Fuels for the future

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The increase in world population and greater environmental awareness are putting ever-increasing pressures on available land resources, both in terms of food production and a 'bio-based economy'. Literally, there are more mouths to feed. The current world population of about 6.7 billion is anticipated to rise to around 9 billion by 2050 (Figure 1). In addition to requiring increasing amounts of better quality food, many of these individuals will also demand consumer products whose origins can ultimately be traced back to oil. While modifying the consumer's behaviour is one way to reduce the consumption of oil, another route is to replace oil with materials and products originating from biomass. This concept is at the centre of the 'bio-based economy'.

Maximising the agricultural utility of lower grade land which is not suitable for the effective production of food crops, while maintaining its ecosystem benefits, is one of the central themes involving many scientists working at IBERS. As will be demonstrated later in this paper, the best use of such marginal land can offer a potential solution to the 'food *vs* fuel' debate, whether real or imagined.

IBERS is aiming to use its science to tackle issues such as climate change, fuel security, resource limitation, policy obligations and the maintenance of the rural economy, which all have major implications for Wales, Europe and beyond. In the Biorenewables & Environmental Change Division, researchers are specifically involved in projects aimed at utilising biorenewables to replace many of the components traditionally supplied by the petro-chemical industry, including transport and heating fuels. These projects are supported by a range of funding bodies including BBSRC, DECC, DEFRA, EPSRC, the EU, the Technology Strategy Board and the Welsh Assembly Government, as well as cash and technical support from industrial collaborators. The diversity of these funding bodies and of our academic and commercial partners collaborating in this research reflects both the complexity and the potential of this area of study.

The production of biomass and its conversion into a liquid transport fuel can be achieved using a wide range of techniques, operated either in isolation or in concert.

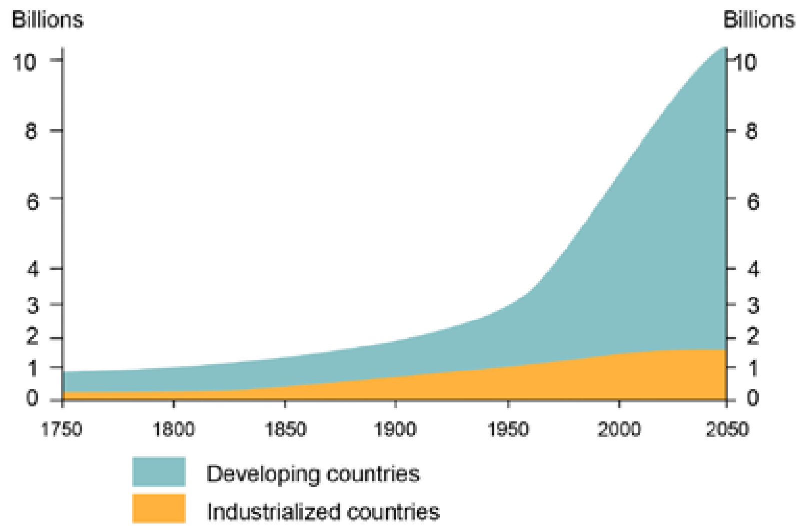

Figure 1. *World population growth forecast.*

Breeding methodologies include genetic, molecular, biological and traditional selective approaches to increase the accumulation of target molecules, improve agronomic performance and raise yields. Physical processing methods can then assist in the refinement of the molecular entities produced, such as the isolation of soluble sugars, enzyme treatments to degrade constituent fibres, microbial bio-transformations to convert sugars into bioethanol, and thermo-chemical treatment processes such as pyrolysis.

IBERS is not only committed to the provision of economic solutions for bioresource production and use but, even more importantly, to developing solutions that are environmentally friendly. We are therefore focusing our efforts on biomass crops which are not in direct competition with the food industry, have low input requirements and which can be grown on poorer soils in UK climatic conditions. Internationally, our research aims to develop crops which address forecasted changes in climatic conditions both in the UK and in other regions of the world.

Grassohol Project (DEFRA Renewable Materials LINK, BBSRC and Welsh Assembly Government)

A number of bioethanol facilities are either planned or currently under construction in the UK. At this point, however, total UK biofuel production is still relatively low and there is high reliance on imports from countries such as Brazil. The new UK facilities will be primarily focused on using arable crops such as wheat and sugar beet. Whilst the science and technology involved in conversion of these particular feedstocks into bioethanol is well understood, the competition between using the high quality arable land required to grow them for the production of food or fuel is a debate that still rages.

In comparison, the Grassohol project is focused on using high-sugar varieties of perennial ryegrass which perform well on a wide range of marginal lands, and exploiting these as a source of sugar for conversion into bioethanol. A key element of this research programme is the utilisation of a microorganism that is able to convert the sugar polymer fructan into the sugar monomer fructose. Fructose is then easily converted into bioethanol using microorganisms such as yeast.

The benefits of using ryegrass as a source of biomass for converting into bioethanol are multiple:

- the plant is well adapted for growth in the UK environment
- methodologies for cultivation are well understood by farmers
- breeding programmes at IBERS have resulted in certain varieties of ryegrass with water soluble carbohydrate levels as high as 30-40%
- ryegrass production will have a minimal impact on landscapes and therefore increased production will not impact on tourism
- the ryegrass fibre is low in lignin and highly digestible, which offers an additional route to bioethanol and other products

Fibrzymes Project (Welsh Assembly Government)

To maximise the impact of the Grassohol research project, it was realised that we needed to devote additional resources to improving the efficiency of the enzymes used to release sugars trapped within the ryegrass fibres. The Fibrzymes project was therefore devised with objectives to:

- develop bespoke enzyme formulations to maximise sugar release from grass fibre
- optimise the fermentation and conversion of the sugars released from the ryegrass fibre into bioethanol
- develop a process for large-scale production of a key enzyme necessary for converting sugar polymers into sugar monomers.

For more information visit www.grassohol.org

Miscanthus Renewables Materials LINK (DEFRA and BBSRC)

This project is focused on the use of *Miscanthus* (elephant grass) as an energy crop. Research will be directed towards:

- improving *Miscanthus* yield
- identification and supply of *Miscanthus* genotypes adapted to a broad range of environmental conditions such as variations in temperature, day length and water availability
- reduction in the cost of establishment by investigating seed propagation

As with ryegrass, there is the potential to convert biomass from *Miscanthus* into bioethanol, and one work-package within the project will be focused on this area.

The hydrolysis of *Miscanthus* structural polymers to their composite sugars is a more complicated process than that associated with ryegrass. There is a different range of sugar components in the lignocellulosic molecules and the bonds between the sugars and their associated lignin molecules are more complex. As enzymes typically act on one particular bond or a small group of similar bonds, the lignified fibres in *Miscanthus* cannot be fully hydrolysed unless a full complement of enzymes is applied. Additionally, natural enzyme inhibitors may also be present within the fermentation. Incomplete breakdown of the polymers into a series of oligomers (short sugar chains) does not necessarily enhance the sugar output either, as the secondary enzymes capable of converting the short chains to individual sugars may not be available.

Compared with sugar cane, which can be squeezed to remove the fermentable juice immediately, lignocellulosic crops need the addition of a balanced sequence of different enzymes, which may still not release all the available sugars. However, the sheer volume and availability of lignocellulosic material and associated sugars in *Miscanthus* makes it an attractive proposition to try to utilise. A small improvement in the balance of the enzymes applied and in their formulations will increase both the efficiency of conversion and reduce costs (**Figure 2**).

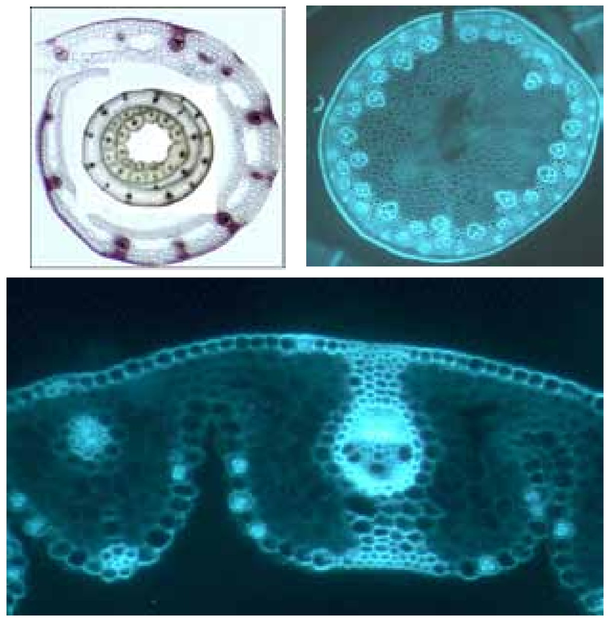

Figure 2. *Lignification of cell walls and vascular system.*

By screening a wide range of accessions available through the UK *Miscanthus* collection based at IBERS, it is possible to determine which lines may be most suitable for biological conversion e.g., fermentation to ethanol.

Biochar Project (ABATE - an A4B project - Welsh Assembly Government)

Biochar is a black carbon-rich material produced by thermally treating biomass materials in zero or limited oxygen conditions using processes such as pyrolysis and gasification. The biochar produced has been shown to have great potential to act as a carbon sink when applied to land. It can also act as a soil improver by increasing the water- and nutrient-holding capacity of the soil, and has the potential to reduce the greenhouse gas emissions coming from within the soil structure. Biochar applications could therefore offer considerable benefits in terms of mitigating climate change, improving food security, and reducing reliance on chemical fertilisers, all of which would have considerable environmental and economic advantages.

In traditional methods of charcoal production, 50-70% of the biomass is lost through the chimney as gaseous and particulate emissions and much of the heat produced during the process is not fully utilised. Modern pyrolysis facilities may overcome these limitations by exploiting the residual heat and gases produced using a combined heat and power (CHP) approach within the biorefining sequence. This would produce not only biochar, but also a range of useful additional products such as bio-oil, syngas and heat which could be captured and reutilised for other processes (**Figure 3**). In order to investigate these options, IBERS has received funding from the Welsh Assembly Government's

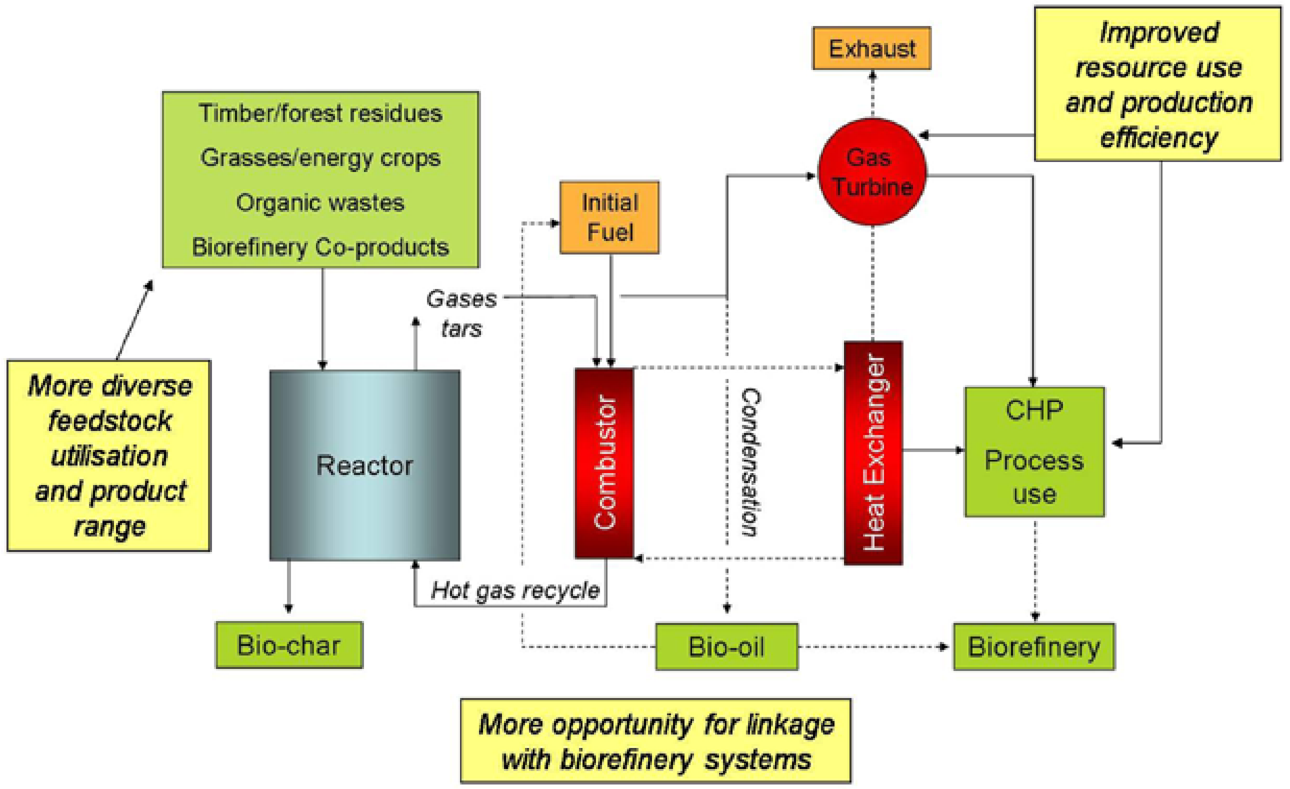

Figure 3. *Biochar production and potential linkages with CHP and biorefinery systems.*

'*Academic Expertise for Business*' *(A4B)* programme to carry out research into the production and application of biochar through IBERS '*Biochar for Business and the Environment*' (ABATE) project. This has involved our researchers in the design and commissioning of a state-of-the-art experimental production facility (Figure 4), capable of producing biochar in 100-300 kg quantities from a diverse range of feedstocks such as grasses and organic wastes, and not just from wood. Our aim is to use this experimental biochar facility to trial a wide variety of under-utilised feedstocks and wastes, looking to maximise the potential for economic and environmental 'added value' in biochar and bio-oil conversion. IBERS will also look at methods for process optimisation to enhance both conversion efficiency and product quality. Parallel trials will be performed to assess the environmental benefits of biochar, both as a carbon sink and soil conditioner, through a series of pot and field experiments. These will attempt to measure the effects of biochar amendments on land, plant productivity and soil environmental services in the UK.

Integrated approach

The strength of the research associated with the production of liquid biofuel from biomass is the complementary nature and integration of the various projects (**Figure 5**). The integration of projects encapsulating both discovery and translational science provides the foundation upon which science with maximum impact can be built.

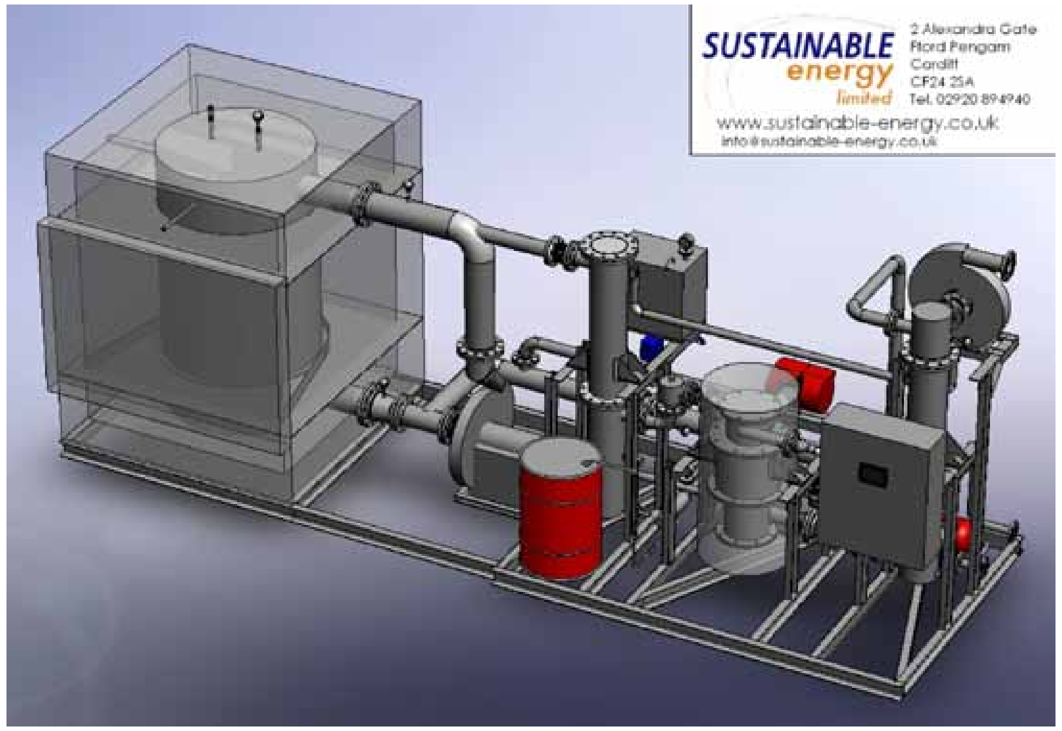

Figure 4. *IBERS experimental biochar facility.*

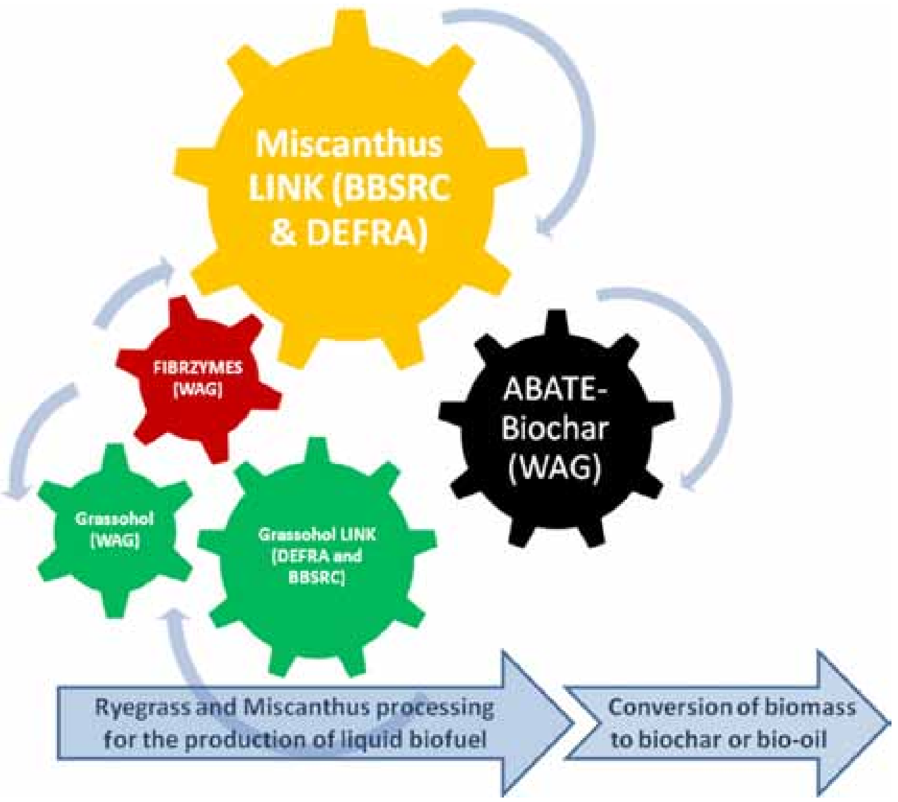

Figure 5. *Scientific integration.*