulation for bioethanol is supportive, such as Canada, USA, Sweden and Spain.
- Most recently (31/1/06), US President George Bush called for increased investment in new technologies to produce bioethanol. The administration's fiscal 2007 budget request will include $150 million for enzyme R&D to make fuel ethanol from cellulosic biomass, which is a $59 million increase over fiscal 2006.
- Introduction of new technology will depend largely on subsidy and the establishment of market certainty over demand. Ethanol from conventional feedstock cannot meet demand therefore lignocellulosic drivers are strong.
- It is expected that significant progress in these areas will be demonstrated before the end of the decade, particularly in fermentation of Xylose to increase production efficiency, and a transition to feedstocks containing less starch, perhaps through GM technology.
- Simultaneous saccharification and fermentation (SFF) is also being considered since simultaneously removing simple sugars can reduce inhibition of enzymatic hydrolysis, although each process requires a different optimal temperature. The use of thermo-tolerant bacteria to convert sugars at higher fermentation temperatures may be possible.
- Amongst the most significant initiatives include the demonstration plant built by Iogen from Canada, the National Renewable Energy Laboratory (NERL) in the USA and ETEK from Sweden.
- At the enzyme level, Novozymes and Genencor are both producing enzymes for conversion of starches into fermentable sugars. Other major organisations tackling C5 fermentation include VTT Biotechnology (Finland), ATO (Netherlands) and the Danish Biofuel Centre.

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...with Iogen making significant progress

In January 2006, Volkswagen, Shell and Iogen Corporation (Canada) announced that they would conduct a joint study to assess the economic feasibility of producing cellulose ethanol in Germany.

Iogen has commercialised technology making it economically feasible to convert biomass into cellulose ethanol using a combination of thermal, chemical and biochemical techniques. The yield of cellulose ethanol is more than 300 litres per tonne of fibre due in part to addressing the following key areas of production:

Pretreatment: pretreatment aims to increase the surface area and "accessibility" of the plant fibre to enzymes, reducing overall conversion costs. This is achieved through a steam explosion process, a core Iogen technology.

Enzymatic Hydrolysis: Iogen has developed enzymes able to break down cellulose thanks to their expertise in producing enzymes for fibre processing industries including pulp, paper and textiles.

Ethanol Fermentation: Iogen has licensed a strain of *Sacharomyces cerevisiae,* 424A(LNH-ST) from Purdue University. This modified yeast can co-ferment glucose and xylose. The ability to ferment xylose increases the yield of ethanol from straw by about 40%.

The output from fermentation is then distilled using conventional technology to produce cellulose ethanol for fuel grade applications.

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Fact or Fiction: the net energy balance of bioethanol production

- Where energy balances are used the concern is generally with the amount of non-renewable energy used to produce renewable energy.
- Some researchers have long argued that renewable fuels such as bioethanol, and to a lesser extent biodiesel, take more energy to produce than they provide – giving a negative "net energy balance" and should also consider energy contained in by-products of production.
- It should be noted however, that the energy balance for bioethanol depends on a portion of renewable energy throughout production and processing.
- It is argued that old evidence fails to account for dramatic increases in production efficiency through industrial biotechnology and improved enzyme efficiency with significantly lower costs.
- Energy balance varies according to a range of input and output conditions such as yield, fertiliser and pesticide application and variation in grain moisture content at harvest.

"We are burning the same amount of fuel twice to drive a car once" **Tad Patzek, University of California, Berkeley**

"Virtually all studies before 1990 show a net energy loss. Virtually all of the studies after 1990 show a net energy gain. This is because the ethanol industry…. has become more efficient over the years" **David Morris, Institute of Self Reliance, Minneapolis**

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For bioethanol, it depends where you draw the line

From a study by Batchelor (1994), when bioethanol was the only output considered, the energy balance was less than one. If the by-product distillers dried grains with solubles (DDGS) was included, the balance became positive, but was still low. Including the use of straw as a fuel, the energy balance became positive under all conditions, but only just.

More recent energy balance calculations (Richards, 2000) indicated an energy balance of 1.11 for bioethanol, and 2.51 where straw is burned for fuel. These balances reflect the continuing increase in crop yields and efficiency improvements in nitrogen fertiliser manufacture.

Work in France (Poitrat, 2003) considered the energy balance in terms of energy released as a proportion of non-renewable energy used in production. Bioethanol produced from wheat and sugar beat resulted in an energy balance of 2.05 for both crops compared with 0.87 for gasoline.

However, the International Energy Agency (2004) revealed a loss when considering the amount of process fuel required to grow crops, transport to distilleries, production of bioethanol and delivery to refuelling stations.

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Improving the net energy balance of bioethanol provides scope for innovation

There appears to be greater scope for reducing energy input in the processing rather than the field production area. There has been a significant focus on improving enzyme technology.

It is thought that in some cases such innovations have doubled yields, greatly reduced energy inputs and reduced capital costs.

In the production process, enzymes hold a number of advantages with potentially high efficiency, control of by-products, mild process conditions and relatively low process energy demand.

However, due to the tough crystalline structure, the enzymes require several days to achieve good results. The long process times thus requires expensive plant capacity.

Recently, scientists in the USA have reported that ethanol produced from switch grass or other cellulosic biomass with newly engineered industrial enzymes cuts petroleum use by 70% and reduces greenhouse gas emissions by 64% in flexible fuel vehicles.

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But how critical is the net energy balance overall?

Despite the differing points of view on the overall net energy balance, it is clear that overall the balance is not particularly compelling from an environmental point of view.

It should be considered whether the energy used in the production and processing phases is in reality being traded at a lower level than its true value. As outlined, the processing stage accounts for the largest proportion of the energy input (60-90% of the energy).

Investigation of the cost of this energy compared to the value obtained for the transport energy produced as the final product may help to explain this.

In the greater context, political and market driven forces will outweigh concerns over the net energy balance.

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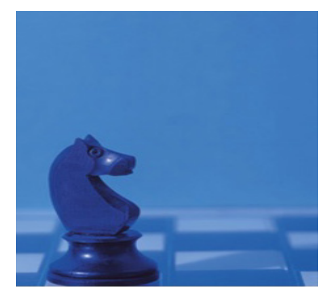
Some fundamental questions need to be asked:

Is there sufficient feedstock or land in the UK/Scotland for domestic bioethanol production?

Is bioethanol production in Scotland economically viable?

What significant strategic issues need to be addressed?

Could Scotland contribute useful know-how and technology to Global bioethanol production?



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Is there sufficient feedstock in the UK/Scotland for bioethanol production?

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UK cereals production in 2005

The following table shows the area, yield and production of wheat and barley in the UK in 2005. Wheat production is nearly 3 times that of barley production, which has been falling in the UK.

	2005
Wheat	
Area ('000 ha)	1,870
Yield (t/ha)	**8.0**
Production ('000 t)	14,950
Barley	
Area ('000 ha)	**941**
Yield (t/ha)	5.9
Production ('000 t)	5,545
Total Cereals	
Area ('000 ha)	2,926
Yield (t/ha)	**7.2**
Production ('000 t)	21,147

Source: DEFRA

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The UK Supply & Demand balance

	2002/03	2003/04	2004/05	2005/06
Wheat ('000 t)				
Total availability	19,074	17,218	18,298	
Total domestic consumption	13,633	13,122	13,490	13,488
Balance	5,411	4,096	4,808	
Exports	3,405	2,211	2,979	
Intervention stocks	2	-	-	
Exports and intervention	3,407	2,211	2,979	
End of season stocks	**2,304**	**1,885**	**1,829**	
Barley ('000 t)				
Total availability	7,475	7,386	6,763	
Total domestic consumption	5,420	5,613	5,037	4,905
Balance	2,055	1,773	1,726	
Exports	1,427	900	-	
Intervention stocks	142	-	-	
Exports	1,427	900	877	645
End of season stocks	**808**	**873**	**849**	

The UK wheat and barley supply and demand balance is shown. Over the last 20 years the UK has moved from a net importer to a net exporter of wheat.

Conversely, UK barley production has been steadily declining due to area planted and higher profits from wheat. Trade estimates suggest that Scotland has a barley surplus of c 500,000 t.

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Source: DEFRA

Scotland lacks domestic scale?

- While the UK is a net exporter of wheat overall, Scotland is a net importer of wheat for blended whisky and livestock placing Scottish farmers at a cost disadvantage.
- The shortfall varies with season, but is likely to be in the order of 150-200,000 tonnes. The wheat premium therefore reflects the cost of transporting wheat from Yorkshire, which is normally around £8-10/t placing additional economic pressure on bioethanol production from wheat in Scotland.
- Additionally, grain distillers are competing for wheat against the more expensive maize alternative so can pay a higher price.
- Importantly, barley price in Scotland is consistently low compared with the rest of the UK due to oversupply.
- However, it is important to note that in many cases bioethanol production utilises a number of feedstocks such as barley and wheat.
- The problem is that reallocation of resources to feedstock for bioethanol production is not as profitable as other verticals such as food.
- Ultimately, as things stand, Scotland does not have an appropriate domestic feedstock for large scale production of bioethanol, unless inefficiencies in barley can be overcome. Some reliance on imports is therefore inevitable.

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Production of sugar beet in Scotland?

Sugar beet has agronomic potential for cultivation in the UK and has the advantage of producing high yields of sugar per hectare, beet pulp and beet top co-products.

However, sugar beet has not been grown in Scotland since the 1960s since the processing plant in Fife closed, and it is unlikely that circumstances will change.

Reintroduction of sugar beet would be possible but:

- Agronomy knowledge in Scottish conditions would require updating for new varieties and growing practices;
- Familiarity of growers with the crop needs re-establishing and in many cases, initiated;
- Growers would need to re-tool with consequences for fixed costs;
- The provision of appropriate inputs and market links would need to be re-established.

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Is bioethanol production in Scotland economically viable?

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The aim of this section is to estimate the economic viability of bioethanol production and how it compares with alternative fuel costs.

This will be achieved by calculating the production cost of bioethanol from a commercial facility. A number of industrial manufacturers involved in the erection and equipping of bioethanol plants were approached for information on their products.

The main costings were provided by Chematur Engineering AB who are based in Karlskoga, Sweden (www.chematur.se) The company operates internationally with subsidiaries in USA, Finland and India. To date the company has established 42 ethanol plants over the last 25 years around the world, using a variety of feedstocks. These plants have been for both technical and fuel alcohol.

The scale of plant selected was based on an understanding of Scottish production/ conditions and on the recommendation of the plant manufacturer (Chematur). This was the smallest plant they would recommend (200,000 l/day), which is described as medium scale.

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The plant specification

The production of ethanol will require 4 main stages:

- milling of wheat
- hydrolysis and fermentation
- distillation
- drying and pelleting of distillers dark grains

The details of the plant specified and costed are as follows:

- Daily plant production - 200,000 litres of ethanol (medium scale)
- Annual production - 70 million litres (350 days)
- Annual wheat requirement - 186,000 tonnes, 530 tonnes per day (3.37t wheat → 1.0t Ethanol. *Source: Chematur*)
- By-product - distillers dried grains with solubles (DDGS) 64,000 tonnes
- By-product – 47,500 tonnes of CO_2
- The plant operates on a continuous basis 24 hrs per day, for 350 days per year, closed for 2 weeks for annual maintenance
- Staffing levels are constant irrespective of plant size. As the plant is so large, 2 men per shift are recommended for health & safety reasons, although everything is automated. Most plants operate a 4-shift system.

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The consumption of raw materials, utilities and effluent for the 70m litre bioethanol plant are specified as follows:

Consumption of raw materials

Wheat	3.370 tonne
Defoaming oil	0.8 kg
Enzyme 1	0.76 kg
Enzyme 2	1.14 kg
Enzyme 3	0.50 l
Caustic	15 kg
Sulphuric acid	20 kg
Ammonia	2.3 kg
Yeast	600 kg/year

Consumption of utilities

Steam	3.6 tonne
Steam DDGS	3.9 tonne
Process water	1.9 cubic metre
Cooling water	123 cubic metre
Electrical power	475 KWh
Air	17 Nm3

Generation of effluent

Drier condensate	3.0 cubic metre
Waste water	1.5 cubic metre

NB: All figures except for yeast are given for the production of 1.0 tonne of bioethanol

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Estimated Plant Capital Cost

A rough breakdown of costs are presented below:

	Euro €	£ Sterling
Feedstock milling	4,500,000	3,060,000
Hydrolysis fermentation	15,000,000	10,200,000
Distillation	10,000,000	6,800,000
Drier, DDGS pelleting	7,500,000	5,100,000
Utilities	3,300,000	2,244,000
Ethanol storage	3,000,000	2,040,00
Waste water treatment	2,000,000	1,360,000
Site & infrastructure	4,000,000	2,720,000
Environment audit (IPPC)	250,000	170,000
Total cost	**€49,550,000**	**£33,694,000**

Chematur have quoted a turn-key price (Western Europe) of €45- €50 million for the plant specified utilising Biostil technology.

NB: assumed conversion rate € = 68p. (Dec 2005).

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Production cost for a 70m litre plant

	Annual Cost (£)	Cost per litre (p/l)
Annual capital costs	3,942,900	6.57
Purchase of wheat	14,880,000	24.80
Denaturant	600,000	1.00
Fuel Costs	1,380,000	2.30
Electricity	600,000	1.00
Water treatment	60,000	0.10
Enzymes, yeast, chemicals	1,260,000	2.10
Staff costs	333,000	0.56
Repair & Maintenance	510,000	0.85
General & admin	300,000	0.50
Working Capital interest	595,200	0.99
Sub total	24,461,100	40.77
By-product income DDGS (64,000)	6,400,000	10.67
Net cost	**18,061,000**	**30.10**

Assumptions

1. Source of capital costs: Chematur Engineering AB
2. Annual capital charge: Repayment over 15 years @ 8%
3. Cost of feedstock: 186,000t wheat @ £80/t delivered
4. Staffing (14): Manager (£40k), 8 shift workers (£24k), 1 lab (£15k), 2 office (£18k), 2 security (£20k).
5. Other operating costs adapted from HGCA / Chematur
6. Annual maintenance: 1.5% of capital cost
7. Working capital, 50% of annual feedstock costs @8%
8. DDGS 64,000T @ £100/t

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Bioethanol is competitive with fossil petrol providing the bioethanol production costs are no greater than c.18p/l of the refining cost of petrol.

The table opposite attempts to show the competitiveness of bioethanol compared to unleaded petrol as things stand.

It must be acknowledged that production costs for bioethanol are higher than mineral petrol and that the potential for higher costs poses a real threat.

	Petrol ULS		Bioethanol		
Refinery costs	20.00	25.00	30.10	35.00	40.00
Distribution & retailing costs	5.00	5.00	7.00	7.00	7.00
sub-total	25.00	30.00	37.00	42.00	47.00
Excise duty	47.10	47.10	27.10	27.10	27.10
sub-total	72.10	77.10	64.10	69.10	74.10
VAT @ 17.5%	12.62	13.49	11.22	12.09	12.97
Price on road	**84.72**	**90.59**	**75.32**	**81.19**	**87.07**

NB:

1. Petrol refinery costs are based on informed industry estimates.

2. Bioethanol production costs represent normal market range.

3. Distribution and retailing costs are estimated at 7p/l for bioethanol in recognition of blending and higher distribution costs.

4. ULS (Ultra Low Sulphur)

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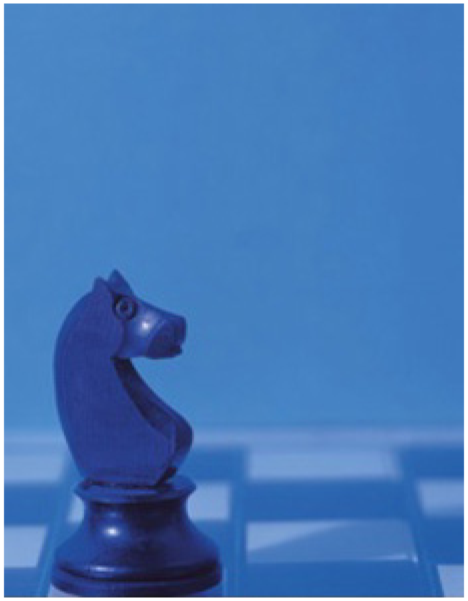
The 70ML bioethanol plant examined was budgeted to produce bioethanol at 30.10 p/l. This was considered to represent an appropriate scale for Scottish production.



For biodiesel, a medium scale processing plant, of 33.3ML was evaluated to be an appropriate scale for Scotland ("*The Economic Evaluation of Biodiesel Production from Oilseed Rape Grown in North and East Scotland*", available at www.aberdeenshire.gov.uk).

The cost of biodiesel from this plant based on similar costings would be 41.3/l, 10p/l more than for the bioethanol.

The reasons for the better economic viability of bioethanol production compared to biodiesel include 2 major factors:

- The bioethanol plant is larger scale (>2 times), enabling economies of scale to cover fixed costs
- The feedstock price is lower than oilseed rape, which has a high value.

On an economic basis, a bioethanol plant is more viable than biodiesel; however, on a strategic basis it is not so clear cut.

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Sensitivity analysis

To assess the risks involved for any potential development, sensitivity analysis was carried out to determine the impact of key variables on production costs.

If a bioethanol plant is to be successful it needs to be internationally competitive. Sensitivity analysis will also provide a better understanding of the key issues and the critical success factors for a successful bioethanol processing plant.

In this case for simplicity, the key variables examined were:

- Cost of feedstock (wheat)
- Plant utilisation
- Value of by-products (DDGS)
- Capital cost

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Feedstock cost

The table opposite shows the impact on bioethanol production costs (pence per litre) for the medium scale plant (70ML) previously specified and costed. It shows a change of wheat price +/ - £10/t results in a 3.22p/l change in bioethanol cost.

This clearly shows that the cost of feedstock has a major bearing on the production cost of bioethanol and therefore its competitiveness.

Wheat price	Bioethanol p/l
£100	36.55
£90	33.33
£80	30.10
£70	26.88

Production cost

The efficiency of plant utilisation and the ability to work to full capacity has a major impact on production costs.

Any plant that is not fully utilised will incur higher production costs from the fixed cost element.

The following table shows the impact of operating at less than full capacity. At 80% capacity, production costs are estimated to rise by 2.13 p to 32.23 p/l.

Plant Utilisation	Bioethanol p/l
100%	30.10
90%	31.17
80%	32.23

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The impact of DDGS value on production cost

The revenue earned from the by-products of the process makes a crucial contribution to the overall viability and competitiveness of the plant.

There are two principal by-products:

- CO_2
- DDGS

There is a limited demand for CO_2; in theory it can be worth up to £85/t but additional major investment would be required for storage. It is also expensive to transport, at around half the value of the CO_2. There is a UK surplus of CO_2 but in some regions it is imported from Europe.

In the production costs it was therefore assumed CO_2 had no commercial value. The budgeted model in original analysis valued the DDGS at £100/t.

For every £10 per tonne fall in DDGS value, it would equate to roughly an additional 1.07p on to the production cost of the bioethanol.

DDGS value	**Bioethanol p/l**
£100	30.10
£90	31.17
£80	32.24

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Impact of capital expenditure on production cost

The table opposite looks at how changes in capital expenditure might impact on overall production costs. If there was an overspend of 20% would it put the whole project at risk?

The following table shows that within reason the capital cost is not a critical factor.

For every additional £1 million, it would only add a further 0.2 p/l to production costs.

Capital cost	Bioethanol p/l
20% over spend	31.42
10% overspend	30.76
On budget (£33.7M)	30.10
10% under spend	29.44

Production of bioethanol from the plant described is on the borderline of being economically viable and marginally competitive with imported bioethanol. However, the sensitivity analysis indicates that a number of factors could converge to significantly impair cost and price per litre.

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The market value for grain

Another factor which may skew the economic analysis is that the current market value for grain as used in the calculations, is not sufficient to cover growing costs on farm.

Farmers are currently using anticipated subsidy payments under the single Farm Payment to subsidise unprofitable cereal production.

Additionally, the rising demand for grain, sugar beet, rape seeds and other feedstocks is pushing raw material prices higher as major territories like China are experiencing an increasing dependence on agricultural imports.

Again, competition for feedstock for biofuel production comes from the food chain, in a world where millions of people are starving.

Analysis of the sensitivity of the economic analysis shows that the cost of grain is a major factor in affecting the economic balance of the process.

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Use of barley as a feedstock?

	Annual Cost (£)	Cost per litre (p/l)
Annual capital costs	4,118,400	6.86
Purchase of Barley	15,345,000	25.58
Denaturant	600,000	1.00
Fuel Costs	1,380,000	2.30
Electricity	600,000	1.00
Water treatment	60,000	0.10
Enzymes, yeast, chemicals	1,260,000	2.10
Staff costs	333,000	0.56
Repair & Maintenance	510,000	0.85
General & admin	300,000	0.50
Working Capital interest	613,800	1.02
Sub total	25,120,200	41.87
By-product income	5,632,000	9.39
DDGS (64,000)		
Net cost	**19,488,200**	**32.48**

Changes to the wheat bioethanol model for barley use:

1. Capital costs increased by additional £1.5 million as an allowance for changes to the loading/hydrolysis section of the process. Estimated total capital cost increases to £35.2 million.
2. It is assumed that alcohol production from barley is 10% less than from wheat. Therefore to maintain plant capacity and annual output at 70ML of bioethanol will require 204,600 tonnes of feed barley.
3. The price of the barley delivered to the plant was estimated at £75 per tonne - £5 less than the cost of wheat.
4. Barley would produce an extra 10% DDGS → 70,400 tonnes
5. The value of barley DDGS is estimated at £20 less than wheat DDGS at £80 per tonne.

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So surprisingly, barley comes close to wheat…

The estimated production costs from a bioethanol plant of a similar size (70ML) but using barley as its feedstock was 32.48 pence/litre.

Compared to a wheat plant this is an estimated 2.38 p/l higher – nearly 8%.

This is less than expected and although on the downside it is unlikely in itself to dismiss bioethanol production from barley.

Clearly there are other factors to consider which would influence any decision.

However, 2.38p extra cost over 70ML equates to a massive £1,666,000 – which all comes off the bottom line.

…but what if barley rose to £95/t?

If the cost of barley delivered into the plant rose by £20 to £95/t and assuming all other costs and DDG income remained the same, then the production cost of bioethanol would rise 7.09p to 39.57p/l.

When duty, VAT and distribution costs are included this would equate to an on-road price of 87p/l.

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Could barley be used as a feedstock in Scotland?

Disadvantages of using barley as a feedstock for bioethanol:

- Lower yield per hectare compared to wheat
- Lower spirit yield
- More difficult to make into ethanol compared to wheat
- Barley spirit more viscous
- Process produces more by-product DDGS
- Barley DDGS of lower value (£20/t less)
- Compared to wheat, costs additional 2.38p/l to produce bioethanol.

Advantages of using barley as a feedstock for bioethanol

- Secure available surplus in Scotland > 400,000 tonnes
- Although costs more to produce, production costs still competitive

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The net energy balance from Scottish feedstock is poor

All things considered, there is very little energy to be gained from utilising wheat to produce bioethanol. A significant portion of studies show a negative energy balance; consequently the environmental viability of producing bioethanol from wheat is difficult to justify.

No information on energy analysis through barley is available; however it is known that the grain yield of barley is poorer than wheat.

It should be concluded that we cannot argue that we are contributing towards sustainability if the energy balance from feedstocks suited to Scottish production is negative.

Moreover political and market drivers will largely overwhelm environmental concerns.

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So is bioethanol an expensive solution to reducing CO_2 emissions?

To meet the 5% RTFO target by 2010, the UK will need 10 production plants on the scale of Wessex Grain's plant in Henstridge if supply is exclusively domestic. It will be interesting to see how competitive and profitable the domestic market becomes.

– Moves to introduce E85 in the UK is proving costly and difficult - largely due to stiff resistance from service stations, expensive bioethanol distribution tankers and a lack of flexi fuel vehicles in the UK. Therefore development of bioethanol markets in the UK may be less bullish than originally anticipated.

It may be that in the greater context of climate change, biofuels are an expensive method of reducing greenhouse gases. However, political pressure to embrace biofuels is high, and from a commercial point of view, biofuels provide a significant market opportunity in the UK.

It must be emphasised that biofuels are not a total solution to UK motoring emissions and that there is a real danger that targets for reducing greenhouse gas emissions fall short of addressing the true scale of environmental problems within a sufficient time frame.

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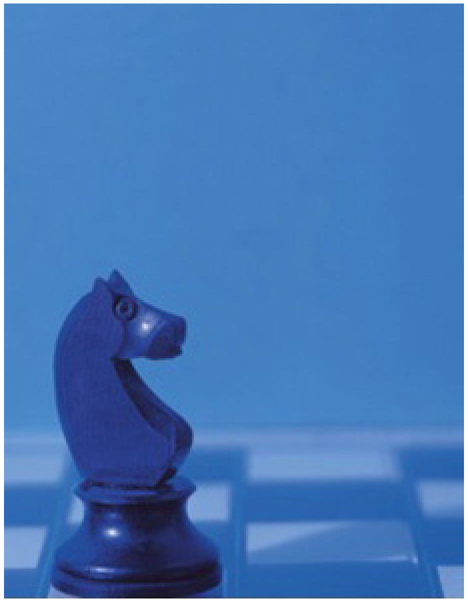
Strategic issues



The aim of this section is to consider a number of key strategic issues and how they might influence the biofuel market in the UK and particularly a bioethanol plant in Scotland.

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Impact of CAP Reform

- Europe has undergone a series of reforms over the last 15 years as it attempts both to control Common Agricultural Policy (CAP) spending, and better align support and European commodity prices at a level acceptable to world trading partners.

- The latest set of reforms introduced the Single Farm Payment – a decoupled support mechanism not linked to production, but rewarding farmers for meeting environmental and legislative standards.

- Policy change developments in the next 1 – 5 years will centre around the Rural Development Regulation (RDR) and its associated support schemes.

- Industry consultations in both England and Scotland will help shape the focus, scope and detail of the new and revised schemes that emerge. The aspirations are high both in Europe and UK for some novel support initiatives.

- However, EU funding arrangements in relation both to total EU funding and the CAP's allocation compounded by lack of availability of national funding may seriously curtail these aspirations.

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EU Sugar Regime Reform

- The Council of Ministers recently agreed (24 Nov 2005) to a major reform of the EU sugar regime, which will have implication for the EU cereals sector and therefore biofuel production.
- The reform was necessary to meet the EU's WTO obligations to cut EU sugar exports and also to liberalise sugar imports from developing countries.
- 36% reduction in the sugar support price phase in over four years commencing in 2006/07. This will bring the support price down from €631/tonne to €404/tonne by 2009/10.
- Sugar will now be brought under the Single Farm Payment (SFP) scheme.
- Growers will receive compensation under the SFP scheme at an average rate of 64% of the price cut.
- Intervention will be retained for the next four years but limited to 600,000 tonnes of sugar/year and at 80% of the reference price.
- A restructuring scheme will be introduced to encourage growers to stop sugar beet production.
- There will also be changes to the production quota system.

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What does this mean for the cereals sector and the biofuels industry?

The review of the sugar regime will have a major impact on the EU cereals sector, as growers are likely to replace sugar beet with cereal production.

Over time, a significant percentage of the area grown of sugar beet will transfer into cereal production, which will have knock-on effects on the economics of bioethanol production.

The reform and resulting reduction in sugar beet price will provide a major boost for bioethanol production within the EU and will impact on the competitiveness of bioethanol production from other feedstocks in the UK.

Existing factories and growers will now actively consider non-food markets and ethanol production in particular.

This, allied to the EU Directive for the RTFO, should result in significant bioethanol production from sugar beet within the EU, including the UK, as emphasised by British Sugar's plans to establish a significant bioethanol plant near Norwich.

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Market Outlook for Cereals

The medium term perspectives for the cereals market are modestly positive as the impacts of CAP Reform are seen along with more favourable market conditions.

There are high levels of EU stocks which will have to be dispersed onto the markets, leaving them fragile over the next two years. This will result in a gradual fall in stock levels supported by moderate gains on the feed markets, favourable conditions in world markets and stimulation of EU export opportunities. The trade are quite bullish over cereal prices in the medium term.

Long term prospects will be controlled largely by conditions in world markets, which are difficult to predict. Furthermore cereals are a commodity market, influenced more by the global situation than national factors.

What is clear is that stock levels, albeit at historic lows, are rising. The success of economies in developing countries and particularly China will play a key role in world cereal markets.

One would expect cereal prices in the longer term to rise. Demand will continue to rise from conventional cereal users and in addition, from the growing non-food market, particularly for biofuel production.

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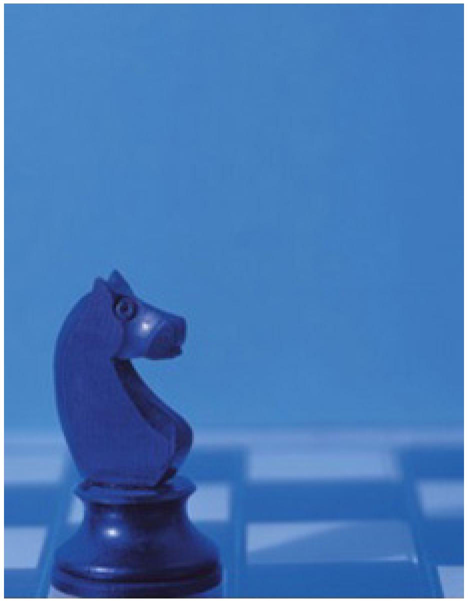
Imports of bioethanol

The cost of imported bioethanol is currently 21.98p/l for Brazilian and 27.59-28.98p/l for American bioethanol putting Scottish production marginally above the USA cost, and well above the Brazilian cost.



Brazil is scaling up ethanol exports to reach 9 million tonnes a year by 2010, of which around 50% will go to Japan and approximately 17% to the USA. China is exploring major investments in Brazil for ethanol, castor oil and biodiesel for export to China.

- Costings for Scotland do not give credits for potential values of all co-products or allow for any market effects of the RTFO. Supplementary income from these sources could make costs of bioethanol more competitive.

- Market analysis suggests that Brazilian exports will be limited due to increasing domestic demand for transport fuel within Brazil as car ownership increases and as availability of fossil fuels reduce.

This blend of factors will influence the threat of imports.

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The RTFO proposal

In 2004, the Government announced an intention to investigate the implementation of an Renewable Transport Fuel Obligation (RTFO) in its pre-budget report. Through the RTFO, 5% of ALL UK fuel sold on UK forecourts must come from a renewable source by 2010.

At present the tax break of 20p/l on biofuels is only guaranteed by Government on a rolling 3 year basis. This does cause investors concern as without a tax break biofuels would not be competitive with fossil fuels.

There is a view that the RTFO could be phased over 20 years and the tax break would be retained for the first 7 years, thereafter reduced and phased out. The reality is, once the RTFO is legislated, it forces the market to adopt biofuels, thereby creating a real demand.

It should also be noted that the inclusion of biofuels at 5% is likely to add only 1p/litre at most to the pump price, which is well within the normal variability.

The introduction of an RTFO would give industry greater certainty to invest in biofuel production for the longer term and stimulate innovation and investment in new technologies and infrastructure where required.

If the RTFO moves from 5% to 10% in the future, this will create further market opportunity and demand which if not met domestically will further shift emphasis onto imports.

An RTFO could be introduced by April 2008.

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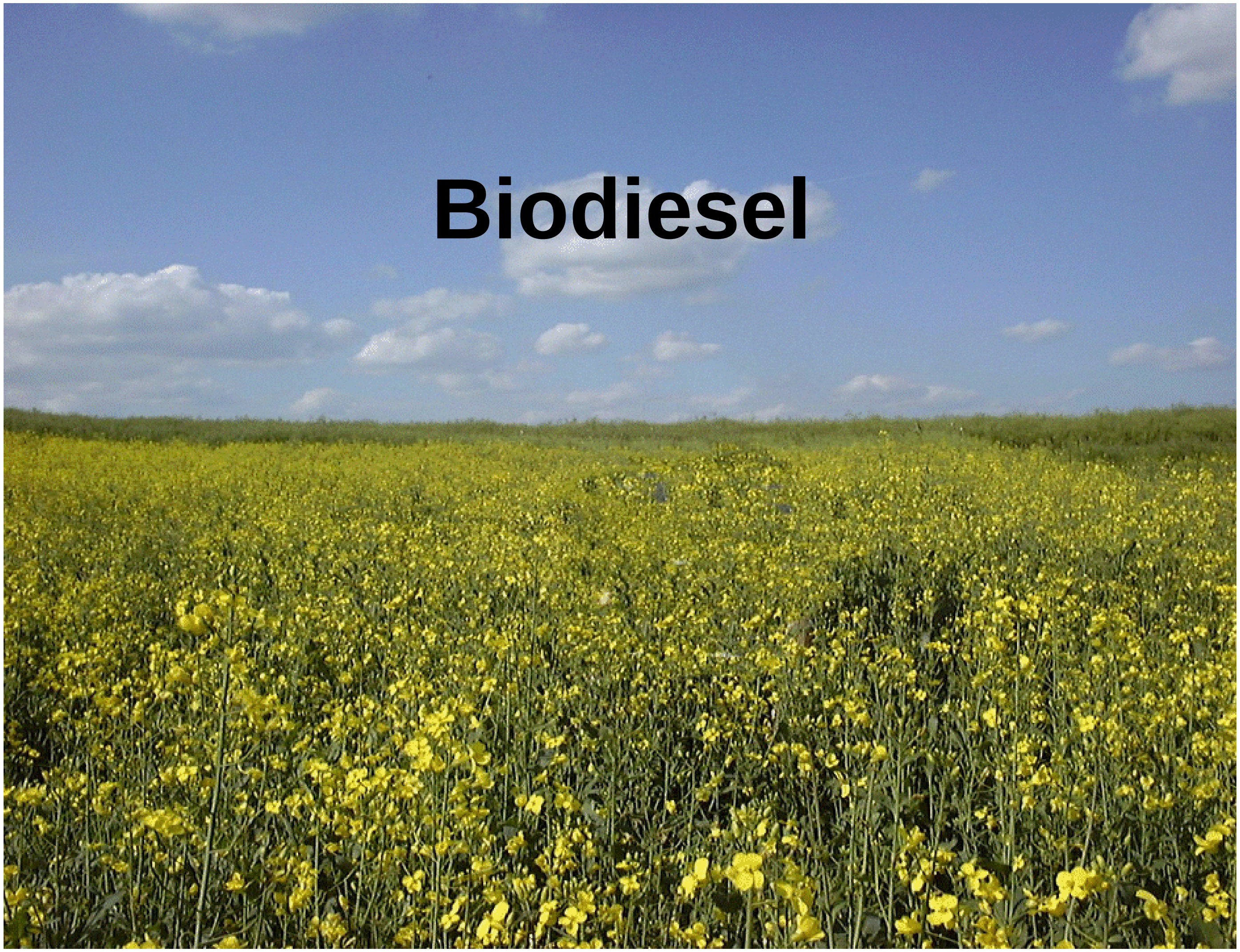

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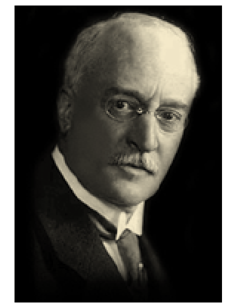
Biodiesel

Commonly derived from triglyceride sources such as oils and fats, biodiesel (alkyl monoesters) can serve as a substitute for any process using mineral diesel.

Vegetable oils have been used as a fuel for diesel engines since their inception by Rudolf Diesel in the early 1900s, with small scale use since the 1930s.

Biodiesel's importance emerged from the oil crisis of the early 1970s, as many countries sought to limit exposure to petroleum imported products. Reforms of the Common Agricultural Policy in 1992 arguably drove biodiesel to centre stage as farmers were encouraged to grow crops for non-food use, giving birth to large scale growth of energy crops and a commercial market for biodiesel.

European production of biodiesel reached approximately 2.6m tonnes in 2004, and is set to double by 2008. In this context, the UK is also considering an ambitious mandatory target for 2010. Argent Energy currently produce biodiesel in Motherwell from tallow and waste vegetable oil.



Rudolf Diesel

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The environmental case for biodiesel appears robust…

- Biodiesel reduces CO_2 emissions by approximately 50%.
- Biodiesel contains fewer aromatic hydrocarbons:
  (56% less benzofluoranthene, 71% less Benzopyrenes).
- Biodiesel is sulphur free thus eliminating SO_2 emissions.
- Increased NO_x emissions could be circumvented with catalytic converters.
- Biodiesel improves engine lubrication and can extend engine life.

..and the market potential is considerable

- UK sales of biodiesel represents round 1% of mineral diesel sales and 0.04% of total petrol and diesel sales.
- Argent covers 4.2m l/month, around 5% of Scotland's current diesel needs.
- Total UK biodiesel planned capacity of approximately 470m l/year
  = 2.75% of consumption.
- Europe is facing a substantial deficit of diesel which may not be satisfied by imports from Russia or the Middle East.

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In Europe, bio-diesel is mostly produced from rape seed and sun-flower oils. Animal fats and used cooking oil have the potential to provide significant additional quantities. The environmental footprint of the feedstock used, and the impact of its specification on biodiesel quality is a key element in selecting feedstocks.

Rapeseed for RME

Transesterification is the reaction of a triglyceride with an alcohol to yield esters such as Rape Methyl Ester (RME) and glycerol as shown below. The resulting biodiesel can be used in unmodified engines.

Tri-glyceride + Methanol ⇌ **Esters + Glycerol**

Catalyst

This by-product is sold on

Biodiesel

Hydrocracking *and* ***hydrogenation*** *of vegetable oil mixed with mineral oil at the refining stage could lead to the production of high quality biodiesel. A number of processes do currently exist, but are not yet commercially viable. The DTI is inviting proposals in this area.*

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Nearly all biodiesel is produced via base catalyzed transesterification since it gives a 98% yield at low temperature and pressure

1-8 h, RT

Vegetable oils, cooking oil, animal fats → **transesterification** → **neutralisation** → **phase separation** → **crude biodiesel** → **purification** → **quality control** → **methyl ester**

purification → **methanol recovery** → **catalyst mixing** → **transesterification**

Complete removal of glycerol, catalyst & alcohol

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The UK biodiesel market has a compelling growth story going forward

As a large consumer of diesel and a large producer of rapeseed, the UK has large market potential. Due to poor tax incentives however, the market has failed to flourish and thus competition until recently has been minimal.

With planned levels of biodiesel production in the UK, only 2.27% of UK diesel requirement will be met. To meet the UK Government's target of 5.75% a significant remainder will have to be sourced.

Importantly, it is likely that the UK will move beyond the current 5% biodiesel blend limit in future years.

Additionally, the UK car industry has seen a boom in the number of new cars registered with a diesel engine. Diesel cars accounted for 14% of new car registrations in 2000 with 313,149 being registered. That has since leapt to 23.5% in 2002 and 37.2% in 2004.

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But many challenges remain

- Worldwide production of vegetable oil and animal fat is not sufficient to replace liquid fossil fuels.
- To produce the required vegetable oil a vast amount of farming, pesticide and land use conversion would be required.
- Used vegetable oil is the cheapest source for biodiesel, but conversion into other products such as soap is more economically profitable at present.

European countries will largely depend on imports alongside domestic production

- In 2004, approximately 1.9m tonnes of biodiesel were sold in Europe, as the market grew by 19%.
- During 2005 Europe is expected to be deficient in mineral diesel by around 25m tonnes per year, requiring significant imports.
- In order to meet the 2005 EU Directive target of 2% then 5m tonnes of biodiesel will be required.
- To meet the 2010 target of 5.75%, 14.38m tonnes of biodiesel are required based on current diesel consumption in the UK.
- The actual figure is likely to be higher due to the anticipated growth in diesel consumption in forthcoming years.

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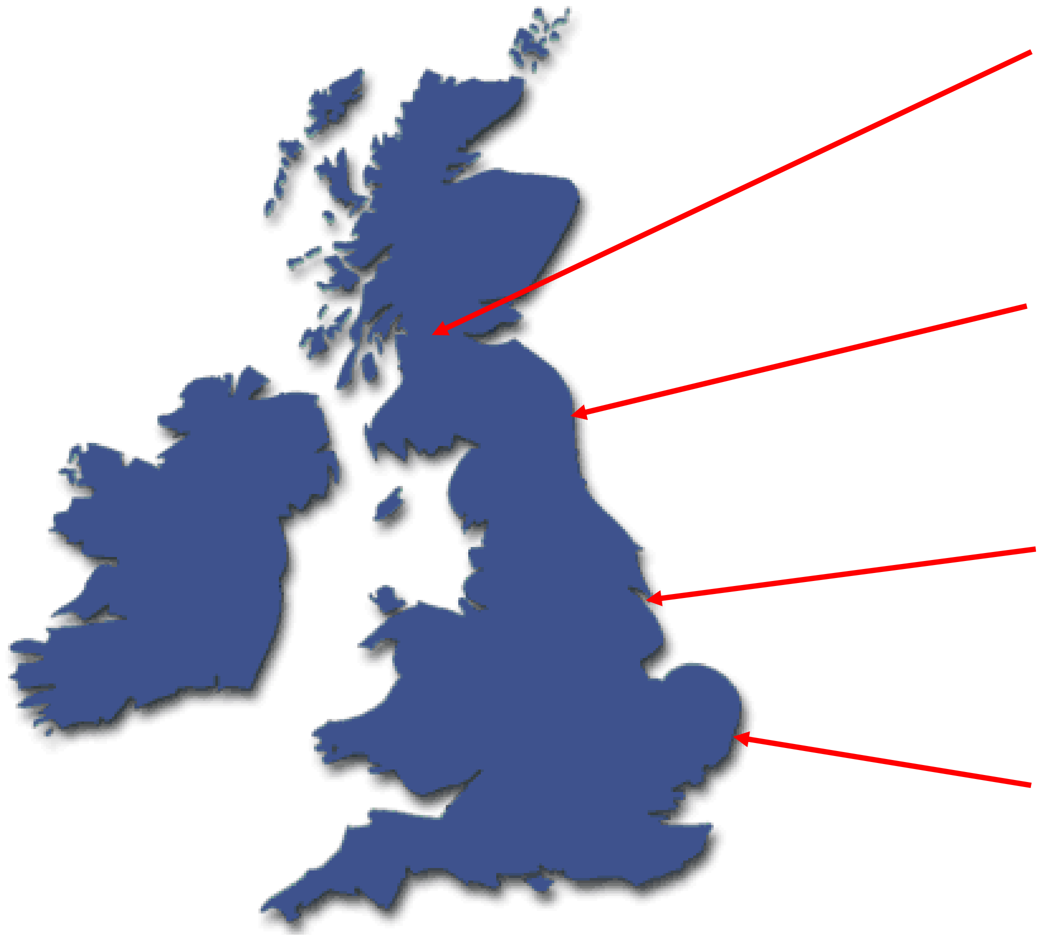
Current UK Biodiesel production*



Company: Argent
Location: Motherwell
Plant size: 50 ML
Investment: £15m
Status: Operational

Company: Northeast Biofuels
Location: Teesside
Plant size: 284 ML
Investment: £46m
Status: In construction

Company: Greenenergy Fuels Ltd
Location: Immingham
Plant size: 130 ML Bioethanol
Investment: £50m
Status: Production in 2007

Company: Global Commodities
Location: Norfolk
Plant size: 30 ML
Investment: >£10m
Status: Early planning

Biodiesel is currently available at around 100 service stations in the UK, mostly located in the South of England

*See appendices for company information

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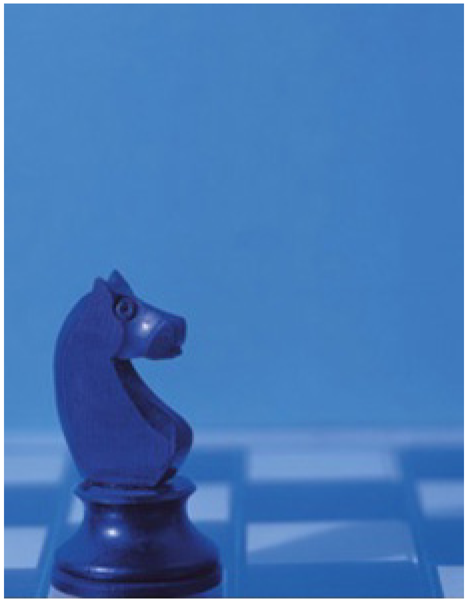
Strategic issues

A number of key factors will influence the success of a biodiesel market in the UK and Scotland, including the following:



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The outlook for European biodiesel markets looks positive

This is for a number of reasons including:

- **The lower price of biodiesel compared to mineral diesel**
- **Biodiesel can be blended with mineral diesel**
- **Growth of mineral diesel market**
- **Good lubrication properties and low sulphur emissions**

But a range issues remain unresolved such as:

- **CFPP* values limit biodiesel usage and certain feedstocks**
- **Feedstock availability**
- **Engine warranty fears**
- **Ethical questions**

*Cold Filter Plugging Point. The CFPP value is a measure of the temperature at which certain fractions in the oil solidify and block the filter, resulting in the engine arresting due to diesel shortage.

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Production in Scotland has additional issues

- While pure plant oil as a fuel has generated interest in Ireland and elsewhere, the jury is still out in the UK as long term effects on modified engines have not been assessed nor has appetite for modification kits. Pure plant oil does not qualify for the tax rebate.

- While used cooking oil is a potentially cheaper feedstock, only limited quantities are available in Scotland.

- Production of biodiesel via hydrogenation with straight vegetable oil, while at an early stage of development, could compete with methods described here in future years should a taxation system be introduced.

- Biodiesel production in Scotland via rapeseed oil is not at a large enough scale to justify a solvent extraction plant deemed essential to maximise the extraction of oil.

- There remains a gulf between production of biodiesel in the UK and supply of domestic feedstock for production.

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Hydrogenation (1)

A major threat for any potential UK biodiesel producer is the action taken by the multinational oil companies who currently operate refineries and supply transport fuels in the UK.

The ‘hydrogenation’ process could potentially undermine the ability of biofuels to compete if it is adopted by the oil refiners. The UK is unique in considering introduction of hydrogenation for this application at present.

Hydrogenation would allow crude vegetable oil to be mixed with mineral oil at the refining stage and qualify for the rebate on the tax levy. From the UK’s perspective this route does have attractions in that it uses existing distribution channels, ensuring continuity of supplies, and guarantees the quality of product.

It would address the issue of ‘backstreet’ blending of biodiesel with the associated risks for quality that the oil companies have previously indicated as a potential problem.

However, it should be stressed that this process is at the very early stage of development, with only a small-scale trial having been carried out in Germany.

Further experimentation and development of the taxation system is required before its introduction.

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Hydrogenation (2)

Following the 2005 Budget the Government called for tenders to establish a pilot scheme using hydrogenation in the refinery process.

The project would support research into the hydrogenation process for the production of biodiesel and the development and demonstration of how it might work on a larger scale.

It would also have to clarify the environmental benefits of the process and prove it could be commercially viable.

Tenders were invited in 2005 from companies who operate refineries producing road fuels. The pilot project would run for a maximum of 5 years.

The Government also stated there was no guarantee that fuel produced from the hydrogenation process would continue to be exempt from duty once the pilot project was completed.

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Biodiesel presents a relatively limited number of opportunities for ITI Life Sciences in Scotland

Despite the attractive market, there are limited opportunities for Scotland's life sciences sector to add value.

However, a number of key challenges remain to be resolved, which ITI Life Sciences and the Scottish life sciences industry could tackle, including:

- Improving oil yield from existing crops and investigating the development of new crop varieties.
- Finding alternative high value-added uses for by-products, an area that ITI Energy is actively exploring.

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Conclusions and recommendations

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1. ITI Life Sciences believes that there is an opportunity to create a liquid biofuels market in Scotland, if the political will is there to do so. However, much of what is required is infrastructure development, which is not ITI's core mandate, this being technological advancement.
2. ITI Life Sciences believes that there is significant scope and need for technological advancement that would make the production of bioethanol more efficient and more competitive.
3. However, improving the production process is competitive and there are dominant players (eg Novozymes, Iogen, Abengoa) none of whom are located in Scotland. ITI believes that Scotland currently lacks a research base actively involved in the development of leading-edge bioethanol technologies, with the exception of resident expertise in the optimisation of feedstocks. Consequently, any initiative is likely to involve collaborations between academics and companies both within and outwith Scotland working to generate intellectual property and know-how that could be leveraged by bioethanol producers around the globe. ITI's existing programmes demonstrate our commitment to crafting cross-border collaborations to deliver market driven solutions.
4. Scotland has yet to enter the bioethanol arena. However, we believe there is a case for looking at the production of bioethanol in Scotland as a means of meeting environmental targets, addressing fuel security and diversity of supply issues and offering options for rural development. In terms of ITI's role, we will continue to explore ways in which potentially valuable bioethanol technology could be developed in Scotland.

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Mind the innovation gap (1)

Aside from building infrastructure to satisfy production demand, it is vital that technology gaps related to life sciences are assessed to determine areas for innovation.

This is where ITI Life Sciences seeks opportunities.

From our research so far, the following challenges present opportunities :

Bioethanol

As bioethanol production is currently very inefficient due to a large number of energy-intensive steps in the production process, it is important to fully assess and address a range of issues including:

- The net energy balance of bioethanol production. Development of patentable processes, enzymes or any enabling technology to address the energy efficiency of bioethanol production is exciting.
- Suitable feedstock availability in the UK/Scotland. There is scope to improve feedstock for biofuel processing and review technology on barley and improve the spirit yield.
- Production yields of bioethanol from lignocellulose or whole-crop cereals and other forms of biomass such as forestry products remain a major area for innovation and an area Scotland may be well placed to serve.

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Mind the innovation gap (2)

Biodiesel

Although biodiesel production is highly efficient thanks to room-temperature processing a number of key challenges remain to be resolved to which ITI Life Sciences could contribute, including:

- Improving oil yield from existing crops and investigating the development of new input crops.
- Finding alternative high value-added use for by-products, an area that ITI Energy is actively exploring.

You may know something we don't…

The ITIs are also interested in other innovations that would relate to biofuels and demonstrate commercial viability in the near term.

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What happens next?

To determine if and where opportunities lie within liquid biofuels, we would very much welcome dialogue with our Members.

To arrange a discussion, please contact ITI Life Sciences at:

email@itilifesciences.com
tel. +44 1382 568060

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Some key bioethanol initiatives to watch

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British Sugar (Somerset)

In June 2005, British Sugar announced plans to design the UK's first bioethanol production facility. The production plant will be located at British Sugar's Wissington site, near Downham Market, Norfolk and will use sugar beet.

The UK sugar beet industry produces 1.1 million tonnes of sugar each year, just over half the country's requirements. The British Sugar plant in Wissington is claimed to be the largest and most efficient operation of its type in the world.

A major element which has allowed the project to proceed, was agreement between British Sugar and the National Farmers' Union on the contractual arrangements for the supply of the sugar beet needed to supply this plant.

The bioethanol plant is designed to produce 70m l of bioethanol each year, utilising all of the UK's previously exported beet sugar.

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Wessex Grain (Somerset)

Wessex Grain are a farmer co-operative grain storage and marketing company handling 400,000t of grain per year.

Greenspirits Fuel was established in 2005 to develop a bioethanol plant at Henstridge, with investment from Tudor Capital and Credit Suisse. The proposed £45m plant will produce 100,000 tonnes of bioethanol per year using 330,000 tonnes of wheat.

3 co-products will be marketed: bioethanol, DDG and CO2 for industry, while the company explores opportunities to extract non-starch fractions from wheat which many be sold to the pharmaceutical and cosmetics industries.

The plant will enjoy an ideal location with wheat sourced from Wiltshire and ready access to livestock areas of the South-West to market DDG.

The project contractor is Abengoa SA (Seville, Spain).

To meet the 5% RTFO target, the UK would require 10 similar plants.

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Iogen Energy Corporation (Canada)

The only company close to commercialising a technology for bioethanol from plant fibre. Royal Dutch/Shell has a 20% share in the company.

Currently has a demonstration plant processing 40 tonnes per day with intentions to scaling up to two million kg of feedstock per day yielding 220 million litres of bioethanol per year.

Lignin is removed prior to fermentation and diverted to alternative uses in chemicals.

Two main drivers of Iogen's commercial viability:

- The company has been using steam explosion technology since 1974 to convert wood chips into cattle feed and strongly utilises economies of scale to overcome process costs.
- Iogen has been using genetically engineered enzymes since 1994 for the paper and pulp industry.

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Novozymes (Denmark)/Abengoa (Spain)

- The Industrial enzymes specialist has received over $17m from the US Department of Energy to aid research in enzyme development for bioethanol production.

- The company is working in collaboration with Spanish industrial and technology company Abengoa and VTT of Finland.

- Novozymes launched 3 new enzymes in November 2005 which make the production of ethanol from wheat, barley and rye up to 20% more efficient.

- Viscozyme® Barley, Viscozyme® Rye and Viscozyme® Wheat break down components of the grain which would otherwise result in a thick consistency. The thinner mash is more optimal for enzymes in the fermentation process.

- Abengoa established the first dedicated barley bioethanol plant in Spain in 2000 and now have 5 plants in operation with one plant in Spain under construction giving a total production capacity of 175 M gallons. Spanish bioethanol plants received considerable funding from the EU as "pilot plants" including 5-year tax breaks.

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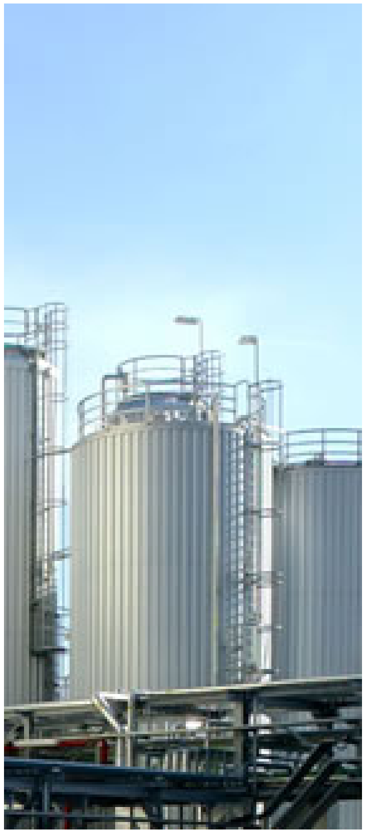
UK Biodiesel initiatives to watch



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Argent Energy Limited

Founded in 2001 to maximise value from the Argent By-Products business, Argent built the UK's first large scale biodiesel plant near Motherwell with technology from BioDiesel International (BDI).

Argent currently produce a blend of 5% biodiesel to 95% mineral diesel to EN 14214 which is sold to Petroplus in Teeside and branded as Bio-plus.

The company now produces 50m l per year from vegetable oil and tallow (animal fats) accounting for 5% of current Scottish biodiesel demand and displaces around 200,000 tonnes of CO_2 emissions per year.

The project cost £15m, supported by grants from the Scottish Executive (£1.2m) and the European Union (£2.18m). The Venture Capital firm Cinven own 60% of the parent group.

Argent plans to float in 2006 with funds allocated for the £35m cost of building two new plants in the North West and East of England.

Capacity is expected to ramp up from 50,000 tonnes to 200,000 tonnes by end of 2007.

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North East Biofuels

A cluster of companies from a range of sectors developing biofuels for transport in the NE of England with capacity to compete with any Scottish development.

Companies include East Durham Biofuels Ltd, Monsanto UK Ltd, PetroPlus, SembCorp and K Home International Ltd with public sector input from One Northeast and Renew Tees Valley Ltd.

The group plans to set up a £18m crushing plant in Teesside alongside development of biofuel supply chains including Biofuels Corporation plc in the area.

The crushing plant will be optimised for oilseed rape using solvent extraction, but will also crush palm and soya at a total initial capacity of 500,000 tonnes per year.

Finance to support this project is currently being arranged with production expected early 2007.

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Biofuels Corporation Plc

The Biofuels Corporation site under construction in 2005

Biofuels Corporation is in the process of building its first 250,000m tonnes biodiesel processing plant at Seal Sands, Middlesbrough on the north east coast of England at a cost of c.£30m. Public support of £1.2m came from One North East via a grant. Around 40 people are employed. Once complete, the Biofuels Corp facility on Teesside will be the biggest plant in Europe.

The company floated on AIM in March 2005, raising £30.6m overall net of expenses and intends to be Europe's leading biodiesel producer.

A large proportion of its output, produced from used vegetable oil, has already been sold on a long term contract basis.

The company also intends to develop into markets outside transport.

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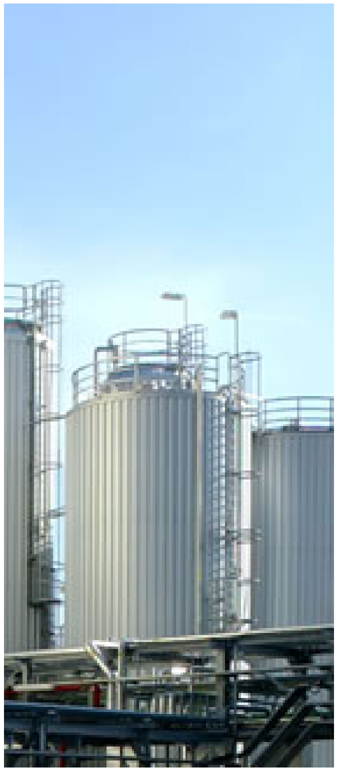
Greenenergy Fuels Ltd (GFL)

Greenenergy imports, blends and distributes 5% biodiesel in the UK through 22 Tesco outlets, other supermarkets and local authorities. The company also processes 12,000 tonnes of biodiesel per annum under an exclusive deal with BIP (Oldbury) Ltd in the West Midlands. Tesco own 25% of the business.



The company has a "field to forecourt“ strategy in which farmers produce on a long term contract and in turn benefit from a secure long term market. There are currently 1500 farmers growing rapeseed under the contract and the rapeseed they grow will supply the oils used for production of biodiesel at their Immingham plant.

In partnership with Novaol, the proposed biodiesel processing plant at Immingham is due to begin production Q2 2006 and will produce 100,000 tonnes of biodiesel per annum with technology from Desmet Ballestra. Rapeoil will account for c.65% of feedstock usage.

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Global Commodities UK Ltd

Established in 2001, the company has produced biodiesel via cooking oil through the 5% driveECO brand since 2002. DriveECO is sold in East Anglia only.

Like Greenergy, the company plans to use rapeseed oil grown by local farmers under long term contracts.

With current capacity of c.80, 000 tonnes per annum, the company has acquired an esterification plant in partnership with RiX Biodiesel and converted it for biodiesel production with increased capacity of 100,000 tonnes. The capital investment for the new factory was c.£10m.

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D1 Oils plc

D1 was founded in 2002 to design and build a modular biodiesel refinery for the UK transport industry. The company initially investigated rapeseed oil as its primary feedstock. However, the high cost of rapeseed and the shortage of land for increased rapeseed production prompted the search for alternative energy crops.

D1 identified *Jatropha Curcas*, a tree that produces seeds with a high content of inedible oils. The oil is extracted by crushing the seeds and can be refined into high quality biodiesel. Jatropha grows in climatic conditions commonly found in the developing world.

D1's first priority was to establish operations in Africa, India and South East Asia to source a supply of crude jatropha oil and initiate the planting of jatropha in order to secure and maintain sufficient supply. Operations were established in these regions by the summer of 2004.

In October 2004, D1 Oils plc listed on the Alternative Investment Market of the London Stock Exchange with an initial market capitalisation of £34 million. D1 completed a second round fundraising in June 2005, raising a further £26 million on a market capitalisation of around £100 million.

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Acknowledgement

The section of the report examining Bioethanol in Scotland draws on research commissioned by ITI Life Sciences from Kerr Walker and Elaine Booth of SAC, Aberdeen.

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