Biofuels and the biorefinery concept

Gail Taylor, University of Southampton and UK Energy Research Centre

Background

Liquid biofuels may be made from a variety of biomass sources, through a number of conversion routes to produce several types of product suitable for road and other forms of transportation fuel. Fuels include bioethanol, biodiesel and other bio-based products such as biobutanol and feedstocks include oil-based crops such as oil seed rape, that are used for the production of biodiesel, sugar and starch based crops such as sugar beet that are used for the production of bioethanol. All lignocellulosic biomass (all biomass which is mostly plant cell walls that have a high carbon content) can be converted to liquid fuels through biological processes (esterification, fermentation) or through thermochemical routes such as pyrolysis. Hydrogen may also be produced from biomass. As with heat and electricity, this complexity may hinder the development of biofuel chains, but this may be an advantageous to the UK, where identifying a clear 'winner' is unlikely, given the complexity but small size of our agricultural landscape. As part of a wide range of measures drawn up by the EC in response to international agreements to reduce green house gas emissions, the European Commission has introduced the Biofuels directive and the UK has committed to this directive. This means that the UK is moving towards development of transport biofuels with a target of 5.75% replacement of petroleum-based fuels by 2010[1]. It has been estimated that liquid fuel demand in the UK in 2010 will be 44.5 M tonnes, requiring 2.56 M tonnes of biofuel at that time, providing a carbom saving of approximately 2 M tones. In the international market, biodiesel (derived commercially from vegetable or other plant oils) and bioethanol (derived from fermentation of starch or sugar crops) dominate as the most technically feasible and commercialized alternative renewable fuel sources. Biodiesel can also be derived from animal fats, grease and tallow that would otherwise be disposed of as waste.

Table 1. Summary of commercial activity in biofuel production within the UK – May 2005

Name	Description	Sub-topic	Funding	Duration
British Sugar	55,000 tonnes per annum (70 million litres) plant being constructed in Wissington, Norfolk.	• Bioethanol production at commercial scale	£20 M capital cost of plant	Construction initiated in January 2006
Greenerg y	Biodiesel plant at Immingham on the east coast of England. The plant will initially process 100,000 tonnes/114 million litres of biodiesel per year and is expected to begin by the end of 2006. Preliminary planning and design work for a second phase to double our biodiesel production capacity at Immingham to 200,000 tonnes/228 million litres per year.	• Biodiesel production at commercial scale	unknown	Construction completed by end of 2006
Green Spirit Fuels	Wessex Grain company to develop wheat grain as a source of bioethanol in the UK. Plant in development in Somerset for 141 million litres bioethanol (100,000 tonnes) by 2007.	• Bioethanol production	£50 M	Construction completed in 2007

The UK has seen considerable industry 'pull' in the area of biofuels in the last year or so following the introductive of the directive and a summary of some of this activity at May 2006 is shown in Table1. It is also apparent that the current high price of oil and likelihood of a sustained high price is having a marked effect on the development of a biofuel industry. Bauen (2004)[2] showed that biofuels begin to become financially competitive over $65 per barrel of oil and further environmental benefits are not even considered in such an analysis. For the sugar beet bioethanol development it is also likely that world sugar prices and deregulation of EU sugar prices which has effectively inflated sugar prices by three times of those on the world market. A summary of UK biomass resource suitable for liquid bioenergy production if given below. It reveals that it is unlikely that any single supply stream will be adequate to meet the UK commitment to biofuels for 2010.

Table 2. Summary of feedstock availability in the UK, processing routes – meeting the 2010 biofuel directive.

Crop Type	Harvest Fraction	Feedstock area (100 ha)	% of current crop area	Fuel Proposed M tonnes	Biofuel
Oil seed rape	seed oil	459	+ 102 %	0.7	Crushing and esterification of the oil to biodiesel
Wheat	straw				Breakdown, hydrolysis and fermentation of lingo-cellulose to bioethanol
Wheat	grain	346	21 %	0.8	Breakdown, hydrolysis and fermentation of starch to bioethanol
Sugar beet	sugar	202	+ 202 %	0.83	Breakdown, hydrolysis and fermentation of sugar to bioethanol. A recent suggestion is the formation of biobutanol from this route.
Waste oil/fat	-			0.1	

Current agricultural practices in the UK suggest that the main sources of liquid biofuels in the near future will be bioethanol derived from wheat grain and sugar beet combined with biodiesel from oil seed rape and also oil waste products. For dedicated cropping systems, analysis reveals that approximately 1 M ha of agricultural land would be required to meet the 2010 biofuel target for the UK, and that this would require more than doubling in the agricultural land dedicated to oil seed rape production, doubling in the recovery of wheat for bioethanol. In Table 2, above, the equivalent of 0.8 M tones of fuel produced from wheat grain is currently exported from the UK in the vast majority of years and so linking this to biothanol production as proposed in new developments rather than export would be most useful. Any more than doubling of OSR (oil seed rape) is unlikely to be feasible since this might require the use of set-aside land with implications for a loss of biodiversity and further intensification. This implies that the UK can make the directive commitment by 2010, if commercialization is successful, as seems likely.

Current Status of Research

In general, research dedicated to biofuels in the UK is fragmented and extremely limited, but core expertise to address some of the issues highlighted below, is extremely good.

Fundamental Plant Biology and Crop Science

It is clear from the analysis above, that any technology available to increase crop yield in current and future climates should be of value to the future development of the biofuel industry. More importantly, improving plant quality – for example by increasing sugar content or starch content and decreasing protein content, will enable for efficient process and extraction for biofuel.

●The UK has good expertise in crop science and plant improvement, but it is only being applied in a limited way to bioenergy cropping systems

● The UK has excellence in fundamental plant science research, but it is only being applied in a small way to address specific bioenergy quality and quantity traits (e.g. different oil quality for better processing in OSR).
● GM technologies and non-GM biotechnology may provide the step-change necessary for future improvements, but the public acceptance of these technologies is still uncertain.

Industrial Microbiology
New enzymes, plant-based enzymes and better fermentation are examples of how the processes for biofuel production could be improved. We have good expertise in microbiology but this is not being largely applied to the production of biofuels.

Environmental Impacts
In the UK and Europe, one of the key drivers for investment in biofuels is environmental – meeting our commitment to Kyoto and more generally wishing to develop carbon-neutral technologies is of high strategic importance. Given this, considerable emphasis is needed to assess the whole life cycle carbon costs of all of the technologies considered above. Currently there is some discrepancy and contention between different studies to assess the greenhouse gas balance of a variety of bioenergy cropping systems. At the point to crop harvest, the GHG or carbon costs are very dependent on what the bioenergy crop might be replacing. There are large carbon savings, for example, if winter wheat is replaced with OSR, but these savings are more than trebled if trees or grasses are grown in replacement rather than OSR (Pete Smith, Aberdeen University, pers. com). If conversion and production are considered, again LCA may give contrasting results. Current research tools are now available to ensure correct full life cycle analysis and these must be linked to policy developments to ensure that environmental as well as economic drivers are considered in any regulatory framework.

Conversion Technologies
Engineering technologies for bioethanol and biodiesel are more or less available 'off the shelf'. However, inefficient and expensive enzymes and chemicals are involved in these processes that form the challenge for future research.

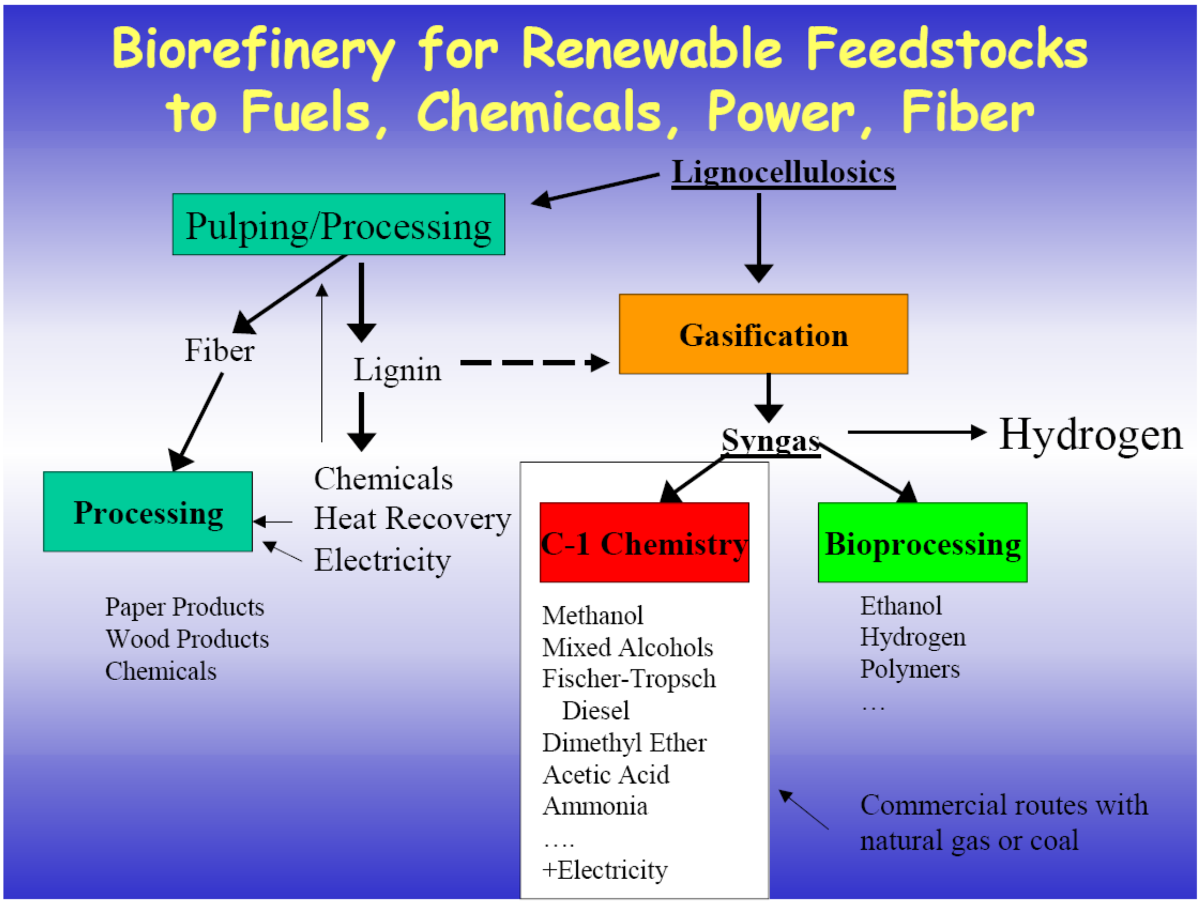
The Future Challenge for 2050 and beyond
Future Developments and the necessity for 'step-change' research discovery – making the biorefinery work

Although technically possible to meet the 2010 biofuel directive target from domestic feedstock resources, it is unlikely that this target can be achieved with current cropping systems – this is because of farm-scale considerations, where crop rotations determine farm-scale plans and also because of spatial limitation, in the growth of sugar beet, for example. It also assumes an extra 1 M ha of agricultural land will be available for this activity whilst this amount of land is also being considered to grow dedicated biomass bioenergy crops for heat and power. This scenario also assumes that no further demand for biofuels will occur and yet all energy analysis suggest that this is unlikely. Although imports of bioethanol and biodiesel will contribute to our net requirement, in the long term, with full LCA, this is not likely to be environmentally sustainable.

In contrast, the UK has a considerable ligno-cellulosic biomass resource. Ligno-cellulose is the intimate mix of plant biomass that constitutes the cell wall – a complex material largely consisting of lignin and cellulose. Up to 6 M tonnes of forest residues (waste wood) may be available in the UK each year, for example and of this only approximately 1 M tonnes is recovered and utilised. Other lignocellulosic resources, for example wheat straw 0.2 M tonnes per annum is also available. Dedicated lignocellulosic biomass crops include woody short rotation coppice (SRC) willow and poplar and miscanthus grass. These crops, unlike conventional crops such as OSR are low intensity, low inputs crops with a much improved GHG balance with other environmental benefits such as enhanced biodiversity. All research analysis suggests that *perennial* crops will be favoured over annual crops since they have a greater seasonal capture of solar energy and again produce biomass without the complications or reproductive yield.

Linked to this and given limitation on land resource and the concept of enhanced efficiency, in future plants will be used more generally as part of the 'bio-based economy' as we become less dependent on the 'oil-based' economy. Plants are the ultimate source of renewable sustainable bioproducts and this extends way beyond simply using plants for energy. High quality, low volume chemicals will be harvested alongside that of energy. Several such conversion routes are possible but the basic feedstock for all second generation biofuels will be ligno-cellulosic[3]. Step-wise research challenges linked to this development are necessary and currently it is extremely difficult to extract and process lignocellulosic feedstocks efficienctly. Several bottle necks exist and some are identified below[3,4,5].

Figure 1. A conceptual biorefinery with lignocellulose feedstock being used for lignin to energy to combustion through thermochemical process, pulp recovery for paper, gasification for gaseous fuel and biological processing for bioethanol. Other fuels are also possible. Taken from Overhend and Chum (2002).



Key Scientific Advances necessary for the biorefinery to work
Challenge – better use of available feedstock
●Plants cell walls are lignin and cellulose. These are complex structures are still far from understood and key to their utilisation for bioenergy will be new research on understanding construction and de-construction. Linked to this a key scientific challenge is to make hydrolysis and fermentation reactions effective.
Likely to occur: up to five years - tractable and could occur over a five year timescale

Challenge - New designer feedstock and microbial processes for breakdown
●Fundamental biosciences must be utilised to develop new and novel plants with different plant characteristics. A new generation of bioenergy plants with enhanced sustainability, yield and altered composition. High lignin plants for pyrolysis and gasification. High cellulose plants for bioethanol.

This requires a Systems Biology approach linking biology to phenotyping to high throughput computing. New microorganisms and biological routes to plant breakdown are required. Novel discoveries to improve hydrogen production from plants may also be possible.
Likely to occur: 5-10 years - Heavy investment of USA and BP has just announced a new Bioenergy Centre to be funded either in the UK or the USA.

Challenge – better technologies for assessment of lignocellulose and break-down processes
● Cross-cutting interdisciplinary approach and new technologies are required to visualise plant cell walls, microbial systems and their functioning. New computing developments will be necessary to enable the biorefinery concept at all levels from modelling microbial function, to predictive experiments through to systems engineering and moving to pilot-scale and commercial plant.
Likely to occur: more speculative but possible 10 years plus

Bibliography

[1] Turley D, Ceddia G, Bullard M, Martin D (2004). Liquid biofuels – industry support, cost of carbon savings and agricultural implications. Report prepared for DEFRA Organis Farming and Industrila Crops Division.
[2] Bauen A (2005). Evidence to the Stern Committee on ‘Global growth of CO_2 emission from Transport, and prospects for new technologies to deliver emissions cuts.
[3] EPOBIO - http://www.epobio.net/epobio.htm.
[4] Biofuels in the European Union – a vision for 2030 and beyond (2006). Draft report 14.03.06.
[5] From Biomass to biofuels – a Roadmap to the energy future Draft Report from DOE Workshop, Rockville, December 7-9 2005.