Analysis of the UK Capabilities in Industrial Biotechnology in Relation to the Rest of the World

Follow-up Report to:

Assessment of current activity in the production of platform chemicals from renewable sources and horizon scan to forecast potential future developments in science and technology activity in biocatalysis

A sector assessment for the
Industrial Biotechnology Innovation and Growth Team (IB-IGT)

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Prepared by

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About this document

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Executive Summary

Industrial biotechnology is the modern use of biotechnology for the sustainable production of chemicals, materials and fuels. It can offer industry the opportunity to increase its sustainability by moving to a low carbon economy by the use of sustainable bio-based products and processes. This report summarises the UK's capabilities in industrial biotechnology, and compares them with developments in other countries.

Historically the UK's biotechnology activities have been focussed on the life science sector, but the use of biotechnology for the production of energy, chemicals and materials from renewable resources has also created significant interest. The UK has a strong research base, underpinning industrial biotechnology. Although its industry has applied biotechnology mainly for healthcare technologies, a small but increasing number of companies develop processes to produce biomass-based chemicals and materials. Governmental support is also in place to ensure growth of this sector, however, only few dedicated funding programmes exist. Especially dedicated funds to reduce industry's risk in developing novel bio-processes and products are required.

Several countries besides the UK support the development of bio-based products and processes. Europe and the USA have emerging policies on the use of biomass for transformation into products. The European Union develops a rapidly growing industrial biotechnology industry. In the USA the sector is driven by the desire for a greener and a more sustainable society, but mainly by the political will to reduce the country's dependency on foreign oil. The use of industrial biotechnology in Asia is very diversified. Japan was one of its first appliers, and China and India are interested in developing the sector, driven by the biofuel market. Other countries like Australia and New Zealand develop also an interest in industrial biotechnology.

A significant number of countries develop an interest in industrial biotechnology, mostly driven by energy and fuel security, environmental concerns, and economic benefits. The UK is in league with the European countries and the USA regarding underpinning research, but is behind interdisciplinary research. However, the Centre of Excellence in Biocatalysis, Biotransformations and Biocatalytic Manufacture together with the National Industrial Biotechnology Facility provide an excellent backbone for industrial focussed research. The UK does not have the chemical industry with a strong interest in industrial biotechnology that other countries have, but there are an increasing number of companies developing bio-processes. There is a lack of contract manufacturing and demonstration facilities in the UK. Unlike in other countries (in particular USA and Germany) no policies are currently in place to support the bio-based materials and chemicals sector, but several strategies exist or are currently developed.

The UK has the capability to become one of the world leaders in industrial biotechnology, however, there are still several weaknesses, which needs addressing.

Introduction

Industrial Biotechnology is the modern use and application of biotechnology for the sustainable processing and production of chemicals, materials and fuels.[1] It can offer the UK chemical industry the opportunity to increase its sustainability by moving to a low carbon economy by the use of sustainable bio-based products and processes.

Similar to other biotechnologies, industrial biotechnology is capital intensive and require long term research and investment. Lack of relevant expertise and lack of access to funding or financing options for capital investment can be significant barriers to industrial biotechnology take-up. With the increasing interest in industrial biotechnology world-wide a number of countries have started to develop research and development and policy measures to support this growing sector.

This report summarises the UK's technological strengths in industrial biotechnology and the existing relevant research and development and supporting activities. To provide a global context, these activities were compared to the developments in other countries which have a significant interest in industrial biotechnology (Europe, USA, Japan etc.).

The data analysed in this report is mainly based on the previously produced report 'Assessment of current activity in the production of platform chemicals from renewable sources and horizon scan to forecast potential future developments in science and technology activity in biocatalysis' and the 'Bio-based economy' website[2], produced by the European Association for Bioindustries (EuropaBio).

UK Capabilities in Industrial Biotechnology

Overview

Historically the UK's biotechnology activities have been focussed on the life science sector. A productive biotechnology industry and the UK's strong life science research base have ensured that new and enhanced products and processes were continuously developed for this market. Government support together with investment in world-leading research institutes enables industry to maximise the benefits of discoveries, and to establish a comprehensive supply chain. The strength of the UK's biotechnology research expertise and the support of government could ensure that a strong industrial biotechnology sector could be established in this country.

The use of biotechnology for the production of energy, chemicals and materials from renewable resources has created significant interest in the UK. Academic groups have started to explore this area closer. Companies have initiated development programmes. Several biomass-based processes outside of the pharmaceutical industry are operated in the UK. Government has produced relevant strategies and supports research and development. However, the majority of these activities are focussed on bioenergy.

Academic Expertise

The UK has already a strong research base in areas of importance for industrial biotechnology. Significant expertise exists in:

- Development of enzymatic catalysts for manufacturing processes
- Fermentation technologies
- Bio-prospecting
- Utilizing the functionality of molecules
- Chemical transformations

Although research was often focussed on non renewable chemicals, for example development of pharmaceuticals, a number of UK academic centres have developed active research programmes encompassing the use of biomass-based chemicals. Several centres exist which are of importance in developing this technology area:

- Green Chemistry Centre of Excellence, York[3]
- The Satake Centre for Grain Process Engineering, Manchester[4]
- BioComposites Centre of Excellence, Bangor[5]
- Centre for Sustainable Chemical Technologies, Bath[6]

University-based research efforts are often spread across chemistry, chemical engineering and bioscience departments. Areas of research include

- Chemical catalysis for polymerising biomass-based monomers
- Chemistry to improve the properties of renewable polymers
- Chemical transformations of biomass-based molecules into commercial ingredients
- Biocatalysis to transform renewable chemicals into functional products
- Fermentation routes for production of renewable chemicals

Table 1 University departments involved in research on renewable chemical feedstocks

Chemical Polymerisation	**Modification of biopolymers**	**Chemical transformations of renewable molecules**	**Biocatalysis**	**Fermentation**
School of Chemistry, The University of Edinburgh	Biocomposites Centre, University of Bangor	School of Chemistry and Chemical Engineering, Queen's University Belfast	School of Applied Sciences, Cranfield University	School of Science & Technology, University of Teesside
Department of Chemistry, Imperial College London	Warwick Manufacturing Group, University of Warwick	Department of Chemistry, University of Nottingham	Biomedical Research Centre, Sheffield Hallam University	The Satake Centre for Grain Process Engineering, The University of Manchester
Centre for Sustainable Chemical Technologies, University of Bath		Green Chemistry Centre of Excellence, University of York	Institute for Cell and Molecular Biosciences, University of Newcastle upon Tyne	Centre of Excellence for Biocatalysis, Biotransformations and Biocatalytic Manufacture
Department of Chemistry, University of Warwick		School of Chemistry, Cardiff University	Centre for Extremophile Research, University of Bath	Genomics Research Centre, Warwick University
		Centre for Sustainable Chemical Technologies, University of Bath	Biocatalysis Centre, University of Exeter	
			Department of Biochemistry, University of Leicester	

Besides of research centres directly related to the use of biomass and biomass-derived products a number of world-leading specialist institutes exist in the UK, whose scientific expertise and commercial awareness will be extremely valuable for the development of enabling technologies and industrial biotechnology products and services.

These research centres include:

Development of biocatalysts for manufacturing processes:

- The Centre of Excellence in Biocatalysis, Biotransformations and Biocatalytic Manufacture (CoE Bio3)[7]
- The Centre for Extremophile Research, University of Bath[8]
- Exeter Biocatalysis Centre[9]
- The Centre for Bioactive Chemistry[10]

Engineering of biotechnology processes:

- Innovative Manufacturing Research Centre for Bioprocessing, UCL[11]
- School of Chemical Engineering and Advanced Materials, University of Newcastle upon Tyne[12]
- School of Biosciences, Nottingham[13]

Development of plant-based feedstocks

- The John Innes Centre[14]
- Rothamsted Research[15]
- Institute of Biological, Environmental and Rural Sciences, Aberystwyth University (IBER)[16]
- Scottish Crops Research Institute[17]
- Centre for Novel Agricultural Crops (CNAP)[18]

Development of marine feedstocks

- The Scottish Association for Marine Sciences[19]
- The European Centre for Marine Biotechnology[20]
- The Plymouth Marine Sciences Partnership[21]
- The Institute of Aquaculture, University of Stirling[22]

Development of biofuel and bioenergy

- Biofuel Research Centre, Edinburgh[23]
- Porter Alliance[24]
- BBSRC Sustainable Biotechnology Institute[25]

Industrial Expertise

In the UK industrial biotechnology has historically been mainly applied by the pharmaceutical industry. To a lesser extent it has been applied by the UK personal care products industries. Target products were mainly high value, low volume products (e.g. pharmaceutical intermediates).

The use of both biocatalytic and chemical methods to produce biomass-based chemicals is a slowly growing area in the UK. Relatively few companies develop processes to produce such chemicals in the UK. A small number of commercial organisations work on the conversion of renewable chemicals (C-Tech Innovation, Centre for Process Innovation, Croda). Downstream processing methods are also being developed by several companies (e.g. EKB Technology, C-Tech Innovation, Centre for Process Innovation, Green Biologics). Very few of these organisations have the facilities to demonstrate their new processes at a commercial stage with the exception of Croda.

Significantly more activity exists in the biofuels sector, where the feedstocks and processes are often similar. Green Biologics, an SME based in Oxfordshire, works on the development of integrated fermentation processes for the production of both biofuels and biochemicals. Other companies working on fermentation processes to produce mainly biofuels are TMO Renewables, Biocaldol, and British Sugar; the later one is the only producer of bioethanol in the UK.

UK companies using renewable chemicals operate also in the consumer product market (Croda, Kemcare, Unilever, Boots), the coating markets (AkzoNobel, Arizona Chemicals, Croda) and the polymers market (Lucite International, Industrial Copolymers, Warwick International, Lake Chemicals & Minerals).

The number of biotechnology companies in the UK is significant larger than the number of companies which can be classified as operating in industrial biotechnology. Although the majority of them work in life science or biocleaning, a number of biotechnology companies are also relevant for the industrial biotechnology sector:

SMEs:

- NCIMB (supply of bacteria cultures)[26]
- Ingenza (development of enzymatic processes)[27]
- Novacta Biosystems (development of microbial processes)[28]

Biocatalytic manufacturing processes in development:

- Oxford Chemicals (flavour and fragrance chemicals)
- Baxenden Chemicals (polyesters and polyurethane)
- Nicholas Piramal India Ltd (pharmaceutical intermediates)

Financial and Regulatory Incentives and Barriers

The UK strongly supports academic research. However, as industrial biotechnology is not always clearly defined, there are almost no funding streams that can be directly related to research in this area. The most relevant funding bodies are:

- Biotechnology and Biological Science Research Council (BBSRC)
- Engineering and Physical Sciences Research Council (EPSRC)
- Department for Environment, Food and Rural Affairs (DEFRA)
- Technology Strategy Board

In addition UK academic groups receive funding from the European Framework Programme 7 (FP7).

Relevant funding programmes are:

- BBSRC Integrated Biorefinery Technologies Initiative (IBTI) Research and Technology Club (£5 million funding for 5 years, started 2008)
- BBSRC Sustainable Bioenergy Institute (£27 million)

To ensure that research discoveries are transformed into commercial opportunities technology transfer organisations and programmes have been established in the UK. A number of UK's leading research organisations have their own commercial arms or business development initiatives to interact with industry and the investment community. In addition a number of Government programmes have been developed to support industrial/academic and industrial/industrial interactions. Two Knowledge Transfer Networks (KTNs) in particular stimulate innovation in industrial biotechnology, the Bioscience for Business KTN and The Chemistry Innovation KTN. The Environmental KTN and The Resource Efficiency KTN also support industrial technology. One NorthEast has established The Centre for Process Innovation as a UK wide resource to drive innovation in the Process Industry. Their National Industrial Biotechnology Facility is designed to assist industry in up-scaling of biocatalytic processes. The National Non-Food Crop Centre is another organisation established by government. It promotes knowledge transfer in areas such as biolubricants, plant-derived pharmaceuticals, biochemicals and biopolymers.

No policies are in place in the UK regarding the industrial biotechnology market. In contrast, the Renewable Obligation (RO) and Renewable Transport Fuel Obligation (RTFO) set clear targets for the bioenergy and transport sectors. However, two strategies have been published that strongly support Industrial Biotechnology. 'A Strategy for non-food crops and uses – creating value from renewable materials' has been produced by DEFRA and DTI (Now BERR) in 2004. It includes areas such as tackling climate change, funding scientific research and increased use of sustainable products. The UK Life Science Strategy was published in 2007, and it covers amongst others the use of biotechnology to produce more sustainable products. The 2004 established Biomass Task Force shall assist Government and industry in optimising the use of biomass for sustainable development. In 2006, the Government asked the Task Force to concentrate on the use of biomass for heat and electricity generation, while other non food uses of crops should only be taken account of if cross-cutting issues arose.

Industrial Biotechnology outside the UK

Overview

The development of bio-based products is supported through strategies in different regions of the world. A lot of these strategies have a strong focus on biofuels and bioenergy. Most countries and regions have no comprehensive policies on the use of biomass for transformation into products. Only Europe and the USA have emerging policies in this area, driven by their strong chemical and biotech industries.
However, industrial biotechnology is raising interest in most regions in the world, and countries like China, India, Australia, New Zealand start to develop an industrial biotechnology sector.

European Union

Overview

The European Union develops a rapidly growing industrial biotechnology industry. Countries like Germany, France, Denmark, Netherlands have the industrial and academic background and substantial governmental support in this area. In addition, the European Commission is a strong supporter of bio-based products and processes. A significant number of groups and platforms exist on both national and EU-wide level, driving the agenda of industrial biotechnology.

Academic Expertise

Biological sciences are strong in the European Union. Extensive academic experience exists in applied biocatalysis. Universities like the University of Ghent, University of Technology Graz, University of Greifswald, University of Delft, University of Wageningen are on the forefront of biocatalytic research.

In addition a number of research centres have been established that are hubs of industrial biotechnology. These include:

- Frauenhofer Gesellschaft[29] (Pilot Plant Center (PAZ) for polymer synthesis and polymer processing; Institute for Chemical Technology; Institute for Environmental, Safety and Energy Technology UMSICHT): Germany
- GAIKER Technological Centre[30]: Spain
- Instituto Nacional de Engenharia, Tecnologia e Inovação[31]: Portugal
- Institut Univ . de Ciència i Tecnologia" (IUCT)[32]: Spain
- Planta Piloto de Química Fina[33]: Spain
- VTT Technical research centre[34]: Finland
- Research Centre, Applied Biotechnology[35], Austria

Industrial Expertise

European industry is a strong supporter of industrial biotechnology. Companies like BASF, Ciba Speciality Chemicals, DSM, Henkel, Evonik have operated biocatalytic processes for manufacture of bio-based materials and chemicals for decades. They are also on the forefront of development of novel bio-processes. Companies like Roquette are leading development of biomass-based processes. Novozymes and Danisco are the world leaders in enzyme technology.

The number of industrial biotechnology SMEs is also increasing in the EU. Companies like B.R.A.I.N.[36] and CLEA Technologies[37] develop tools for more sustainable bio-processes.

To assist industry in the development of new industrial biotechnology processes, a number of demonstration facilities and pilot plants exist in the European Union (see: Appendix 1 – Biofuels and Biochemicals Demonstration and Pilot Plants in the EU). Access to a number of them is restricted, but there are several that are open to all organisations. Demonstration and pilot plants of relevance for bio-based materials and chemicals with open access include:

- Photobioreactor to produce microalgal species[38]: Germany; Bioprodukte Prof. Steinberg GmbH; funding: public (federal funding) & private
- Stirred vessels (up to 1000 litres) and 450 litres-fermentor for processing of starchy materials: Germany; funding: €3,2 million (75% funding by EU/ERDF; 12,5% Federal and 12,5% Regional Government respectively Investitions-Bank des Landes Brandenburg - ILB)
- Pilot plant facility for the biotechnological manufacture of valuable products based on renewable resources[39]: Germany; Leibniz-Institute for Agricultural Engineering Potsdam-Bornim e.V.; funding: public
- Photobioreactor to produce microalgal species: Germany; Subitec GmbH; funding: Public (federal funding) & private
- Plant for Cultivation and processing of microalgae for biomass production: Spain; Canary Islands Institute of Technology[40]; funding: public
- Fermentors up to volumes of 300 litres[41]: Spain; Biopolis; funding: Public-private co-funding
- Fermentors and bioreactors up to 300 litres. (now in processes of expanding up to 1000 L) [42]: Spain; Biotgensystem; funding: private
- Vertical tubular photobioreactors up to 500 litres[43]: Spain; Centro de Biotecnologia Marina; funding: public
- Fermentation pilot plant (300 litres)[44]: Spain; Autònoma de Barcelona; funding: public
- Pilot plant facility for the biotechnological manufacture of valuable products (up to 300 litres): Switzerland; University of Applied Sciences of Western Switzerland; funding: Public (cantonal and federal) and private
- Bioreactors up to 300 litres[45]: Switzerland; Biotechnet Switzerland
- Pilot plant facility for the biotechnological manufacture of valuable products[46]: Switzerland; Empa; funding: Public and private (industry)
- Fermentors up to 300 litres[47]: Portugal; Instituto de Biologia Experimental e Tecnológica; funding: mainly public

Financial and Regulatory Incentives and Barriers

Biotechnology was acknowledged at two summits in Lisbon and Stockholm as the backbone of a knowledge-based economy. Following these summits the EU's Life Science and Biotechnology Strategy[48] was published in 2002, setting out 30 action points to develop biotechnology in Europe. The Bio4EO[49] study showed that life sciences and biotechnology has generated almost 1.56% of EU gross value added. This includes all sectors of biotechnology (healthcare, agri-food and industrial).

The European Union has a number of initiatives that support the development of a bio-based economy. These initiatives include:

- European Technology Platforms (in particular SusChem[50] and Plants for the Future[51])
- Environmental Technology Action Plan (ETAP)[52]
- Lead market initiative for bio-based products[53]
- European Research Area Networks (ERA-NETS) including Industrial Biotechnology (ERA-IB)

These actions aim to develop support policies to stimulate demand for bio-based products. They encourage innovation and assist the transfer of knowledge into new bio-processes and products.

Suschem (the European Technology Platform for Sustainable Chemistry) produced a 'Vision for 2025 and Beyond' which also covers the development of industrial biotechnology in Europe. This was followed by the 'Industrial Biotechnology Policy Agenda for Europe'[54] which gives recommendation how to overcome barriers to innovation and market access. This document was used to prepare the European Commission's Lead market initiative for biobased products.

EU member states have also established a number of working groups and technology platforms to discuss the future of industrial biotechnology and necessary policy measures are also being established:

- Belgium: Belgian Interdisciplinary Platform for Industrial Biotechnology; recommendations have been published[55] but not implemented yet
- Germany: 'Weiβe Biotechnologie'[56]; a brochure discussing the opportunities of industrial biotechnology which resulted in several policy measures
- The Netherlands: Policy Agenda on sustainable biomass[57]
- Italy: Working Group on Industrial Biotechnology of the Committee for Biosafety, Biotechnology and Life Sciences; identifies short term R&D priorities
- Lithuania: National Biotechnology Platform (LNBP); currently drafting a long-term strategy for the development of industrial biotechnology in Lithuania
- Poland: Action Plan: Towards the Development of Industrial Biotechnology in Poland'[58]

Other countries are in the process of establishing technology platforms for industrial biotechnology (e.g. Turkey).

The EU wide industry group for industrial biotechnology is EuropaBio[59]. It promotes the use of bio-based products and processes, coordinates relevant initiatives and produces recommendations for the development of the bio-economy.

There are a number of dedicated national research programmes funding industrial biotechnology innovation and development. Several of them are integrated in the ERA-Net for Industrial Biotechnology (ERA-Net IB)[60], the aim of which is the reduction of fragmentation of research activities in industrial biotechnology carried out at national level.

Dedicated national research programmes are:

- BioRefine[61]: Finland; budget: €137 million over the period 2007 to 2012; by Tekes (The Finish Agency for Technology and Innovation)
- SymBio – Industrial Biotechnology[62]: Finland; budget: €80 million over the period 2006 to 2011; by Tekes
- IBOS Integration of Biosynthesis and Organic Synthesis[63]: The Netherlands; budget: €13.6 million (of which €4.54 million are provided by the chemical and life science industry) over the period 2003 to 2010; by The Netherlands Organisation for Scientific Research (NOW)
- B-Basic – Bio-based Sustainable Industrial Chemistry[64]: The Netherlands; budget: €50 million (of which €12 million are provided by industry) over the period 2004 to 2009; by: The Netherlands Organisation for Scientific Research (NOW)
- CatchBio – Catalysis for Sustainable Chemicals from Biomass[65]: The Netherlands; budget: €29 million (of which €14 million is provided by industry and universities) over the period 2007 to 2015; by Ministry of Economic Affairs
- National Industrial Biotechnology Development programme: Lithuania; budget: €8.7 million over the period 2007 to 2010
- Swedish programme dedicated to industrial biotechnology[66]: Sweden; budget: around €4.6 million was granted in the first call in 2008; by Vinnova (The Swedish Governmental Agency for Innovation Systems)
- VINVÄXT[67]: Sweden; budget: around €1.2 million was granted in 2008; by Vinnova (The Swedish Governmental Agency for Innovation Systems)

Besides of these national programmes research funding within the EU is provided by the Seventh Framework Programme for Research and Technology Development (FP7). One of the areas covered by this funding programme is 'Food, Agriculture and Fisheries, and Biotechnology'[68] for which more than €1.9 billion have been earmarked for funding over the period 2007 to 2013.

Funding for industrial biotechnology on a European level is also provided by ERA-IB. A first call was published in 2008[69]. It was sponsored by Belgian Federal Science Policy Office (BelSPO), Belgium; Danish Agency for Science, Technology and Innovation (DASTI), Denmark; Finnish Funding Agency for Technology and Innovation (Tekes), Finland; French Environment and Energy Management Agency (ADEME), France; Fachagentur Nachwachsende Rohstoffe (FNR), Germany; Sächsisches Staatsministerium für Umwelt und Landwirtschaft (SMUL)/Freistaat Sachsen, Germany; National Center for Research and Development (NCBiR), Poland; Fundação para a Ciência e a Tecnologia (FCT), Portugal; Spanish Ministry of Education and Science (MEC), Spain; and Netherlands Organisation for Scientific Research (NWO)/ACTS, The Netherlands.

Industrial biotechnology research in the EU is also funded via general biotechnology programmes or via parallel programmes (e.g. energy, agriculture, environment). The large majority of industrial biotechnology projects are still supported through general research funding schemes.

Very few industrial biotechnology-specific initiatives exist to support the transfer of research results to the market. Germany has established the BioIndustrie 2021 programme[70], which provides €60 million over the period from 2006 to 2011, supplemented by additional funding from industry. Its aim is to develop interdisciplinary clusters in which research institutions, industry and the finance community develop strategies for future markets, and implement projects in their common interest. In 2006 the Netherlands' Small Business Innovation Research Programme (SBIR), a programme supporting entrepreneurs in the development of products or services, included bio-based products in its themes. In France the OSEO agency currently supports three major projects in the field of industrial biotechnology and biorefinery: BioHub[71] (€42 million); Osiris (€31.2 million) and Futurol (€29 million). Other countries, like Finland, Italy and Belgium support industry and demonstration activities in industrial biotechnology via general funding programmes.

The European Commission encourages green public procurements to support the introduction of greener products and sustainable modes of production. In 2005 seven EU member states (Austria, Denmark, Finland, Germany, Netherlands, Sweden and UK) are implementing more elements of green public procurement than the other member states.[72] However, no member state has included biobased products into their public procurement schemes. The only initiative comes from France, where the French Environment Agency (ACDEME) published a guidebook on bio-products in 2005.[73]

USA

Overview

Industrial biotechnology in the USA is driven by the desire for a greener and more sustainable society. However, the main driver is the political will to reduce the dependency on foreign oil. Another important driver in the USA is the economic benefit particularly for rural economies. The third driver is the environmental benefit. As a result industrial biotechnology is moving forward at an impressive pace in the USA, especially in the area of biofuel and biorefineries.

Academic Expertise

Excellent research is performed in the USA. The most important innovations to drive the implementation of industrial biotechnology into manufacturing are:

- Novel biocatalysts from unusual environments (e.g. marine)
- Designer enzymes from genes
- Metabolic pathway engineering
- Bioinformatics
- New process tools like unconventional solvents and microreactors
- High-throughput screens
- The use of renewable lignocellulosic feedstocks

Research in the USA has a strong focus on bioenergy. The National Renewable Energy Laboratory (NREL)[74] is the nation's primary laboratory for renewable energy, and it has established a pilot facility for production of ethanol, other fuels and chemicals.

Universities and research centres which are also involved in industrial biotechnology related research include:

- North Carolina State University
- Oak Ridge National Laboratory
- Iowa State University
- Lawrence Berkeley National Laboratory
- Massachusetts Institute of Technology
- National Center for Agricultural Utilization Research

Industrial Expertise

A strong chemical and biotech industry drives the development of bio-based products and the increased use of renewable materials in the USA. Industrial biotechnology is well accepted by industry. Companies like Cargill, Archer Daniels Midland, and DuPont are strongly involved in industrial biotechnology processes and developments. The strong governmental support ensures that SMEs like Metabolix[75] can develop their new technologies and products rapidly. One of the main players in the development of biocatalytic processes is the US company Codexis[76]. Founded in 2002, this company has quickly become one of the main players in biocatalysis.

Financial and Regulatory Incentives and Barriers

Political commitment for bioproducts has developed very fast over the last ten years, driven by the countries increasing dependence on foreign oil. The first initiative was President Clinton's Executive Order of 1999, which set the goal to triple the use of bio-based products by 2010. A recent publication, the Roadmap for Biomass Technologies in the United States[77], provides policy recommendations to remove barriers.

The Biomass Research and Development Initiative (BRDI) coordinates all US biobased products and bioenergy research and development. In 2003 alone $384 million were provided by the US Department of Energy (DoE) and the Department of Agriculture (USDA) for biomass utilisation research. In addition, $100 million is spent by the DoE on bio-refinery demonstration projects, in which it works closely with industry.

The US government also supports market development via several initiatives. Federal procurement of bio-based products when they are available was mandated by the 2002 Farm Bill. Procurement standards and targets for federal government purchase of bio-based fuels and products have been set. These shall ensure market pull for bio-based materials.

Brazil

There are very few initiatives dedicated to industrial biotechnology in Brazil, but it has energy and biofuels policies that could offer the base of upcoming policies for other bio-based products. This country has almost a century of history in bioethanol production. In the 1970's the governmental programme PROALCOOL was created, which aims to increase sugar-cane production to be used as a substitute to petrol. Ethanol, however, can not only be used as a fuel but also as a chemical feedstock, and Brazil becomes the focus of a supplier of ethanol as a bio-based platform chemical.

Asia

Overview

The industrial biotechnology sector in Asia is very diversified. Japan was one of the first appliers of industrial biotechnology, while other countries are just starting to develop this sector, mostly driven by the biofuel market (e.g. China and India). Several countries have string capacities in health biotechnology (e.g. Singapore, Israel) and could become potential players in industrial biotechnology.

Japan

Japan has historically been strong in bioprocessing and fermentation. It is one of the earliest adopters of industrial biotechnology due to its long tradition of making fermented food. The Japanese fermentation industry is world-class, especially in specialised markets like amino acids, and Japanese companies were among the first to use enzyme as biocatalysts (production of acrylamide by Mitsubishi Rayon).
However, Japan does not have the capacity to supply home-grown biomass to industry at a competitive price. Economically viable bio-refineries rely on locally supplied biomass, therefore it is more likely that growth will focus on higher-value, niche markets rather than bulk chemicals.

The government-sponsored Biotechnology Strategy Council published in 2002 an action plan covering biotechnology strategies. Within five years funding of biotechnology research was doubled. A significant proportion was focussed on industrial biotechnology. In contrast to the USA and Europe, Japan puts significantly more funding into biotechnology for health-oriented foods, the environment and power generation than in healthcare research. The Japanese biomass strategy was reviewed in 2006 and a new strategy developed.

Major academic centres of industrial biotechnology research are:

- University of Tokyo
- Osaka University
- Kyoto University

Large pharmaceutical and chemical companies together with the companies from the food industry play the central roles in Japanese biotechnology. Major players include:

- Mitsubishi Chemical Corporation
- Ajinomoto
- Mitsui Chemicals
- Kirin Brewery

China

Industrial biotechnology initiatives in China are focussed on energy and biofuels. China aims to meet 15 percent of its transportation energy needs with biofuels. The new renewable energy laws are designed to provide a sustainable financial source for biomass energy projects. Research and development grants are provided by the National Development Reform Commission and the Ministry of Science and Technology. Low interest loans and generous income tax concessions during the first years of investment are provided by government as capital investment subsidies.

India

There are over 800 biotechnology companies in India, but most of them operate in the healthcare market. In 2005 it was estimated that industrial biotechnology provided about 7% of the Indian biotechnology market. Companies of interest include Nicholas-Piramal, which acquired the fine chemical part of Avecia several years ago. One of the UK's major industrial biocatalytic groups became thus part of an Indian company. The use of fermentation processes to produce bulk chemicals is also an area which attracts interest from Indian companies. India is one of the world largest sugar producers, almost equally placed to Brazil in terms of sugarcane production.[78] An ethanol-based chemical industry already exists in India, and industrial ethanol use has grown steadily over the last years. Therefore a task force on the sugar industry has suggested the development of a national policy on increased ethanol production from molasses.

Oceania

Overview

New Zealand and Australia are developing an interest in industrial biotechnology. Both can offer supporting research expertise. Australia with its wide biodiversity has good access to biocompounds and organisms for potential industrial use. New Zealand has a good background in plant biotechnology offering the chance to develop novel feedstocks for industry.

Australia

There are a number of drivers for industrial biotechnology in Australia. One of the most prominent is the increased need for sustainable resource use. As Australia is one of few mega-diverse countries its researchers have access to a large number of unique biocompounds and organisms which could be used in industrial applications.

A number of R&D research organisations exits in Australia. These include the Sugar Research Institute (SRI) and the Australian Institute for Bioengineering and Nanotachnology (AIBN). There are also a number of partnerships between

government, research institutions and industry. An example of such activities which may produce outcomes for industrial biotechnology is the Mawson Precinct[79] in South Australia – a high-tech commercial, research and teaching hub with excellence in Information and Communications Technology, defence and biomaterials.

Australia's expertise in industrial biotechnology include:

- Gene and pathway manipulation for the production of value addeded industrial products
- Biomass processing
- Use of integrated biorefineries

In addition there is expertise in agricultural biotechnology, which involves the development of enhanced transgenic plants as improved feedstocks.

There are a number of opportunities in Australia for growth in industrial biotechnology:

- Development of bio-processes for replacement of conventional manufacturing routes
- Construction of superior microbes for particular substrates and products
- Manufacture of bio-based food additives and specialist chemicals

New Zealand

New Zealand has always been strong in plant biotechnology, so far focussed on the agricultural sector. However, recent innovations have been made in industrial biotechnology, too. Plants, microbes and enzymes have been applied to find new solutions in fuels and chemicals. About 14% of employment in New Zealand's biotechnology industry is provided by industrial biotechnology.

Industrial and academic research is performed on creating new speciality biopolymers and chemicals. The Biopolymer Network[80] is a collaboration between three research institutes (AgResearch, Scion, Crop & Food Research), with the aim to develop a range of high performance products for industrial applications.

Africa

Only South Africa shows some initiatives which can be related to industrial biotechnology. As one of the last countries that used fermentation technologies to produce butanol (due to its political isolation), it has a history in fermentation technologies. However, the main focus in South Africa is on biofuels, and the country aims to develop a biofuels value chain based on local production.

Biotechnology in general, in particular plant biotechnology, gets increasing attention in African countries as a tool to provide food security.

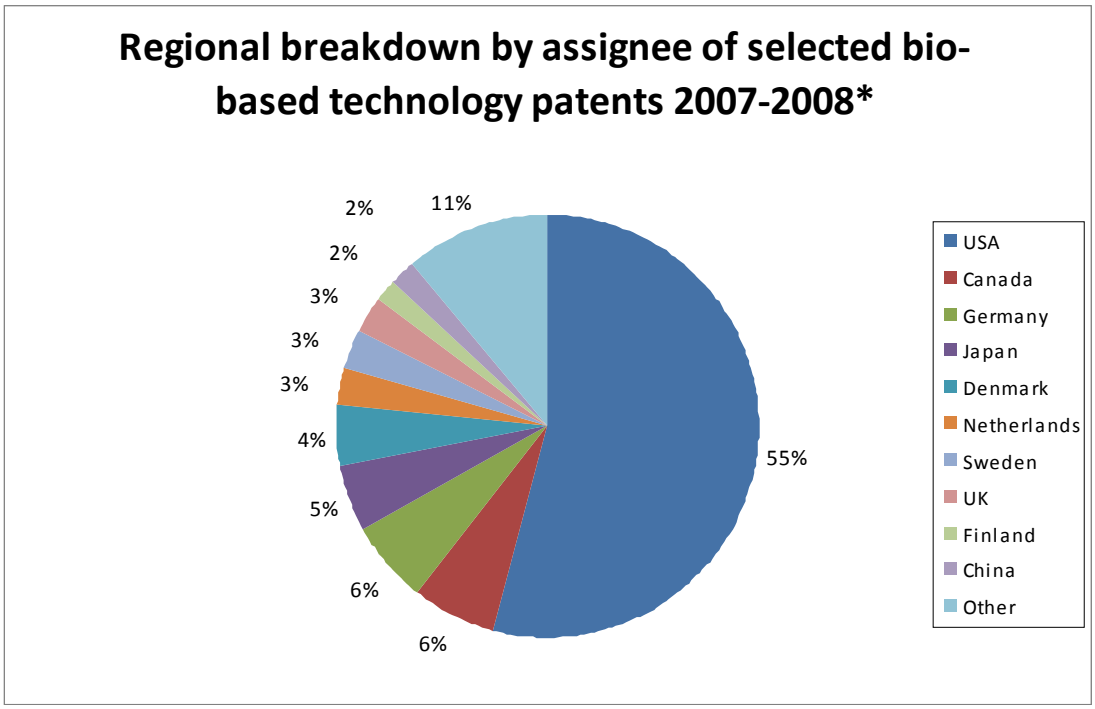
Comparison of UK Industrial Biotechnology Activities with the Rest of the World

Introduction

The industrial biotechnology sector in the UK is growing. The UK has strong expertise in academic science, both in academia and in industry. But other countries also have strong expertise, and often the will to exploit it. The majority of developed regions in the word has an interest in industrial biotechnology. Very often this is driven by energy and fuel security, environmental concerns, and economic benefits. The main focus in most countries is on the use of biomass as a feedstock for fuel and energy generation. The conversion of biomass into materials and chemicals is less supported and therefore less developed. However, significant activity can be seen in this area, too.

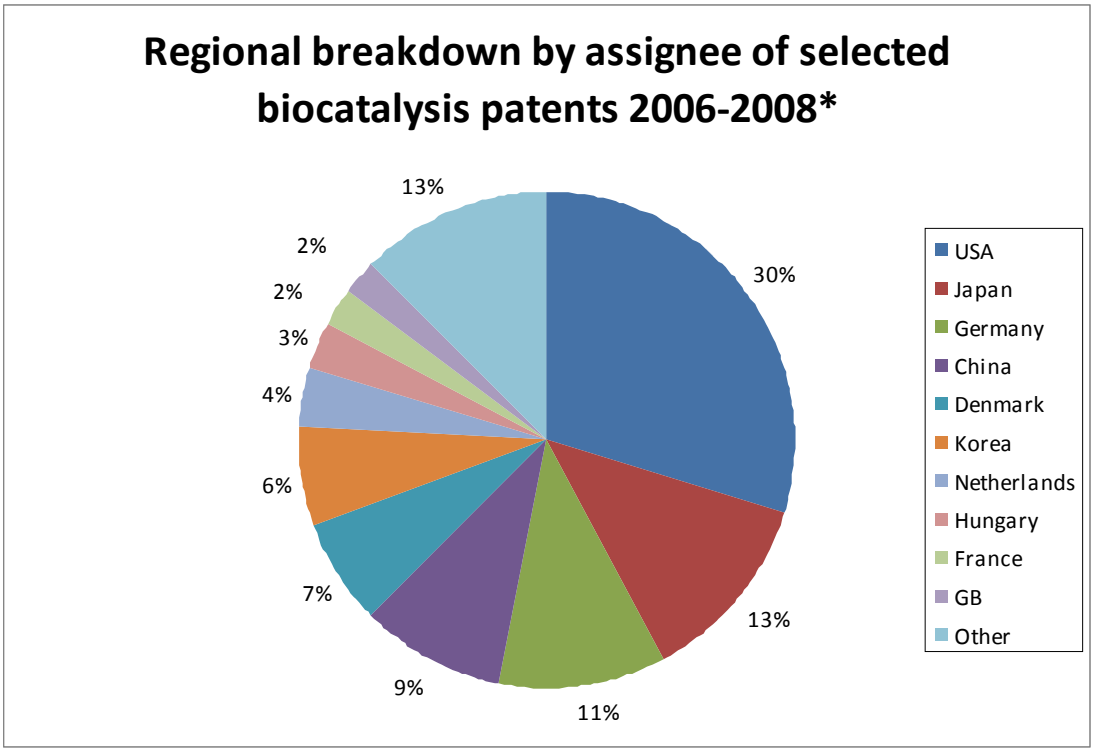
A regional breakdown of bio-based technology and biocatalysis patents and demonstration projects in biomass-based chemicals (Fig. 1 to 3) shows that the USA is clearly leading in industrial biotechnology. However, the European Union is not far behind. Especially France, German, Netherlands, and Belgium show strong activities and have several processes close to the market. The UK is behind these countries in both research and demonstration. Other countries (China, Japan, Brazil) also are active in industrial biotechnology, but still on a lover level. This might change, however, very quickly as several of these countries have significant expertise and relevant infrastructures to support bio-based processes.

In addition the agricultural sector and arable land availability of a country is very important. Countries like India have s strong advantage as they can grow their biomass feedstocks locally. Countries like Japan, with a less developed agricultural sector, will be less likely to implement manufacture of bio-mass based bulk materials, but they can look a high-value, low volume products based on bio-derived intermediates.



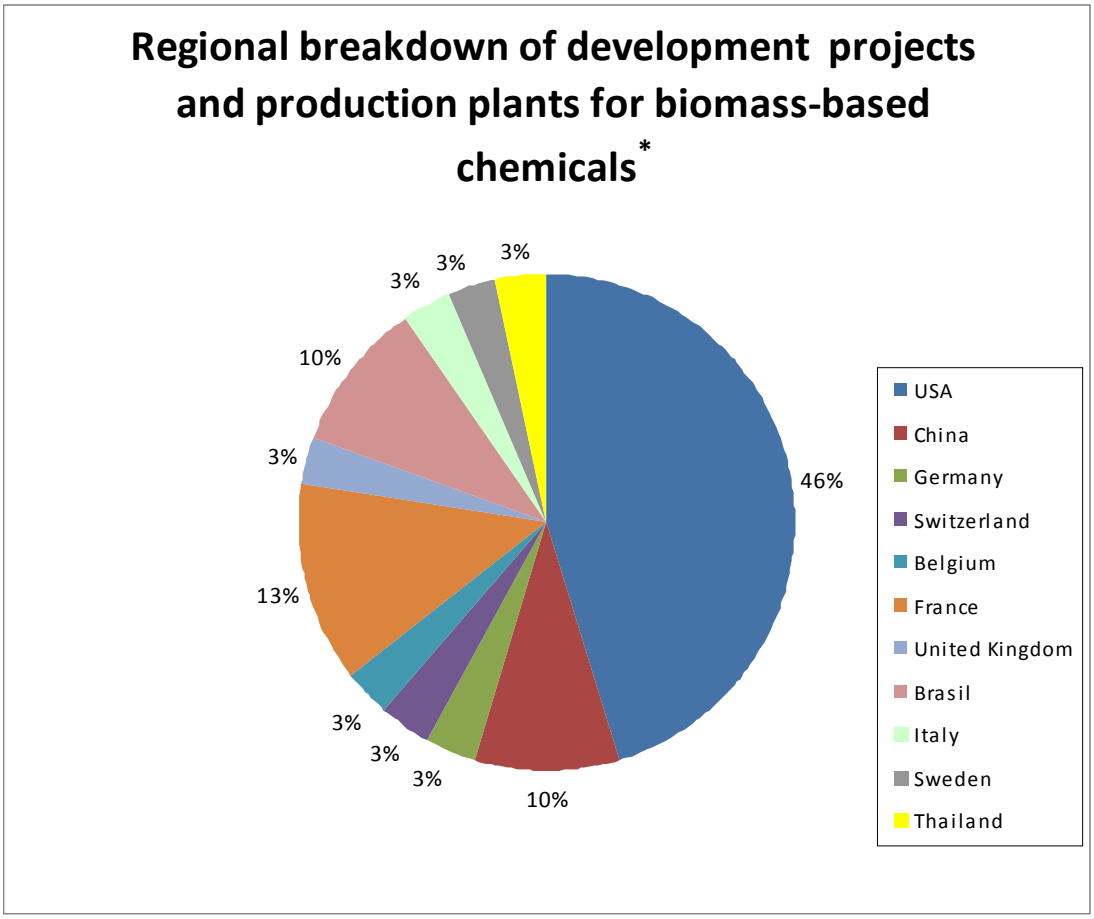
*Based on 243 relevant patents reviewed by Biofuels, Bioproducts & Biorefining (Biofpr) in the period from March 2007 to June 2008 (see 'Assessment of current activity in the production of platform chemicals from renewable sources and horizon scan to forecast potential future developments in science and technology activity in biocatalysis')

Fig. 1



*Based on 128 selected patents from 2700 patents identified in the area of biocatalysis for the years 2006 to 2008 (see 'Assessment of current activity in the production of platform chemicals from renewable sources and horizon scan to forecast potential future developments in science and technology activity in biocatalysis')

Fig. 2



*based on a total of 31 industrial investments in renewable platform chemicals and polymers reported since 2006 (see Appendix 2 – Industrial investments in renewable platform chemicals and polymers); regional breakdown based on either location of headquarter or of the plant

Fig. 3

Academic Expertise

The UK has a long history in underpinning research (microbiology, molecular and structural enzymology, biochemical engineering, plant sciences etc.). The country is well recognised as providing world-class research in biotechnology (although with a strong focus on healthcare). It is definitively in a league with the European countries and the USA in terms of excellence of the academic research base.

CoE Bio3, together with the National Industrial Biotechnology Facility, provides an excellent backbone for industrial focussed research and demonstration activities in biocatalyis. Other centres like the Innovative Manufacturing Research Centre for Bioprocessing and the Green Centre of Excellence are also well connected to industry. However, there are still a significant number of UK research groups which are not aware of industrial needs, and their excellent research is not targeted towards these needs. Countries like Germany (e.g. Frauenhofer Gesellschaft) have established far more research centres which are closely linked to industry. Very often industry provides a significant percentage of funding for these research centres.

The UK seems also to be behind other countries (for example the USA) in interdisciplinary research. Microbiologists, biochemists, chemists, chemical engineers have to work closer together to ensure that industrial biotechnology research delivers the most applicable results. This already should be addressed at the education stage, where chemist should learn the language of biochemists and vice versa.

Industrial Expertise

The UK does not have the chemical industry with a strong interest in industrial biotechnology that other countries have (for example Europe, USA). Thus development of an industrial biotechnology industry will be more difficult. There are exceptions like Croda and Syngenta which are strong supporters of bio-based processes. In addition there are a number of industrial biotechnology companies (Green Biologics, Ingenza, Aquapharm etc.) which develop promising technology platforms.

There is also a significant interest in non-UK companies to work with UK research groups to develop bio-processes. For example, BASF and DSM, two of the main industrial players on continental Europe, are industrial affiliates of CoE Bio3. Thus, processes and products developed in the UK, might be exploited in other countries.

To develop a significant UK industrial biotechnology sector, it will be important to retain manufacturing sites in the UK. However, competition from low-cost producing countries, like India and China, is decreasing due to implementation of more stringent environmental regulations and growing salary costs in these countries.

There is definitively a lack of contract demonstration and manufacturing facilities in the UK. The availability of such facilities would reduce companies' capital costs if they would wish to develop industrial biotechnology processes. This would provide UK companies (and also non-UK companies) with a good incentive to develop new processes in the UK.

Financial and Regulatory Incentives and Barriers

The UK government is very supportive of bio-based processes. Only countries like Germany, France, and in particular the USA have stronger governmental support.

One problem in the UK is that there are not sufficient dedicated R&D programmes, unlike in other countries (e.g. the German BioIndustrie 2021 programme, the US Biomass Research and Development Initiative). Although significant support is provided to bioenergy research, research into bio-based materials have less dedicated funding programmes in the UK. In addition, it is more difficult to obtain grants for interdisciplinary research, due to the UK's system of dedicated research councils.

Several organisations in the UK are active in knowledge and technology transfer in industrial biotechnology (Bioscience for Business, Chemistry Innovation, NNFCC).

However, there is a requirement of dedicated funds to reduce industry's risk in developing novel processes and products. At the moment no dedicated funding programmes for industrial research exist.

No policies are currently in place in the UK to support the bio-based materials and chemicals sector, but several strategies do exists or are currently developed (Strategy for non-food crops and uses, Innovation and Growth Team on Industrial Biotechnology). A lot of countries are also developing strategies for the implementation of industrial biotechnology, but only a few (USA, Germany) have actually implemented policies to support these strategies.

There are no specific guidelines on bio-based products in UK public procurement, but some examples of renewable products have been incorporated into public procurement contracts. The USA has a federal public procurement system (BioPreferred program[81]) that requires that bio-based products have to be selected when they are available.

Conclusion

The UK has the capability to become one of the world leaders in industrial biotechnology, however, there are still several weaknesses, which have to be addressed before the UK can become one of the main players in this sector.

Table 2 Qualitative comparison of the UK with 'competing' countries regarding factors influencing the industrial biotechnology sector

	UK	USA	Germany	France	Spain	Nether-lands	Japan	Brazil
Arable land	😐	☺	☺	☺	☺	☹	☹	☺
Research excellence	☺	☺	☺	☺	😐	☺	☺	😐
Technology transfer	☺	☺	☺	☺	😐	☺	☺	😐
Dedicated funding programmes	😐	☺	☺	😐	😐	☺	☺	😐
Demonstration facilities	😐	☺	☺	☺	☺	😐	😐	☺
Supporting industry	😐	☺	☺	☺	😐	☺	☺	☺
Governmental support	😐	☺	😐	☺	☹	😐	☺	😐

☹: limiting factor or non-existent; 😐: existing, but needs improvement; ☺: well established

UK Strengths:

- Strong history of research in underpinning areas: microbiology, molecular and structural enzymology, biochemical engineering,
- Strong expertise in biomass feedstock research; both in plant and marine sciences
- UK well placed in systems biology particularly as mathematics and biology links are being established
- Consolidation of activities by Bioscience for Business and Chemistry Innovation KTNs resulting in a core community comprising both academics and industrialists, with good relationships amongst its members
- Established Centre of Excellence for Biocatalysis, Biotransformation and Biomanufacturing, including close contact with industry and access to scale-up facility
- Centre for Process Innovation at Wilton providing consultation and scale-up facilities
- Genuine commercial interest evidenced by company financial commitment to industrial biotechnology research (e.g. IBTI)
- Close contacts with European and US groups through CoEBio3 and KTN infrastructure
- Governmental support of sustainable products and technologies

UK Weaknesses:

- Lack of dedicated funding programmes for industrial biotechnology research
- Grants for interdisciplinary research are difficult to obtain
- Lack of chemists with biotransformation experience and know-how
- Not enough spin-out activity and capitalisation on expertise/discoveries
- No dedicated funds to reduce industry's risk in developing novel bio-processes and products
- Scale-up and demonstration facilities are limited
- Chemical industry is less advanced in industrial biotechnology than their continental European counterparts
- Almost no capability in contract manufacturing in industrial biotechnology
- Lack of governmental incentives for the development of bio-based products
- Limited arable land will make the development of sustainable supply chains of biomass feedstocks more difficult

Appendix 1 – Biofuels and Biochemicals Demonstration and Pilot Plants in the EU[82]

Country	Type	Accessibility	Name
Finland	Demonstration	Restricted	Aromtech Oy
Germany	Demonstration	Partly restricted	Aufwind Schmack Betriebs-GmbH & Co; RES projects GmbH
The Netherlands	Demonstration	Restricted	Bio Methanol Chemie Nederland (Bio MCN)
Spain	Demonstration	Restricted	Biocarburantes Castilla y Leon (Abengoa Bioenergy)
Germany	Demonstration	Partly restricted	Biogas-Brennstoffzellen GmbH
France	Demonstration	Restricted	BioHub
Germany	Demonstration	Open to all	Bioprodukte Prof. Steinberg GmbH
Germany	Demonstration	Restricted	CHOREN Industries GmbH
Finland	Demonstration	Restricted	Danisco
Germany	Demonstration	Restricted	Demonstration Plant Carbo-V®
Finland	Demonstration	Restricted	Forchem Oy
Belgium	Demonstration	No information	Ghent Bio-Energy Valley
Germany	Demonstration	Restricted	Gras refinery
Germany	Demonstration	Restricted	Green Biorefinery Demonstration Plant (Planned)
Spain	Demonstration	Open to all	Instituto Technologico De Canarias, S.A.
Finland	Demonstration	Restricted	Kokemäen Lämpö Oy
Germany	Demonstration	Open to all	Kreiskrankenhaus Wolgast
Germany	Demonstration	Partly restricted	Landwirtschaftszentrum Eichhof, Landesbetrieb Landwirtschaft Hessen
Iceland	Demonstration	Restricted	Lignocellulosic Feedstock Biorefinery
Finland	Demonstration	Restricted	Metso Paper
Finland	Demonstration	Restricted	M-Real Oyj
Finland	Demonstration	Restricted	Neste Oil Oyj
Germany	Demonstration	Restricted	Nordhanf GmbH
The Netherlands	Demonstration	Restricted	NUON
France	Demonstration	Restricted	Osiris
Finland	Demonstration	Restricted	Preseco Oy
Germany	Demonstration	Partly restricted	PYTEC GmbH Thermochemische Anlagen
The Netherlands	Demonstration	Restricted	Royal Nedalco
France	Demonstration	Restricted	Safisis
Germany	Demonstration	Partly restricted	Schornbuscher Biogas GmbH & Co KG
Sweden	Demonstration	No information	SEKAB's Ethanol Research and Development Plant
Finland	Demonstration	Restricted	St1 Biofuels Oy
Germany	Demonstration	Restricted	Stadtwerke Düsseldorf AG, Holzvergaseranlage
Finland	Demonstration	Restricted	StoraEnso
United Kingdom	Demonstration	Restricted	UNDER DEVELOPMENT: Associated British Foods/BP/DuPont – Bioethanol plant
France	Demonstration	Partly restricted	UNDER DEVELOPMENT: Bio-Démo

Germany	Demonstration	Restricted	Vattenfall Europe AG, Biomasse- HKW Sellessen
Germany	Pilot	Partly restricted	Agrargenossenschaft Bergland Clausnitz e.G,
The Netherlands	Pilot	Restricted	Agrologistiek BV, WUR
France	Pilot	Partly restricted	ARD - Agro-industrie recherche et développements
Italy	Pilot	No information	AREA Science Park
Finland	Pilot	Open to all	Aromtech Oy and BioTrim/Agropolis Oy
Germany	Pilot	Open to all	ATB Potsdam-Bornim e.V
Germany	Pilot	Partly restricted	ATZ Entwicklungzentrum
Estonia	Pilot	Open to all	Bioconcersion research facilities in the Laboratory of biochemistry and environmental chemistry
Italy	Pilot	No information	Bioindustry Park Canavese SpA
The Netherlands	Pilot	Restricted	Biomass Technology Group
Spain	Pilot	Open to all	Bioplis, S.L.
Norway	Pilot	No information	Biosentrum
Italy	Pilot	No information	BioSphere SpA
Spain	Pilot	Open to all	BIOT
Switzerland	Pilot	Open to all	Biotechnet Switerland
Portugal	Pilot	Partly restricted	Biotrend
United Kingdom	Pilot	Restricted	British Sugar plc – Bioethanol plant
France	Pilot	Open to all	Centre de recherche et de transfert de technologies (CRITT) – Bio-industries
Spain	Pilot	Open to all	Centro de Biotecnologia Marina
Spain	Pilot	Open to all	CIEMAT
Italy	Pilot	No information	CRAB Consortium
Germany	Pilot	Partly restricted	CUTEC-Institut GmbH
France	Pilot	No information	CVG & Fermensys
Turkey	Pilot	Open to all	Ege University Department of Bioengineering Pilot Plant
Switzerland	Pilot	Open to all	EMPA Materials Science and Technology
The Netherlands	Pilot	Open to all	Energy research Centre of the Netherlands (ECN)
Spain	Pilot	Open to all	Fermentation pilot plant. Chemical Engineering Department Edifici Cn-Universitat Autònoma de Barcelona
Germany	Pilot	Partly restricted	Forschungszentrum
Germany	Pilot	Open to all	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V. (FhG), Pilot Plant Center (PAZ) for polymer synthesis and polymer processing
Germany	Pilot	Open to all	Fraunhofer Institute for Chemical Technology
Germany	Pilot	Open to all	Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Oberhausen, Branch Teterow
Germany	Pilot	Open to all	Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, Oberhausen, Branch Willich

Germany	Pilot	Partly restricted	Fraunhofer-Institute for Environmental, Safety and Energy Technology (UMSICHT)
Spain	Pilot	Open to all	GAIKER Technological Centre
The Netherlands	Pilot	Open to all	Groningen University (RUG)
The Netherlands	Pilot	No information	Harbour Delfzijl
The Netherlands	Pilot	No information	Harbour Rotterdam
The Netherlands	Pilot	No information	Harbour Terneuzen
Finland	Pilot	No information	Helsinki University of Technology
Portugal	Pilot	Open to all	IBET – Instituto de Biologia Experimental e Tecnológica
Denmark	Pilot	No information	IBUS pilot plant
Portugal	Pilot	Open to all	INETI – Instituto Nacional de Engenharia, Tecnologia e Inovação
France	Pilot	No information	Institut Français du Pétrole, Biotechnology and Biomass Chemistry Department
Switzerland	Pilot	Open to all	Institute of Biotechnology, ZHAW, Zurich University of Applied Sciences
Switzerland	Pilot	Open to all	Institute of Life Technologies, University of Applied Sciences of Western Switzerland
Spain	Pilot	Open to all	IUCT
Lithuania	Pilot	Partly restricted	JSC Biocentras
Finland	Pilot	Open to all	KCL
Austria	Pilot	Restricted	Lactosan Biotech
Finland	Pilot	Open to all	Lappeenranta University of Technology
Germany	Pilot	Open to all	Leibniz-Institute for Agricultural Engineering Potsdam-Bornim e.V., Dept. Bioengineering
Germany	Pilot	Open to all	Leibniz-Institute for Agricultural Engineering Potsdam-Bornim e.V., Dept. Bioengineering
Lithuania	Pilot	Open to all	Lithuanian Agricultural University
Lithuania	Pilot	Partly restricted	Malsena
Denmark	Pilot	No information	Maxi-Fuels, BioCentrum, Denmark Technical University
France	Pilot	Restricted	Metabolic-Explorer
United Kingdom	Pilot	Open to all	National Industrial Biotechnology Facility (NIBF)
Italy	Pilot	No information	Park Padano
Spain	Pilot	Restricted	PEVESA
Germany	Pilot	Restricted	Pilot-plant VERENA
The Netherlands	Pilot	Restricted	Prograss Consortium
Italy	Pilot	No information	R&D Center of ENEA
Portugal	Pilot	Partly restricted	RAIZ – Instituto de Investigação da Floresta e Papel
The Netherlands	Pilot	Restricted	Royal Nedalco
Germany	Pilot	Open to all	Sauerkraut- und Gemüseverarbeitungs-GmbH

Norway	Pilot	No information	SINTEF/NTNU
Sweden	Pilot	No information	Solander Science Park
Italy	Pilot	No information	Spin
Germany	Pilot	Open to all	Subitec GmbH
The Netherlands	Pilot	Open to all	Technical University Delft (TUD)
The Netherlands	Pilot	Open to all	Technical University Eindhoven (TUE)
Germany	Pilot	Open to all	Technische Universität Hamburg-Harburg
The Netherlands	Pilot	Open to all	TNO
Germany	Pilot	Restricted	Uhde Inventa-Fischer GmbH
Portugal	Pilot	No information	UNDER DEVELOPMENT: Algafuel
Portugal	Pilot	No information	UNDER DEVELOPMENT: Biotempo - Biotechnology Consulting, Ltd.
Spain	Pilot	Open to all	Universidad de AlcalÃ¡ - Planta Piloto de Quimica Fina
Finland	Pilot	Open to all	University of Oulu
The Netherlands	Pilot	Open to all	University Twente (TU)
Austria	Pilot	Partly restricted	VogelBusch, Single Column SMB Chromatography
Finland	Pilot	Open to all	VTT Technical research centre
The Netherlands	Pilot	Open to all	Wageningen University (WU)

Appendix 2 – Industrial investments in renewable platform chemicals and polymers

Company (Headquaters)	Project	Status		
		R&D	Demonstration (Scale)	Commercial (Capacity)
ADM (Decatur, Illinois, USA)	Development of bio-based plasticizers. JV with Polyone Corporation	☑		
	Mirel™ (PHAs) JV with Metabolix	☑	☐	Planned 2008 Clinton, Iowa (110 million pounds/year)
ARD (France)	Sugar based surfactants JV with Oleon	☑		
	Succinic Acid JV with DNP	☑	Planned 2009 Pomacle-Bazancourt, Reims, France (2,000 tons/year)	
Arkema (Colombes, France)	Vegatable Oil based polyamide Rilsan® 11	☑		
Ashland (Covington, Kentucky, USA)	Propylene Glycol JV with Cargill	☑		
Braskem (Brazil)	Polyethylene	☑	Planned 2009 Brazil (commercial scale)	Planned Brazil (200,000 tonnes/year)
Cargill (Minnetonka, Minnesota, USA)	3-hydroxypropionic acid JV with Codexis	☑		
	Bio-based polyols BiOH™			Planned 2008 Chicago, USA
	PLA (Natureworks) JV with Teijin	☑	☐	Operational Blair, Nabraska, USA (140,000 tons/year)
Cereplast (Hawthorne, California, USA)	Starch Bioplastics			Planned 2008 Seymour, Indiana, USA (500 million pound/year)
Ceres (Thousand Oaks, California, USA)	Methyl methacrylate JV with Rohm & Haas	☑		
Dow (Michigan, USA)	Propylene Glycol		Opperational Houston	Planned Houston
Dow (Michigan, USA)	Epichlorohydrin			Planned 2010 Caojing, China (150,000 tonnes/year)
Dow (Michigan, USA)	Liquid Epoxy Resins			Planned 2010 Caojing, China (100,000 tonnes/year)

Dow (Michigan, USA)	Polyethylene			Planned 2011 Santa Vitória, Brazil (350,000 tonnes/year)
DSM (Netherlands)	Succinic Acid JV with Roquette	☑	Planned 2009 Lestrem, France (100's tonnes/year)	
DuPont (Wilmington, Delaware, USA)	1,3-Propanediol JV with Tate & Lyle			Operational Loudon, Tennessee, USA (45,000 tonnes/year)
DuPont (Wilmington, Delaware, USA	Biomax® Thermal 300 (Plastic additive)			□
Elevance (Bolingbrook, Illinois, USA)	Specialty chemicals from vegetable oils Cargill & Materia company	☑		
Galactic (Brussels, Belgium)	PLA JV with Total Petrochemcals	☑	Planned 2009 Tournai, Belguim (1,500 tonnes/year)	
Genencor (Rochester, New York, USA)	Bio-isoprene JV with Goodyear	☑		
German Bioplastics	PLA (Pyramid Bioplastics) JV with Pyramid Techhnologies	☑		Planned 2009 Guben, Germany (60,000 tons/year)
Huntsman (Texas, USA)	Propylene glycol	☑	Planned 2008 Conroe, Texas, USA	
Innovia Films (Cumbria,UK)	Cellulose films			Operational Cumbria, UK (15,000 tonnes/year)
Novamont	Starch Bioplastic Mater-Bi®			Operational Terni, Italy (60,000 tonnes/year)
Perstop (Sweden)	Production of propionic acid and 3-hydroxypropionic acid	☑		
Purac (Netherlands)	Lactic acid/PLA PLA Technology with Sulzer Chemtech	☑	Planned 2008 Winterthur, Switzerland	
Solvay (Brussels, Belgium)	Ethylene (PVC)	☑		Planned 2010 Santo Andre, Brazil (60,000 tons/year)
Solvay (Brussels, Belgium)	Epichlorohydrin	☑	Operatonal Tavaux, France (10,000 tonnes/year)	Planned 2009 Map Ta Phut, Thailand (100,000 tons/year)
Tianjin Green Bio-Science (China)	PHAs (DSM investment)			Planned 2009 Tianjin, China (10,000 tonnes/year)

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