IB 2025

Maximising UK Opportunities from Industrial Biotechnology in a Low Carbon Economy

A report to government by the Industrial Biotechnology Innovation and Growth Team

May 2009
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secretary of State’s Foreword</td>
<td>2</td>
</tr>
<tr>
<td>Chairman’s Introduction</td>
<td>4</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>6</td>
</tr>
<tr>
<td>Section 1: Vision of UK Industrial Biotechnology</td>
<td>8</td>
</tr>
<tr>
<td>Section 2: Evidence Base</td>
<td>16</td>
</tr>
<tr>
<td>Section 3: Where to from Here?</td>
<td>30</td>
</tr>
<tr>
<td>Section 4: Barriers to Success</td>
<td>40</td>
</tr>
<tr>
<td>Section 5: Recommendations – Closing the Gaps</td>
<td>48</td>
</tr>
<tr>
<td>Annex A: Acknowledgements</td>
<td>64</td>
</tr>
<tr>
<td>Annex B: International Snapshot</td>
<td>68</td>
</tr>
</tbody>
</table>

All figures quoted in this report are in 2008 real terms unless otherwise stated.
Secretary of State’s Foreword

The full scale of the impact IB could have on our day-to-day lives in the future is still being uncovered. But what is clear now is that this field has the potential to equip our society to live more sustainably and our economy to compete more effectively in the decades ahead.

IB will be one of the strongest driving forces behind the world’s low-carbon revolution. Offering businesses the capability to develop and use less carbon intensive products and processes, whilst also reducing costs and opening-up new, emerging and established markets.

This is an area in which the UK, with its strong science base, can lead. It presents powerful opportunities across our economy, but in particular for the UK’s chemical industry.

The global chemical sector generates over £1.25 trillion in sales every year. In the past decade, it has grown in value by more than 60%.

Now the world’s seventh largest chemicals producer, UK sales alone in this industry exceed £60 billion, with exports worth £43 billion. This is one of our most high-value manufacturing sectors, employing thousands of people and has a trade surplus of around £6.5 billion.

In the years to come, the UK’s success will increasingly be defined by our competitive edge in this and other knowledge-intensive industries. That is why this report is so important and I welcome its findings.

As the report recognises our people have some of the best ideas in the world. But we need to do more to ensure that UK knowledge and talent is translated into producing the successful, commercial products and solutions of the future.

Sustaining this comparative advantage calls for co-ordinated action at every level of Government – to remove barriers to our global competitiveness, wherever they exist, and ensure a business environment where UK companies and workers can better capitalise on our world-class research and expertise.

The recommendations in this report set out a clear plan from industry on how we can work together to achieve that in the field of IB, reaping the benefits for sectors throughout our economy.
I would like to express my thanks to all those who contributed to this report. The Industrial Biotechnology Innovation and Growth Team draws its expertise from senior representatives and leading thinkers in industry and academia. I am grateful for the time, resources and input they have given this report and I look forward to continue to work with them, as we seek together to deliver on its recommendations.

IB offers us the opportunity for sustainable growth and progress in the future and we must take this chance to ensure the UK is at the forefront of its development.

Lord Mandelson
I have been involved in IB for 25 years as my career has developed with a number of European and American multinationals. I now run my own fast growing small to medium sized enterprise and am ever more involved.

I have seen the various ebbs and flows of this technology sector with market investment windows opening and closing over the last three decades. However never have I been more certain that the growing maturity of this technology, combined with its all pervasive breadth, and ever increasing depth will ensure that it makes a major contribution to the opportunities and challenges facing the world as we strive for global sustainability.

The UK has a long, rich and very strong heritage both in terms of its fundamental research base, ranked second after the USA, but also in ground breaking innovation. Many British and particularly foreign owned multinationals have a substantial R&D and business development presence in the UK and there are a wealth of diverse biotechnology start ups.

The big question is whether or not the full potential of the intellectual asset base is recognised, realised and exploited.

I was therefore delighted to be invited by BERR to chair this Innovation Growth and Team for Industrial Biotechnology. I felt then and still feel that the UK must seize the opportunity and fully leverage its great strength in its research and innovation heritage and become the best global location from which to pursue IB business.

It has been particularly encouraging that so many very senior executives, scientists and financiers from leading bioscience and chemistry using companies joined the steering group and working groups to energetically and thoughtfully drive this project with vast accumulated experience and judgement. I extend my heartfelt thanks to all the contributors. This project benefited enormously from the rich cross section of companies (global to local), academics, professional institutions, industry associations and Government departments that were involved.

The global financial turmoil has escalated during this project and has provided a sharp focus on the need to have a balanced and sustainable economy. The UK Government has seized this theme and under the leadership of Lord Mandelson is focusing on industrial activism to ensure that where there is international comparative advantage there is support and growth. During the recent times we have seen a greater government focus on innovation, high-value manufacturing and the low carbon
economy. IB resonates strongly in all four of these highlighted areas and will have a substantial positive impact on the balance of payments for decades to come as well as providing options for resolution of important societal challenges.

The IB-IGT’s vision is to make the UK “Easy to do business in” with “two front doors” providing guidance and support for:

- Research and development, and
- Industrial demonstration and scale up.

Enormous value can be added to the global chemistry-using supply chains by building on the capability and strengths already in place in the UK. Success will require effective cooperation between the well established bioscience/biotechnology sector and the downstream chemistry using industries in addition to strong collaborative working between biological and chemical scientists and chemical engineers. I am confident that all involved in IB and its exploitation are eager to work together to deliver major progress and success against the challenges and opportunities identified.

This independent report to Government identifies a number of issues that if addressed will make a real difference and put in place the mechanisms to ensure that the UK truly seizes this global opportunity.

Ian Shott, Chair of the IB-IGT
Executive Summary

“A transition towards renewable bio-based feedstocks is vital for the production of chemicals, materials, fuels and energy to lessen dependence on fossil energy and achieve climate change goals. For companies like British Sugar these market changes will lead to further opportunities, bringing together scientific skills, process engineering and marketing.”

Mark Carr, Chief Executive, British Sugar Group

Industrial biotechnology (IB) – the use of biological substances, systems and processes to produce materials, chemicals and energy – will play an essential part in the creation of a low-carbon knowledge-based economy in the UK.

IB can play an important role in maintaining UK competitiveness in global markets, where bio-based systems and processes are rapidly gaining strength and scale.

This means that a ‘business as usual’ approach is no longer an option if the UK is to maintain its global competitiveness. It is therefore vital that the UK become more proactive in its take-up of IB.

A new industrial activism is required from government – the application of ‘market pragmatism’ such that policy direction complements markets in order to achieve a better long term outcome for our economy and society.

To position itself for the ‘new’ low-carbon bio-based future, the UK needs to play to its sources of comparative advantage. The UK has an enormously strong science and technology base, and natural resources that are of particular importance in the domain of biotechnology.

The UK is one of the world’s leaders in terms of quality of research in this area. Knowledge and experience of applied biotechnology are growing and advancing rapidly in this country. Medical biotechnology has already made major inroads in the pharmaceutical sector, to the benefit of companies and patients alike.

IB offers the prospect of similar and even greater benefits. It is rapidly gaining ground in the energy sector, spurred on by consumer choices and government policies and

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1 E.g. plants, algae, marine life, fungi, micro-organisms

A report to government by the Industrial Biotechnology Innovation and Growth Team
quotas relating to bioenergy, for example. Other chemistry-using industries are starting to recognise and harness the environmental and economic benefits of IB.

As the chemicals and chemistry-using sectors are among the sectors least exposed to the recent economic downturn, these sectors should be able to take advantage of the benefits of IB as quickly as possible, to underpin the UK’s international competitiveness.

The return on any investment of money and effort in IB – the ‘size of the prize’ – will depend on several factors, including (but not restricted to) the prices and availability of petrochemical feedstocks. However, robust estimates of the global IB market by 2025 range from £150 billion to £360 billion; similar estimates for the UK IB market range from £4 billion to £12 billion. A connected and favourable research and policy environment and increased levels of technology development are critical to UK being able to attain these market opportunities.

Currently, IB is being impeded from delivering this prize in the UK – primarily because of low awareness of the potential of the technology, a lack of the necessary facilities to demonstrate its commercial feasibility, and insufficient connectivity between the key players. These are inhibiting the UK’s establishment of an IB foundation for the low-carbon, knowledge-based economy so urgently needed – using bio-based resources to make products and provide services that are not only less damaging to the planet and its people, but are also able to offer new additional features and benefits.

The Industrial Biotechnology Innovation and Growth Team (IB-IGT), a collaboration of scientists, engineers and other decision-makers from business, academia and government, has identified the most significant barriers to the progress of IB in the UK.

This report presents the IB-IGT’s summary of the evidence base for urgent action to remove the barriers, including both a snapshot of the UK’s present strengths and a scenario-based analysis on future market opportunities for IB.

Recommendations for action in five specific areas are presented, which will:

- Improve the connectivity of UK IB activities in order to grasp the necessary opportunities
- De-risk access to new products and technologies
- Accelerate the innovation and knowledge transfer process
- Retain and develop the necessary interdisciplinary talent in science and management
- Create a ‘public’ and ‘business’ environment that is supportive of IB

Greater detail on the issues raised and analysis carried out for the report is provided online at http://www.berr.gov.uk/files/file51144.pdf

Executive Summary
Section 1: Vision of UK Industrial Biotechnology

“Our vision of IB for 2025 sees its power and benefits being fully evidenced across the UK chemistry-using industries, driven by coherent manufacturing, skills, environment and technology policies, judicious investment, and a sense of urgency, to deliver innovation, jobs and prosperity.”

Ian Shott – Chairman of the IB-IGT

COLLECTIVE VISION

A powerful consensus has emerged from the work of the Industrial Biotechnology Innovation and Growth Team (IB-IGT):

“The UK needs IB. It is key to creating a low-carbon economy. It is vital in maintaining UK competitiveness in global markets, where IB is rapidly gaining strength and scale. And it provides a sustainable, commercially viable route out of over-dependence on fossil fuels and on financial services for economic growth.

“The UK has enormous advantage in terms of the knowledge base and collaborative mechanisms required to deliver the benefits of IB – environmental, social and financial. But that advantage risks being eroded by the pace of IB uptake in other countries, and insufficient coordination in this one.

“Our vision of IB for 2025 sees its power and benefits being fully evidenced across the UK chemistry-using industries, driven by coherent manufacturing, skills, environment and technology policies, judicious investment, and a sense of urgency, to deliver innovation, jobs and prosperity.”

INDUSTRY-LED COLLABORATION

This is the combined view of a diverse industry-led group involving scientists, engineers and other decision-makers from business, academia and government.

The IB-IGT’s work over the last year has focused on putting the UK in the strongest possible position to gain maximum benefits from the new strategic market in renewable chemicals, and low-carbon manufacturing.
What is IB?

The definition accepted by BERR and EuropaBio is the use of biological resources for producing and processing materials, chemicals and energy. Such resources include plants, algae, marine life, fungi and micro-organisms.

IB uses biotechnological knowledge – about genomes and complex cell functions – to develop new processes for making products such as industrial enzymes or chemical building blocks. These are used, in turn, in the production of chemicals, detergents, textiles, paper, and much more. This kind of work requires an understanding of enzymes, proteins and DNA at a molecular level. It involves the ability to work with cells, tissues and whole organisms; the use of process engineering and fermentation; and the use of advanced techniques such as bioinformatics and genomics.

Biotechnology applied to energy and fuels is already the subject of significant investment, development activity and government support. The work of the IB-IGT broadens the picture to other chemistry-using sectors where IB holds the promise of a major dividend.

IB is not an industry sector in its own right. Rather, it is a key underpinning technology with applications across the highly diverse chemistry-using industries – effectively, every manufacturing sector.

Figure 1 The UK chemistry-using industries
Figure 2. Value added market structure in biotechnology

THE ‘SIZE OF THE PRIZE’

The size of the market for IB – the ‘size of the prize’ – will depend on several factors. These include (but are not restricted to) the prices and availability of petrochemical feedstocks, and how quickly the world emerges from recession.

Furthermore, economic analysis (see section 3) has shown that the pace of technology development is one of the most important factors that determine the rate of market growth.

Analysis carried out for this report has produced estimates of the global IB market by 2025. These range from £150 billion to £360 billion. In the same analysis, estimates for the UK IB market range from £4 billion to £12 billion.

Comparing different kinds of chemical (high-value low-volume vs. low-value high-volume), it was found that an IB-favourable research environment and technology development in high-value low-volume chemicals has a high likelihood of creating substantial market opportunities in the future. (Low-value high-volume chemicals, in contrast, are more strongly reliant on the future price of oil, making this an area of greater uncertainty in terms of investment in IB.)
The United States International Trade Commission\textsuperscript{2} using data submitted in response to US International Trade Commission questionnaire, for 2007, this revealed a total of $30 billion in bio-based chemical sales, roughly 80\% of which can be attributed to pharmaceutical companies. The sales figures include:

- Chemicals derived from biocatalysis and fermentation, \texttilde{} 75\% of total
- Chemicals produced using renewable resources, \texttilde{} 15\% of total
- Enzymes and microorganisms, \texttilde{} 10\% of total.

Figure 3 below shows the predicted market penetration of bio-based chemicals in world chemical production.

Figure 3. Projected market penetration of bio-based chemicals in world chemical production

Pharmaceuticals are excluded. Sources OECD, USDA

\textsuperscript{2} USITC publication 4020, “Industrial Biotechnology: Development and Adoption by the US Chemicals and Biofuel Industries”, July 2007
WHAT PERSUASIVE IB ACTIVITY WILL MEAN FOR THE UK

Widespread use of IB will contribute to the Government’s wider innovation, manufacturing and climate change strategies.

- **Manufacturing: New Challenges, New Opportunities**³ pointed out how the UK’s manufacturing is not in decline, as some commentators would claim, but changing – to embrace and pioneer technologies such as biotechnology, as well as nanotechnology and information and communication technologies.

- The 2006 UK Climate Change Programme⁴ committed the Government to supporting the expansion of technologies that will help meet the ambitious emissions reduction targets set by the Government in order to demonstrate leadership on this global challenge.

- This commitment gained further substance with the publication of *Low Carbon Industrial Strategy: A Vision*⁵ in March 2009. This reinforces the Government goal of making the UK the best place in the world to locate and grow a low-carbon business – which, it points out, depends on seizing the opportunities that come with change in “a new green industrial revolution”.

- **New Industry: New Jobs**⁶ highlighted that in the industrial biotechnology sector the shift from a chemical industry based on oil to one based on renewable and biological substances will redefine chemical manufacture in the 21st century.

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³ *Manufacturing: New Challenges, New Opportunities*, BERR and Department for Innovation, Universities and Skills, September 2008, p 7

⁴ *Climate Change – the UK Programme 2006*, Department for the Environment, Food and Rural Affairs, March 2006


⁶ *New Industry: New Jobs*, BERR, April 2009, p 31
“Recent developments in technology fields such as information and communication, genetics and biotechnology, advanced materials and nanotechnology have helped create new opportunities for business and manufacturing.” *Manufacturing: New Challenges, New Opportunities*

“We need a new industrial activism that brings together different strands of government policy to ensure low carbon companies based here have access to the infrastructure, skilled workers, R&D and investment opportunities they need. We need to make sure that we drive the green industrial revolution from the regions as well as nationally, building on distinct regional and local advantages across the UK, and market British strengths in a competitive global marketplace.” *Low Carbon Industrial Strategy: A Vision*

“The global economic order will continue to be reshaped ... forcing us to consider our comparative advantages, and our emerging strategic markets. Our specialisations must be built on knowledge and value-added. They will be in business and financial services... But they will also be in the knowledge and creative industries and the technological and manufacturing process revolutions that will define the current century, for example in the biosciences.” Lord Mandelson, *RSA Lecture – A New Industrial Activism, December 2008*

As *Innovation Nation* noted, two of the biggest challenges facing our society are global warming and sustainable development. Connected features in the global outlook include the diminishing supply of global resources of ‘low cost’ oil and gas, the geopolitics of fossil fuels, and increasing concern about CO₂ and other greenhouse gases in the atmosphere, all driving a reduction in dependence on fossil fuels. Meanwhile, supply/demand tensions exist in markets for today’s strategic metals and minerals. And waste from existing industrial processes is subject to increasing scrutiny and criticism.

Clearly, there is an urgent need to develop renewable alternatives to fossil feedstocks for power, transport fuel, chemicals and materials. The chemical industry faces the challenge of replacing or reducing its dependence on petrochemical-dependent processes and feedstocks. The world’s chemistry-using industries are looking for more ways to reduce their energy consumption and increase the sustainability of their products and operations.

IB offers the UK a key route to addressing these challenges.
Case study: IB underpinning multiple sectors

*Ingenza* provides biotechnology services in the areas of microbial strain construction, discovery and improvement of biocatalysts, and development of industrial biomanufacturing processes.

This technology is used to prepare proteins and small molecules for applications in pharmaceuticals, agrochemicals and other fine chemical areas.

*Ingenza* also develops engineered microbes for use in the area of biofuels.

The company is founded on a proprietary platform of enabling technologies: in fermentation, molecular biology, genetic engineering of microbes, biocatalyst production, biocatalyst formulation and scalable chemo-enzymatic process development.

*Ingenza* works with a diverse range of partners and end users including fine chemical manufacturers, pharmaceutical companies and biopharma (therapeutic protein) companies.

Research commissioned for this study⁷ has concluded that IB products, processes and technology offer important potential for primary energy and greenhouse gas savings. These findings are supported by sector examples recently published by the European Association for BioIndustries⁸. IB can help the Government meet its existing commitments: internationally, greenhouse gas emission reductions of at least 80% by 2050; and, at home, reductions in CO₂ emissions of at least 26% by 2020, against a 1990 baseline as outlined by the UK Climate Change Act 2008.⁹

IB can contribute to the UK's future ability to live within environmental limits and achieve a sustainable economy. *New Challenges, New Opportunities* noted how recent developments in biotechnology and other areas have already helped create new opportunities for business and manufacturing.

Support for the advance of IB in the UK will enhance the public and business environment's capacity and support for innovation. With the right information and guidance, people – whether in business life or as consumers – will gain better ability to understand, assess and deploy new and more sustainable ways of production and consumption.

Sustainable wealth creation will result from the UK’s ability to compete internationally through products and services based on renewable sources of materials and low-carbon processes.

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⁷ *Study into the Potential Energy and Greenhouse Gas Savings of Renewable Chemicals and Biocatalysts*, commissioned by BERR, 2008


IB’s socio-economic impact will not be restricted to job creation and upskilling in manufacturing and service businesses. The input requirements for IB – e.g. biological materials, crop residue, bio-based processes – will also, when it achieves scale, contribute to renewal and regeneration in rural (and possibly coastal – see page 18 below re algae) communities.

IB will enhance UK competitiveness because of its knowledge-intense requirements. These play to the strengths of the UK’s education system, R&D capabilities, scientific knowledge base, engineering expertise and business acumen.

The multidisciplinary nature of IB calls for new management skills, and more collaborative ways of working than have traditionally prevailed in scientific and engineering sectors. Enabling IB to achieve its growth potential over the coming decade will foster in the UK a growing high-quality scientific and managerial base, providing added leverage for leadership in international markets.
“The UK is fortunate in having a track record in IB – both academic and industrial – and can point to resulting commercial products and processes. This has created a knowledgeable constituency of talented researchers operating across many disciplines and industry sectors.”

John Sime, Director, Bioscience for Business Knowledge Transfer Network

ECONOMIC GROWTH THROUGH IB

The 2007 paper *En Route to the Knowledge-Based Bio-Economy*\(^\text{10}\) sees biotechnology as a key pillar of Europe’s economy by 2030. The report’s perspective includes biomaterials and bioprocesses, bioenergy, biomedicine and emerging technologies. It suggests that, by 2030, one-third of chemicals and materials will be produced from biological sources, including biopolymers and bioplastics.

The global market for bio-based products is estimated to grow to US$250 billion by 2020. This growth rate is driven by the scale of needs and opportunities that IB addresses.

Instigated by the European Commission’s Competitiveness Council, a Lead Market Task Force on bio-based products has published a *Vision for Sustainable Growth*.\(^\text{11}\) This report highlights the potential of existing and emerging bio-based products and puts forward policy recommendations to help realise that potential.

To fully appreciate the economic significance of IB for the UK, the scale and scope of the chemical and chemistry-using companies that *could* be utilising IB in their operations need to be recognised.

The UK chemical industry is a major player in a global sector that underpins nearly every aspect of daily life. Chemical sales worldwide exceed £1.25 trillion, more than 60% higher than a decade ago. In part this reflects the near three-fold increase in chemical sales in Asia, driven by economic growth there. Currently, Europe remains the world’s largest chemical producer with a market approaching £400 billion.

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\(^\text{10}\) [www.europabio.be/articles/cologne_paper.pdf](http://www.europabio.be/articles/cologne_paper.pdf)

On the world stage, the UK is the seventh largest producer of chemicals. Sales exceed £60 billion, generating around £18.5 billion of value added which represents some 12.5% of all UK manufacturing. Exports total £43 billion. The chemical sector is one of very few in UK manufacturing with a trade surplus, some £6.5 billion, with a particular focus on high-value chemicals.

In addition to its economic contribution, the chemical industry provides essential inputs to a wide range of other sectors. (See Figure 4 for EU data.)

To estimate the dependence of the overall UK economy on inputs from the chemical sector, the IB-IGT undertook an analysis using national input/output tables. The results of this analysis show that the UK’s chemistry-using sectors have an aggregate output of some £1150 billion, and generate a value added of over £550 billion.

**Figure 4. EU chemicals consumption by user sector**

Sources: Cefic and Eurostat (input-output) analysis
* EU 15
** End users: Final consumption = final consumption in households + government consumption + non profit organisations

12 Including services (e.g. education, recreation and advertising) as well as manufacturing.
Market opportunities for bio-based products have been identified in many sectors. These include: fibre-based materials (e.g. in construction or the auto industry); bioplastics and other biopolymers; surfactants, biosolvents, biolubricants (used in, for example, cosmetics, household and industrial detergents, paints, adhesives, inks, and papermaking); ethanol and other chemicals and chemical building blocks; biodiesel; pharmaceutical products including vaccines; enzymes (with industrial, healthcare and consumer applications); and cosmetics.

Particular interest has focused recently on the potential uses of fungi in a diverse range of important applications. These include food production, production of economically viable chemical feedstocks, waste treatment, and genome sequencing.

Algae form the centre of another area of special interest. Both micro-algae (small aquatic plants, requiring a microscope to view them) and macro-algae (large aquatic plants) have potential as a fast-growing source of marine crops to be harvested for chemicals and fuels. Issues around producing them economically and effectively are being investigated in a number of centres in the UK.

DNA sequencing technologies have recently undergone a revolution. This has lowered the barrier in terms of cost and time to obtain genomic and other valuable data from any organism. Significant advances have also taken place in genetic manipulation, marker-assisted selection and more efficient analytical methods for screening and extracting biochemicals. As a result, it is now feasible to identify, evaluate and rapidly domesticate new species for the supply of sustainable feedstocks.

It is likely that in many cases only genetic manipulation of plants and other organisms will be able to deliver the full benefits of IB to downstream chemistry-using sectors. The most significant will be those systems that can deliver high-value products in high concentrations, and high yielding plants that need less inputs (and hence have lower environmental impact). Genetic manipulation is therefore an important tool in the armoury of techniques available to the plant breeder and developer, particularly for innovations linked to industrial product development.
Case study: Optimising plant oils for skin care applications

Plant oils offer a rich diversity of high-value fatty acids as sustainable feedstocks for the speciality chemical industry. To maximise the potential of plant oils as renewable feedstocks, cutting edge R&D will need to engage closely with end user needs.

MetAnOil, a project funded by the Technology Strategy Board, has succeeded in achieving this goal.

In the project, the Centre for Novel Agricultural Products (CNAP) at the University of York has teamed up with Boots Company plc. Patented CNAP technology has allowed the molecular composition of a range of plant oils to be determined to a greater level of complexity than ever before. A pipeline of new products has emerged from the resulting ability to map oil composition to product performance.

In a parallel track within the project, the knowledge gained from the analytical work has been used in molecular breeding of hemp, leading to new lines with novel oil compositions. Once fully trialled and registered, these new varieties of hemp will add significantly to the range of novel oils that can be produced in the UK for skin care and other, industrial, applications.

The three year MetAnOil programme (2005-2008) has demonstrated the feasibility of integrating feedstock development with end user requirements, using cutting edge analytical chemistry and post-genomic technologies.

Anaerobic digestion (the use of micro-organisms to break down biodegradable materials in the absence of oxygen) is becoming well established for converting waste to useful products, initially fuel. Efficient conversion of appropriate wastes to energy is an important societal requirement: it reduces the need for landfill, has a positive impact on sustainable consumption and production, and reduces the emissions of climate changing gases (including the potent greenhouse gases methane and nitrous oxide). The Department for Environment, Food and Rural Affairs has identified considerable support for the goal of anaerobic digestion’s making a significant contribution to the UK’s climate change and wider environmental objectives by 2020 13.

IB also helps in the more effective capture of carbon dioxide from combustion units in power plants for carbon capture and sequestration (CCS) purposes. 14 Given the urgency to stabilise the concentrations of carbon dioxide and other greenhouse gases in the earth’s atmosphere, all viable routes to this end need to be pursued as rapidly as possible, and plant-based carbon capture schemes provide just such a route.

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13 Anaerobic Digestion – Shared Goals, Department for Environment, Food and Rural Affairs, February 2009
14 For example, see http://www.algaeatwork.com/technology/
UK RELEVANCE

In the UK, IB is a key enabler for Government aspirations of sustainable growth and UK competitiveness. It reflects the responsible use of sound science. It provides solutions for living within environmental limits, and for achieving a sustainable economy. Combining all these characteristics, IB contributes to ensuring a strong and healthy society.

Government has already given public recognition of IB’s importance, in the following contexts.

The UK Biomass Strategy of 2007 explicitly recognised the need to make optimum use of plants and other biological resources, and to link bioscience with commercial developments, in order to move to a low-carbon economy.15 It particularly cited the importance of biorefineries – efficient mechanisms for converting, for example, crop waste into biofuels and feedstock for industrial processes.

The Integrated Biorefineries Technology Initiative (IBTI) has been set up by the Bioscience for Business Knowledge Transfer Network (KTN), with the Biotechnology and Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC). It is conducting research and demonstration projects to establish the economic potential of biorefineries for sustainable industrial production.

Case study: Bio-based revolution in the UK

The biodegradable fraction of municipal and industrial waste is an abundant and cheap source of renewable waste carbon. However, its composition can be highly variable, making it expensive and difficult to efficiently use; so traditionally it has been sent to landfill.

Global firm INEOS has now developed a break-through technology that can unlock unused waste biomass potential to provide feedstocks for making renewable polymers, chemicals and fuels – while, at the same time, generating renewable power.

Bioethanol produced using the INEOS process delivers 100% greenhouse gas savings compared with petrol as a transport fuel. Further advances in INEOS’s technology offer the prospect of a revolution in parts of the polymer materials industry, delivering long-term sustainability of materials for everyday life in the UK and worldwide.

15 UK biomass strategy, Department for Environment, Food and Rural Affairs, 2007, p 35
In light of the high-level skills (both technical and managerial) needed for IB, the BBSRC and the EPSRC have expressed their commitment to working together to support the development of these skills. Examples of collaboration include centres of Doctoral training, and Masters training in higher education institutions. The Research Councils are also funding ten IB-relevant projects – mainly health and therapy centred – jointly with the Technology Strategy Board.

The Technology Strategy Board is currently developing a strategy for biosciences-inspired technologies, which prioritises those related to IB for investment. The technologies highlighted in the document are: discovery tools to identify novel properties from organisms, biocatalysts for more efficient chemical conversions and biorefineries as multi-product production plants.

The UK chemical industry and learned institutions are working together to promote sustainable chemistry. SusChem United Kingdom, formed by the Chemistry Innovation Knowledge Transfer Network, the Bioscience for Business Knowledge Transfer Network, the Chemical Industries Association, the Institution of Chemical Engineers, the Royal Society of Chemistry and the Society of Chemical Industry, is expressly focused on aligning existing sustainability activities and sponsoring projects that will cause a step change in sustainable chemistry in UK companies.

Meanwhile, FROPTOP (From Renewable Platform Chemicals to Value Added Products) is working to close the gap between renewable biomass-derived platform chemicals and existing chemical and biochemical processes. This joint Special Interest Group of the Chemistry Innovation Knowledge Transfer Network, Bioscience for Business Knowledge Transfer Network, the Royal Society of Chemistry and the Institution of Chemical Engineers is working with industry, academia, government and other networks to develop the market for renewable chemicals in the UK.

The Carbon Trust, set up as an independent company by the Government in 2001, has announced a multi-million pound investment in micro-algae biofuel technologies. The Algae Biofuels Challenge is a two-phase programme designed to stimulate proposals for development and commercialisation of micro-algae-based technologies that will reduce carbon dioxide emissions. The total programme cost is expected to be in the region of £20-30 million, with up to £10-16 million of Carbon Trust funding.

**UK IB CAPABILITIES**

As Lord Sainsbury’s 2007 review of UK Government science and innovation policies noted\(^\text{17}\), the UK is internationally renowned for its research capabilities. This is as true in biotechnology as it is in other disciplines, putting the UK in an excellent position to maximise the opportunities that arise as a result.

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\(^{16}\) For further explanation of indirect land use change see *The Gallagher Review of the indirect effects of biofuels production*, Renewable Fuels Agency, 2008

http://www.dft.gov.uk/ha/reportsandpublications/reviewoftheindirecteffectsofbiofuels.cfm

\(^{17}\) *Race to the Top 2007*
In terms of citations of papers on biological sciences, the UK has a 12.7% share of the world figure. This compares with the US share of around 50% of world citations, which has remained constant for the last 7 years, while the UK has risen from about 11% in 1996. The UK currently leads Germany, Japan, France, Canada, Italy, China and Russia; however, the gap with Germany has been closing.

The Bioscience for Business Knowledge Transfer Network has highlighted UK strength in areas such as applied biocatalysis, pure enzymology, pathway engineering or ‘combinatorial biosynthesis’, and biochemical engineering.

Examples include the work of the UK Biocatalysis Centre of Excellence (CoEBio3) in Manchester, supported by One NorthEast, NWDA and Yorkshire Forward.

**Case study: Vital role for Centres of Excellence**

*Shell* has been working with a Canadian company called Iogen since 2002, to develop a commercially viable process to convert wheat straw to bio-ethanol for transportation fuels. These so-called ‘second generation’ biofuels have the potential to be produced in a more environmentally and socially sustainable way, avoiding some of the issues caused by indirect land use change.

By working with biotechnology companies, and with universities and institutes such as CoEBio3, Shell is able to accelerate progress in developing the next generation of sustainable biofuels, and also enhance its reputation as an innovative company, with added benefits in terms of recruiting and retaining engineers and scientists. The world’s first commercial demonstration plant opened in Ottawa in 2004, demonstrating that the CO₂ profile at the plant is significantly less than that of fossil fuel derived gasoline.

**STRENGTH IN ACADEMIA**

Given the nature of IB – the industrial deployment of biological processes using plants, microbes and marine organisms – its exploitation requires that specialist knowledge in all three fields is combined in multidisciplinary research to develop new ideas for industry. The UK is well placed to achieve this and has a significant heritage and background in these fields.

The examples listed in the following subsections show that IB is already the subject of a wide range of R&D activities at numerous academic institutions, providing the foundations for commercial exploitation of that work.

**Work on biocatalysis, fermentation and enzymology**

CoEBio3’s research facilities, based in the Manchester Interdisciplinary Biocentre, bring together specialist groups with expertise in enzymology, molecular biology, microbiology, synthetic organic and analytical chemistry, protein biochemistry and
crystallography, bioreactors and robotics. Their focus is on delivering cutting edge research in biocatalysis and metabolic engineering, to enhance UK competitiveness in R&D and manufacturing.

The Wellcome-funded multidisciplinary Biocatalysis Centre at the University of Exeter studies the structure, mechanism and commercial application of enzymes.

The Bioconversion-Chemistry-Engineering Interface (BiCE) initiative at UCL brings together a multidisciplinary group of researchers interested in development of the next generation of complex pharmaceuticals. Biochemical engineering is also very strong in the UK, as demonstrated by, for example, the work at UCL and Imperial College.

Durham University’s Centre for Bioactive Chemistry facilitates interdisciplinary research programmes in biological chemistry and bioengineering.

At the University of Bath, the Centre for Extremophile Research provides a platform from which the biotechnological potential of extremophilic organisms (organisms adapted to living in extreme conditions of temperature, pressure, acidic or salt concentration, etc.) and their products can be commercially exploited.

In pure enzymology, UK universities employ several world leaders: at York, St Andrews, Oxford, and Manchester. Cambridge is among leaders in engineering microbes to produce variants of established drugs such as erythromycin.

Work on trees, plants and crops

Biotechnology related to trees, plants and crops is covered or the primary focus in several UK centres.

The John Innes Centre, Norwich, is an internationally recognised centre of excellence in fundamental research for applications in agriculture, biotechnology and pharmaceuticals. Rothamsted Research, Hertfordshire, is the oldest agriculture research institute in the world.

IBERS (the Institute of Biological, Environment and Rural Sciences) at Aberystwyth University conducts basic, applied and strategic research related to grassland and the wider environment, and promotes agricultural systems that are efficient, sustainable and able to deliver quality products. The Scottish Crops Research Institute is a long-standing centre of excellence improving crop utilisation by combining molecular genetics techniques with conventional plant breed, novel agronomy practices and plant protection.

Horticultural Research International is the world’s largest horticultural institute, known for its work on crop improvement and biotechnology, environmental microbiology and sustainable horticulture. Gaining an international reputation is the Centre for Novel Agricultural Crops, based at York University.

The BioComposites Centre, Bangor, conducts world-leading research into products and processes based on wood, industrial crops, recycled materials and industrial residues.
The National Institute for Agricultural Biotechnology carries out plant science research, developing material, research and technical services for worldwide use.

Table 1. UK university departments involved in research on renewable chemical feedstocks

<table>
<thead>
<tr>
<th>Chemical polymerisation</th>
<th>Modification of biopolymers</th>
<th>Chemical transformations of renewable molecules</th>
<th>Biocatalysis</th>
<th>Fermentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>School of Chemistry, University of Edinburgh</td>
<td>Bicomposites Centre, Bangor University</td>
<td>School of Chemistry and Chemical Engineering, Queen’s University Belfast</td>
<td>School of Applied Sciences, Cranfield University</td>
<td>School of Science &amp; Technology, University of Teesside</td>
</tr>
<tr>
<td>Department of Chemistry, Imperial College London</td>
<td>Warwick Manufacturing Group, University of Warwick</td>
<td>Department of Chemistry, University of Nottingham</td>
<td>Biomedical Research Centre, Sheffield Hallam University</td>
<td>The Satake Centre for Grain Process Engineering, University of Manchester</td>
</tr>
<tr>
<td>Centre for Sustainable Chemical Technologies, University of Bath</td>
<td>Green Chemistry Centre of Excellence, University of York</td>
<td>Institute for Cell and Molecular Biosciences, University of Newcastle upon Tyne</td>
<td>Centre of Excellence for Biocatalysis, Biotransformations and Biocatalytic Manufacture</td>
<td></td>
</tr>
<tr>
<td>Department of Chemistry, University of Warwick</td>
<td>School of Chemistry, Cardiff University</td>
<td>Centre for Extremophile Research, University of Bath</td>
<td>Genomics Research Centre, University of Warwick</td>
<td></td>
</tr>
<tr>
<td>Centre for Sustainable Chemical Technologies, University of Bath</td>
<td>Centre for Extremophile Research, University of Bath</td>
<td>Biocatalysis Centre, University of Exeter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Department of Biochemistry, University of Leicester</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: IB-IGT

Marine and algae

UK centres with an interest in or primary focus on marine and algal biotechnology are mainly in Scotland and the South West.

The Scottish Association for Marine Sciences provides expertise in isolating novel natural products from marine bacteria. It has developed commercially exploitable bio emulsions and bio surfactants for use in healthcare, food, bioremediation, waste management and textiles.

The European Centre for Marine Biotechnology stimulates the development of biotech companies by conducting commercial research, acting as an incubator for start-ups,
and providing a unique collection of algae and protozoa cultures for research by businesses and academics.

Strong and commercial marine biotech R&D programmes are under way at the Marine Biological Association of the UK, Plymouth Marine Laboratory, and the University of Plymouth’s Algal Research Group.

The Institute of Aquaculture at Stirling University is the largest of its kind in the world, dealing in every aspect of aquaculture from fish health and nutrition to genomics and genetics.

The University of Aberdeen has several departments and associated institutes interacting to create an important platform in marine biotechnology developments.

The Centre for Sustainable Aquaculture Research and Aquaculture Wales – based at Swansea University – focuses on the use of advanced engineering for environmentally sustainable aquaculture and mariculture.

Other notable centres of excellence include the University of Southampton for deepsea technologies, and Newcastle University for biofilm and applied marine biotechnology.

Case study: Value creation through marine-based IB

Aquapharm, founded in 2001, is a marine biotechnology company pioneering the discovery, isolation and subsequent development of novel biochemicals isolated from marine microbes.

Its proprietary screening Technology SeaRch™ is generating a large diversity of new chemical compounds.

It achieves an excellent ‘hit rate’ for potential new anti-infection treatments, and delivers further high-value products for use in other commercial sectors such as cosmeceuticals (e.g. anti-inflammatories) and nutraceuticals (e.g. anti-oxidants).

Aquapharm sees IB adding value to the company because commercial partners increasingly recognise the ability of IB to produce novel technologies and products. The company gains competitive advantage through the natural production of molecules, and access to a new and exceedingly diverse range of chemicals.

Becoming a leader in marine IB also helps Aquapharm to recruit and retain staff, gain access to venture capital and grant finance, and attract customers and licence deals.

Utilisation of IB in the UK

For the purposes of this report, companies involved in IB in the UK have been divided into two classes: IB ‘Core’ companies whose main business is creating and supplying IB products and services; and IB ‘Utilising’ companies, which buy in IB products/processes and adapt them for the purposes of their main business, e.g. chemical production, food/beverages, energy, healthcare etc.
IB ‘Core’ companies in the UK

These are defined as companies that have development and provision of IB products and/or services as a major activity.

As of December 2008, 42 had been identified in the UK. Of these, 37 are SMEs (mostly at the small/micro end of the size range). Yet their potential for impact on the UK economy is very large, given the size of the chemistry-using industries they could serve and supply20. (See pages 16–17 above.)

In total, IB ‘Core’ companies in the UK employ an estimated 1,500-2,000 people. For the 25 companies for which figures are available, the combined annual turnover is £108 million.

Most of the UK’s IB ‘Core’ companies are mature: only 15% of them were established since 2005.

The most frequent application of IB for these companies is pharmaceutical. The most commonly developed IB technologies by these companies are biocatalysis, biotechnology-based diagnostics/analytics and bio-based molecules for industry.

Figure 5. Industrial applications for IB ‘Core’ companies

20 Office of National Statistics, 2004
Case study: Price-competitive bio-butanol for fuels and chemicals

Oxfordshire-based Green Biologics Ltd (GBL) pioneers advanced fermentation technology for the conversion of agricultural by-products, wastes and cellulosic feedstocks into renewable fuels and chemicals.

GBL focuses on the production of n-butanol. The technology is based on advanced microbes together with novel butanol fermentation and separation processes.

Butanol is an important bulk chemical intermediate for polymers and plastics. Bio-butanol offers an attractive solution for chemical companies seeking to improve their ‘green’ credentials. Bio-butanol is also a superior renewable fuel additive for liquid transportation fuels and fits the existing fuel infrastructure. It has the potential to be produced in an environmentally and socially sustainable way, avoiding some of the issues caused by indirect land use change.

The butanol fermentation process was first commercialised in the UK in 1916. However, it was largely abandoned in the 1950s because it was cheaper to derive butanol from mineral oil. Today, due to higher oil prices and GBL’s improved technology, bio-butanol competes with oil-derived butanol on price.

IB ‘Utilising’ companies in the UK

IB is well established in the UK pharmaceutical industry already because of its contribution to high-value, high-speed drug development. Almost all penicillins are produced by the biotechnology of fermentation.

A survey conducted by the Chemistry Innovation Knowledge Transfer Network for this IGT identified the current and potential take-up of IB in a broad spectrum of other chemistry-using industries.

Take-up was found to be high in the water treatment, agrochemicals and renewable energy sectors. In terms of potential users, the UK food industry is uncovering new product opportunities and environmental benefits from uses of IB.
Figure 6. Current IB take-up in UK companies as a function of segment*

![Graph showing IB take-up by segment with bubbles proportional to number of responses.]

*The size of the bubble is proportional to the number of segment responses

Source: IB-IGT

Figure 7. Current and potential IB take-up in UK companies as a function of segment

![Graph showing current and potential IB take-up by segment with color-coded bubbles.]

Source: IB-IGT
**Case study: World-beating products**

Codexis’ approach to chemical manufacturing based on IB has applications in pharmaceuticals, biofuels and other global markets. For example, some of the enzymes developed by the company have enabled significant improvements in the manufacturing process involved in the production of cholesterol-lowering Lipitor, the world’s best selling prescription drug; in one case, the performance of the biocatalytic reaction was improved 4,000 times. As the Codexis process runs at room temperature, significant savings were also achieved in relation to expensive and energy intensive cryogenic equipment.

The company’s processes reduce the waste generated by conventional chemistry-based processes, and generate biodegradable waste. They yield products with very high purity, eliminating the need for a costly and wasteful purification step in the process.

Codexis finds its ‘green’ profile is a key market differentiator for potential business partners, under scrutiny in today’s more environmentally sensitive climate. This profile also helps in recruitment and retention of first-class employees looking for opportunities to make a difference in the company and in the world.

**THE REST OF THE WORLD**

Competitor countries such as Austria, the Netherlands and Germany have committed long-term significant resource and effort to bring on IB (see Section 4). Without similar coordinated effort the UK risks falling behind.

**Figure 8. Regional breakdown by assignee of selected bio-based technology patents 2007–2008**

*Based on 243 relevant patents reviewed between March 2007 and June 2008
Source: IB-IGT*
Section 3: Where to from Here?

“To raise new questions, new possibilities, to regard old problems from a new angle, requires creative imagination and marks real advance in science.”

Albert Einstein 1879-1955

TRENDS AND DRIVERS

Economic analysis commissioned for this report highlighted that UK IB chemical sales are projected to grow between 5% and 11% per annum especially in the areas of high-value low-volume speciality and fine chemicals. In addition, the UK is in a strong position in this knowledge-intensive area that would allow UK-based companies to increase their share of the much larger global market. Global IB sales are estimated to grow to £150–360 billion by 2025 in the chemical sector alone.

Potential drivers for investment in IB by producers of materials, chemicals and energy fall into two basic categories.

The first set of drivers is centred on growth in future demand for bio-based products. This stems partly from the diminishing availability and increased cost of fossil resources compared with renewable bio-based resources; and partly from the potential IB offers to discover new molecules and new effects, unachievable with conventional chemistry. Policy development will also be a strong factor, especially in relation to climate change mitigation, sustainable production and consumption, the Lisbon Agenda, industrial policy and employment growth. Changing consumer demand will play a part, based on awareness of the need to ensure sustainable production and consumption.

The second set of drivers derives from the potential of bio-based products, in the longer term, to deliver outcomes that are sustainable economically, environmentally and socially. They can substitute at lower cost for fossil-based products. Bio-based products can be part of fostering a low-carbon economy, through creating greenhouse gas neutral eco-cycles. Such products can also impose a smaller eco-footprint, coming from manufacturing processes that have lower energy and water use and lower waste generation.

21 Source ‘IB-IGT Horizon Scan’, December 2008
22 See reference 11 above
23 The EU’s action and development plan to to make the EU “the most dynamic and competitive knowledge-based economy in the world capable of sustainable economic growth with more and better jobs and greater social cohesion, and respect for the environment by 2010”. Set out by the European Council in Lisbon in March 2000.
24 See, for example, references 3 and 7 above

A report to government by the Industrial Biotechnology Innovation and Growth Team
Benefits for investors could include better economic return through reduced feedstock costs, environmental benefits through lower carbon emissions, and an improved opinion of the chemical and chemistry-using industries in the public perception.

Trends and influences on several fronts – societal, technological, economic, environmental and policy – could impact whether the potential benefits of IB will be realised.

Meanwhile, society – here in the UK, and increasingly elsewhere – is maintaining and raising its requirement for socially acceptable products. Levels of acceptance of genetically modified products and processes – one of biotechnology’s underpinning technologies – vary significantly from one country to another, affecting both commercial and government decisions. Society also has strong views on land use change, and the potential for competition between crops for food and crops for other uses. Public perception – strongly shaped by the media – will influence how fast and how far IB advances.

Technology factors relevant to such advance include the cost and scale of biocatalyst availability, the development of and access to supporting technologies, the yields achieved in plant/product conversion, and the availability of the skills specific to IB.

The analysis carried out for this report and summarised below highlighted that, for most chemical groups, limitations on the market come from technology development.
Technology breakthrough rates are a key driver in the model, therefore any changes to these rates have a direct bearing on the results.

Several economic factors can affect whether IB will progress and spread sufficiently quickly to contribute properly to the UK’s prosperity and sustainability goals. These include how quickly the availability of fossil feedstocks declines, the relative prices of fossil and bio feedstocks, energy prices, the costs of biocatalysts, the real and expected market demand for sustainable products, and the impact of IB on the logistics/supply chain.

Environmental factors favour IB. Having the option of sustainable competitive feedstocks, in eco-efficient manufacturing, with reduced waste and reduced contribution to global warming would be attractive in virtually any industry sector.

On the political front, the success of IB in delivering desired goals is related to future decisions on environmental policy, chemical regulation and ‘green’ incentives.

**ECONOMIC SCENARIOS**

IB offers attractive opportunities for growth, both nationally in terms of manufacturing, and internationally in terms of leveraging knowledge and expertise developed in the UK.

However, parts of the sector depend crucially on the availability of land to grow biomass, and on technology breakthroughs to ensure feedstock and production costs that are comparable to current petrochemical alternatives.

To properly appreciate what will determine success for IB in chemicals, a scenario-based analysis was commissioned by this IGT. The analysis distinguished six different IB chemical categories, and assessed quantitatively their development under four viable future scenarios.

This section presents the results of a study commissioned from Arthur D. Little that analysed the types of chemical studied, the scenarios that were developed, and the main findings of the analysis. More detail is then given of the model used in the analysis; a full report of the scenario study is available at [http://www.berr.gov.uk/files51252.pdf](http://www.berr.gov.uk/files51252.pdf)

The different categories of chemical are summarised in Table 2.
Table 2. Categories of chemical in the scenario analysis

<table>
<thead>
<tr>
<th>Production method</th>
<th>Dedicated single-compound production</th>
<th>Biofuel-derived</th>
<th>In planta production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Chemicals produced using (modified) enzymes (biocatalysis) and (modified) whole cells (fermentation)</td>
<td>Chemically useful products, produced as a by product of biofuel production</td>
<td>Chemicals produced through (modified) crops or algae, and extracted after harvesting</td>
</tr>
<tr>
<td>Feedstock</td>
<td>Various, high-value, glucose, sucrose</td>
<td>Low-cost sugars, vegetable oils</td>
<td>Arable crops</td>
</tr>
<tr>
<td>Low-volume high-value speciality and fine chemicals</td>
<td>(Category A1) Penicillins, amino acids, 50chloropropionic acid (Avecia UK), PHA, stereospecific alcohols</td>
<td>(Category B1) Protein-based plastics</td>
<td>(Category C1) PHA (commodity form)</td>
</tr>
<tr>
<td>High-volume low-value commodity and platform chemicals</td>
<td>(Category A2) Acrylamide (from acrylonitrile), citric acid, LA/PLA, glycerol/1,3-propanediol, isoprene (Genencor)</td>
<td>(Category B2) Ethanol, Butanol, 1,3-propanediol (from glycerol)</td>
<td>(Category C2) Rubber, MMA, acrylamide from cyanophycin</td>
</tr>
</tbody>
</table>

Source: Arthur D. Little

The scenarios are summarised in Table 3.

Table 3. Scenarios developed in the IB economic analysis

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stuck</td>
<td>The focus for growth is in fine and speciality chemicals; the absence of biofuel technology breakthroughs means the world cycles between high and low prices for oil and food crops. Biofuels production is seen to compete with other land uses.</td>
</tr>
<tr>
<td>Knock On Wood</td>
<td>There is an initial boom in cellulosic ethanol technology due to technology breakthroughs and high oil prices. The long-term growth levels off due to competition with food and reduced availability of alternative low-cost feedstocks from the UK or internationally. The secondary biochemical industry remains focused on smaller-scale biocatalysis and fermentation opportunities. These continue to grow based on successful technology development.</td>
</tr>
<tr>
<td>Green Bloom</td>
<td>The ability to exploit feedstocks which do not compete with arable crops results in the development of a thriving biochemical industry akin to the petrochemical boom of the early 1900s. At the same time IB is increasingly important for speciality and fine chemicals due to ongoing technology development.</td>
</tr>
<tr>
<td>Electrified</td>
<td>Despite IB technology breakthroughs, a sustained drop in demand for crude oil (due to alternative and renewable energy sources) makes IB only competitive for low-volume/high-value chemicals.</td>
</tr>
</tbody>
</table>

Source: Arthur D. Little
Overall findings

Depending on the scenario, UK IB chemical sales are projected to grow between 5% and 11% per annum, up to at least £4 billion and at most £12 billion in 2025. This would be equivalent to between 7% and 16% of total chemical industry sales. While UK IB manufacturing opportunities may remain comparatively modest for the foreseeable future, a strong position in this knowledge-intensive area would allow UK-based companies to increase their share of the much larger global market. Global IB sales are currently estimated at £35-53 billion (3-4% of global chemical industry sales); under different scenarios, these will grow to £150-360 billion by 2025.

High-value low-volume chemicals

Direct production processes such as fermentation and biocatalysis, mainly applied in the manufacturing of high-value and low-volume chemicals, have been developing successfully in the past few decades. Building on this existing knowledge base to extend the technology know-how to other high-value, low-volume chemicals is therefore much more likely to succeed.

For the UK, a growth of the sales of high-value low-volume chemicals from dedicated single-compound production (known as ‘direct production’) or in planta production has been shown to occur in all four scenarios.

It is therefore not unreasonable to assume that there will be a clear opportunity for companies to operate in the UK and to focus on low-volume highly selective catalyst design and manufacturing to satisfy a growing and diverse market need for biocatalysts.

The above implies that a favourable research environment and technology development in this area will create substantial market opportunities in the future.

Direct production has proven itself in the past few decades and can further increase its ‘market share’ through support for incremental technology development.

Meanwhile, the potential for sales of in planta derived chemicals is surprisingly high; while it relies on technology development and public acceptance of genetically modified crops, the UK industry could take a strong position in this area based on its capabilities in nature-derived chemicals and chemical formulation, and a strong customer base for such products.

Biofuel-derived chemicals

Until 2025, sales of chemicals derived from biofuel production appear to be comparatively modest, even under favourable scenarios. Sales of such chemicals are expected to develop independently of government intervention if and when a viable biofuel industry forms.
The market is most attractive when production of biofuels and their feedstocks is competitive with, or preferably more cost-effective than, crude oil derived fuels and when competition between biofuel and food or feed crops is avoided.

A chemical industry that relies on biofuel production for raw materials is structurally different from the current petrochemical industry. While the latter is based on the scale and efficiency of the oil refining industry, the former could be significantly smaller and more distributed in order to cost-efficiently source biomass from surrounding lands (unless significant feedstock imports are involved). The same observation is true for in planta chemical production.

High-volume Low-value chemicals
For low-value chemicals derived through in planta and direct production, sales have been shown in the present analysis to be strongly reliant on the future price of oil: (although fatty acids and other chemicals directly extracted from crude vegetable oils (e.g. rape seed oils) are excluded from this assessment).

The UK in the global market place
Compared to the global market for IB, actual production in the UK of IB chemicals for the local market is likely to be constrained. However, an interesting opportunity for the UK is to be one of the top three IB knowledge centres of the world. Further development of these markets can be enhanced by making sure the UK is a prime location to establish IB-related business and institutes.

The global employment and gross value added (GVA) associated with IB will be much higher than the UK figures. While this study did not look at this in detail, there are undoubtedly opportunities for the UK to exploit IB knowledge through export of technology and know-how developed in the UK.

Quantifying the IB opportunity
To quantify the opportunity for IB in the time horizon of this IGT (2025), estimates were calculated for global and UK market values, UK production volume, and CO₂ savings in each of the four scenarios. The results are summarised in Table 4.
Table 4. Summary of scenario results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Stuck</th>
<th>Knock On Wood (oil price $150/barrel)</th>
<th>Green Bloom (oil price $150/barrel)</th>
<th>Electrified (oil price $50/barrel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global IB market value (billion £)</td>
<td>150</td>
<td>346</td>
<td>360</td>
<td>220</td>
</tr>
<tr>
<td>UK IB market value (billion £)</td>
<td>4.4</td>
<td>11.4</td>
<td>11.8</td>
<td>6.2</td>
</tr>
<tr>
<td>UK IB production (million tonnes)</td>
<td>0.8</td>
<td>1.9</td>
<td>2.2</td>
<td>0.5</td>
</tr>
<tr>
<td>CO₂ savings (million tonnes CO₂ per annum)</td>
<td>2.0</td>
<td>4.7</td>
<td>5.2</td>
<td>1.4</td>
</tr>
<tr>
<td>CO₂ savings (million tonnes CO₂ per annum)</td>
<td>2.0</td>
<td>4.3</td>
<td>4.7</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Source: Arthur D. Little; Note 1: This does not include the wider biofuel market which could range from less than £1 billion to over £7 billion for the UK; Note 2: the global market for biofuels could be $50 – $250 billion. Note 3: If calculated based on the production volumes for the UK the model is using in this study, CO₂ savings from bioethanol production would be between 1.3 and 10.0 million tonnes of CO₂ and savings from biodiesel production would be between 3.0 and 9.7 million tonnes.

Way forward

The scenario-based analysis shows that there are significant opportunities for the UK if action is taken to improve the UK’s attractiveness for IB-related companies and institutes to develop and commercialise new ideas, products and processes.

For most of the chemical categories considered, the main limiting factor is technology development – and, for high-volume chemicals, the price of oil. Financial incentives will have limited effect in many markets. However, governments can facilitate by improving the business climate.

Of particular importance is action to stimulate the development of a knowledge industry on which in planta and direct production can thrive. Such stimulation would include enhancing technology development rates and de-risk projects to allow a rapid exploitation of new products produced by genetic modification, fermentation and biocatalysis. Key concerns about genetic modification technology – e.g. avoiding unwanted diffusion of genetic material in the environment, and assuring the long-term stability of modified crops – would need to be addressed.

Specific interventions are not needed to encourage high-volume low-value chemical using direct or in planta methods, beyond those already mentioned. These kinds of chemical production will occur provided industry is able to produce chemicals cost efficiently and oil prices are sufficiently high.
Stimulating the development of a UK biofuel industry relates to decisions about whether the UK wants to decrease its dependence on foreign sources of oil and/or be less vulnerable in periods of high oil prices. Support for biofuel developments could be provided by stimulating breakthrough technologies that do not compete with food production and that address issues of geographical location – e.g. technologies based on offshore algae, which are not tied to the UK’s location and would draw on offshore capabilities already in place.

Scenario modelling

The modelling carried out to generate the scenario results aimed to illustrate how the IB market in the UK may develop over the period to 2025. It began with identifying clearly distinguishable, singular movements in the wider environment with a high direct and/or indirect impact on the UK. These were split into:

- **Drivers** – developments that have high impacts on a company, with high uncertainty about the outcomes; they include oil/naphtha prices, biofeedstock prices and technology breakthroughs
- **Trends** – developments with medium to high impact, but rather high certainty of direction; they include incentives, market demand for chemicals, development of high-volume biomass conversion, changes in arable land, economic prosperity, and consumer interest in product attributes

The four scenarios were primarily based on high/low differentials between feedstock prices and high/low levels of technology breakthrough. Their development was supported by information on other trends.

The nature of scenario work in general does not lead to identifying which scenarios are more or less likely to occur. Rather, scenarios provide an insight into those actions or positions that could enable future market opportunities and growth to be realised in each alternative future. Further, this work could help to identify and prioritise where resources and efforts should focus to realise such opportunities.

Differences between the four scenarios

The highest market value is achieved in the Green Bloom scenario, with a UK market of £11.2 billion and 2 million tonnes of chemicals produced. Beyond 2025, it is expected that this market will continue to grow at a similar rate (5–10% per annum); further growth would be associated with chemical production requiring minimal use of land.

The differences between the Green Bloom and Knock On Wood scenarios are due to two factors: the absence of breakthroughs in algal technologies, and limitations on land use for lignocellulosic feedstocks linked to competition with food and feed in the Knock On Wood scenario.

In comparison, under the Electrified scenario approximately 70% less chemicals are produced than in Green Bloom, primarily owing to low oil prices. While the rate of market growth could be higher between 2015 and 2020, it will level off after 2025.
owing to low differentials between biofeedstock and naphtha prices. Growth will also be constrained post 2025.

The Stuck scenario has the lowest market value at £4 billion. A lack of technology breakthroughs forces the biofuels industry to remain dependent on arable crops where there is strong competition with food and feed. Volatile oil prices further prevent long-term investments, restraining the growth of IB.

Figure 9 compares UK market values for 2025 between the scenarios, showing the split between the six chemical categories.

Figure 9. UK market values for 2025 split by scenario and chemical category

Source: Arthur D. Little

An overall conclusion is that market opportunities for biofuel-derived chemicals are limited in all scenarios, as producing biofuels in the UK remains comparatively expensive. However, there are niche markets for all biofuel-derived chemicals in three of the four scenarios. Where technology breakthroughs occur through the use of lignocellulosic materials, bioethanol-derived chemicals (speciality, fine, commodity and platform chemicals) are more attractive compared with biodiesel-derived products (commodity and platform chemicals). Biodiesel-derived chemicals become more competitive when algal feedstocks can be exploited (as in the Green Bloom scenario).

High-value low-value chemicals produced in planta (speciality and fine chemicals) and chemicals produced through dedicated production (speciality, fine, commodity and platform chemicals) represent the largest market values in all scenarios. As the technology and processes for dedicated production are more advanced, incremental
technology developments are important in developing these markets; however, the production of these chemicals is less affected by changes in feedstock prices.

Lower-value and high-volume products produced through dedicated production (commodity and platform chemicals) are more dependent on both feedstock prices and technology breakthroughs. The market will be attractive as long as there is a clear cost differential between traditional and bio-based feedstock prices. High-value chemicals produced \textit{in planta} are relatively competitive when feedstock availability is not limited.

Low-value and high-volume products produced \textit{in planta} (commodity and platform chemicals) are attractive only when significant technology breakthroughs are achieved and in scenarios with high oil prices. Relatively high production costs restrain the required scale-up for high-volume production. Owing to the high-volumes of feedstocks needed, competition with food and feed is likely where feedstock availability is limited.

Land availability can become a limiting factor in three of the scenarios. Current UK agricultural land area is around 18 million hectares and the land requirements for the Knock On Wood, Green Bloom and Stuck scenarios represent 13-15\% of this area. It is possible, however, that crops such as switchgrass can also be grown on marginal or even non-agricultural land. Therefore, significant breakthroughs in lignocellulosic and algal feedstocks (and especially offshore cultivation of the latter) would decrease these land use requirements and help avoid competition with food.

Model sensitivities and tipping points

Whether chemicals are produced using traditional or biochemical routes, feedstock costs are the most important driver of their market attractiveness and a key risk for the development of the IB markets. For the purposes of this study, the key factor is the relative cost-competitiveness of bio-based feedstocks with traditional feedstock prices, namely crude oil and naphtha prices.

By adjusting the oil price, tipping points were identified at which bio-based chemicals become attractive compared with their petrochemical counterparts. These tipping points vary from one scenario to another, where different oil prices have been used.

With current bio-based feedstock prices, the new market potential of IB will not be fully realised when the oil price falls below $60 per barrel for any of the scenarios.
The risk associated with changes to oil prices is significant and not readily mitigated. By maintaining or increasing efforts to develop low-volume high-value speciality and fine chemicals, the UK can avoid excessive exposure to oil price volatility. While reducing biofeedstock prices can be important in some cases, it is unlikely to counteract a scenario where oil prices are low as this would require considerable government support.

The chemical industry in the UK accounts for just over 4% of emissions out of a total level of UK emissions of 636 million tonnes in 2007. Even when embedded carbon is considered (as in this study), the overall proportion of national CO₂ savings from IB is not high. However, IB is the main option for reducing emissions within this sector.

While there are numerous mechanisms used by governments to reduce emissions, the use of a carbon price through markets (e.g. Emissions Trading Scheme) is important. In this case, carbon prices are not the cause of chemical production’s becoming unattractive under the Stuck, Green Bloom and Knock On Wood scenarios, as oil prices are already high; further carbon prices would only raise the price higher. However, where there is a low oil price (i.e. $50 per barrel in the Electrified scenario), a carbon price of £30-70 per tonne of CO₂ increasingly switches on production. (If carbon prices rose above £300 per tonne, chemicals within the C2 category could be produced in the Stuck scenario.)
The model only considers the chemical industry itself. Added value derived from the IB chemicals produced could therefore be even larger. The market for downstream industries has not been assessed but could dwarf that of the chemical sector. Furthermore, we are only at the beginning of the curve for the expansion of IB market, this study primarily only looked to 2025, the markets to 2050 were postulated to have grown even further.
“The use of microbial fermentation technology to convert waste feedstocks into renewable chemicals represents one of the best opportunities for IB in the UK. The UK has a strong academic and SME base but needs demonstration facilities to bridge the gap between lab-based research and commercial deployment.”

Edward M Green, Founder & CTO, Green Biologics Ltd

FIVE KEY AREAS

The IGT has identified barriers in five key areas that need to be addressed to enable IB to realise its potential.

The five areas are:

- Facilities and funding for projects, especially at the demonstration stage of the development lifecycle
- Innovation and knowledge transfer
- Skills
- Public and commercial perception and awareness
- Connectivity in the UK

FACILITIES AND FUNDING

Each stage in the product or process development lifecycle has its own challenges.

Equipment and facilities for demonstrator projects suffer, in particular, from a lack of publicly funded business support schemes. The demonstrator risk/reward profile is not attractive enough for private investors or large corporates. As a result, there is a shortfall of such facilities in the UK. Companies often go overseas to prove their ideas, as in the experience of Excelsyn (see page 43).

For the purposes of this report, medium and large scale are defined as being typically 0.5 – 10 tonne capacity fermentation assets with aligned upstream and downstream process capability for speciality and higher value chemicals. For volume chemicals such as the biofuels sector, economics suggest there may be a need for intermediate scales at a further ten-fold scale.
There is a particular shortage of demonstration facilities for fermentation, for certain key areas such as upstream pre-treatment of biomass and for certain downstream operations. More widely available in the UK (and overseas) are extraction and biocatalysis facilities.

In the UK chemistry-using industries, some large companies with development projects requiring fermentation are investing in assets as required. Others delay investment until technical risks have been reduced, particularly since IB routes are inherently more difficult to scale up than conventional chemical technologies. Those that have invested are unlikely to offer secure long-term manufacturing options to others. Small companies, in particular, find it difficult to develop and acquire the necessary capital assets. The principal UK provider of facilities is the National Industrial Biotechnology Facility (NIBF) at the Centre for Process Innovation (CPI).

**Case study: Why invest in fermentation capability**

**Excelsyn** develops platform biotechnologies that provide low-cost routes to making the so-called ‘unnatural’ amino acids that are an increasingly important group of registered starting materials for active pharmaceutical ingredients.

Such products need to be made at large scale and with high purity. Full exploitation of the biotechnologies involved requires a combination of fermentation, bioprocessing and classical chemistry isolation methods.

Excelsyn has successfully leveraged funding of about £750,000 from the Welsh Assembly Government and the Department for Business, Enterprise and Regulatory Reform in recent years to work with universities and continue its R&D of these biotechnologies.

However, the scale-up and commercial exploitation has proved more difficult. Appropriately equipped partners could not be found in the UK to carry out the necessary pilot and intermediate scale fermentations and biotransformations – no companies exist in the UK to provide such services.

Excelsyn has therefore worked with partners in Italy and the US to complete the development cycle. Total sales of almost £2 million have been generated by satisfactorily supplying three major pharmaceutical companies in Europe and the USA with the end results.

Thus, despite the lack of UK facilities, Excelsyn was able to succeed against the odds and demonstrate the potential benefits available. Those benefits and the probability of success could be considerably increased if the delays and barriers created by having to go overseas to commercialise innovations were removed.

Important measures that could help to quantify financial risks and benefits in IB deployment – for example, for carbon footprint, bio-based content, and lifecycle analysis – are lacking.
Case study: Some of the concerns from the public

**Croda**, a global manufacturer of speciality chemicals for personal care, pharmaceutical and household products, polymers, coatings and crop protection, is investing in a multimillion pound fermentation technology capability at its Ditton site just outside Runcorn.

Fermentation technology gives Croda access to low-carbon, low-energy and resource-efficient methods. These will replace multistage energy-intensive processes with greener, single-stage processes using less energy, with a smaller carbon footprint, that are more environmentally benign.

This new capability will also give Croda access to novel products and processes not available through conventional chemistry. For example, Croda is using fermentation technology to produce dioic acid, a product used in skin lightening products. When traditional chemical processing is used, the synthesis of dioic acid is complex, multi-stage, energy inefficient and low yielding.

Croda has also committed to reducing the amount of energy it uses. The company has invested in a wind turbine to generate the electricity for its Hull plant, with scope to roll this out across other Croda sites.

INNOVATION AND KNOWLEDGE TRANSFER

Support for IB R&D is currently fragmented in the UK, mainly coming from two Research Councils (the EPSRC and BBSRC), each with its portfolio of research activities. Although the research councils have stated a commitment to greater collaboration in the future, a fully integrated approach still needs to be more fully developed.

Without concerted support for demonstrator projects and equipment from UK business support schemes, IB project development lifecycles are much less likely to reach completion. This in turn could damage the UK’s reputation for, and experience of, innovation. It would also result in failure to make the most of the huge body of UK expertise described in Section 2 above – at a time when such expertise is essential to helping the UK retain its comparative advantage in world markets.

That advantage also relies on mechanisms for transferring knowledge and experience from successful development projects, quickly and effectively. However, for IB such mechanisms are limited in the UK, because of the fragmentation described (in the Connectivity section) below.

The adoption of IB is also hampered by lack of expertise in IB in most UK university Technology Transfer Offices. Technology transfer (early-stage university research and commercialisation) requires the ability to value the related intellectual property. Lack of this ability in relation to IB is impeding the flow of ideas from universities into commercial deals.
SKILLS

Central to the issue is a lack of interdisciplinary skills – the ability to understand the whole picture, rather than simply the biology, the chemistry or the engineering of an IB proposal. The situation is made worse by the fact that the relevant sectors skills councils and trade associations are separate, and home Research Councils are different.

Improvements in skills are required at every level. In particular, Masters level training is needed in the UK to deliver appropriate interdisciplinary IB skills, to transcend traditional disciplinary boundaries and enable shared strategies and collaborative thinking at each stage of the product or process development lifecycle. In addition, skills are needed to scale up production (‘from genes to tonnes’) to generate wealth from IB.

Students at A level and degree level need greater competence in basic laboratory skills than they currently show, so that they are capable, for example, of preparing their own solutions rather than depending on those prepared by lab technicians.

PUBLIC AND COMMERCIAL PERCEPTION AND AWARENESS

Although IB is the subject of much academic research and some manufacturing applications, as noted above, it nevertheless remains relatively low profile as a promising new technology. The work of the IB-IGT highlights especially how lack of understanding of IB and its potential – among businesses, consumers and policy
makers – means that the UK risks falling behind other countries as they strive to exploit the opportunities created by IB. This needs to be tackled.

As was noted in Section 3, public perception and expectations have great significance in determining whether something like IB advances at the necessary pace and scale to deliver its many benefits.

A Sciencewise study\textsuperscript{26} commissioned for this report found that the main initial barrier to public acceptance of IB is a lack of knowledge or understanding of such new technologies. This is linked to a limited knowledge of science in general, as well as a fundamental lack of understanding of IB specifically. However, the study also found that providing clear, balanced information helps to a large extent to increase consumer confidence and generate support for IB as a technological solution to the economic and environmental challenges ahead.

\begin{quote}
Some of the concerns form the public perception study\textsuperscript{26}
“We just don’t know what’s going into the stuff”
“If it sounds too good to be true it probably is”
“We don’t know what the long term effects might be”
“There is not enough land to produce biofuels and bioplastics, the world is straining to make enough food now”
\end{quote}

Equally, people in business need to understand how IB products and processes will benefit their performance. At the moment, when IB-derived products and processes come to market, they can hope to attract a premium price because of the new benefits they deliver. However, this premium is limited and only in selected segments; it also has a limited time window, as customers will come to expect such benefits as the norm in time. Ultimately, IB products must compete on performance and cost.

People in both society and industry are keen to hear what green groups think about the emergent technologies of IB. These organisations, and others independent of government and industry, such as think tanks, are largely perceived as credible sources.

Therefore the IB-IGT, as part of its wider stakeholder engagement, sought at various junctures to gain input and engagement from a number of non-governmental organisations. These efforts are ongoing.

\textsuperscript{26} Public Perceptions of Industrial Biotechnology, A report prepared for BERR and Sciencewise, Opinion Leader, 2009
CONNECTIVITY IN THE UK

IB is an important route to prosperity and sustainability in the UK and internationally. However, companies and centres developing IB products and processes and the chemistry-using industries that will generate the rewards of IB are not well connected in the UK.

A significant communication and strategy gap exists between existing and new upstream and downstream supply chains. Within downstream sectors, knowledge of the UK’s considerable IB capabilities is limited. Conversely, people in IB companies and centres exhibit limited understanding of the unmet customer needs and technical challenges that the chemistry-using industries face.

People working in IB need to become more alert to any developments in advanced biofuel technologies that could provide opportunities for the manufacture of chemicals. So far, none of the current options for advanced biofuel production is fully developed technologically.

Scope for profitable production of fine and potentially speciality chemicals via IB is high. However, linking market knowledge with technological expertise remains challenging. The market operating on its own will not necessarily achieve the connection without a stimulus. The UK’s strong science base in plant science, marine organisms and mycology is not linked effectively enough to the needs of the end user markets.

Taking IB to market requires technologies to be developed at conventional subject boundaries. This creates a need for the Technology Strategy Board, the EPSRC and BBSRC to work together to resolve key science challenges and support translation of IB to downstream sectors.
Section 5: Recommendations – Closing the Gaps

“How can the intervention of a smart, strategic government better complement the market in allocating resources in the UK economy to ensure UK companies have the best possible chances to compete in a globalised world?”

Rt Hon Lord Peter Mandelson, Secretary of State for Business, Enterprise & Regulatory Reform
A new industrial activism, The RSA Lecture, 17 December 2008

OVERVIEW

IB – sustainable, bio-based chemicals, materials and processes – could be as transformational for the 21st century economy and lifestyles as oil was in the 20th century.27

By 2030, biotechnology – including biomaterials and bioprocesses, bioenergy, biomedicine and emerging technologies – is expected to be a key pillar of Europe’s economy28, with one third of all chemicals and materials produced from biological sources, including biopolymers and bioplastics.

In the UK economy, chemicals is a major sector with a turnover in excess of £63 billion and exports of £43 billion. Chemical companies directly employ 200,000 people; several hundred thousand additional jobs are chemicals related. In this sector, and in others, IB will contribute to the Government’s aims of creating green jobs and delivering low-carbon manufacturing processes and products.

Beyond the traditional chemical industry, businesses in the UK depending on chemical science include pharmaceuticals, personal care, coatings, food processing and beverage companies, as well as companies in parts of other sectors such as energy, automotive and aerospace.

With an aggregate output of some £1150 billion and an added value of over £550 billion, the chemistry-using industries are a major contributor to the UK economy,

27 Highly varying estimates of the current size of IB have been put forward, but all of them show the industry still to be in the embryonic growth stage, or less than 5% of total chemical and pharmaceutical sales. Growth potential is significant, however. Arthur D. Little estimates a global market size of between €50 and €75 million in 2007, expanding to between €150 and €360 million in 2025, or 7-17% of total industry sales with the majority in developed economies.


A report to government by the Industrial Biotechnology Innovation and Growth Team
and an important source of solutions for a broad spectrum of UK society’s current challenges.

IB will contribute to sustainable growth and increased UK competitiveness by contributing to the UK’s ability to live and work within environmental limits while making the most of its world-class intellectual property and industrial know-how. It will also help the Government meet its existing commitments to greenhouse gas emissions reductions of at least 80% by 2050 through action in the UK and abroad, as outlined by the UK Climate Change Act 2008.29

However, in order to fully exploit our innovation heritage, our strong R&D base, and the potential of IB in the UK for enhanced and sustainable economic output, there are barriers and issues that need to be addressed. Dealing with these sooner rather than later will better position UK companies globally to leverage and generate IB wealth-creation opportunities.

The Industrial Biotechnology Innovation and Growth Team (IB-IGT) has focused its work on ensuring that UK businesses can take maximum advantage of these global opportunities.

The IB-IGT has looked at the whole business environment affecting IB, with the full involvement of the key Government departments (BERR; Department for Environment, Food and Rural Affairs; Department for Innovation, Universities & Skills; Department of Energy and Climate Change), the Technology Strategy Board and Research Councils. It has worked closely with industry and with users to identify what needs to be done to position the UK as strongly as possible to generate the maximum benefits.

The IB-IGT identified five critical recommendations that will ensure the UK is well placed to translate the opportunities IB presents into innovations, jobs and prosperity:

- Provide leadership to promote and connect IB activities across all supply chains;
- De-risk access to new IB products, processes and technologies;
- Accelerate the innovation and knowledge transfer process for IB;
- Position IB to attract and retain high quality scientists, engineers and managers; and
- Create a truly supportive ‘public’ and ‘business’ environment for IB.

These recommendations can be further categorised as driving, delivering or enabling the necessary change (see Figure 10 below).
Figure 11: How the recommendations drive, deliver or enable change
Driving Change

DRIVING CHANGE: CONNECTING IT ALL TOGETHER

IB Leadership Forum

IB is a broad and rapidly expanding area. This leading edge technology (involving the processing and production of chemicals, materials and energy) has the capacity to underpin business growth in the UK across a range of sectors.

The IB-IGT has identified a need for the provision of leadership to ensure that capability in, and understanding of, IB is, and remains, a priority for both Government and industry.

**Recommendation 1:** The IB-IGT recommends that an overarching industry/Government Leadership Forum be established by autumn 2009. This Forum would have ownership of the IB-IGT recommendations, power to oversee implementation, and responsibility for assessing and reviewing new ideas and opportunities.

Furthermore, the IB-IGT has identified that potential users of IB have only limited familiarity with the technology. Likewise, those working to further develop IB products and processes do not have a complete understanding of which sectors and companies may best benefit from their technology and how to interact with the complex supply chains.

This lack of familiarity and understanding is acting as a brake on the diffusion and uptake of IB technology in the UK. Hence, there is a need to more effectively link the user and developer communities together. This will ensure that new developments better match industry needs and that the players can work together to find new business opportunities.

**Recommendation 2:** The IB-IGT recommends that the leadership forum be responsible for raising awareness in the private and public sectors regarding the capabilities and potential of IB; as well as leading on the long-term development and promotion of IB into new and existing supply chains.

The IB-IGT believes that the Leadership Forum should be jointly chaired by a Minister and senior business leader. It would operate through co-ordinated and focused sub-
groups drawn from key existing organisations active and interested in IB – such as the Knowledge Transfer Networks, trade associations, professional bodies, non-governmental organisations (NGOs), and cluster organisations.

Proposed activities for the Leadership Forum should include:

- Overseeing a 3-yearly cycle for strategy refresh;
- Identifying champions in Government, academia and business and supporting them in this role;
- Improving the dialogue between the UK knowledge base (through university Technology Transfer Offices) and industry about needs, research capability, inventions/intellectual property, and infrastructure;
- An annual horizon scanning exercise to monitor for developments in advanced biofuel technologies that provide opportunities for the manufacture of chemicals;
- The development of iconic products, processes and research;
- Improving investor awareness of IB;
- Promoting and recognising the potential of industrial symbiosis;
- The development of new business models and new supply chains; and
- Encouraging the creation of new and expanded networks of users and providers.

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30 The IGT recommends that this build upon the Bioscience for Business Knowledge Transfer Network’s Bioventures Special Interest Group.
DELIBERATING CHANGE: DE-RISKING ACCESS TO NEW PRODUCTS AND TECHNOLOGIES

Demonstrator facilities

To increase the adoption of IB processes, it is important to reduce the level of risk during the IB innovation process. This is clear from the scenario development analysis above (see Section 3) and its presentation of the conditions that create tipping points for the development and adoption of IB.

In relation to specific gaps in the UK chemical and chemistry-using industries, the following issues were noted:

- Some large companies with development projects invest in assets as required; others delay investment until technical risks have been reduced, particularly since IB routes are inherently more difficult to scale up than conventional chemical technologies. Those who have invested are unlikely to offer secure long term manufacturing options to others. Small companies, in particular, find it difficult to develop and acquire the necessary capital assets;
- The development asset base for the UK is being limited by the restructuring of the UK chemical industry;
- The opportunities that exist with SMEs have the most significant barriers to entry on process and product development, given the limited availability of open access scale-up equipment;
- As well as limitations on assets there exists a very limited skill base in terms of both numbers and capability to take advantage of promising opportunities; and
- Certain gaps exist in upstream processing (production of proteins using genetically engineered cells) at scale, and in certain downstream processes (manufacturing marketable products) at scale – for example, in the biofuels sector.
Availability of pilot scale fermentation equipment in the UK is also very limited. The IB-IGT has identified the need for integrated strategic investment in demonstration-scale facilities.

Recommendation 3: The IB-IGT recommends the development of an open access demonstrator facility, particularly for fermentation (up to 10 tonne capacity), with associated upstream and downstream facilities by 2010.

A facility of this type would be novel for the UK and is not replicated elsewhere in Europe.

To build a new facility the estimated costs would be of the order of £20-35 million; an additional £2 million per year would be needed for running costs. If built upon an existing generic capability, the facility would require about £10 million to construct.

The preferred option should be for building upon existing centres of excellence. The potential to secure equipment being released as a result of chemical and pharmaceutical sector mergers and rationalisation should also be considered, if deemed practicable.

Furthermore, the importance of IB in delivering significant societal benefits in two key areas should not be overlooked: the use of biomass for CO$_2$ capture; and the combination of IB and process industry skills to radically improve anaerobic digestion technologies. In the first of these areas, a key driver is the ability to achieve delivery of the long-term climate change targets by CO$_2$ capture and sequestration from oil refineries, combustion power generation units, cement plants and chemical processing plants. In relation to the second area, the importance of the biotechnology of anaerobic digestion has been especially highlighted in the Department for the Environment, Food and Rural Affairs publication of February 2009. This publication summarises the technology’s potential positive impact across the UK’s waste management, energy, transport, water and agriculture sectors, with the necessary support from Government and regulators, regional authorities, and the R&D community.31

It is critical that the demonstration facility proposed in this report is aligned with schemes across Government that are aimed at bringing forward the development of new low-carbon technologies in the UK.

Demonstrator fund

The IB-IGT has also identified the need for a fund for companies to develop and demonstrate ideas for new products and processes. This investment would alleviate blockages at this stage of the development process by reducing risks for companies and catalysing the uptake of IB. It is therefore important to ensure that the right support is in place for those wishing to transform a new IB process into a viable business.

31 Anaerobic Digestion – Shared Goals, Department for the Environment, Food and Rural Affairs, February 2009
Recommendation 4: The IB-IGT recommends that an IB fund (of £2.5–5 million per year for 3–5 years) should be established by the end of 2009 to allow industry, particularly SMEs, access to demonstration facilities.

The optimal solution is a new fund to allow eligible businesses access to demonstration facilities and complement the new 1-10 tonne demonstration facility described above.

Improving access to existing demonstration funds

Further to the above recommendations, and the recommendation (see page 56) regarding business support schemes, the IB-IGT has identified a need to ensure that companies wishing to demonstrate IB products, processes and products can access new and existing commercial scale demonstrator funds.

Recommendation 5: The IB-IGT recommends that the Government should improve access to demonstration funds by broadening the remit of existing commercial-scale demonstration funds to ensure that IB is included within the scope of eligible technologies.

DELIVERING CHANGE: ACCELERATING THE INNOVATION AND KNOWLEDGE TRANSFER PROCESS FOR IB IN THE UK

Building on UK expertise

Long-term funding of R&D to allow the development of centre(s) of excellence with critical mass and self-sustaining capability is considered essential for any technology. The IB-IGT has recognised a need for the UK’s existing IB centres of expertise to be extended, supported and co-ordinated, in order to provide a stable, expert pathway for the development and commercialisation of IB opportunities across the UK.

Recommendation 6: The IB-IGT recommends that the Technology Strategy Board, EPSRC and BBSRC work together to support a single, virtual, centre of excellence in IB research and development that will capitalise on, and augment, existing academic centres where biologists, biotechnologists, chemists, chemical engineers and other relevant disciplines are co-located.

It is envisaged by the IB-IGT that this would be a virtual network of physical centres, each of which has a defined area of expertise, in a ‘hub and spoke’ model. This will ensure that the UK’s world-leading expertise and research are more effectively capitalised on and used to position UK companies to leverage and generate IB wealth-creation opportunities on a global scale.

Economic analysis has shown that the pace of technology development is one of the most important factors that could constrain the growth of UK IB.
IB is a key application area with the capacity to play a major role in delivering the technological innovation required to meet the challenges facing the UK in the 21st century from climate change to sustainable living.

As Lord Sainsbury’s 2007 review of UK Government science and innovation policies noted, the UK is internationally renowned for its research capabilities; this is as true in IB as it is in other areas.

Therefore, the IB-IGT stresses the critical importance of the UK continuing to build upon its internationally renowned and world-leading research and knowledge base to develop new and innovative IB processes and products for exploitation by both UK and global industry.

**Recommendation 7: The Technology Strategy Board, EPSRC and BBSRC should work together through joint calls to ensure that the UK’s world leading science base in genomics fermentation, biocatalysis, plant science, marine organisms and mycology is effectively developed and translated into IB applications.**

The IB-IGT recognises that the Research Councils and Technology Strategy Board are increasingly jointly funding cross-organisational interdisciplinary projects, such as the Integrated Biorefining Technologies Initiative (IBTI), and urges that this should continue, not only for IBTI, but other new projects from the outset.

**Business Support Schemes**

There is also a need to ensure that the right framework is in place to support those wishing to transform a new IB process into a viable business. The IB-IGT welcomes the Government’s Business Support Simplification Programme, but notes that the current funds and schemes present a complex picture to prospective applicants. Companies may be unaware of many of the sources of funding, or smaller companies may simply be unable to resource the task of accessing or applying for them. A phone contact to a ‘sector expert’ would be an appropriate and cost-effective way of building upon the ongoing generic programme of promotion through Business Link.

**Recommendation 8: The IB-IGT recommends that the availability and uptake of general business support schemes is facilitated by providing a single point of contact, by the end of 2009, which can give clearer signposting to schemes relevant to IB companies.**

**Recommendation 9: The IB-IGT recommends that the scope of any new business support schemes should be defined in a way that does not exclude or impede IB, and that existing funding schemes that may unintentionally exclude or marginalise IB be modified to remove this blockage.**
Knowledge transfer

Successful knowledge transfer requires experts to act as connectors between academia, industry and funding organisations.

The IB-IGT’s economic analysis highlighted the role the pace of technology development will have in the creation of substantial IB market opportunities in the future. Therefore, the speed of dissemination and commercialisation of new ideas is also critical.

In a role founded on building relationships as part of a national network, an expert connector would act as a broker and deal facilitator, actively working with industry, academia and Technology Transfer Offices to develop and commercialise new IB innovations. This expert connector would be a resource for all UK university Technology Transfer Offices which may lack relevant industry contacts and/or expertise in IB applications or markets.

The main goal of the expert connector is to enhance opportunity and deal flow on a national basis. The role complements the recommendations previously made to support and co-ordinate the UK’s existing IB centres. The expert connector will also broker connections to relevant funding and business support schemes for both industry and researchers (it may be beneficial for the expert connector to fulfil the signposting function of the earlier recommendation as part of the broader role).

**Recommendation 10: The IB-IGT recommends that a ‘sector expert’ be based within the IB Leadership Forum.**

Overseas promotion of UK expertise

In order to fully capitalise on the global opportunities IB presents for inward investment and trade development, the IB-IGT has identified a need for UK Trade & Investment (UKTI) to work with the IB Leadership Forum to improve the overseas promotion of the UK’s IB capability and infrastructure.

**Recommendation 11: The IB-IGT recommends that UKTI, in conjunction with the IB Leadership Forum, undertakes a co-ordinated approach to promoting UK IB capability and infrastructure overseas from 2010 onwards.**
Interdisciplinary talent

Effective exploitation of IB requires specific high level skills at the graduate and post-graduate level. There is a shortage of appropriate skills at all levels to take IB to market. Not only are deep scientific and engineering skills required but also the abilities to understand and link the conventional subject areas of biology, chemistry and chemical and biochemical engineering.

The IB-IGT has identified a need to develop and retain highly skilled individuals who work at the chemistry-biology-engineering interface to lead the next generation of research as well to act as industry leaders for the future.

**Recommendation 12:** The IB-IGT recommends that the Research Councils, EPSRC and BBSRC, the professional institutions in chemical engineering, chemistry and biology, the Sector Skills Councils, SEMTA and Cogent, should continue to work together to develop a joint strategy by the end of 2009 for the provision of IB skills; and ensure the pipeline of talent is captured.

**Recommendation 13:** The IB-IGT recommends that industry works with EPSRC, BBSRC, academia and the professional institutions to develop and fund a new taught MSc, MRes or similar type of programme for co-development of advanced practical skills in IB.

This is a vital element for establishing the skilled workforce necessary to deliver the promises of IB in the UK. Apart from taught MSc provision, the IB-IGT also recognises the need to develop Master’s level Continuing Professional Development courses.

There is a lack of graduates qualifying in IB. Therefore, there is a need to alert high quality chemists and chemical engineers to the challenges and rewards of working in the IB area; this could be a function of the IB Leadership Forum working with the appropriate professional institutions.
Industry engagement

IB centres of excellence in the UK are well connected to the pharmaceutical industry. However, for IB to realise its full potential, the UK needs to take action to enhance engagement with the petroleum, commodity and speciality chemical sectors. Subsidies for students and post-doctoral researchers in Europe currently put UK centres of excellence at a disadvantage in terms of their ability to attract industry collaborators.

Recommendation 14: The IB-IGT recommends that industry works with the EPSRC, BBSRC and Higher Education Institutions to identify additional mechanisms for co-funded post-doctoral researchers to allow UK Centres of Excellence to compete effectively with equivalents in the EU.

ENABLING CHANGE: CREATING A SUPPORTIVE ‘PUBLIC’ AND ‘BUSINESS’ ENVIRONMENT FOR IB IN THE UK

Standards

One of the fundamental benefits of IB lies in its potential to improve the environmental footprint of many industrial processes. Understanding this strongly influences the adoption of IB technology.

There are manifold current methodologies that attempt to measure the extent of improvement: for example, through lifecycle analysis, carbon footprinting and bio-based content. However, not only have these been complex to apply and interpret, but there was no widely accepted and reliable standard for getting a lifecycle carbon footprint. For any IB product or process there was a lack of precision about its environmental benefits.

The development of PAS 2050 last year has established a new method that enables robust, consistent and transparent assessments of the lifecycle greenhouse gas (GHG) emissions of a product or service, and this method is already being used by many companies around the world.

Recommendation 15: The IB-IGT recommends the endorsement, and recommended adoption, of PAS 2050 for lifecycle GHG emissions as the standard methodology for accessing lifecycle greenhouse gas emissions in goods and services.

Recommendation 16: The IB-IGT recommends the endorsement, and recommended adoption, of Carbon Calculations over the Life Cycle of Industrial Activities (CCaLC) as the preferred toolkit for the calculation of a product’s carbon footprint33.

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33 Subject to trialling and confirmation that CCaLC is compliant with PAS 2050
**Recommendation 17**: The IB-IGT recommends the endorsement, and recommended adoption, of a standard for calculating the bio-based content of a product.

**Reviewing the impact of existing incentives**

The IB-IGT accepts that existing obligations and incentives were established with specific goals in mind. However, it recognises that the current financial incentives for renewables have the potential, in certain instances, to inadvertently affect investment in IB (through the price and use of feedstocks, for example).

There is a need to ensure that incentives do not deter people and organisations from developing, and investing in, sustainable IB technologies.

This is even more important in light of recent developments in Europe which could leave the UK at a competitive disadvantage if it does not have appropriate incentive structures in place. The European Commission is driving forward a move towards a knowledge-based bio-economy.

The Commission recently launched a joint call in the biorefinery area with a budget of €57 million. Within this is a call for proposals for research on developing technologies for the entire value chain from biomass production, logistics and pre-treatment to conversion (thermochemical and biochemical technologies) using different types of biomass feedstock to produce bio-based products and energy.

Meanwhile, developments in advanced biofuel technologies will provide significant opportunities for the manufacture of chemicals.

It is therefore clear that existing UK incentives and obligations may need to be re-examined to identify where any possible ‘blockers’ to IB may inadvertently be in effect.

**Recommendation 18**: The IB-IGT recommends that, where areas of concern are raised by industry, with supporting evidence, new and existing obligations and incentives be reviewed by the Government with a view to addressing any identified unintended consequences blocking the application of IB to high-value chemical usage; and, where appropriate, this evidence be used to raise relevant issues with the European Commission where the Commission holds the mandate.

**Public procurement**

Bio-based products, and products made via bioprocesses, are often similar to ‘conventional’ products (bioplastic is plastic, biofuel is fuel, biochemicals are chemicals, etc.), and they are often produced in a more sustainable way.

The UK Government Sustainable Procurement Action Plan highlights that, within the wider context of sustainable development, climate change mitigation and natural

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34 http://ec.europa.eu/research/biosociety/index_en.htm
resource protection are the highest priorities. The use of bio-based products, and products made via bioprocesses, has considerable potential to address these priorities. However, the current Office of Government Commerce’s (OGC) calculation of carbon savings for Sustainable Operations on the Government Estate targets does not always include all the impacts of a product, such as the carbon and energy saving in the manufacture of the products, and therefore do not take account of the full lifecycle impact of a product.

Public procurement ‘pull’ provides vital market certainty that can play a catalytic role in encouraging successful commercialisation of innovation. This requires the Government to accept and proactively increase the role that bio-based products, and products made via bioprocesses, play in delivering sustainable public procurement across the Government Estate and in wider public procurement.

**Recommendation 19:** The IB-IGT recommends that the Government accepts and includes the role bio-based products, and products made via bioprocesses, can play in delivering sustainable public procurement across the Government Estate, and specifically acts by spring 2010 to:

- Develop an evidence base to identify and quantify the potential of bio-based products in terms of their contribution to reducing the Government Estate’s carbon footprint, GHG emissions and overall sustainability (including lifecycle analysis, carbon foot-printing and bio-based content calculations);

- Adopt a whole lifecycle approach to decisions related to Government Estate and procurement policy;

- Identify where the opportunities lie for Government to lead by example through procuring, and stimulating innovation in, bio-based products and processes; and

- Integrate with and seek to influence the work on sustainable procurement in the European Commission, such as the Lead Market Initiative for bio-based products, the call for proposals to support lead markets public procurement networks, the Strategic Energy Technology (SET) Plan, and the Sustainable Consumption and Production (SCP) and Sustainable Industrial Policy (SIP) Action Plan.

**Land use**

The issue of the land use has become critical, whether biomass is used for feedstocks for materials and chemicals, or for biofuels. Increasing demand for land for these purposes is competing with increasing demand for land use for food. The UK has taken a lead role internationally in examining this for biofuels, and similar analyses must be conducted when using feedstock for other non-food uses. The land use implications

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35 This recommendation is linked to the IGT’s recommendation on Standards
for the development of IB need to be addressed head on, and strategically. Conversely, the direction of IB should be influenced by this strategy.

The IB-IGT scenario analysis shows that limiting the land available for IB production will considerably restrict both the production of IB chemicals and the benefits derived therefrom (especially in terms of CO₂ emission reduction).³⁸

The main considerations are land conversion and impacts on global climate change; threats to biodiversity; increased demand for water resources; the geographical location of ‘available’ land; suitability of land for different agricultural uses; and the displacement, or indirect, effects of using land which had previously been dedicated to food production (indirect land use change). All these issues are controversial and sensitive.

Overall, the issues of land use to produce biomass for IB need to be addressed. Criteria for sustainability need to be established and implemented in relation to global climate change, biodiversity, and water use, on the one hand, and economic sustainability with regard to competing demands for agricultural uses on the other. Strategic management of land use is necessary to ensure production of food, energy, chemicals and materials from biomass.

Recommendation 20: The IB-IGT recommends that IB is considered as a value-creating demand factor when developing a strategy for managing sustainable land use in the context of intensification of demand for all purposes.

Public perception

It is well documented that the public can find science and technology confusing. A report on Public Attitudes to Science prepared for Research Councils UK and the Department for Innovation, Universities and Skills³⁹ has shown that over half of the population believe that ‘science and technology is too specialised to understand’. Research⁴⁰ commissioned by the IB-IGT demonstrates that there is little thought about the processes behind the products in people’s everyday lives and very little awareness of biotechnology. For most, the science behind biotechnology is a complete unknown and for this reason can appear intimidating, in some cases even sinister.

Compounding this uncertainty and ‘fear of the unknown’ is a pervading mistrust of Government and industry who are not felt to be working in the public interest. ‘Profit’ or anything associated with industry are viewed with great suspicion and there is little faith that the Government will control and monitor industry. While suspicious of ‘Government’, people are supportive of ‘the national interest’. People are particularly protective of the UK’s position in relation to global economies and interests; keen that we get our ‘fair share’ by gaining economically from developing IB whilst not making

⁴⁰ See reference 26 above
disproportionate efforts (relative to other countries) in areas such as reducing carbon emissions.

Recommendation 21: The IB-IGT recommends that Government, industry*, Research Councils, NGOs, and professional institutions should develop an effective, balanced and informative communication strategy, including stakeholder and public engagement, for IB.

*this will include brand owners and retailers

The strategy should utilise academic scientists to provide factual information on IB processes, regulations and fit to daily life; involve the environmental NGOs in the process; and give consideration to the consequences of indirect land use change through moving to a more bio-based economy.
Annex A: Acknowledgements

The following people gave their time and energy to this project; the Chair and BERR wish to extend their thanks.

The IB-IGT Steering Group Membership

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Annex B: International Snapshot

Canada started developing a technology road map including biotechnology in 2001. Since 2005 it has been implementing its vision of biotechnology, based on the country’s competitive advantage of massive natural resources.

The Dutch Government has set out a Policy Agenda focused on more efficient use of biomass, sustainable biomass production, encouraging the production of green gas and sustainable electricity, and promoting market developments.

Germany positions itself as one of Europe’s most important IB players, with 500 biotechnology companies as well as the headquarters of several global corporations such as BASF, Bayer and Evonik.


Several public and private initiatives have been undertaken in France to accelerate the development of IB and increase the awareness of citizens, public authorities and enterprises about bio-based products.

The Australian Government hosted workshops in October 2008 to highlight the competitive benefits that biotechnology can bring to Australian industries, focusing on supply chain opportunities with major multinationals and Australian companies that are successfully using IB.