The Biorefining Opportunities in Wales

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The Biorefining Opportunities in Wales:

From Plants to Products

Understanding the potential for building a sustainable biomass based economy in Wales, using plants as a renewable source of key commodities (chemicals, transport fuels and energy)

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Understanding the potential for building a sustainable biomass based economy in Wales, using plants as a renewable source of key commodities (chemicals, transport fuels and energy)

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Foreword

I am pleased to provide the foreword to this important report which makes a clear and well founded case for establishing a 'centre of excellence' for biorefining in Wales.

It is becoming increasingly clear across all sectors of society, that the world cannot sustain its current dependence on fossil fuels as the key source of energy, fuels, chemicals and related products. Several issues have been prominent in the press over the last twelve months including dwindling crude oil resources, volatile fuel and raw material costs, food versus fuel supply and demand, sustainability of resources and EU CO2 emission targets. Against this global back drop there is an urgent need for the UK to have an effective and sustainable position for the future and biorefining has an important role to play.

Many countries are already embracing the opportunities which biorefining presents as a solution to the sustainable development and consumption needs of the 21st Century. The work of the Industrial Biotechnology Innovation and Growth Team*, seeks to ensure that the UK builds on its world renowned research and knowledge base to develop the full range of technologies and mechanisms required to ensure that UK companies are better positioned and encouraged to leverage opportunities in Industrial Biotechnology.

With a world leading science base and established high-tech businesses operating across the UK, I firmly believe that we are well placed to capitalise on the opportunities that biorefining presents. In particular, Wales has a very strong research base and intellectual asset combination that will be vital for the delivery of a national biorefining strategy.

The use of high sugar grasses as a feedstock would provide an excellent opportunity to initiate a biorefining industry within Wales and would be highly complementary to the existing UK activities in this sector. This potential could be further exploited through the use of additional plant feedstocks and a wide range of processing technologies, in turn providing a valuable platform for creating a diversified farming industry that could contribute significantly to the social and economic regeneration of Wales's rural communities. With a focus on platform chemicals for leading bio-derived chemical-using markets, Wales is ideally placed to serve one of the largest clusters of chemical-using companies in the UK.

I believe that this feasibility study will act as a catalyst for the effective coordination of a National strategy that will see the establishment of a new centre of excellence in biorefining and position Wales at the forefront of the UK's low carbon, knowledge-based economy.

Ian Shott
President and CEO of Excelsyn
Chairman of the IB-IGT

**The Industrial Biotechnology - Innovation and Growth Team (IB-IGT) was formed in 2007 to facilitate a collective view from the UK chemical and bioscience industries on the innovation and growth challenges in industrial biotechnology. It is an industry-led project facilitated by BERR's Bioscience and Chemicals units.*

Executive Summary

This report was commissioned to consider whether it is possible to reverse the economic impact of the decline in traditional rural economies by creating a sustainable biorefining industry in Wales, through the use of renewable, non-genetically modified, non-food crop based feedstocks, which would include high sugar grasses.

This study concludes that:

- Wales has access to a feedstock suitable for biorefining without disrupting land use patterns.
- To a first approximation, Wales has at worst cost parity with competing feedstocks and infrastructures in the UK.
- Wales has a strong relevant science and technology base that could underpin the development of the necessary supply chains.
- Wales has a growing base of local user industries, but more importantly, is adjacent to some of the largest downstream users in the country; approximately 25% of target sectors which represents a £560m market opportunity.
- Market drivers for a shift to renewable feedstocks exist and are affecting the target sectors (cosmetics, personal care, pharmaceutical, agrochemical, water treatment, surfactants, polymers, lubricants, adhesives, coatings, biofuels, essential oils and nutraceuticals).

Given the inevitable emergence of biorefining and the existing agricultural and scientific base in Wales it is apparent that a leading position in the use of renewable bio-based materials could be achieved. Such activity would contribute considerably to building a low-carbon economy in Wales as well as reversing the decline in rural communities and diversifying their commercial opportunities.

In summary, establishing a biorefinery industry in Wales would address the three pillars of sustainability: it is economically viable, environmentally sound and socially beneficial.

Answers to Key Questions

This feasibility study was commissioned by The BioComposites Centre, Bangor University to address certain key questions.

1) What is the economic case for developing biorefining and the associated technology and supply chains across Wales and will this lead to sustained economic and social regeneration across the region?

This report makes a clear case for the establishment of an economically viable fermentation biorefinery in Wales. To achieve full potential, such a facility would need to be supported by the existing and specialised expertise that Wales possesses in high-tech companies, academic and research institutes in the development of high-energy crops and the application of bio-based materials and substances. The utilisation of **high-sugar grasses grown on 50,000 ha of recovered temporary grassland** as a feedstock would reverse the decline in Welsh farming and diversify production without changing the landscape, affecting food production or utilising GM technology. Crucially the use of grasses is theoretically competitive with sugar-beet as a feedstock. The associated supply chains and diversification of farming would lead to increased employment, increased attractiveness to technology companies and students and a regeneration of rural communities.

2) What is the potential market size for bio-derived unmodified natural materials and chemicals, as well as chemically and / or biologically transformed platform chemicals in Wales and what strategic value can be added to the Welsh economy through the increased use of bio-renewable feedstocks?

The report concludes that given the existing transport links bio-based chemicals from a fermentation biorefinery could be economically competitive in a readily **accessible market of up to £560m per annum.** Given the increasing demand for bio-based products this is considered to be a conservative estimate of the market value, with considerable further growth potential.

Increased use of bio-based renewable feedstocks would contribute significantly towards developing a low carbon economy within Wales. Longer term, such a strategy would stimulate the growing knowledge-led economy, and would continue to sustain agriculture providing new outlets for products from farming.

3) How will biorefining activities in Wales integrate with complementary activities in the rest of the UK in order to maximise impact?

Fermentation biorefining using high-sugar grasses as feedstock can be **competitive with East Anglian sugar-beet** and North East wheat. With a focus on the production of chemical intermediates and being well connected to serve large clusters in Mersey basin/M62 corridor, Birmingham area and Bristol/M4 corridor, Welsh biorefining activities would be complementary to existing biorefinery activity in the UK.

The focus on platform chemicals for leading bio-derived chemical using markets such as personal care, agrochemicals, coatings, surfactants, lubricants, pharmaceuticals and polymers would establish Wales in a lead position in the UK's low-carbon, knowledge-based economy of the future. Welsh bio-based chemicals would supply leading innovative companies developing sustainable products in neighbouring clusters and, increasingly, in Wales.

4) Can the existing regional integrated infrastructure and skill base (academic and industrial) offer sustainable long term opportunities for supporting a leading position in implementing a biorefining strategy?

Wales is well placed to develop such a biorefinery facility given a co-ordinated approach and sufficient support from policymakers and funding bodies. World-leading centres of research excellence such as IBERS at Aberystwyth University, BC and SENR at Bangor University, the Chemistry Department at Cardiff, and the Institute of Life Science at Swansea University **should be encouraged to collaborate and focus on developing the technology to process the whole feedstock material.** Development of a biorefining activity will lead to a focus on the knowledge and skill gaps and reinforce the existing expertise base.

Transport links between North and South Wales are poor; however there are good road and rail access to neighbouring regions with highly active downstream clusters.

5) How will the development of biorefining capacity in Wales affect and be affected by the development of the existing industrial base (including service companies), regional capabilities and skills over the next 20 years?

The feedstock requirements of a commercial fermentation biorefinery **would reverse the decline in agriculture in Wales** by restocking grassland to 1990's levels. A reinvigorated agricultural sector would revive associated rural industry and provide opportunities for personnel and skills to be retained and passed on.

Biorefinery activity in Wales will **support and stimulate Wales' current chemistry-using industry, which is characterised by high growth high-tech SMEs.** The resulting image of a sustainable, innovative nation will attract students, scientists and engineers as well as new enterprises to Wales.

With a reduced reliance on fossil fuels the chemistry-using sector in Wales and adjacent markets will be more robust in dealing with variations in feedstock costs and supply. The sector will also be more responsive to changes in policy, legislation and consumer demand as environmental concerns increase. Industry will be encouraged to site manufacturing operations in Wales near supplies and neighbouring downstream markets that will grow through increased availability of bio-based materials. The academic base will be strengthened, particularly in links with industry. Development of renewable energy projects will also gain from technology and infrastructure development associated with biorefinery activity.

Recommendations

1. Establish a Welsh Centre of Excellence for Biorefining.

Greater co-ordination of the biorefining technology development activities in Wales will lead to a UK leading position. Establish an R&D centre of excellence in biorefining which addresses the scientific challenges associated with converting biomass into chemicals and which will facilitate skills and knowledge transfer across the different industrial/academic sectors. Further development of ryegrasses for high sugar yield and lignocellulosic technology is crucial in realising the potential of biorefining in Wales.

2. Develop Supply Chains.

Create regional partnerships encompassing a wide range of expertise including farmers, scientists, economists, business experts and politicians. Promote the creation of robust supply chains starting from agricultural producers to processing companies and end users (customers from the chemical/ pharmaceutical sectors). This would ultimately be achieved by establishing closer links between the rural economy, academic institutions and SMEs/large companies (including representatives from the chemical, petrochemical and service industries). In particular focus on developing strong relationships with the target industry sector clusters in Mersey basin and M62 corridor. It is important to market the biorefinery capability early with important target customer clusters such as personal care, surfactants, polymers, coatings and nutraceuticals as likely first markets will be outside Wales with inward investment a consequence.

3. Invest in Infrastructure.

Ensure that the existing infrastructure is utilised to optimum capacity (i.e. road, rail and port links) and can support the planned expansion in industrial-scale biorefining. The logistics of transporting 1 million tonnes of feedstock per annum is a huge challenge. Regional processing centres are likely to be required to smooth the supply of feedstock and return fertiliser to the ground. This model would increase the involvement and economic potential for rural communities and simplify the economic logistics. A demonstrator facility for this model should be an early priority to develop the process to commercial reality.

4. Develop a Fermentation Biorefinery.

A central facility using a high-sugar grass feedstock (via regional processing centres) would be hugely important to Wales and the neighbouring regions. The biorefinery would drive the development of improvements in fermentation technology and establish Wales in the forefront of low carbon technologies. The facility would kick-start rural regeneration and build upon long-established expertise in Welsh academic departments and institutes. The construction of a demonstrator facility would be an important stage in the development.

5. Commission a Full Life-Cycle Assessment.

An understanding of the energy intensity and green house emissions for the production of bio-based chemicals will be important for successful commercialisation of any biorefinery. The life cycle analysis (LCA) of bio-based chemicals is strongly influenced by feedstock cultivation practice. Data on the energy required and the green house gas emissions resulting from high sugar grass cultivation on temporary grassland is poorly understood. A life-cycle assessment of high sugar grass cultivation and its conversion to bio-based chemicals should be performed at an early stage in the development of the biorefinery.

Contents

What is Biorefining?

The Biorefinery Concept

Biorefining is the sustainable processing of biomass[1] into a spectrum of marketable products and energy[2]. A biorefinery is therefore a facility that converts biomass into purified materials and molecules that result in usable products such as chemicals, fuels and fibres.

Biomass feedstocks are plant matter such as crops, forestry and agricultural waste through various processing techniques can be fractionated into lignin, hemicellulose, cellulose and starch components. Residue materials isolated during the fractionation process include minerals (used in e.g. plasterboard), enzymes (used in e.g. laundry products), proteins (used in e.g. food processing) and fibres (used in e.g. composite plastics). The fractionated components can be converted using a combination of state-of-the-art biological and chemical process technologies into useful products (both high-value fine chemicals and commodity substances) and chemical intermediates. These processes include long-practiced technologies such as fermentation and thermochemical methods such as gasification and pyrolysis. A generic biorefinery is shown schematically in Figure 1.

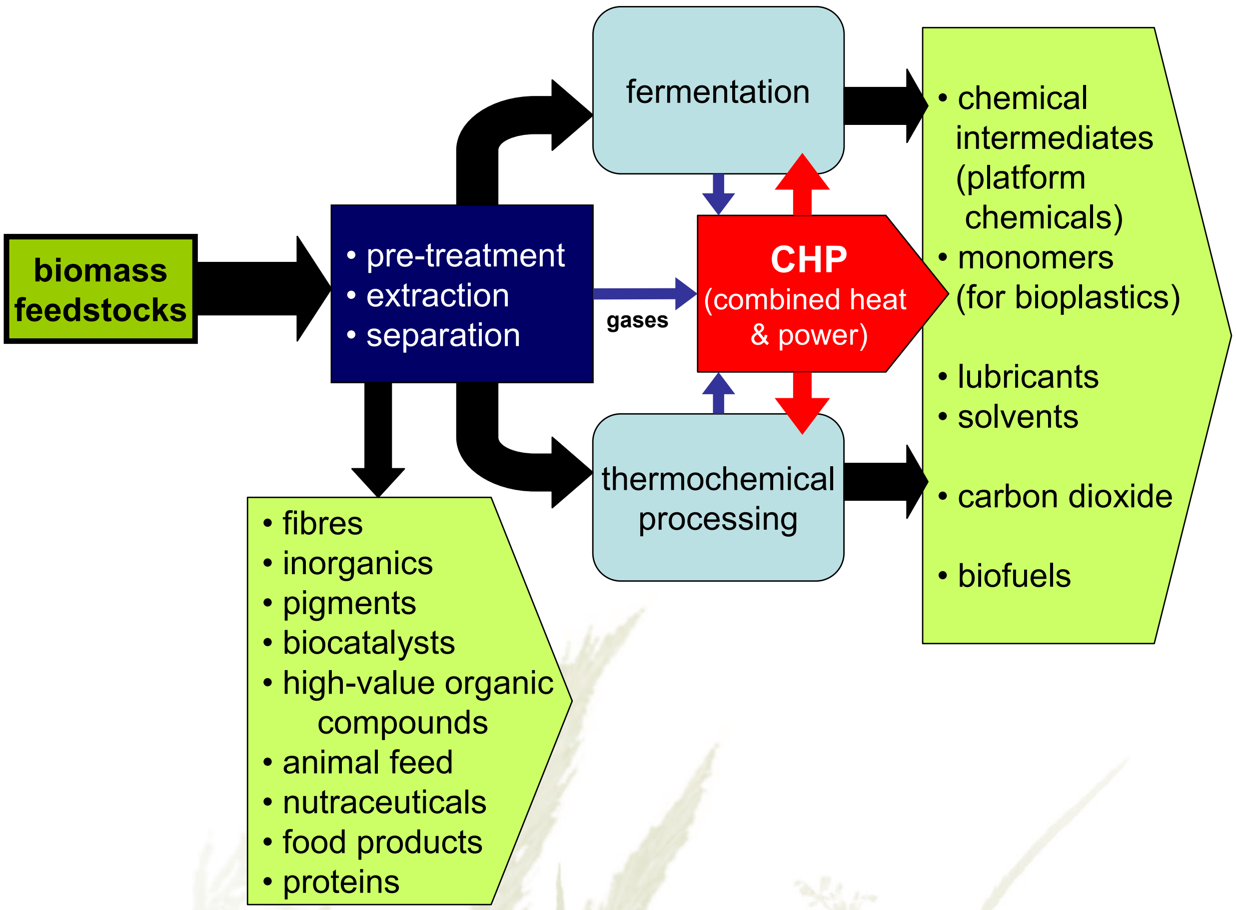

Figure 1: a schematic of a generic advanced biorefinery

[1] Biomass refers to living and recently dead biological material that can be used as fuel or for industrial production. Most commonly, biomass refers to plant matter grown to generate electricity or produce biofuel, but it also includes plant or animal matter used for production of fibres, chemicals or heat. Biomass may also include biodegradable wastes that can be burnt as fuel. It excludes organic material which has been transformed by geological processes into substances such as coal or petroleum (Wikipedia definition).

[2] IEA Bioenergy task 42 on Biorefineries (definition)

In the same way that an oil refinery processes crude oil into fuels and chemicals, a biorefinery performs the same task with plant matter. As with oil refineries, the efficient management of complex flows of materials and energy in the biorefinery complex will be paramount to utilise every element of the raw material feedstock and maximise integration benefits for improved energy savings and reduced processing costs.

It is instructive to draw comparisons between a biorefinery and an oil refinery[3]:

- Crude oil and biomass are both complex mixtures of compounds. Crude oil is fractionated using distillation whilst biomass requires more complex physical and chemical fractionation methods.
- Crude oil has a relatively fixed composition related to the location of extraction. Biomass feedstocks could be modified for both optimum processing and maximising end product yields through the utilisation of both plant breeding and genetic engineering.
- An oil refinery uses a variety of heterogeneous catalytic processes. A biorefinery requires both catalytic processes and advanced biochemical processes but may generate products with greater chemical functionality.
- An oil refinery uses highly efficient and mature catalytic technology that has been optimised to near practical limits. The processes employed by a biorefinery include novel biocatalytic reactions which will be radically improved over time.
- Oil refineries have huge capacities to achieve economies of scale. A typical oil refinery processes around 200,000 barrels of crude oil per day (~10 million tonnes per year). For a biorefinery the feedstock logistics are likely to limit processing capacity.
- Crude oil is processed by a refinery with virtually no waste – all raw material is converted to useable products. Similarly, all biomass should be converted to useable products by an advanced biorefinery.
- Oil refineries and petrochemical complexes produce chemical building blocks such as olefins and aromatics which are derivatised to form intermediates for the polymers, solvents and detergents markets. Biorefineries will produce highly functionalised unique platform chemicals for derivatisation to valuable chemical intermediates.

Development of biorefinery technology could take advantage of co-location with existing infrastructure such as petrochemical plants, pulp mills and power stations.

Drivers for Biorefining

The chemistry-using industry is increasingly focusing on biorefineries as a future source of raw materials with the plastics industry and consumer care products leading the way. Much of this is driven by consumer demand for 'green', 'natural', and ethical products but is more and more being seen as a route to deliver low-carbon and cost effective technology solutions. The uses of renewably sourced chemicals demonstrate a greenhouse gas saving across their life-cycle when compared to conventional equivalents from petrochemical sources[4]. The CO2 emissions released in the manufacturing and consumption of bio-based products are offset by the CO2 captured in the growth of the biomass used for their production. The extent to which such a closed eco-cycle of CO2 can be achieved might vary between products. The potential for non-renewable greenhouse gas savings from the manufacture of products from second generation biorefineries compared with petrochemical sources varies between 30% and 85%[5]. Within Europe, adoption of biorefining is seen as a key technology in the efforts to mitigate climate change and ensure security of supply against fluctuating crude oil prices.

3 "Mapping the Development of UK Biorefinery Complexes", Tamutech Consultancy, 2007, NNFCC, see: **http://tiny.cc/2n8zN**

4 "Study into the Potential Energy and Greenhouse Gas Savings of Renewable Chemicals and Biocatalysts: Synthesis and Analysis Report", North Energy, 2008, BERR

5 BREW report, executive summary, see: **http://www.chem.uu.nl/brew/**

Biorefining offers support to rural development by providing additional market outlets for farmers and decentralised production facilities can provide new income and employment opportunities in rural areas. Due to the fact that the raw materials grow over large areas, bio-based production favours a decentralised structure. Regional biomass processing facilities can bring local economic benefits as well as simplifying the logistics and contract situation for a large central biorefinery and lowering the capital requirements. The regional facility separates fibres, animal feed and, potentially, high-value organic compounds from niche crops from the raw biomass. The sugar components can then be separated and concentrated to supply the central biorefinery while the protein fraction recovered and used as high-quality animal feed. Figure 2 shows a schematic of such a facility.

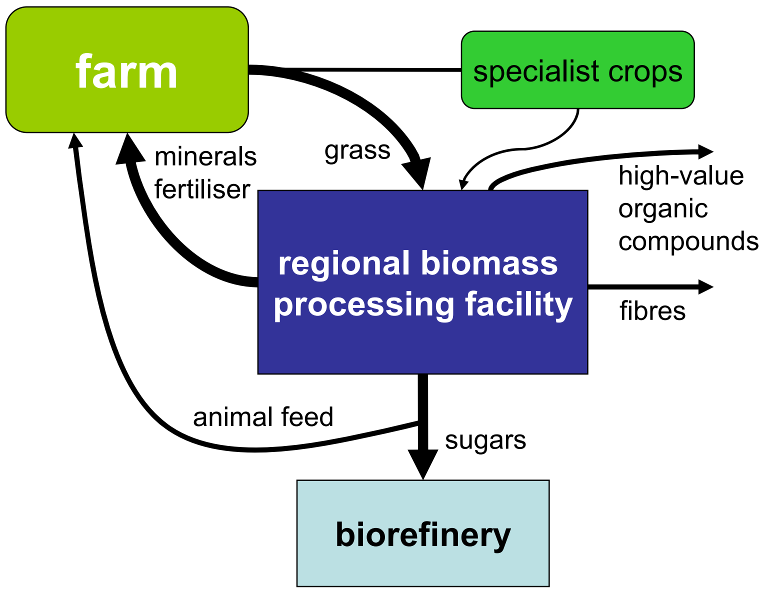

Figure 2: Schematic of a Regional Biomass Processing Facility

For certain downstream sectors complex, high-value organic molecules used in low volume, such as pharmaceutical and agrochemical ingredients can be accessed via specialist crops grown particularly for that purpose. The waste material following extraction of the value component can then be processed by a biorefinery to maximise efficiency. However, the extraction of pharmaceutical products (e.g. artemesinin as a current example) where the commercial activity is driven by the extraction of the active compound, biorefining would only take place if justified by the marginal cost or as a means of disposal of the biomass. Bio-based products in general have low toxicity and have a strong potential as novel pharmaceuticals, vaccines, food and feed additives, providing increased functionality and quality at possibly lower production costs.

Sourcing chemicals, materials and energy from biomass also offers increased energy and feedstock security, rural regeneration through diversification and drives innovation in downstream industries. Indeed, the development of a bio-based industry is predicted to become a vital part of the EU economy by 2030 and will be indispensable to sustainable economic growth, employment, energy supply and to maintaining the standard of living. Bio-processing will encompass a one third share, worth €300bn[6], of industrial production. Combined with advanced bioprocess engineering the development of high performance crop plants is the key to this vision becoming reality. Crops will serve as factories for enzymes, amino acids, pharmaceuticals, polymers and fibres, and will be used as renewable industrial feedstock to produce biofuels, biopolymers and chemicals. This will lead to agriculture thriving without subsidies. Underpinning this will be a growing need for interdisciplinary education and joint research that is closely entwined with technological development.

[6] "En Route to the Knowledge-Based Bio-Economy" (KBBE), 2007, EuropaBio, see: **http://www.europabio.be/articles/cologne_paper.pdf**

The main drivers for wider adoption of bio-based products are therefore:

- to create emission neutral life-cycles of products thus contributing to a low carbon economy;
- to substitute, at lower costs, fossil-based products;
- to be manufactured with lower overall ecological footprint, i.e. lower energy and water use and lower waste generation;
- to develop new, and support for, existing industrial activity.

All of these drivers are linked to the pillars of the Welsh Assembly Government's Science Policy: Health, Low Carbon Economy and Enabling Sustained Social and Economic Renewal[7].

Biorefinery Types

So-called first generation biorefineries operate by processing the "valuable" parts of a crop such as the grain from wheat and discarding the unwanted parts such as straw and chaff. These are used/disposed of according to normal agricultural practice but they can be burnt to produce power where economical to do so as identified as part of the renewable energy strategy in Wales[8]. These technologies are established and in industrial use today.

Developing second generation technology will process the entire plant leading to higher productivity from a given area of land as all the biomass is used in the process resulting in a greater yield of biorefined products from a given agricultural crop. This technology should also enable use of a broader range of feedstocks including those grown on land unsuitable for farming. Second generation bioprocessing technology is still in the process of development with demonstrator plants now being built. Given its potential for higher yields and broader range of feedstocks it is expected that second generation biorefineries will come to dominate over time.

There are two fundamental types of biorefinery technology with different characteristics: the fermentation and thermochemical routes. Both technologies require energy which can be met by an on-site combined heat and power plant fuelled by residues from the biomass processing (see figure 1).

Fermentation

Fermentation processes are well understood and are currently used in so-called first generation systems to produce bioethanol from sugars and starches in essentially the same way alcoholic spirits are produced. The process can be adopted to yield other "platform chemicals"; these are simple functionalised molecules readily produced from fermentation that can serve as building blocks for further chemistry.

Evolving second generation fermentation processes can produce a similar range of platform chemicals through the processing of sugars and cellulose as well as lignins. These technologies are still in development (mainly in the US) and because they use the whole plant, require additional stages to first break down the plant's structural materials, using micro-organisms or chemical treatment, into sugars that can be fermented. As these processes improve the range of raw materials and the proportion of feedstock actually converted to useful products will increase. Second generation technologies provide higher yields per hectare of grown feedstock than the currently used first generation techniques. Both processes produce solid residues high in proteins. These can be sold into the animal food industry or burnt to satisfy the high power demands of the fermentation process.

Fermentation processes have the potential to make a wide range of different chemicals. Compounds such as ethanol, succinic acid, lactic acid, citric acid, 1,3-propanediol, lysine and glutamic acid are already made via fermentation processes on a commercial scale with established markets as fuels, nutraceuticals, personal care and cosmetics ingredients, elastomers, polymers and adhesives and surfactants[9]. A commercial scale fermentation biorefinery would cost of the order of £300m[10].

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[7] "A Science Policy for Wales", 2006, Welsh Assembly Government, see: **http://new.wales.gov.uk/about/strategy/publications/978365/?lang=en**

[8] "Renewable Energy Routemap for Wales", 2008, Welsh Assembly Government, see: **http://wales.gov.uk/consultations/closed/environment/renewenergymap/?lang=en**

[9] "Renewable Feedstock for Sustainable Materials - Bioproducts - Their Importance to Wales: A Scoping Study", 2002, Centre for Advanced and Renewable Materials **www.bc.bangor.ac.uk/suscomp/assets/pdf/CARM_Bioproducts_report.pdf**

[10] "The Biorefinery Opportunity - A North East England view: A report on the opportunities for the development of a renewable raw material based process industry in North East England", Chemistry Innovation, 2007, NEPIC, see: **http://tiny.cc/U6yzS**

Thermochemical

Thermochemical processing is very different from fermentation in that it uses heat to break down the biomass into a gas containing hydrogen and carbon monoxide (known as "syngas"). This method is known as gasification and produces a mixture that can be processed using well established technology widely used in the petrochemical industry[11]. Here biomass operates as a substitute for fossil fuel in petrochemical type processes.

Other thermochemical technologies can be applied to biomass as pre-treatment steps.

Torrefaction can be used to upgrade biomass for combustion and gasification applications and is achieved by heating in the absence of oxygen. This results in decomposition reactions and the biomass to become completely dried and to loose its fibrous structure. This improves the grindability, hydrophobicity and increases the calorific value of the material. The resulting material is more efficient for co-firing in existing power stations and for gasification for the production of chemicals. Energy dense fuel pellets (15-18.5 GJ/m3)[12].

Pyrolysis is used to convert biomass to a dense liquid (bioOil) for ease of transportation[13]. This can be done using small units near to where the crop is produced. Such an approach reduces straw volume by 94% for example. Although bioOil can be used for gasification or burnt for heat and power it is not interchangeable with fossil fuel-based oils.

The different temperatures these thermochemical processes operate at are:

torrefaction	180-290 ˚C
pyrolysis	290-600 ˚C
gasification	higher than 600 ˚C

The distinction between the technologies is not as strict as suggested by this list. A staged approach can enable the separation of different products and chemicals and can offer an advantage over producing syngas directly through gasification. These methods will evolve with improvements in catalyst technologies for the various stages.

The products from thermochemical processes are different from fermentation. Syngas can be used to make bulk chemicals such as methanol, ammonia and naphtha with the most likely commercial application the production of dimethyl ether for blending with diesel. Current focus for thermochemical technology is on the production of fuel.

Prior to thermochemical treatment certain chemicals can be isolated from biomass or bioOil. In general it is considered that this will not be a primary driver for biorefining and is unlikely to be economic. The types of chemicals that could feasibly be obtained include phenols (phenol, eugenol, cresols, xylenols but mostly alkylated (poly-)phenols), levoglucosan, hydroxyacetaldehyde, acetal, furfural and furfurylalcohol.

A commercial scale thermochemical biorefinery requires a capital outlay of approximately £450m with further investment needed to build bioOil plants to feed it [10].

[11] Preliminary Screening – Technical and Economic Assessment of Synthesis Gas to Fuels and Chemicals with Emphasis on the Potential for Biomass-Derived Syngas, P.L. Spath, D.C. Dayton, see: **www.nrel.gov/docs/fy04osti/34929.pdf**

[12] Torrefaction for biomass upgrading, P.C.A. Bergman and J.H.A. Kiel, Published at 14th European Biomass Conference & Exhibition, Paris, France, 17-21 October 2005; see: **http://tiny.cc/hCF7f**

[13] An assessment of biomass feedstock availability to a large scale Biomass to Liquid plant in the United Kingdom, 2008, Zsolt Kalmár MSc Thesis, School of Applied Sciences Cranfield University, see: **http://tiny.cc/nMzTj**

The Biorefinery Supply Chain

Biomass is bulky compared to fossil sourced liquid hydrocarbons; particularly in terms of the mass can be gainfully transformed. Localised pre-treatment through onsite processing at farms is necessary to the logistics and economics of the overall biorefinery process. The presence of a deep water port, road and rail links as well as storage and localised processing infrastructure is important to cost-effective handling of raw materials.

Figure 3 describes the basic supply chain involved and the disciplines engaged in the overall route.

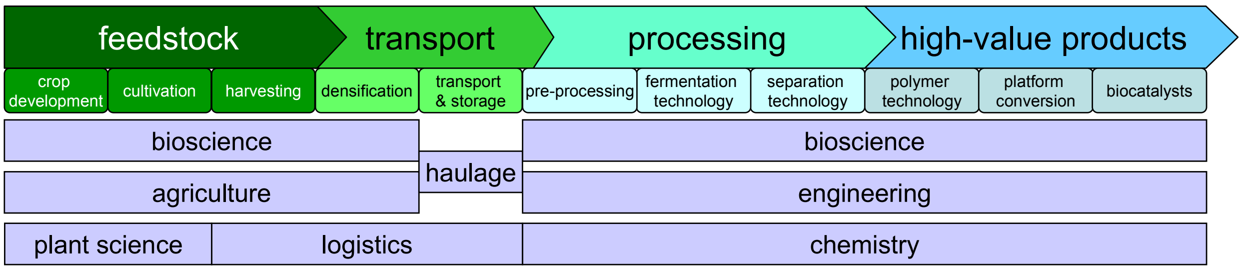


Figure 3: Biorefinery supply chain and related disciplines

Each of the supply chain stages presents particular technical challenges that require an inter-disciplinary approach to tackle. There are also associated economic, societal and environmental concerns with each stage.

Feedstocks

Expertise in developing novel and improved crops tailored to the processing conditions or to maximize desired components is important in improving the efficiency of the biorefining process. The cultivation and harvesting of feedstocks can affect composition and an experienced agricultural base is therefore important.

At the feedstock end of the supply chain, issues concerning competition for land-use, competition between food and fuel, preservation of biodiversity and the use of scarce water resources are dominating the public debate.

Transport

The pre-processing of feedstocks can ease logistical and transport considerations as well as generating new job opportunities. Increased haulage traffic in rural areas can affect the environment and be unpopular with the general public. There is also a careful cost balance to adopting a hub-and-spoke model for feedstock supply.

Processing

Improved, second generation fermentation holds particular challenges in scale-up both in finding the right enzyme technology for breaking down cellulosic material and in the separation of products. For thermochemical routes, the catalysts used to convert syngas into fuel-based and chemical products must be robust and resistant to poisoning.

High-Value Products

Novel chemistry will be required to adapt to chemical feedstocks which are characterised by greater functionality and are oxygen-rich compared to traditional petrochemical feedstocks. The development of new bio-based polymers is underway and will improve with access to new monomers and additives. New chemistries for the conversion of platform chemicals to high value products will be needed. The co-location of businesses near the suppliers of such materials will aid product innovation as well as satisfy the increasing consumer-driven demand for environmentally benign goods, e.g. household products (paints, cosmetics, cleaning, fibres and textiles), transport (fuel and fuel additives, coatings, metalworking, hydraulics, automobile plastics), pharmaceuticals and agrochemicals.

Commercial Biorefining - International Situation

Considerable worldwide investment in technology and biorefining activity is underway demonstrating the economic case for action. Given conclusions in the European Commission's "BREW report" on projected markets for renewable chemicals and biomass supply in the EU, demand seems likely to exceed supply in the near future[14].

Biorefinery activity worldwide has been driven by the production of bioethanol, with world production reaching 45bn litres in 2005 [15]. The largest producers by far are Brazil and the United States, each with a market share of approximately 35%. Multi-national companies with active biomass research projects include car manufacturers such as General Motors (GM), DaimlerChrysler and Volkswagen; oil companies including Shell and BP; chemical producers notably DuPont and Dow and agricultural processors such as Archer Daniels Midland (ADM) and Cargill.

In addition to biofuels, which have been supported by government subsidies for use in transport, there is a wide range of bio-based products gaining substantial market acceptance.

These include:

- fibre based materials (e.g. for construction or biocomposites for vehicles manufacture);
- bioplastics and other biopolymers;
- surfactants;
- bio-lubricants;
- bio-solvents;
- chemicals and chemical building blocks;
- pharmaceutical products including vaccines;
- enzymes;
- cosmetic ingredients.

The total European market for soap, detergents and similar products amounts to about €30bn with 30-50% of the products incorporating enzymes which are bio-based. Production of enzymes is strong in Europe with potential of increasing their use in food, paper and textiles production.

In Europe 50,000 tons of bio-plastics were produced in 2005 which represent a limited market share (0.1%). Although bio-plastics are at present "niche markets" a dynamic market growth is forecast. Market shares in the order of 1-2% by 2010 and 2-4% by 2020 are projected [16]. The fastest growing application is in packaging with supermarkets increasing demand for biodegradable packaging with estimates suggesting a 5% market share by 2010.

Bio-solvents produced from vegetable oils and from starch are progressively replacing petrochemical solvents. The current market share of bio-solvents in the EU is about 1.5 %. EU legislation on reduction of volatile organic compound (VOCs) emissions to the atmosphere is a driver for this adoption and could result in as much as 40% of the solvents market.

Health sector disposables, detergents, hygiene products, cosmetics and paints are all areas in which bio-based products could potentially reach a substantial market share. Significant development is being undertaken by lead companies in these sectors as they are all strongly influenced by health and environmental concerns. The sales in the EU in these markets were roughly €250bn in 2005 and in particular the health sector is expected to grow due to the ageing population profile in Europe.

[14] page 209/210 in "Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources - The Potential of White Biotechnology", final report of the BREW project, University of Utrecht, 2006, see: **www.chem.uu.nl/brew/programme.html**

[15] Renewable Fuels Association, The Industry, **www.ethanolrfa.org**

[16] Estimations made by the report JRC-IPTS, 2005 - "Techno-economic Feasibility of Large-scale Production of Bio-based Polymers in Europe".

The markets for several platform chemicals currently produced from bio-based materials have strong growth forecasts. Table 1 shows predictions for North American markets for some high-growth chemical intermediates in 2020 [17].

Table 1: North American markets for some high-growth platform chemicals in 2020

Intermediate	Production in 2020 (tonnes)
Polylactic acid	640,000
Citric acid	450,000
Propylene glycol	1,300,000
Sorbitol	400,000
Formaldehyde	7,500,000
1,4-butanediol	860,000

The total markets for bio-based products globally and within the EU are difficult to estimate. There is a tendency to focus on markets where bio-based products can substitute products based on other raw materials while the possibilities to estimate markets for new bio-based products are limited [18]. In 2005 bio-based products accounted for 7% of global sales and $77bn in value within the chemical sector, with the EU industry accounting for approximately 30% of this value. McKinsey & Company predicts that by 2010 bio-based products [19] will account for 10% of sales within the global chemical industry, accounting for $125bn in value. However the share could rise to as much as 20% depending on the development of technologies, feedstock prices and policy framework.

	2005	2010	2020
Volume of the new bio-based product markets	$77bn (global) $23bn (EU)	$125bn (global)	$250bn (global)*
Jobs dependent on new products**	120,000	190,000	380,000

* conservative estimate assuming that best case scenario predicted by McKinsey for 2010, i.e. that 20% of chemical industry output is bio-based, is achieved latest in 2020.
** Estimate by assuming that relative sales figures of 7%, 10% and 20 % also apply to employment levels (current EU chemical industry employment at is at 1.9 million (CEFIC data); these jobs include those generated in the bio-fuels area).

Biorefining activity varies from country to country. The following details the major players worldwide.

USA

Based on concerns about energy security, the US government has invested heavily in biorefining technology and have set the ambitious goal to replace 30% of the country's fuel supply with bioethanol by 2030. There is major activity using first generation fermentation production of ethanol, principally from corn feedstocks with production growing at a rate of 20% pa [20]. Over 120 ethanol biorefineries are currently operational with a combined production capacity of ~25,000m litres pa [21]. Plans exist to build sufficient new plants to double this figure. These biorefineries tend to be located in the main corn producing states of the mid-West.

[17] Status Report Biorefinery 2007, Energy Research Centre of the Netherlands, 2007, see: **http://tiny.cc/BE7C9**

[18] see also the recent IPTS "Bio4EU" study published by JRC, **http://bio4eu.jrc.es**

[19] McKinsey & Co report, see also: **http://www.bio-economy.net/Docs/McKinsey.doc** (this report includes chemicals made from biotechnology routes)

[20] U.S. Dept Of Agriculture, The Economic Feasibility of Ethanol Production From Sugar In The United States, July 2006, see: **http://tiny.cc/WwLD9**

[21] Chemistry Innovation Sustainable Technologies Roadmap, (Technology, Feedstocks, Biofuels), see: **http://tiny.cc/huX2Q**

Moving to second generation ethanol production, the US is currently investing $1.2bn in six commercial-scale cellulosic biorefineries with another $200m allocated to the development of smaller-scale demonstration plants.

The six commercial projects are:

BlueFire Ethanol, Inc.	2nd generation fermentation
Broin Companies	2nd generation fermentation
Iogen Biorefinery Partners	2nd generation fermentation
Abengoa Bioenergy	2nd generation fermentation
Range Fuels	syngas into ethanol using catalytic process
Alico, Inc	syngas into ethanol using fermentation

Some of these will be producing bioproducts by 2010.
The small-scale demonstration plants are to develop technology for cellulosic biorefineries and operate as demonstration facilities (i.e. at 10% of commercial scale). Range Fuels will open the first cellulosic production plant in the US in 2009. The US Department of Energy has also invested up to $375m in three Bioenergy Research Centres to support basic research for the development of cellulosic technology.

Brazil

The key driver for Brazilian production is also security of supply and the ability to utilise their efficient sugar cane production infrastructure. Brazil is the most economic location for bioethanol production and has a similar output to the US. Many international chemical companies are now locating production facilities in Brazil to manufacture downstream products such as bio-polyethylene competitively.

Canada

Ensyn have several commercial bioOil plants in the US and Canada. The bioOil is used for energy and chemical feedstocks. Canadian company Dynamotive [22] also produces bioOil at its facility in Ontario from wood (36,000 tonnes pa). Dynamotive are now constructing six pyrolysis plants in Argentina to produce bioOil from forest and agricultural residues.

Japan

BioEthanol Japan Kansei opened the world's first commercial second generation cellulosic biorefinery in Osaka utilising wood debris derived from construction waste. The plant has a reported operating capacity of 4m litres pa. The technology was licensed from US company Celunol.

Europe

Choren in Germany is developing commercial operations using biomass-to-liquid (BTL) technology. A demonstration plant (15,000 tonnes pa) has been built in Freiburg in collaboration with Shell and utilising wood as the biomass feedstock [23]. The plant uses gasification and Fischer-Tropsch technology to primarily produce biodiesel. The next stage is a 200,000 tonnes pa plant near Kiel slated for 2009/10.

Scandinavia is also targeting its widespread forestry resources as a feedstock for producing cellulosic ethanol.

Neste Oil (Finland) with Petrobras (Brazil) are manufacturing diesel from hydrogenated vegetable oil and animal fats at the Porvoo refinery (170,000 tonnes pa). The NExBTL biodiesel product has interested Total (France) and OMV (Austria).

UOP and ENI are building a new biodiesel facility in Livorno, Italy. The plant is due to begin production in 2009 and will process 6500 barrels per day of vegetable oil utilising the Ecofining technology developed jointly by UOP and ENI.

Austria has been developing technology based on grass and silage since 1999 with the aim of exploiting the fibres, proteins and lactic acid components. This is being developed with groups in the Netherlands [24]

[22] **www.dynamotive.com**
[23] First Commercial BTL production facility – the Choren β-plant Freiberg, presentation at 15th European Biomass Conference, Berlin, 2007 see: **http://tinyurl.com/2q6u9y**
[24] see: **http://tiny.cc/0By6y**

Commercial Biorefining Activity in the UK

Biorefining activity is also building in the UK. With limited and varied feedstocks a variety of biorefinery types have and will evolve. Strong opportunities exist for well coordinated new activity, particularly in the production of chemicals.

The chief driver thus far for biorefinery activity in the UK has been the Renewable Transport Fuel Obligation (RTFO, 2005) [25] which became law in 2008 and requires a 5% by volume replacement of fossil based fuels with bio based fuels by 2010. This has resulted in many biodiesel and bioethanol plants being constructed. Several companies formed to develop the technology further and increase the viability of these plants. To date only one bioethanol plant exists in the UK at Wissington run by British Sugar (see case study) whereas several biodiesel plants are operational.

The following is a list of current and planned biorefineries in the UK. Again the focus is on biofuels as primary products; no current integrated biorefinery exists producing a range of platform chemicals. It is worth noting that a commercial scale bioethanol plant typically produces a minimum of 100,000 tonnes pa.

Abengoa Bioenergy

Planned bioethanol refinery at Immingham with a capacity to produce 400 million litres of ethanol from 1.1 million tonnes of wheat pa.
www.abengoa.com

Argent Energy

Produce biodiesel from used cooking oil and tallow, operates 44,000 tonne pa plant in Motherwell with plans for a larger plant in Ellesmere Port.
www.argentenergy.com

Biocaldol

Solutions and systems integration for second generation biorefinery technology.
www.biocaldol.com

Bioethanol Ltd.

Planned 100,000 tonne pa wheat based bioethanol plant in Immingham. In conjunction with Centaur Grain.
www.bio-fuels.co.uk

Biofuels Corporation Trading Ltd.

Manufacture biodiesel from vegetable oils at 250,000 tonne pa on Teesside.
www.biofuelscorp.com

Biofutures International

UK investment company based in Swansea seeking to establish, invest in, or acquire assets, businesses or companies in the renewable fuels industries. Starting with a Malaysian plant for biodiesel from palm oil (200,000 tonnes pa).
www.biofuturesplc.com

British Sugar

Operates UK's first bioethanol plant - 55,000 tonne pa at Wissington, Norfolk (see case study)
www.britishsugar.co.uk

Centre for Process Innovation (CPI)

A UK wide resource to stimulate and drive innovation within the process industry set up by One North East in Wilton. Considerable experience and activity in biorefinery type projects as part of the National Industrial Biotechnology Facility.
www.uk-cpi.com

D1 Oils

UK-based global producer of biodiesel and related technology including agronomy, refining and trading. Development of plant science with a focus on jatropha. Recently closed down plant in Middlesbrough and selling off the proprietary equipment.
www.d1plc.com

Ensus Group

Manufacture of bioethanol from wheat for transport fuel. Production starts in 2009 with a 315,000 tonne pa plant currently under construction in Wilton, Teesside.
www.ensusgroup.com

ESL Biofuels

Biodiesel and heating oil from vegetable oil – grown and waste with 100,000 tonne pa capacity.
www.ebony-solutions.co.uk

[25] www.dft.gov.uk/rfa

Green Biologics

Developing fermentation technology for conversion of biomass to fuel and chemicals exploiting expertise in thermostable enzymes. Leading product is butanol.
www.greenbiologics.com

Green Spirit

Building a bioethanol plant in Henstridge (130m litres pa) from wheat with 120,000 tonnes of animal feed pa. Plans for a larger facility in Humberside.
www.greenspiritfuels.com

Greenergy

Several operations manufacturing bioethanol and biodiesel for UK road fuel from plant oils and waste vegetable oils. Currently supplying 6bn litres pa.
www.greenergy.com

INEOS Enterprises

Plans to have biodiesel capacity of 2m tonnes pa by 2012 from rapeseed. This includes plans for 500,000 tonne pa plant in the UK.
http://www.ineosenterprises.com/estersbiodiesel/default.htm

Losonoco

Gasification conversion of waste materials to products such as diesel, ethanol, methanol, dimethylether and ammonia. Anglo-American with facilities in the US but plans for UK plant.
www.losonoco.com

Phytatec

A spin-out company of the University of Birmingham developing pre-treatment technologies to support the full utilisation of any renewable source of biomass to provide chemicals. R&D facilities in Wales and France. Supply a key Reckitt Benckiser product ingredient.
www.phytatec.com/home.html

Roquette

World leader in production of starch derivatives, including polyols. Roquette leads French BioHub, one of their French plants is a bioethanol refinery, committed to green manufacturing. UK subsidiary uses plant starch products for pharma and personal care applications and have plans for a wheat fed bioethanol plant (95,000 tonne pa) in the UK.
www.roquette.com/index_eng.asp

TMO Renewables

Developing proprietary lignocellulosic technology for producing bioethanol various types of biomass or biowaste. Construction of a factory-scale demonstration plant began in 2007.
www.tmo-group.com

Vireol

Bioethanol production constructing a plant on Humberside to use wheat and sugar beet feedstocks for 150,000 tonne pa output.
www.vireol.com

Vivergo Fuels Ltd (BP/British Sugar/DuPont)

Construction started on a plant on the Saltend, Hull site to produce 320,000 tonne bioethanol pa (420m litres) from wheat.
http://www.vivergofuels.com/

Case Study: The Wissington sugar beet biorefinery

British Sugar's plant in Wissington, Norfolk is an example of a zero-waste plant converting all the raw material (sugar beet) input into sustainable products. Each year the plant processes the UK's entire sugar beet crop (~7m tonnes) into a variety of streams:

- topsoil on the sugar beet is cleaned off, recovered and sold under the brand TOPSOIL (450,000 tonnes pa)
- stone is also washed off the crop and graded for sale into construction use (70,000 tonnes pa)
- solid, fibrous by-products are used a high energy animal feed
- lime by-products are sold as soil improvers under the brand LimeX (425,000 tonnes pa)
- the main products are a variety of sugar grades for various applications (1 m tonnes pa)
- betaine is produced as a by-product which is a natural product used in fish feed
- bioethanol is also made at the plant from the sugars (the UK's first) and calculated at a 60% carbon saving over petroleum (70m litres pa)
- tomatoes are grown in the UK's largest greenhouse (11 hectares) using the low grade heat and CO2 generated from the process; these tomatoes have a lower carbon footprint than imported or other UK grown versions (70m pa)
- a combined heat and power (CHP) plant provides steam and electricity for the manufacturing process with excess electricity sold to the grid

see Appendix I for a schematic of the plant

DEFRA and the National Non-Food Crops Centre (NNFCC) commissioned a series of recent reports assessing the potential for further biorefinery activity in the UK. The report considering the potential and location for second generation biorefineries (lignocellulosic ethanol production) identified North Lincolnshire and the North West of England as the most favourable locations for such a plant [26]. Milford Haven was suggested as the preferred location for a thermochemical biorefinery however this would require the conversion of much of Wales' permanent grassland to short-rotation forestry. This would have a twenty year lag in domestic supply and would rely on imports to operate at viable capacity [27].

An additional report made the case for a polylactic acid (PLA) plant in the UK, with the favoured location in the North East [28]. To be viable at conservative wheat prices the plant would require >490,000 tonnes pa of feedstock and could capture 20% of the PLA market with gypsum and high protein animal feed as co-products.

[26] "Lignocellulosic Ethanol Plant in the UK: Feasibility Study Final Report", Black & Veatch, 2008, NNFCC see: **http://tiny.cc/lE1no**

[27] "Addressing land use issues for non-food crops, in response to increasing fuel and energy generation opportunities", J. Kilpatrick, ADAS, 2008, see **http://tiny.cc/JiC7T**

[28] "Techno-Economic Assessment of the Potential for a PLA Manufacturing Plant in the UK – Summary report", 2008, NNFCC see: **http://tiny.cc/KC2Oo**

Biorefinery Opportunities in Wales

Since 1999, devolution in Wales has resulted in the country being administered by the Welsh Assembly Government (WAG) based in the capital Cardiff. In parallel with the UK government, WAG has been developing its own policy with regards to the production of energy and fuel from renewable sources. Given the nature of the physical landscape in Wales, there is the potential, with careful land management, to utilise the abundant natural resources in the region for this purpose.

The Gross Value Added (GVA) measures the contribution to the economy of each individual producer, industry or sector. Current GVA for Wales in 2005 was £40.9bn compared to the UK £1,064bn [29]. In terms of GVA per head in Wales it is £13,813 compared to £17,677 for the UK. It is therefore clear that efforts must be put into place to stimulate the economic output in Wales. Key to this is the manufacturing output in Wales. In 2007/2008 this rose by 3.5% whilst the UK only rose 0.6%. The development of new bio-based materials will help support the manufacturing output in Wales and therefore further contribute to the economic regeneration within Wales.

The need to stimulate economic regeneration in Wales, coupled with additional social and environmental drivers for change are reflected in several key WAG policy documents.

The Science Policy for Wales[7] seeks to address three keys issues, which are health, a low carbon economy and social/ economic renewal. The use of plant based feedstocks as potential sources of fuels, chemicals and energy is likely to reduce the environmental impact of global warming which has increased in recent years. The use of fossil fuels as a raw material for the production of these three commodities is generally viewed as a contributory factor in this rise. The move to a low carbon economy, through the use of biomass will also have a positive effect on the health of the people of Wales by reducing the global warming potential. These aspirations are also reflected in **Wales: A Vibrant Economy** [30], which focuses on the need to invest in the sustainable economic regeneration of communities and support for business growth and innovation. This document identified ten sectors as important for the future economic growth of Wales, including the agri-food, bio–chemicals and construction industries.

The Environment Strategy for Wales [31] outlines many of the challenges which could affect Wales and its people in the future. Some of these issues include unsustainable resource use, loss of biodiversity (resulting in degraded ecosystems), and loss of landscape resulting in poor local environments. In addition The Renewable Energy Route Map for Wales [8] stresses the need to move away from traditional fossil fuels and the associated problems with carbon dioxide emissions and increased global warming potential and move to a low carbon economy. The utilisation of biomass is one of the preferred options to achieve this along with other forms of renewable energy such as wind and tidal power. The route map does note that the growth of specific crops or plants as renewable feedstocks for industrial processes and the resultant change in land use that this could involve does have potential drawbacks. These include the competition with traditional food crops such as cereals, the impact on rural ecosystems as a result of intense cultivation techniques, and the effects this could have on soil quality/ drainage, flood risk and the increased levels of fertilisers required.

[29] Sustainable Development Indicators for Wales, WAG, 2007, see: **http://tiny.cc/w68Sd**

[30] "Wales: A Vibrant Economy", Welsh Assembly Government, 2005, see: **http://tiny.cc/OEDQq**

[31] The Environment Strategy for Wales, Welsh Assembly Government, 2006, see: **http://tiny.cc/PIJwt**

Feedstock Raw Materials

Given the potential nature of feedstocks in Wales it is unlikely a thermochemical biorefinery is the most economic option. The recent Black & Veatch report suggested a thermochemical plant could be built in Milford Haven [26] but would require turning much of the permanent grassland in Wales to short rotation woodland and would still require imports. Such a strategy would drastically change the landscape. Thermochemical plants also require significantly more investment and infrastructure than fermentation plants. Currently thermochemical technology is focussed on fuel production and not routes to chemicals and Wales has little expertise or experience in such technology.

Given this context and the existing expertise in high-sugar grasses, which could be cultivated on marginal land, this report focuses on fermentation products and the market potential for derived products.

Current land use

Wales covers a total area of 2.1m hectares; of this area 80% is devoted to agricultural use, 12% to forestry and woodland and the remaining 8% to urban and miscellaneous activities [32]. Due to the soil, climate and topography conditions in Wales, permanent grassland and rough grazing dominate much of the agricultural land (see Appendix IIa,b); this is reflected by the predominance of livestock-based holdings.

In 2006 permanent grassland accounted for 62% of the agricultural area in Wales, equating to just over 1m ha; rough grazing covered 24%, around 409,000 ha, of which an estimated 180,000 ha is common grazing land; arable land totalled some 10%, around 164,000 ha; the remaining 4% comprised on-farm woodland and bare fallow, set-aside land.

The 10% of land classed as arable is currently dominated by temporary grassland, totalling some 133,000 ha. The cropped area, which includes mainly cereals and fodder crops, totals around 63,000 ha. The main arable areas are located in the South and South West, where the climate and topography are more favourable permitting an extended growing season and longer harvest window. Mid and North Wales contain only small areas of arable land, with a higher proportion of permanent, rough and common grazing land. Land suitable for arable production is illustrated in Appendix IIc.

[32] "Wales in Figures" and "Welsh Agricultural Statistics", both 2007, Welsh Assembly Government

Figure 4 below provides a breakdown of the areas under crops and grass from 1999 – 2006
(for raw data see Appendix IId).

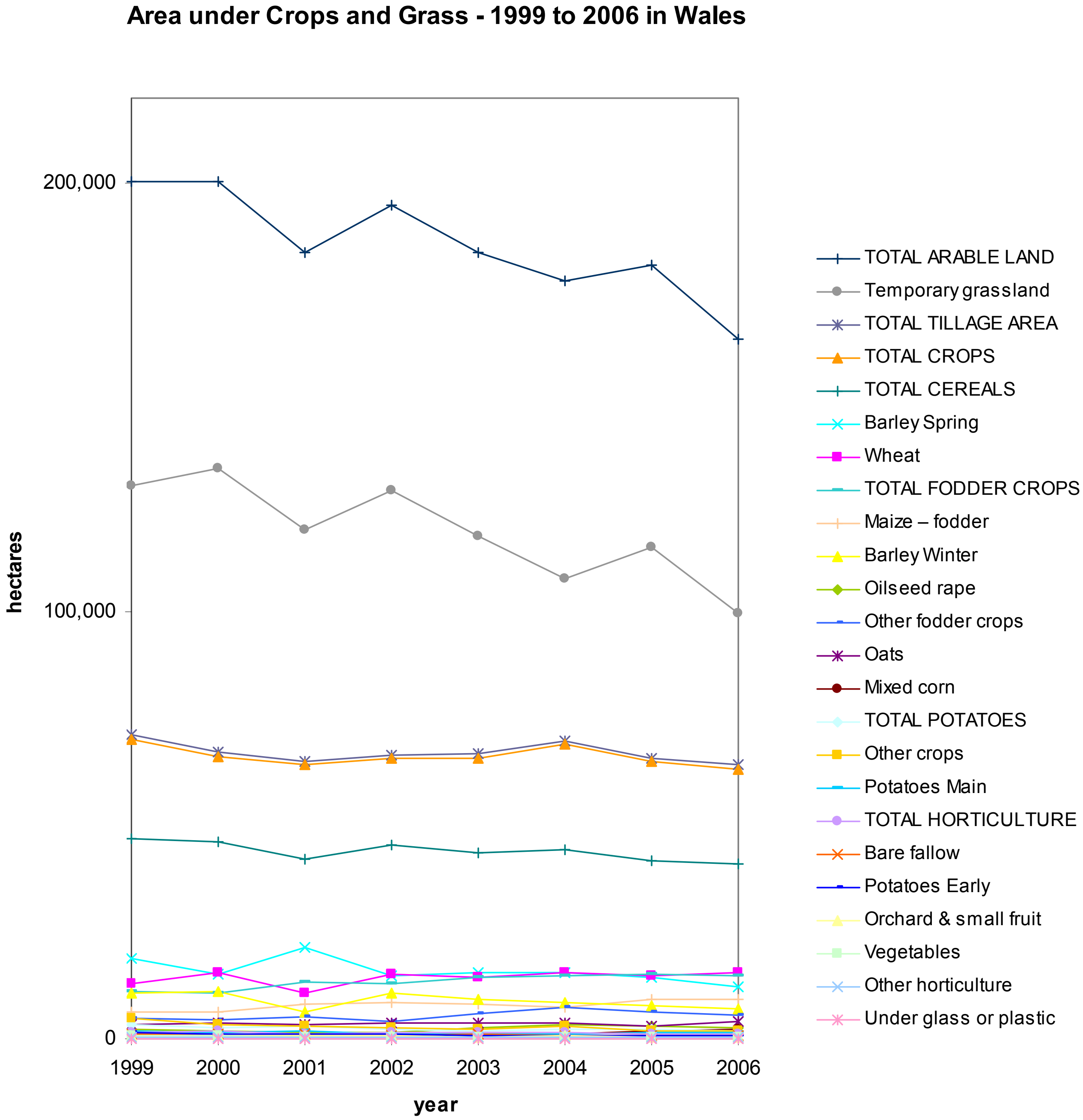


Figure 4: Source: Welsh Assembly Government (2008) *Welsh Agricultural Statistics for 2007*

The data in Figure 4 illustrates some significant changes in cropping patterns over recent years. The area of arable land has dropped; the area of cereals and potatoes has decreased as has the area of temporary grassland and bare fallow. This is probably due to decreased competitiveness with other arable areas in the UK and increased input costs which were not mirrored by increased market prices, hence lower returns. Over this same period the areas of fodder crops, permanent grassland and woodland have increased significantly; the latter requiring less labour and lower inputs than cereals and oilseeds (see Figure 5, raw data in Appendix IId).

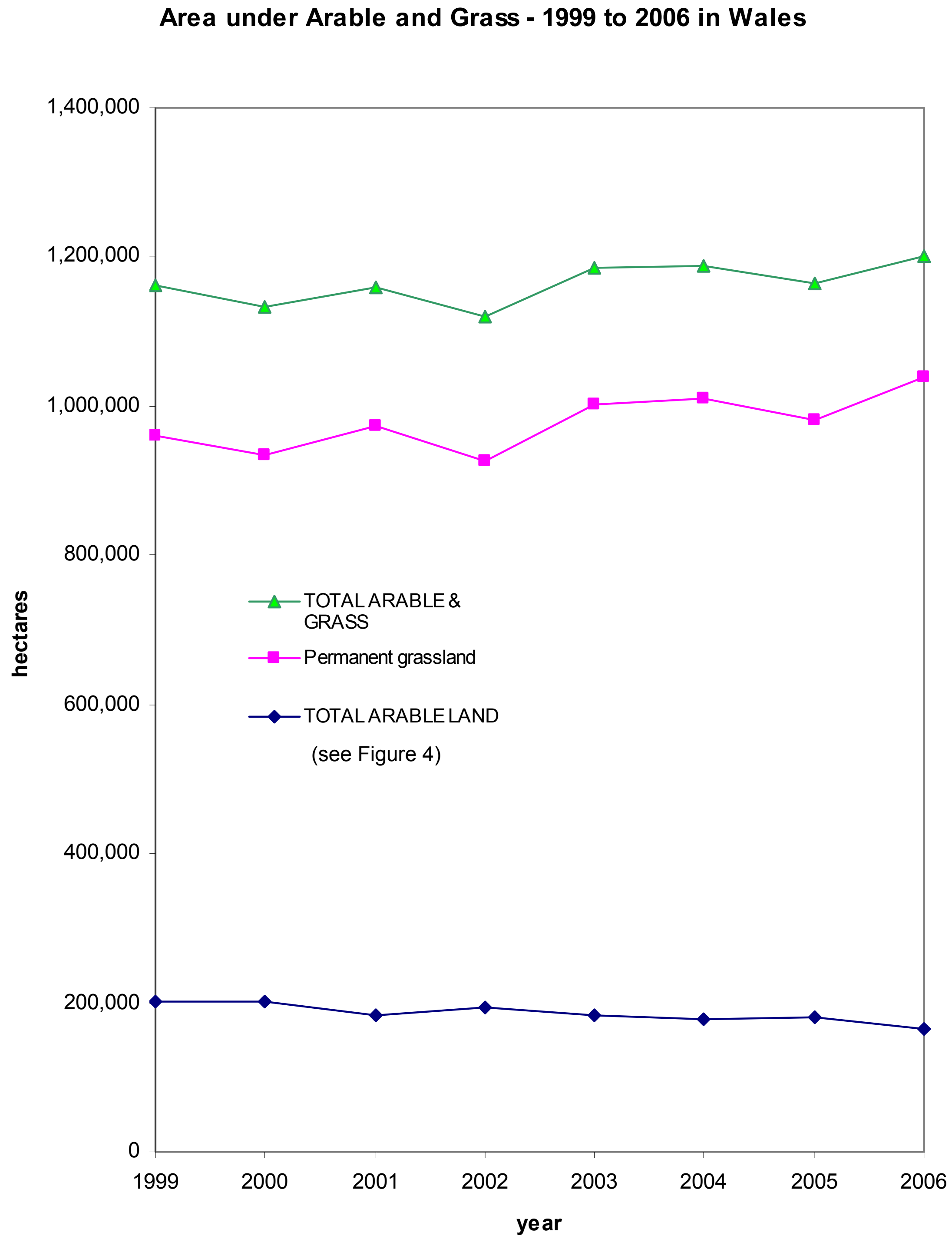


Figure 5: Source: Welsh Assembly Government (2008) *Welsh Agricultural Statistics for 2007*

In 2006 there were over 18,000 ha of set-aside land in Wales; as the set-aside rate was fixed at 0% for the 2008 harvest year, and is likely to be abolished thereafter. This land is now available for cropping. In theory all this land should be suitable for arable cropping, as it would have been arable class land before being set-aside.

DEFRA's strategy for non-food crops and uses suggests a total of 949.9 ha of non-food crops were grown in Wales in 2005; this included winter and spring oilseed rape, plus HEAR, linseed and barley.[33] According to the Energy Aid Scheme data a total of 29.11 ha of energy crops were also planted in 2005. More recent data is not available.

Livestock numbers in Wales have changed; an increase in dairy and beef numbers has been apparent, yet a significant drop in the sheep, pig and poultry sectors. The general trend has been for the larger livestock farms to continue, taking over activity from the smaller holdings; because of this an increased number of general cropping holdings now operate, yet fewer holdings in all livestock sectors.[34]

Although livestock numbers have decreased overall, we have already established that the area of permanent grassland and fodder crops has increased significantly, suggesting that livestock is now being farmed less intensively and is less reliant on grass only, supplementing diets with fodder crops through the winter months.

Potential for change

It is clear that cropping patterns and land use are changing in Wales, primarily in response to market and climate conditions which affect the competitiveness of arable areas of Wales with the major arable areas of the UK. An increase in permanent grassland and woodland suggests labour requirements have been reduced, this is reflected by the decrease in numbers of agricultural workers and farmers over recent years.[34] In recent years, the decline in traditional rural economies such as arable and livestock farming in Wales has had a considerable impact on many communities right across the Principality.[35] Total Income from Farming (TIFF) has fallen from £142.2m in 2005 to £46.4m in 2007, a fall of £95.8m.[36]

In line with this decrease in the labour force, farmers are looking at enterprises which require less labour input at their busiest times of the year. Permanent grassland and woodland do not require regular attention, and are therefore a favourable option and competition is minimal.

The changes suggest the farming community in Wales are willing and able to adapt to changing market conditions; therefore the suggestion of generating feedstocks for fuel, energy, chemicals or materials sectors should not be an issue, as long as the conditions are favourable.

By returning stocking densities to previous levels, it would be possible to release a significant proportion of temporary grassland. It is not feasible to return permanent pasture to arable production, due to the release of greenhouse gases during and after this process. Over the seven year period illustrated above, stocking levels have been reduced but the total area of grassland, temporary and permanent, has increased by around 50,000 ha. This therefore suggests that by increasing stocking densities it would be possible to free up this area for cropping of biomass crops for future markets.

In addition, the total area of arable land has decreased by 37,000 ha over this period, which suggests it would be possible for this to return to cropping in the future.

[33] DEFRA (2006) A Strategy for Non-Food Crops and Uses: Two-year progress report, see: **http://www.defra.gov.uk/farm/crops/industrial/pdf/nfc-strategy.pdf**

[34] Farming Facts & Figures, Wales 2007, see: **http://tiny.cc/8evkn**

[35] Rural Development Plan for Wales 2007-2013, Welsh Assembly Government, see: **http://tiny.cc/Xzn7A**

[36] Aggregate Agricultural Output and Income 2007, Statistics for Wales, 2008 - SDR 26/2008

Feedstock options

Biorefinery feedstocks vary by region and are dependent on land and climate potential. This section of the report will consider the possible feedstocks and assess their suitability to the current Welsh farming system. As biomass feedstocks are often low density, bulky and have high moisture content it is essential that sufficient feedstock is available from a specific area for processing, to minimise haulage costs. Increasing costs of transport and the poor transport infrastructure in Wales make this particularly important in this assessment of feedstock availability.

Cereals and Oilseeds

In 2006 a total of 40,931 ha of cereals and 2,614 ha of oilseeds were grown in Wales. Although a potential feedstock for a biorefinery, there are a number of factors which make them unfavourable. These crops currently occupy much of the Grade 1 and 2 agricultural land in Wales, where yields are relatively high and access is good for cultivation and harvest; such crops, grown on an annual basis, require significant inputs and are therefore less environmentally favourable than perennial or low input crops. Cereals and oilseeds are traded as commodities, therefore prices vary throughout the season and year-on-year based on supply and demand.

Cereals and oilseeds are primarily grown as food crops, and to prevent the displacement of food with biomass crops, it is recommended they should remain so. Food production will always be the priority for UK farmers, so with an increasing population and economic growth across the world it is important that other options are considered.

Cereals and oilseeds are not ideally suited to Welsh climatic conditions, so competition from other more favoured areas to the east of the UK where higher yields can be achieved make production difficult (see Appendix IIe for high-yielding parts of the UK). A high proportion of these crops will be grown as animal feed in Wales, to supply local livestock farms.

Table 2: Volumes of grain, oilseed and straw generated in Wales (2006)

Crop	Area (ha)	Seed yield (t/ha)	Total seed Yield (t)	Straw yield (t/ha)	Total straw yield (t)
Wheat	15,524	8.0	124,192	3.5	54,334
Winter Barley	6,985	6.5	45,402	3.0	20,955
Spring Barley	12,144	5.5	66,792	2.5	30,360
Oats	3,901	6.5	25,356	3.5	13,654
Oilseed rape	2,614	3.0	7,842	1.5	3,921
	41,168	**-**	**269,584**	**-**	**123,224**

There is an opportunity to use co-products of cereal and oilseed production as a biorefinery feedstock However, based on straw yields and livestock requirements (see Figure 6 below), there is no surplus straw currently generated in the west of the UK, including Wales and this is unlikely to change based on historic production figures.

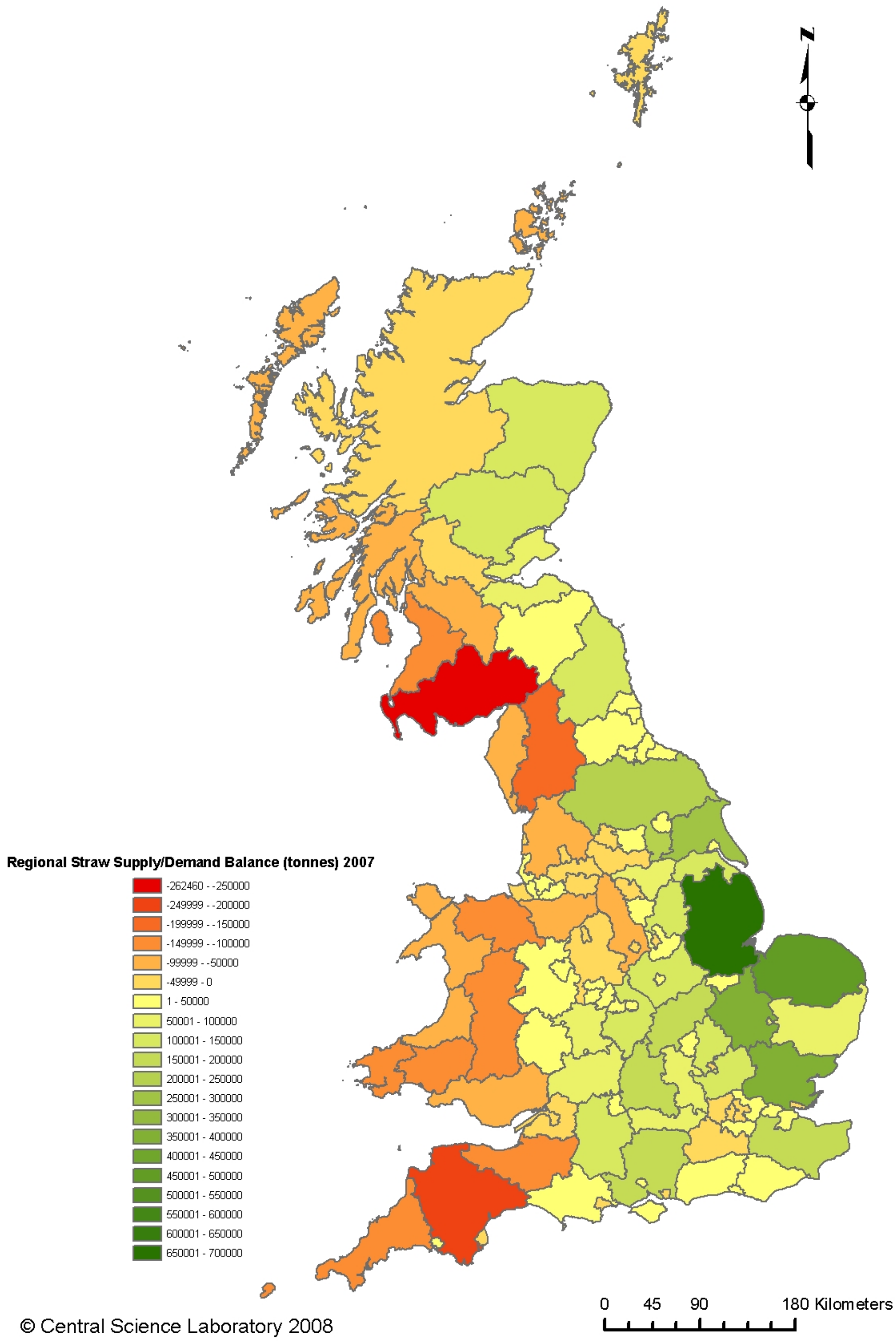


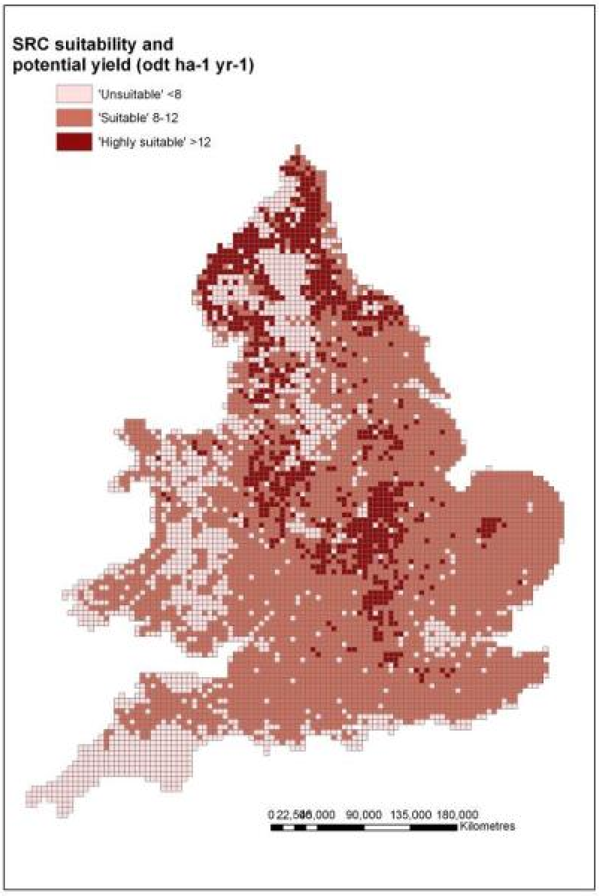
Figure 6: Net production of cereal straw after deduction of volumes required by the livestock sector (*Source: Copeland, J. E. and Turley, D. B. (2008). National and regional supply/demand balance of agricultural straw in Great Britain. Report prepared for The National Non-Food Crops Centre by Central Science Laboratory*)

Energy Crops

Miscanthus is a perennial energy crop with a productive lifetime of around 10 – 15 years. The crop is planted from rhizomes in the spring and harvested annually from year two onwards, yielding around 12 odt [37] per hectare per year. The crop grows well on a range of soil types, preferring moisture retentive soils and mild climates to give an extended growing season to achieve maximum yields. It must be borne in mind that the crop is harvested over the winter months, so particularly wet fields and sandy soils may make the operation difficult and are therefore not recommended.[38]

Short Rotation Coppice (SRC) Willow is another potential high-biomass crop, established from cuttings which are again planted in spring. SRC is harvested every three years, from year two onwards and generally yields around 30 odt per hectare every three years, which when annualised equates to around 10 odt per ha per year. SRC is again harvested over the winter months, so particularly wet areas are not favoured; however, the crop is suited to areas which are not prime arable land. SRC has shown potential in both upland and lowland areas, including areas previously dedicated to sheep farming, so wide areas of Wales are suitable.[39] Significant research has gone into the potential of SRC as a biomass crop in Wales; 'Willow for Wales' is a European project with the remit to demonstrate the potential of willow and its suitability to Welsh farming systems, determining the most favourable areas for production.

Both SRC and Miscanthus are suited to Grade 2 and 3 agricultural land, [40] so should not displace food crops which would be grown on Grade 1 and the best of Grade 2 land.



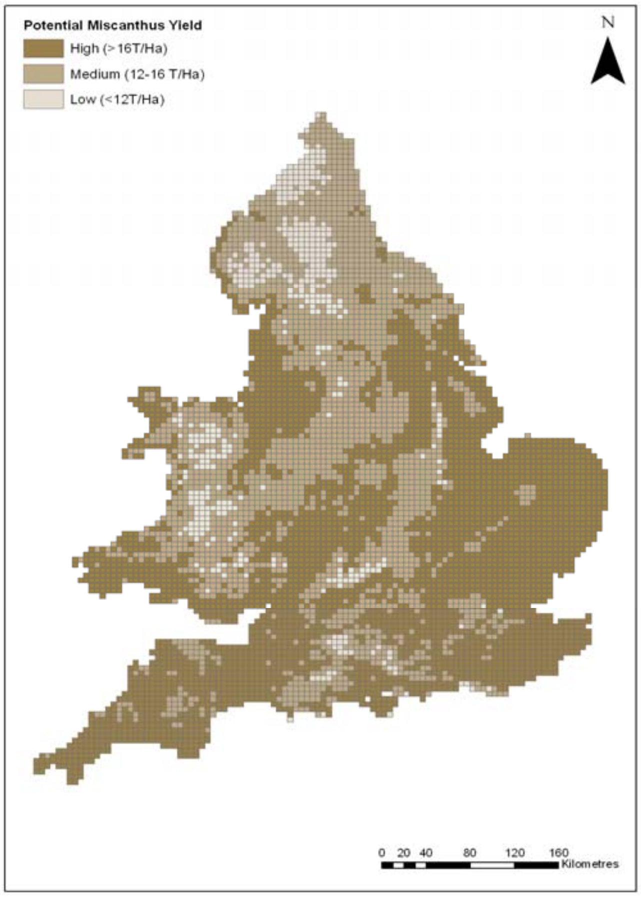


Figure 7: Maps showing potential yield of SRC and Miscanthus (per ha/year)[27]

Figure 7 above shows areas suited to production of SRC and miscanthus, as well as an indication of likely yield.

[37] odt = oven-dried tonnes
[38] Centre for Alternative Land Use (CALU, Bangor) Technical note 2005 see: **http://tiny.cc/ENAEO**
[39] Wales Energy Crops Information Centre, see: **http://tiny.cc/PWu0i**
[40] Valentine, J (2007) Inclusion of short-rotation coppice willow in a new generation of agri-environment schemes, IGER (now IBERS).

The maps illustrate that significant areas in Wales are suitable for both Miscanthus and SRC production, mostly in the coastal regions. Central areas are showing as likely to return low yields and hence the economics will have to be considered with caution.

SRC and miscanthus are more expensive to establish than most arable crops; support is available in England to aide their establishment but currently no equivalent scheme is running in Wales. Previously the Wales Rural Development Plan supported the establishment of SRC; however this scheme has now closed and although a follow-on scheme is under consideration there is currently no financial support available. This makes Wales an unfavourable area for cultivation, when 40% of the planting costs can be claimed for under the RDPE Energy Crops Scheme over the border. SRC and miscanthus also require a long term commitment from a grower, to justify to high establishment costs and to reach maximum yields; this is sometimes perceived as a barrier, particularly when market prices for other feedstocks are so variable. In general in the UK energy crops are not overall economically viable without subsidies.[41] However the development of energy crops is important in producing a sustainable future feedstock mix for renewable energy production as well as biorefining.

Other high-biomass energy crops are in development, but not yet commercialised in the UK. These currently include Switchgrass and Reed Canary Grass, both of which are less expensive to establish and are planted and harvested using conventional grass machinery, so would fit better with current farming practices. Yields of both high-biomass grasses are not yet optimised in UK conditions, but might be worth consideration in the future.

Forage Grasses

In light of the concerns with energy and arable crops as feedstocks for a biorefinery in Wales and considering current expertise, a favoured feedstock could be high-sugar forage grasses which are already widespread. High-sugar forage grasses would only displace existing grassland or other marginal land, as opposed to food or feed producing arable land. They do not require the capital investment or long-term commitment that perennial energy crops, such as miscanthus and SRC do.

Bio-processing of forage and amenity grasses has been used successfully in Europe to produce fibre for the construction industry, high-protein animal fodder, biogas and ethanol. It offers potential for agricultural diversification while adding value to grass cuttings from municipal amenities.[42]

Grasses as a source of high-value materials [43] such as proteins and fibres as well as valuable chemicals such as lactic acid and amino acids is an active programme in Austria.[44] Here the decline in milk quotas is reducing demand for forage grassland and to preserve the cultural landscape by using grass and silage as a feedstock.

In Wales, traditional grass species, such as perennial ryegrass, are highly suitable; they involve management techniques which are familiar to most farmers, are perennial and do not require significant energy inputs, especially if grown as part of a clover mix; they would also support the biodiversity of existing crops and would not cause any visual change to the existing landscape.

The crop statistics in the previous section clearly demonstrate that Wales is well suited to growing grasses; the limiting factor on growing as a biomass feedstock as opposed to a forage area will be the topography and the access for cultivation and harvesting equipment. The areas most suited to high-biomass, high-sugar grasses are likely to be the areas of temporary grassland which may have been cropped and harvested for hay or silage in the past. In areas where livestock numbers are falling there is an opportunity for grassland to become dual use, by supplying both the livestock and biorefinery sectors.

Cultivation of grass as a biorefinery feedstock is a favourable option as it requires little change to current farming practice; the same equipment and machinery can be used; the same skills can be applied; and the land and climate conditions are already proven to be excellent for grass production. With a decrease in livestock numbers, and by increasing stocking densities, grassland will be made available for biomass cultivation. The lack of alternative markets at present for excess grass makes is an attractive feedstock for Biorefining.

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[41] "Sustaining the Land – A Review of Land Management Actions Under Axis 2 of the Rural Development Plan for Wales 2007-2013", 2008, Welsh Assembly Government, see: **http://tiny.cc/wRZ7j**

[42] "Biorefining of Grass in the UK" Agros Associates, (2004), NNFCC/DEFRA, see: **http://tiny.cc/HXUDG**

[43] P.A. Fowler et al: The Potential Industrial Uses of Forage Grasses including Miscanthus (2003), see: **www.bc.bangor.ac.uk/_includes/docs/pdf/industrial%20use%20of%20grass.pdf**

[44] **see: www.fabrikderzukunft.at/results.html/id4119**

The Institute of Biological, Environmental and Rural Science (IBERS, formerly IGER) in Aberystwyth have developed a number of high-sugar grasses (for example, AberDart, AberStar or AberAvon identified by the 'Aber' prefix). Current varieties achieve around 25 percent more water soluble carbohydrate than older varieties, and the latest material coming from IBERS is showing a 50 percent increase on older varieties. The eventual goal is to double the amount of water soluble carbohydrate in new grass varieties. [45]

Although it is difficult to obtain data for new high-sugar varieties, as an indication, data on inputs, outputs and costs are shown in Table 3. This is for standard perennial rye grass variety which is commonly grown at present as a silage crop for forage purposes.

Table 3: Medium-term grass ley (perennial ryegrass) – silage

	LOW INTENSITY £/ha	MEDIUM INTENSITY £/ha	HIGH INTENSITY £/ha
Establishment cost Annual fertiliser (kg/ha) Annual fertiliser cost *	32 170N : 60P : 160K 143	32 275N : 80P : 250K 224	32 365N : 100P : 320K 292
TOTAL ANNUAL COSTS	**175**	**256**	**324**
Fresh yield (t/ha) • 1st cut • 2nd cut • 3rd cut TOTAL FRESH YIELD	 20 – 22 8 – 10 - 35 - 42	 23 – 25 13 – 14 - 45 - 51	 22 - 24 13 – 14 9 – 10 52 – 58
Dry Matter Yield (t/ha)	8.9	11.0	12.7
£ per tonne dry matter	**19.8**	**23.2**	**25.6**

Source: ABC Guide, 2007

* Fertiliser costs are based on 2007 data; costs have increased significantly during 2008

Assuming, as above, a return of stocking densities to levels seen in the 1990's, an area of around 50,000 ha of current grassland would become available. By harvesting ryegrass from this land, a total resource of around 550,000 dry tonnes of feedstock would be generated.

This figure provides a pessimistic estimate; given yield increases and development of new varieties bred as biomass feedstocks as opposed to livestock feed or grazing crops, it is thought that yields of up to 18 dry tonnes per ha can be achieved, with less fertiliser input required. If this is the case then around 990,000 dry tonnes of high-sugar grass could be grown and harvested in Wales each year. As the crop is harvested several times through the year, logistics, transport and storage will become even more important.

A recent report [41] calculates 600,000 ha of available land that is suitable for growing biomass for energy. If a small percentage of this was made available for ryegrass the overall production might easily be doubled. This analysis also shows the vast potential resource available in Wales to accommodate growth in biorefining and other renewable activity. In the future and as the market grows, the economic case for use of such land for energy crops may become compelling.

This report will focus on the products, and their markets, available from high-sugar forage grasses.

[45] IGER, 2003, see: **http://tiny.cc/zFsWp**

Potential Products from a Biorefinery

A very wide range of chemical products can be produced from a biorefinery. The thermochemical routes via synthesis gas can duplicate all of the products of the conventional petrochemical industry. The fermentation route gives access to a range of platform chemicals that cover existing commercially exploited materials, technical substitutes for existing materials, and novel materials whose market is not yet fully developed.

However, as has already been noted, it is unlikely that an integrated thermochemical plant could be established in Wales, as the commercially efficient size of that unit would exceed the locally available biomass. This report therefore focuses on platform chemicals from the fermentation route following removal of extractives such as fibre, proteins and niche compounds.

The fermentation route involves breaking down as much as possible of the biomass into fermentable sugars. These can then be converted by a range of microorganisms into metabolites usually classified by the number of carbon atoms in the backbone. The sugars normally available in plant biomass are C5 and C6 from free sugar, starch, cellulose and hemicellulose. Fermentation metabolites typically range from C2 to C6. These platform chemicals can then be further converted by fermentation, enzymatic treatment, or chemical treatment.

The following table (Table 4) shows the platform chemicals most likely to be economically available from fermentation of plant biomass and the applications where these materials are typically used.

The table has been generated from three recent reports on generating platform chemicals from plant biomass, and standard industrial chemistry texts.[14, 46, 47, 48, 49]

More detail on the structures and the commercially interesting derivatives of these platform chemicals is given in Appendix III.

The table does not include commodity sugars to be used in the food industry, such as glucose, sucrose and fructose, although some of these are also used for industrial applications. These are materials already produced in large volumes from plants, and there is little need for the development of additional sources.

Glycerol is a high potential C3 platform chemical that can be produced from plant sugars. However, for the foreseeable future glycerol will be available in large volumes and at very low prices as a by-product of the biodiesel industry. It is very unlikely that a fermentation-based biorefinery could compete commercially in the production glycerol in the short to medium term.

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46 "Top Value Added Chemicals from Biomass: Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas" National Renewable Energy Laboratory, Pacific NorthWest National Laboratory, US Department of Energy Biomass Programme, 2004, see: **http://tiny.cc/Yc7YF**

47 "Top Value Added Chemicals from Biomass: Volume II —Results of Screening for Potential Candidates from Biorefinery Lignin" Pacific NorthWest National Laboratory, US Department of Energy Biomass Programme, 2007, see: **http://tiny.cc/EgkRK**

48 "Biochemical Opportunities in the United Kingdom" Nexant ChemSystems, 2008, NNFCC, see: **http://tiny.cc/MM0nd**

49 "Handbook of Industrial Chemistry - Organic Chemicals" Ali, Mohammad Farhat; El Ali, Bassam M.; Speight, James G., McGraw-Hill, 2005

Table 4 – Likely Economically Available Platform Chemicals from Fermentation

Carbon Number	Platform Chemical	Applications
2	Acetic acid Ethanol	• fuels and fuel additives • polyethylene and PVC • solvents • ethylene oxide and glycols • polymers • bleaches • antimicrobials • chemical intermediates
3	Lactic acid 3-Hydroxpropionic acid 1,3-Propanediol	• solvents • packaging, fibres and textiles • coatings, adhesives, sealants & elastomers • plasticisers • lubricants • surfactants and cosmetics • antifreeze • water treatment and paper making • pharmaceuticals and agrochemicals • engineering plastics
4	Succinic acid Fumaric acid Aspartic acid 1-Butanol 1,4-Butanediol	• fibres and textiles • engineering plastics and nylons • polyurethanes and elastomers • food additives and sweeteners • solvents (THF in particular) • lubricants • fuel oxygenates • dyeing • water treatment and corrosion inhibitors • detergents • plasticisers • chemical intermediates
5	Xylose / Arabinose Levulinic acid Furfural	• explosives • sweeteners • antifreeze • solvents • fuel oxygenate • plasticiser • pharmaceuticals and agrochemicals • resins, elastomers and polyurethanes • chemical intermediates
6	2,5-Furandicarboxylic acid Sorbitol 5-Hydroxymethylfufural Adipic acid	• polyesters, polyamides and polyurethanes • sweetener, humectants, emulsifiers and antioxidants • surfactants and cosmetics • cosmetics • phenolic resins • solvents, lubricants and plasticisers • fibres
Lignin	Benzene, Toluene, Xylene, Phenol, Aryl ethers, Vanillin, Cresols, Catechols, Resorcinols, Quinones	

The final line of the table shows materials that could in principle be derived from lignin.[47] Lignin is an important structural polymer within plants that is not degradable to sugars and not fermentable. In many models of biorefinery operation, the unconverted lignin fraction is burned to generate energy to operate the plant. However, it has been suggested that lignin could become an important source of aromatic compounds, for which there is no feasible fermentation route currently under development. Production of these materials from lignin does not involve biotransformation, but aggressive catalytic degradation and catalytic conversion of the lignin structure. There is as yet no collection of processes that can be demonstrated to generate more value from the lignin fraction than burning it to generate heat and power.

The platform chemicals currently in full-scale production from biomass are:

- ethanol
- acetic acid
- lactic acid, and the polymer derived from it - polylactic acid (PLA) – (see box)
- 1,3-propanediol - used in polytrimethylene terephthalate (PTT), trade names Sorona® and Corterra® (see box)
- xylose – produced from hardwood and mainly used to produce Xylitol as a sweetener
- furfural – produced in volume from a range of materials including corncobs, cottonseed hull bran, oat hulls, cottonseed hulls, bagasse and rice hulls.
- sorbitol – produced by hydrogenation of dextrose.

Xylose, furfural and sorbitol are produced by chemical treatment of primary materials extracted from plant biomass, and although they seen as good prospects for production in a biorefinery, the processes have not yet been fully developed.

A process for the bio-production of 1-butanol has been developed and is being scaled up. The target market is as a fuel, and bio-butanol is on the verge of being fully commercialised. Investment is planned in a number of full scale plants scheduled to come on stream in the next few years.

Looking slightly further ahead, there is a great deal of interest in the potential of succinic acid, particularly as a monomer for a range of plastics (see box).

Sorona™ Clothing Fibre

Many of the modern, versatile fibres used by the clothing industry rely on dwindling petrochemical feedstocks. Discovery and development of sustainable materials offering the properties expected for modern garments are major challenges for industry.

Sorona™ is a semi-crystalline, synthetic polymer based on 1,3-propanediol with a uniform structure that can be spun into fibres in the same processes as used for petrochemical polymers. The diol is produced via fermentation and results in a 37% renewable content in the final polymer.

Compared with equivalent synthetic polymers Sorona™ has the following benefits:

- 63% less greenhouse gas emissions
- 30% less energy (than equivalent nylon production)
- reduced waste
- softer and stretchier
- UV and chlorine stable (excellent for swimwear)
- holds bright colours well and can be dyed at lower temperatures than polyester

Sorona is manufactured by DuPont: **http://www2.dupont.com/Sorona/en_US/**

Succinic Acid

A joint venture between DSM and Roquette will seek to commercialise succinic acid production from biomass (planned end of 2009 a demonstration plant in Lestrem, France with a capacity of ~5000 tonne pa, commercial scale 2011). Downstream targets are bio-based and biodegradable polymers, 1,4-butanediol and isosorbide.

Polylactic Acid

Society uses immense quantities of synthetic polymers, most of them made from petrochemical sources. This means they are dependent on a depleting non-renewable resource and vulnerable to increasing oil prices. Many companies are now interested in sourcing polymers produced from renewable feedstocks such as plants.

Cargill Dow developed the NatureWorks™ process and enhanced the physical properties of known biodegradable polymer polylactic acid (PLA) to compete successfully with commodity petroleum-based plastics. The enhanced polymer has the following benefits:

- derived entirely from annually renewable resources
- fibres have unique combination of desirable attributes such as superior hand, touch, and drape, wrinkle resistance, excellent moisture management, and resilience
- packaging applications have the benefits of a natural material that is compostable and recyclable without experiencing any tradeoffs in product performance
- the PLA process offers significant environmental benefits: no organic solvents; high yields throughout (>95%); recycle streams to eliminate waste; small (ppm) amounts of catalyst
- requires 20–50% less fossil resources than comparable petroleum- based plastics
- fully biodegradable or readily hydrolyzed into lactic acid for recycling back into the process.

Synthetic Rubber from Renewable Sources

The tyre and rubber industry is very reliant on oil-derived products such as synthetic rubber made from petroleum-derived isoprene monomer.

BioIsoprene™ can be used to produce synthetic rubber, an alternative to natural rubber, and other elastomers. Danisco and Goodyear have been jointly investing for more than a year to develop this technology with the process expected in 2010 and large-scale manufacturing to start in 2012.

Examining the detailed information in Appendix III, there are two very clear features of the platform chemicals from fermentation route biorefineries:

1. All of the target platform chemicals and most of the derivatives are oxygenates. That is chemical entities that contain one or more oxygen atoms in them. This contrasts with the petrochemical sector where many of the platform products are hydrocarbons. In the petrochemical industry the usual approach is to get the main carbon backbone of the target molecule and then to add required heteroatoms. In fermentation-based biorefineries, heteroatoms tend to persist from the original biomass.
2. Partly as a result of this tendency, the applications of platform chemicals from a fermentation-based biorefinery are concentrated in a few areas.[50] Specifically:

- fuel and fuel additives
- polymers and plasticisers
- solvents
- lubricants
- surfactants

User industries include adhesives, coatings, paints, cosmetics, cleaning, fibres and textiles, metalworking, hydraulics, automobile, foods, pharmaceuticals and agrochemicals.[50]

A viable biorefinery in Wales would need to find markets for its products in these sectors.

[50] "Current Situation and Future Prospects of EU Industry Using Renewable Raw Materials", prepared by Working Group on Renewable Raw Materials, European Renewable Raw Materials Association, for the European Commission, 2002, see: **http://tiny.cc/UUJxQ**

There are currently two models for biorefineries. Single product biorefineries closely integrated into a product chain, and free-standing biorefineries selling products to a range of markets. Current fermentation-based biorefineries have tended to be integrated into a product chain, so that production is used captively as a feedstock for another product.

Examples include:

- the NatureWorksLLC PLA plant in Nebraska converts corn into lactic acid and then to polylactic acid
- the 1,3-propanediol joint venture between Tate & Lyle and DuPont
- plants producing ethanol for fuel

This suggests that the reliable consumption of product and the direct involvement of the user in the plant operations reduces the risk and makes it much easier to raise finance for a captive biorefinery. Partners are likely to take a long term view of the viability of the project responding to structural changes in the cost and availability of feedstocks rather than short term market movements.

A free-standing biorefinery would have to build strong relationships with downstream users to generate an income stream less sensitive to fluctuations in commodity prices. This might mean finding partners who have a clear strategic commitment to the use of renewable raw materials.

There is currently little obvious prospect of a major user building a captive biorefinery in Wales; inward investment teams should try and identify suitable partners. Without a captive biorefinery it is important that clusters of user companies are identified in the relevant application areas and with good logistics connections to the potential sites for a biorefinery.

Economic Viability of a Biorefinery

To make a basic estimate of the economic viability of a fermentation based biorefinery in Wales, a number of simplifying assumptions have been made:

- The most attractive and widely available feedstock in Wales is high sugar ryegrass, such as AberDart and variants.
- Use of GM plants is not generally acceptable to the public (not excluding use of GM microorganisms).
- Assuming the conversion technologies exist, the key factor in the economic viability of a fermentation based biorefinery is the cost of sugar at the proposed location and the accessibility of markets.
- Although an immense amount of research has been carried out on conversion of the lignocellulosic fraction of plants into fermentable sugars, no commercially viable route yet exists. We have therefore only considered the water soluble carbohydrates in the grass.
- Any lignocellulosic material at the biorefinery would be used for energy and heat generation.
- That the water soluble carbohydrates are all fermentable and that there are no significant inhibitors in the sugar containing liquor extracted from the grass.
- There are no high value extracts that can be obtained from fodder grasses that would represent a significant income stream. We are aware of none with significant market potential.
- Sugar beet represents a similar crop yielding a high sugar extract that can be readily fermented and is a potential competitor to a biorefinery based on fodder grasses.

The BREW study5 considered three scenarios for bio-based chemicals in Europe to 2050. These are summarised in the Table 5 below.

Table 5: BREW Report Scenarios for Bio-Based Chemicals in Europe

	Scenario		
Factor	**Low** *Unfavourable to development of bio-based chemicals*	**Medium** *Moderately favourable to development of bio-based chemicals*	**High** *Very favourable to development of bio-based chemicals*
Oil price	Up to $30 barrel	Up to $66 barrel	Up to $83 barrel
Rate of technology development	Low – technology remains the same	Future technologies from 2040	Future technologies from 2020
Bio-feedstock cost	€400/t sugar	€200/t sugar	€70/t sugar
Chemicals market	0% p.a. growth	1.5% p.a. growth	3% p.a. growth
Subsidies	none	none	1%-5% of product value

They range from an unfavourable scenario where oil price is low, sugar price high, technology and market stagnant, to a positive scenario where oil price is high (as considered at the date of publication), sugar price low, future processes in the research phase are rapidly commercialised, the market is growing and there are subsidies to change the market.

The team then looked at the potential for substitution of a basket of petrochemical derived chemicals and polymers by bio-based equivalents under the various scenarios.

Bio-based chemical	Petrochemical
Polyhydroxyalkanoate (PHA)	HDPE
PTT	PTT
PTT	Nylon 6
PLA	PET
PLA	Polystyrene
Ethyl lactate	Ethyl acetate
Ethylene	Ethylene
Succinic acid	Maleic anhydride
Adipic acid	Adipic acid
Acetic acid	Acetic acid
1-Butanol	1-Butanol

The projected market substitution for each bio-based chemical and the complete basket by 2050 to the nearest 5% is shown in the following table:

	Scenario		
Bio-based chemical	Low	Medium	High
Complete basket	15%	40%	83%
Polyhydroxyalkanoate (PHA)	5%	20%	26%
PTT/PTT	0%	100%	100%
PTT/Nylon 6	100%	100%	100%
PLA/PET	50%	90%	90%
PLA/Polystyrene	25%	45%	60%
Ethyl lactate	45%	100%	100%
Ethylene	0%	15%	70%
Succinic acid	5%	85%	85%
Adipic acid	0%	0%	100%
Acetic acid	0%	0%	0%
1-Butanol	0%	50%	100%

It is against these scenarios that we can judge which products from a biorefinery are most likely to succeed.

Cost of Sugar

The composition of high sugar fodder grasses has been studied by the Institute for Biological, Environmental and Rural Sciences [51]. They reported maximum water-soluble carbohydrate content of between 25 and 35% of dry matter with a protein content of 10% and a non digestible fibre fraction of 49% (see Figure 8).

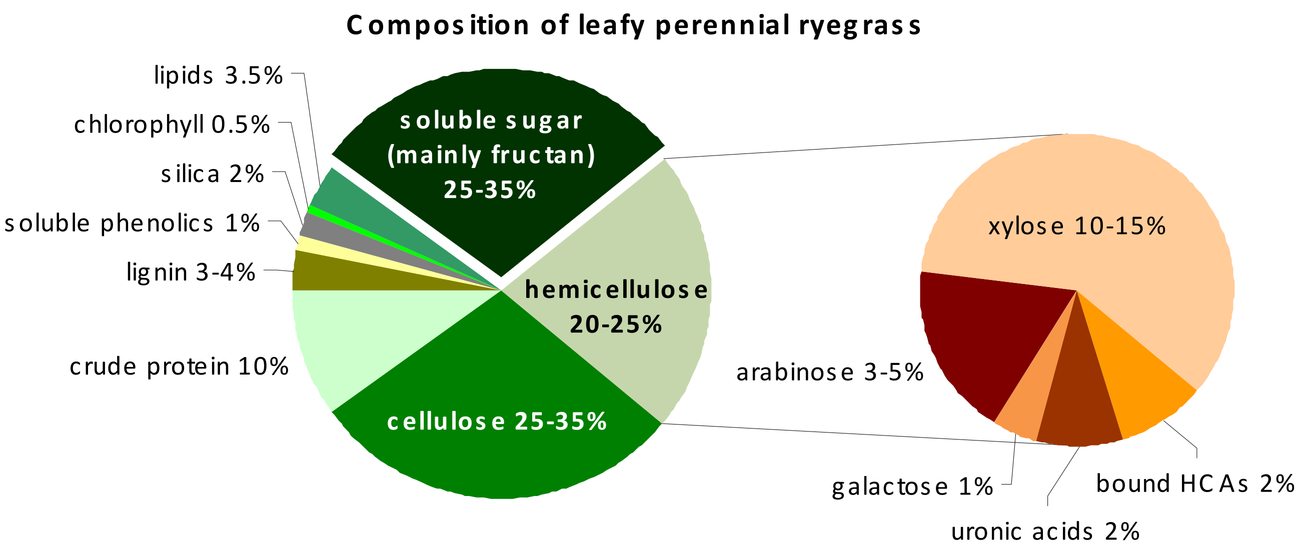

Figure 8: composition of leafy perennial ryegrass; Source: IBERS

As reported in an earlier section, the cost of production for perennial rye grass grown for silage ranges from £20/tonne to £26/tonne depending on the intensity of cultivation. This gives a cost per tonne of sugar in the harvested grass of £83 - £108/tonne.

Going with the low case (25% soluble-sugar content) and assuming that 80% of the available sugars can be recovered by pressing and a hot water extraction, this gives a cost for recovered sugar of £104 - £135/tonne. The 80% figure assumes the sugar is readily recoverable; by comparison the sugar beet industry achieves recoveries up to 90%. Allowing additional costs for pressing and hot water extraction done on a local basis we reach an approximate cost of £120 - £150/tonne for sugar in a dilute liquor processed on farm.

[51] see: http://www.iger.bbsrc.ac.uk/Practice/Publications_&_Leaflets/HSGmilkproduction.htm

There is then a trade off between the transporting the liquor to the biorefinery at whatever concentration is achieved, with the pressing and extraction or by concentrating it before transportation. The logistics costs and impacts are likely to be significant, but they have not been factored into this calculation. Pressing on farm also allows the option of returning the pressed cake back to the land as fertiliser and soil improver. Particularly with marginal land, there is a significant risk that taking away the whole crop for processing will degrade the soil quality over time.

Assuming that the liquor can be fed directly to a fermentation process, the equivalent cost of sugar is in the range of the medium scenario for the BREW project. Given that the current oil price is expected to trend to the upper limit given in the high scenario, there is a realistic prospect of markets developing for platform chemicals from grass feedstocks in Wales.

Given the size of the markets that will develop, and the experience from existing biorefineries and bio-fuel plants, the economic size of a biorefinery is likely to be at least 100,000 tonnes pa output. We do not yet know what the fermentation yield will be for commercial products in Wales. However, given that one tonne of sugar yields 0.385 tonnes of anhydrous ethanol [52] it is reasonable to assume 40% of the available sugar could be converted into platform chemicals. Based on a 25% readily available sugar content this implies a feedstock consumption of 1,000,000 tonnes pa. The estimate made in the Feedstock Options section for the available grass resource without impinging on food production was that approximately 550,000 tonnes pa was in principle available today. With increased yields in the cultivation of the grasses this could increase to 990,000 tonnes pa, but a single biorefinery would clearly take a very large percentage of the grass available for industrial use.

There are two strategies to tackle this challenge; increase the amount of fermentable sugars available from a tonne of grass by converting as much as possible of the lignocellulosic fraction, alternatively reduce the size of a commercially viable plant.

Comparison with Sugar Beet as a Feedstock

The National Non-Food Crops Centre has recently published a report covering the potential of sugar beet as an industrial feedstock.[53] As already mentioned the crop is used by British Sugar at its plant in Norfolk; 65% - 70% of the dry matter in sugar beet roots is sucrose. This is extracted by slicing the root and steeping in water at 70 ˚C for 100 minutes. The resulting raw juice is purified and then concentrated to the point at which the sugar crystallises. Sucrose is then removed in centrifuges, leaving behind a sugar rich molasses fraction used for animal feed. The pulp is pressed and dried and also used for animal feed.

Using the figures in the NNFCC report we get a cost for the sugar content of the refined sugar and molasses combined of ~£390/tonne. In practice, it would not be necessary to process the liquor all the way through concentration, crystallisation and centrifugation if it is intended for fermentation, so the cost per tonne of sugar will be somewhat lower. However, it is clear that sugar beet does not have such a price advantage as a source of fermentation sugars that fodder grasses cannot be economically viable.

Market data on prices for refined sugar are shown in Table 6. There is a large difference between regional prices due to tariffs and production systems.

Table 6: Market prices for Refined Sugar

	2005	2006	2007	2007 (Q4)	2008 (Q1)	2008 (Q2)	2008 (Q3)	Aug-08	Sep-08
Sugar (free market) (cts/lb)	10.1	14.8	10	10.1	12.7	11.8	13.6	13.7	14
Sugar (US) (cts/lb)	21	22	21	20	20	21	23	23	23
Sugar (EU) (cts/lb)	30	31	33	34	33	33	31	31	30

Source: International Monetary Fund
An average EU price of 30 cents/lb translates to $661/tonne and £367/tonne at $1.80.

52 "Australian Liquid Biofuels National Production Boundaries", B. Fleay, 2006, see: **http://www.aspo-australia.org.au/References/Fleay/Fleay06BiofuelsVsPetrol.pdf**
53 "An Assessment of the Opportunities for Sugar Beet Production and Processing in the United Kingdom", G Evans, A Higson, L Hodsman, NNFCC, 2007, see: **http://tiny.cc/nl9jT**

SWOT Analysis of Fodder Grass vs. Sugar Beet

A comparative SWOT analysis of fodder grass in Wales and sugar beet in East Anglia as feedstocks for a regional biorefinery is given below. This shows that neither has an overwhelming advantage, and that fodder grass as a feedstock could be developed in Wales given appropriate research and investment.

SWOT analysis – Fodder Grass

Strengths	Weaknesses
• Low input crop • Can be widely grown on different grades of land • Easy to grow and harvest • Relatively low cost to extract sugar • High amenity value • Can be used for grazing and biomass production interchangeably • Acceptable 'cost of sugar' • Knowledge base on fodder grasses • Can be grown and harvested for a large part of the year	• Dispersed crop – transport costs can be significant • Lower sugar yield per hectare • Less well developed sugar/starch extraction technology than other crops • No established infrastructure • Biorefinery logistics not established • Lack of experience in extraction and fermentation on industrial scale
Opportunities	**Threats**
• Higher yielding varieties • Further reduction of inputs • Increasing available crop area • Valorising protein and fibre • On farm extraction of sugar • Establishment of a new agro-industry in Wales	• Other demands on land use • Requirements for fodder grass for food production • More geographically concentrated sugar beet industry converts rapidly to chemical production

SWOT analysis – Sugar Beet

Strengths	Weaknesses
• High yield per hectare • Simple fermentation substrate • Promotes biodiversity • Rotation Crop • Existing cultivation and processing infrastructure • Well established crop with good knowledge base • Investment to produce fuels from sugar beet already underway – significant commercial production	• Specialist, high input crop • High capital requirements • Limited storage potential • Transport costs • Low value by-products • Rotation currently mandatory • Short harvesting season
Opportunities	**Threats**
• Increasing yield • Decreasing fertiliser input • Potential to valorise beet tops • Improved use of pulp • Conversion of infrastructure to chemicals production	• Decreased demand for sugar for food reduces number of growers • Processing factories close • Loss of specialised equipment and contractors • Other crops offer better economics for chemical production

Value Chains and Markets

Research Expertise

It is clear that for such an approach Wales is uniquely placed within the UK to solve many of the issues identified here. World-class research expertise exists in the region's Universities and institutes:

Aberystwyth University

Home to the Institute of Biological, Environmental and Rural Sciences (IBERS) which has a unique blend of expertise spanning plant breeding, genetics, agronomy, cell biology, biochemistry/ carbohydrate metabolism, enzymology, and microbiology (including aerobic and anaerobic organisms) alongside experience in developing sustainable agricultural practices.

Bangor University

School of the Environment and Natural Resources (SENR) and School of Chemistry together with BC (The BioComposites Centre) have extensive experience in developing technology for the use of renewable materials in the construction, packaging and chemical industries; carbon accounting; life cycle assessment; agricultural policy and the environment; and the economics of nature conservation. The University has core expertise in the chemistry of major classes of plant chemicals and advanced analytical facilities for the identification of natural substances with a track record in the identification of performance chemicals in plants.

Cardiff University

World leading research in catalysis and synthesis, manufacturing engineering and bioscience.

Swansea University

The Institute of Life Science, School of Medicine has internationally recognised experience in the fields of yeast and microbial genetics, microbiology, bio-transformations and fermentation as well as advanced enzymology and chemical analysis. It is home to the UK National EPSRC Mass Spectrometry Service. These relevant areas of expertise are currently utilised in internationally funded projects from Europe and the USA, UK Research Councils, industry and recently from WAG via the WERC project Bioethanol Wales.

Techniums [54]

Are organisations focused on catalysing incubator activities for science and technology businesses, and a key strength for the region. For biorefinery activity the Pembrokeshire region with extensive networks which include the petrochemical industry would be key.

The region's research centres have a good track record of effective collaboration with partnerships such as the Centre for Advanced and Renewable Materials (CARM) and the Welsh Institute for Sustainable Environments (WISE). [55]

Downstream Users

Given the fermentation products discussed earlier, an analysis of the potential markets for those chemicals was undertaken. Figure 9 shows the geographical distribution of companies in the following sectors:

- Agrochemicals
- Bio Fuels
- Coating Adhesives
- Cosmetics & Personal Care
- Essential Oils
- Lubricants
- Nutraceuticals
- Pharmaceuticals
- Specialty Polymers
- Surfactants
- Water & Effluent Treatment

[54] **www.technium.co.uk**
[55] see: **www.carmtechnology.com** and **www.wisenetwork.org**

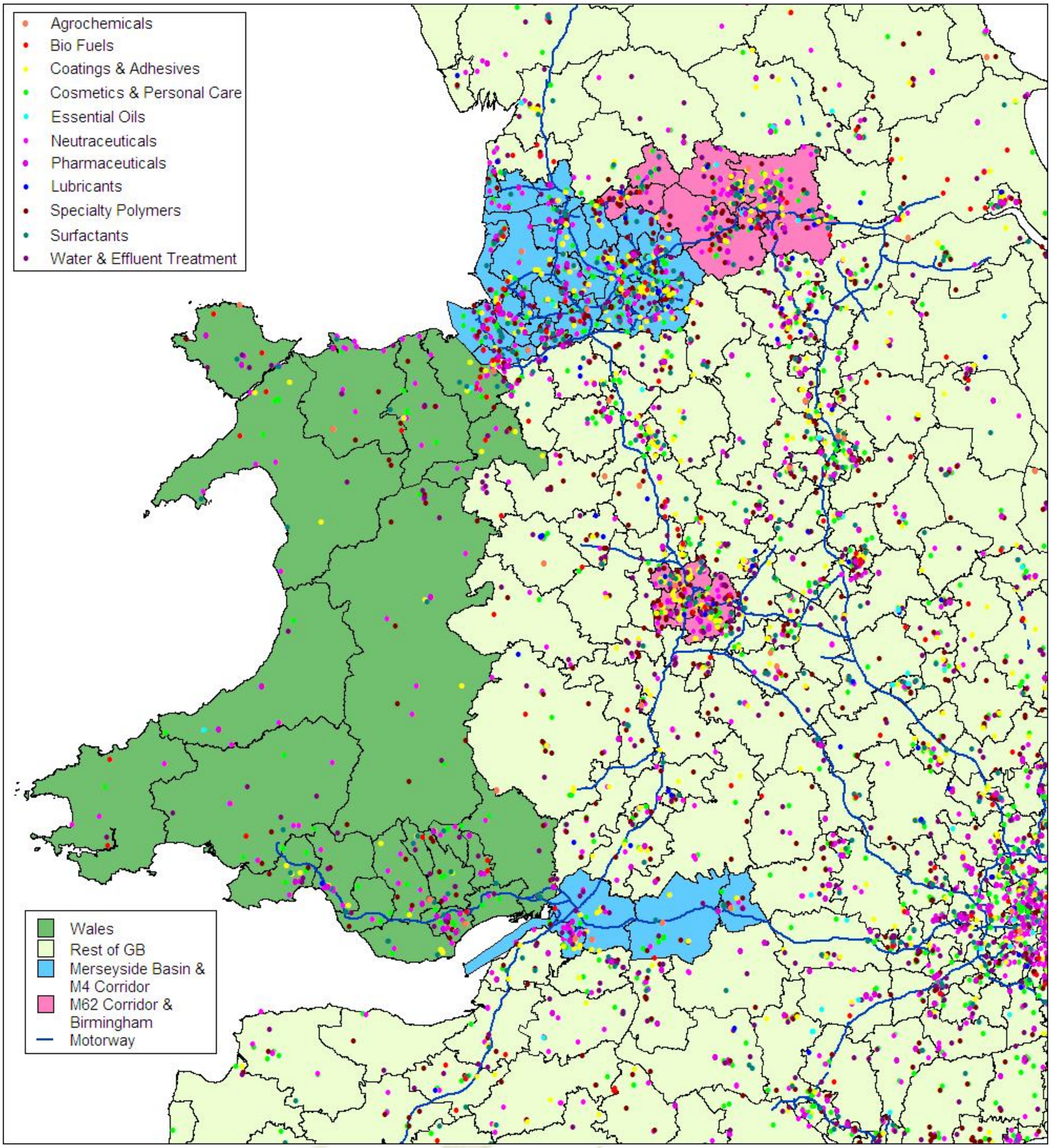

Figure 9 – Geographical Distribution of Companies in Potential Markets for Bio-Based Platform Chemicals

As might be expected there is significant activity in North and South Wales but little in mid Wales. Wales has a significant and growing SME population in chemistry-using businesses. Indeed, a recent report suggested that Wales has the highest percentage of companies growing in this area. Given the poor transport links between the North and South regions biorefining activity could better be developed in two regional areas serving the adjacent clusters in the Mersey basin and Bristol/M4 corridor respectively.

An extensive economic analysis of the companies identified is in Appendix IV with details of selected key firms using bio-based materials in Appendix V.

Overall Economic Impact

Analysis of the size of these market clusters reveals roughly 10% of the UK total market is in the Mersey Basin with a further 3% in Wales and 3% in the Bristol/M4 corridor. This total potential local market is over £6bn in turnover (see Figure 10).

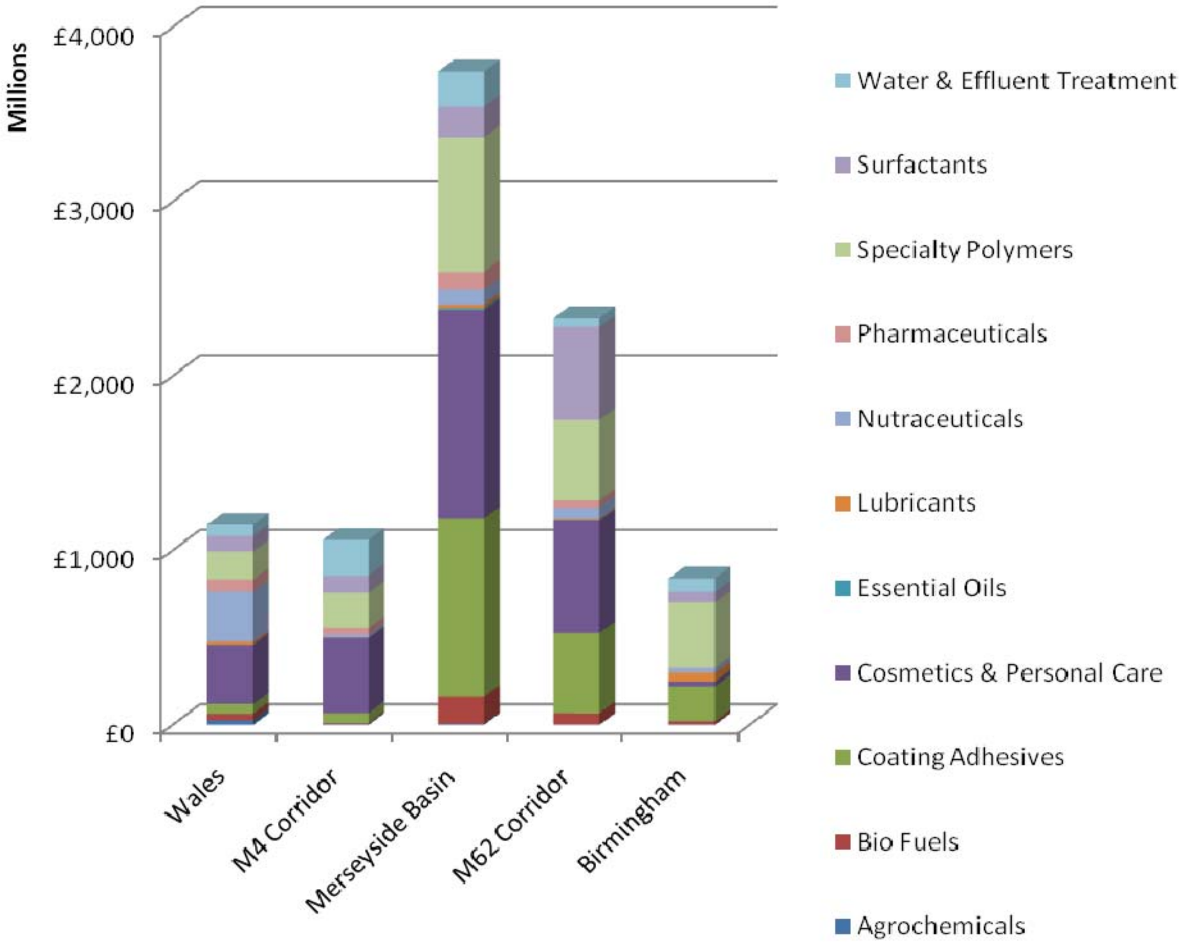

Figure 10: Turnover of Adjacent Market Sectors by Region

Assuming an average chemical feedstock cost to these businesses gives approximately £1.2bn as the market potential. Under the BREW report medium projection a 30% substitution of industrial chemicals is estimated purely on an economic basis in the near term with future growth expected. This equates to a **£360m accessible market.**

[56] "Chemical Science Small Businesses: Realising the Potential", 2007, Royal Society of Chemistry, see: **http://www.rsc.org/ScienceAndTechnology/SME/smallbusinessreport.asp**

Looking at additional strong clusters in the M62 corridor and Birmingham, both readily accessible through good transport links, the share could increase from 16% to 25% of the UK market (see Figure 11; over £9bn) and a **£560m opportunity.**

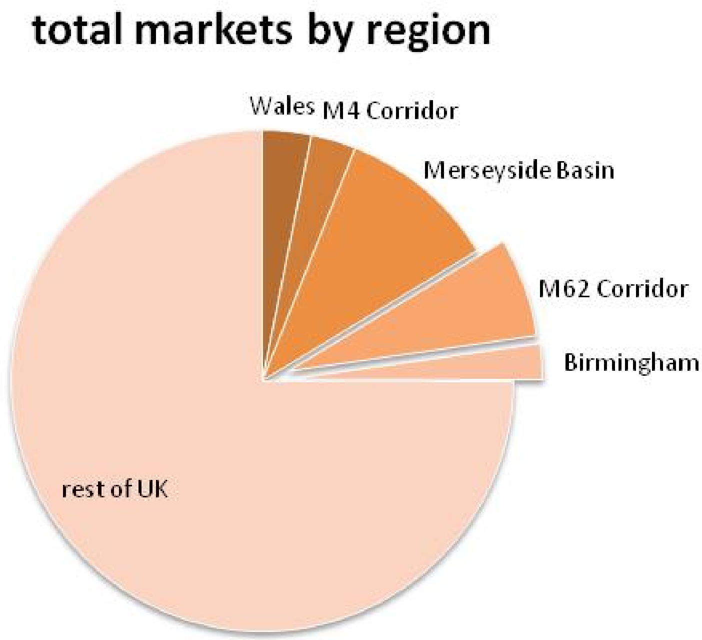

Figure 11: Total Target Market Sectors by Regional Proportion within the UK

The most likely competition would come from East Anglia as the sugar industry restructures to improve feedstock logistics. However, given the correct infrastructure, Wales can compete on cost based on our analysis. Other geographically accessible agricultural areas, such as the Cheshire plains, are committed to food production and there is probably insufficient capacity.

Additional benefits accrue from a reverse in the decline in the agricultural sector in Wales and the creation of new jobs and diversification of production. Businesses will be attracted to Wales to exploit the ready availability of feedstock chemicals with strong environmental credentials and new opportunities will arise for haulage, infrastructure and logistics companies. Importantly the landscape of Wales would be unaffected thus maintaining current major industries such as tourism.

In tackling some of the limitations and technology gaps identified in this report a greater co-ordination of the expertise in Wales that currently exists is advisable. Investment in developing and maintaining a UK leadership position in the exploitation of sustainable biomass is vital. This would have the effect of reinforcing Wales' science base and attract further chemists, bioscientists and engineers to the Principality's universities, research institutes and high-tech companies.

Expertise and Barriers

SWOT analysis of the capability, benefits and impact of establishing biorefinery activity in Wales

	Strengths	Weaknesses	Opportunities	Threats
Social	• regeneration of rural economies • maintaining and broadening skill base		• diversification of farming • new job opportunities • attraction of increased student numbers	• public non-acceptance
Technological	• strong expertise in non-food crops • strong expertise in microbial and fermentation technology • strong expertise in biocomposite materials, including fibre processing • regional strength in biotech companies • academic expertise in use of bio-based chemicals	• second generation fermentation not fully developed so doesn't use all the plant • transport of dilute solutions or low density feedstock	• interdisciplinary work • drive innovation in the chemistry-using sectors • trebling of available sugar from ryegrass through development of lignocellulosic technology	• availability of pre-processing technology • fermentation yields below those expected
Environmental	• low-carbon technologies • reduce fossil fuel dependency • preserve landscape	• impact of transporting biomass • lack of comprehensive LCA information	• lead in manufacture of renewable chemicals	• change in biodiversity
Economic	• competitive with existing UK biorefining activity and feedstocks (i.e. sugar beet) • opening new markets	• transport issues north/south • lack of co-ordinated planning	• competitive regional economy • new jobs in key sectors • increased feedstock security	• risk barriers for industry to development of technology • other facilities developed first and capture target markets
Political	• security of feedstock supply • delivering on renewables targets	• lack of policy support for renewable chemicals	• establish Wales as a UK centre for biorefining	• public backlash against increased rural traffic

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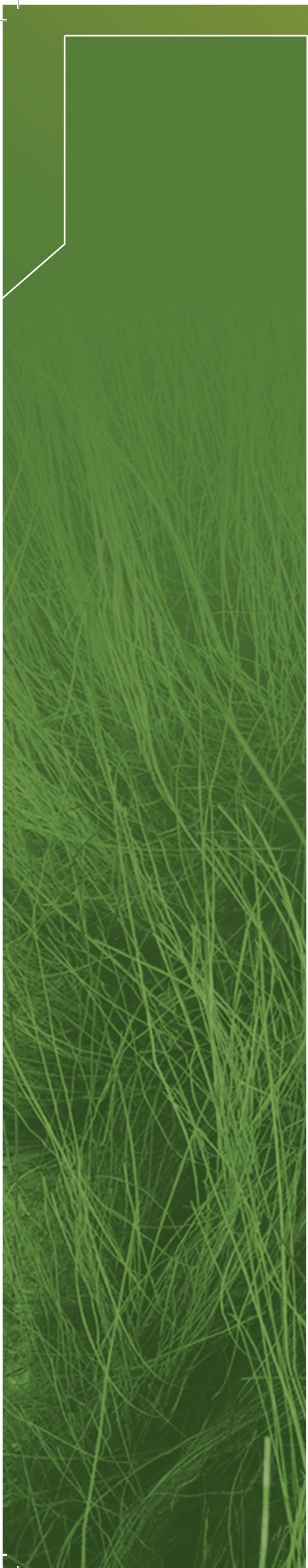

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