Final Report and Recommendations from the Industrial Biotechnology Innovation and Growth Team (IB IGT) Technology and Manufacturing Working Group (T&MWG)

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Purpose of the paper

To provide the IB IGT Steering Group with recommendations from the Technology and Manufacturing Working Group to determine the developments needed to enhance UK competitiveness in the area of industrial biotechnology.

Remit of the Technology and Manufacturing Working Group

The remit of the group was to examine current developments in industrial biotechnology (IB), the requirements for future markets and existing barriers to growth. The principal issues that the group set out to consider were:

- An assessment of the UK's ability to exploit existing technologies, markets and capabilities
- To identify the opportunities, gaps and barriers that exist for the chemical and chemistry using industries to utilise the potential of IB and determine how they can be addressed
- To look at specific types of development in IB that will significantly enhance the UK competitiveness and provide the best market opportunities for UK companies, including the types of business model to add most value, e.g. collaborative innovation, licensed manufacturing, services and systems
- Societal issues and the views of wider society, including climate change, issues of an aging population, training and education issues, together with the most effective way of communicating the benefits of IB to society.

Background

All major facets of society and economic activity, both in the UK and globally are being challenged to demonstrate their sustainability and at the same time to improve profitability. Currently most of the global energy supply is fossil fuel based and similarly most chemicals are sourced from petrochemical feedstocks. In order to tackle the challenge of global climate change, societal and economic pressures are offering significantly increased opportunities for the production of chemicals from sustainable bio-based feedstocks and through routes based on bioprocessing technologies.

The UK chemistry using industries are no exception to these global trends and are being challenged to take competitive advantage of the movement to a low carbon economy by the increased use of sustainable bio-based products and processes. As in the rest of the world the majority of chemicals produced in the UK are sourced from fossil feedstocks. At present the majority of chemical companies have not invested heavily in bio-based production. This is for a number of reasons including initial higher production costs, unfamiliarity with the capabilities and benefits of biotechnology, and the perceived risks associated with investing in technologies new to the sector. Encouragingly however a survey completed as part of this Innovation and Growth Team has concluded that 6the majority of the chemistry-using industry company base would invest in industrial biotechnology if an appropriately favourable business case existed and if the technological risks were acceptable. It is accepted that Industrial biotechnology offers the potential of increased sustainability, lower production costs, more environmentally benign processes, greater greenhouse gas savings and additional product functionalities.

In order to remain internationally competitive, the UK needs to maintain and enhance its internationally renowned recognised research and knowledge base in Industrial Biotechnology and improve the effectiveness of its exploitation for the benefit of UK companies and the economy as a whole. The aim of the IB IGT is to ensure the optimum environment is in place to enable the UK to take significant advantage from recent developments in industrial biotechnology.

Progress

In its preliminary deliberations, the T&MWG identified five key areas that needed to be addressed. These were:

- Markets and products where Industrial Biotechnology could offer advantages
- Feedstocks current and future availability for chemicals manufacture
- Process technology and science requirements for Industrial Biotechnology
- Skills needs
- Public perception of Industrial Biotechnology

Initially the group concentrated on the first three areas, with work commissioned to address skills and public perception for later consideration.

Under each of the three areas, a number of outcome hypotheses were developed to stimulate thinking and discussion. Groups of members worked together to develop responses to the individual hypotheses which were then used to identify the key recommendations for action. The paper outlining the Hypotheses (Annex A) and the responses by group members form the basis of the recommendations from the T&MWG.

Key Recommendations and Conclusions

Key Recommendations

1. The IB sector and the chemistry using industries are currently not well connected. There is limited knowledge of the capabilities of the UK IB sector within the downstream (chemistry using) sectors. There also seems to be limited understanding of the unmet needs of the chemistry using industries customer base in the IB sector. Familiarity with the state of development of bioprocessing technologies is low in the chemistry using industries and the understanding of the sophisticated product performance challenges faced by end users is limited in the IB sector.

There is a clear need for an ongoing senior forum for the linking the needs and capabilities of the respective sectors. Careful consideration is required to determine the level of representation and scope of such a forum's remit and activities.

The group recommends that a high level group should be set up to be responsible for delivering the final recommendations from the IB IGT and to review progress on an ongoing basis.

2. The innovation process for the use of IB needs to be derisked if IB technologies are to have an increased impact in the chemistry using industries.

There is currently limited provision of open access demonstrator units.

There is a particular need for a fermentation capability of 1 – 10te capacity with associated upstream and downstream facilities to allow more effective process scaling to be achieved.

There may be a further need for extraction and isolation capability perhaps in partnership with UK equipment suppliers. Consideration and clear definitions of an effective business model for such a facility is needed.

To develop demonstration and scale up facilities, options should be developed to build on or link to existing centres of excellence such as The Centre for Process Innovation (CPI) and the linked CoEBio3 (Centre of Excellence in Biocatalysis, Biotransformations and Biocatalytic Manufacture). This would provide value for money and develop existing expertise.

Funding should be allocated to fund/co-fund proof of concept demonstrations and to provide special grants for the design, build and commissioning of novel processing equipment.

In addition to de-risking the final stages of process development, where the cost of failure can be high, there is also a need to de-risk the earlier stages of process development. The use of modern microscale engineering and high throughput experimental techniques would quickly identify the optimal process routes and conditions that can subsequently be verified at large scale in the demonstrator facility.

There is a need to identify a lead organisation to provide the funding and assess applications.

Additional funding, either public/private should be made available for the next steps in funding growth for smaller companies after early stage investment – beyond proof of concept.

Specific provision should be made through voucher schemes or similar to provide small companies in the sector with critical expertise not available to them directly.

3. An effective, globally accepted, accessible calculation method for Life Cycle Analysis is required to guide developments in the area and play a part in derisking innovation.

Government and other policy makers need to support and mandate such a tool. The tool should be capable of operating at a number of levels of details to guide innovation at various points in the cycle.

4. Taking IB to market requires technologies to be developed at conventional subject boundaries.

There is a need for more centres, particularly academic (but industry linked) centres where biologists, chemists, chemical engineers etc are co-located and can work together on key technology challenges.   Some of these challenges include engineering industrially useful enzyme and cellular biocatalysts, establishing new synthetic routes, creating new techniques for the rapid analysis of chemical and biological process options and their optimisation, ensuring rapid and predictable scale-up, whole process and cost modelling.

In addition following stakeholder feedback two other key societal challenges are being assessed where IB supported by the chemistry using industries can potentially these are anaerobic digestion to convert waste to useful, initially fuel, products and the more effective capture of carbon dioxide from combustion power units to yield a biomass sequestration product. The assessment of the potential for these options will be complete by the end of February more details of the hypotheses being tested are given in Annex B

The Technology Strategy Board and the two research councils, EPSRC and BBSRC should seek opportunities to work together to resolve key science challenges and to support such centres and the translation of IB to downstream sectors.

Given the strategic importance of IB to the UK economy, it is important that current opportunities for the UK are built upon and not lost. The group recommends that specific initiatives and dedicated budgets are created to provide the support needed in this area.

5. There is a shortage of appropriate skills at all levels to take IB to market.

There is a lack of individuals with basic laboratory skills. This should be addressed both at A level and degree levels

Skills provision takes place in a complex landscape with split responsibilities in Research Councils and Sector Skills Councils (SSCs). SEMTA and Cogent should be encouraged to work together to develop a joint strategy for the provision of IB skills.

EPSRC and BBSRC should work together to deliver the integrated skills required for the translation of IB to downstream sectors.

EPSRC and BBSRC should work with business to design a new taught MSc or MRes type programme for co-development of 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, the group recognises the need to develop Masters level CPD course provision.

One useful funding initiative would be a call for Doctoral / Industrial Doctoral Training Centres in the area of IB. These could be like those recently announced by EPSRC. However an interesting variation would be a centre that provided an integrated and appropriate balance of Doctoral level training (for producing the next generation of IB leaders) and taught Masters level training (for producing the ‘skilled workforce’).

There is a lack of graduates qualifying in IB. There is a need to alert high quality chemists and chemical engineers to the challenges and rewards of working in the IB area.

There are issues which impact on chemists and biochemical/chemical engineers pursuing careers in biotechnology and in particular the need for chartered scientist registration to be easier for non conventional scientists. This is an issue which should be addressed by the relevant learned societies e.g. Royal Society of Chemistry, the Institution of Chemical Engineers and the Institute of Biology

EPSRC and BBSRC both have a strategic interest in industrial biotechnology. A joint funding initiative looking at a 'genes to tonnes' approach to delivering wealth from IB would be a highly valuable development.

Conclusions

6. Any products produced from Industrial biotechnology must compete on both performance and price if their use is to increase in downstream sectors. It has been determined based on current experience that a modest sustainable premium for bio-based products may be achievable in a limited number of market segments.

Consideration should be given to incentives to encourage the use of IB/renewable products where their performance is competitive and sustainable (for example via public sector procurement initiatives).

Costs of reformulating products to use IB based components may be significant and restrictive and incentives should be considered to cover the costs of switching to sustainable IB-based components.

7. Developments in advanced biofuel technologies will provide associated opportunities for the manufacture of chemicals and could provide, at a modest cost, market entry points for some products. These could come from the use of by-products or side stream extraction of useful chemical components. The petrochemical industry grew up in just such a way from the oil industry of the early twentieth century.

Currently a number of options for advanced biofuel production exist but none are fully developed technologically. A system should be in place to alert the chemistry using industries to key developments in this area so that they can move quickly when novel sources of products come on stream. This is an area to be considered by any body set up to take forward the recommendations of the BI IGT.

8. Selected platform chemicals will increasingly be manufactured from renewable sources via IB. Land use limitations and temperate agriculture productivity will limit the scope for basic building block production in the UK to several large scale biorefineries where cost effective raw materials or product diversity provide competitive advantage.

Greater scope exists for the development of technology for medium tonnage platform and speciality chemicals in the UK. There is a need to de-risk the introduction of these technologies by making available demonstrators if the rate of progress in this area is to be optimised.

9. The scope for profitable production of fine and potentially speciality chemicals via IB remains high. A number of products such as citric acid are already produced on a large scale by IB and there are others in the pipeline.

Linking market-based product knowledge with technological expertise remains challenging for speciality chemicals. The strong UK science base in plant science, marine organisms and mycology should be linked more effectively to fine chemicals targets.

10. Products derived from IB, including platform chemicals, will be available for import from areas of the world with high land availability and high biomass yields. There is a need to ensure that UK industry is alert to the opportunities and challenges of adding value to these products via further deriativisation or reformulation.

This is a possible role for any body set up to take forward the recommendations from the IB IGT.

11. Biocatalysts are increasing their share of organic transformations and this is expected to continue to grow. This is an area of strength for the UK and biocatalyst producers should be encouraged to focus on medium to large scale opportunities.

Sourcing of speciality biocatalysts for specific pharmaceutical and fine chemical transformations is currently difficult. There is a potential business opportunity for small suppliers to enter the market.

With the developments in genetic engineering, it is now much easier to produce enzymes at a cost competitive price although there seems to be a lack of UK companies addressing the market. The key to success in this area is to have the appropriate plant and expertise. Given the changes in technology and the increased uptake of biocatalysis in industrial synthesis, there appears to be a strong business opportunity emerging.

12. Genetic manipulation of plants and other organisms will most likely be required to deliver the full benefits of IB to downstream sectors. The drivers will be for systems which express desirable products in high concentration and higher yielding plants. Recent developments in biology including the relative ease of genome sequencing will provide an additional impetus to the development of tools in this area.

Government policy across the UK (including the devolved administrations) will need to agree a supportive, consistent and stable policy for this activity aimed specifically at industrial (rather than human) end uses of products. Research Council policy should continue its support in this area.

Annex A

INDUSTRIAL BIOTECHNOLOGY INNOVATION AND GROWTH TEAM
TECHNOLOGY AND MANUFACTURING WORKING GROUP

HYPOTHESES AND PROPOSITIONS: ISSUE 2

1 MARKETS AND PRODUCTS SECTOR

Hypothesis 1

Some markets will pay a premium for products produced through Industrial Biotechnology with equivalent performance to their petrochemically based equivalents.

Commentary:

There is potential for a modest premium in some markets (for instance personal care) and for IB origin to be a short-term driver, in terms of an early adopter advantage, but in the medium/ long term performance differentiation and regulatory acceptance will take over as primary drivers. In some sectors there will be strong preferences for 'natural' products over their petrochemically derived equivalents with again a likely modest premium.

Hypothesis 2

There are many differentiated products, services and effects produced through Industrial Biotechnology for which markets could be readily developed.

Commentary:

This hypothesis has been combined with original Hypothesis 4 in this section. A number of UK companies are active in exploiting products, service and effects based on IB. There is still a question on the size and shape of the opportunity here with clear potential for products at the fine chemical/ pharma interface but less certainty on the economics of the pure platform chemical opportunity. Technology barriers (see later) still limit the development of IB based opportunities.
Whereas some market segments like water treatment and novel materials appear to offer attractive potential for IB based products, services and effects. It is felt that the potential for IB has not been sufficiently fully explored elsewhere. A focus event with product developers from a wide range of sectors is being scoped for consideration.

Hypothesis 3

Renewable feedstocks can produce platform chemicals via Industrial Biotechnology at a price to compete with petrochemicals on reasonable assumptions for oil and biomass input prices.

Commentary:
Nexant, BREW and DOE studies indicate some opportunities for platform chemicals. At the basic commodity end of the market competition from tropical agriculture economics may limit opportunities for world scale manufacture in the UK from indigenous resources. A key question will be to identify further individual product or product group opportunities where a UK indigenous operation could be economic.

Hypothesis 4

Opportunities will develop in the UK for downstream uses of imported IB-based commodity and medium value products in a number of supply chains.

Commentary:

Formulators will need information and support to adjust their product compositions to take advantage of newly developed IB derived products.

The issue of tariff treatment of IB derived commodity products such as Bioethanol will require clarification if the market is to be encouraged to move in this direction.

2 FEEDSTOCKS SECTOR

Hypothesis 1

Opportunities exist for manufacture of platform and selected fine chemicals from conventional co- and by-product streams using Industrial Biotechnology.

Commentary:

This Hypothesis has been broadened from its original scope of 'waste' to include co- and by-products for example straw, forest brash and food industry by-products etc as well as 'waste' streams. Issues of segregation, collection and applicability of IB will limit the scope of this opportunity.
A clear policy and regulatory framework will be needed to ensure that any emerging opportunities are not hindered by anticipated or unanticipated consequences of energy or waste treatment policies.

Hypothesis 2

Sufficient supplies of indigenous UK (or readily imported?) biomass can be economically obtained to manufacture a range of platform chemicals via Industrial Biotechnology

Commentary:

The UK Biomass Strategy should recognise the medium term opportunities for biomass consumption in downstream applications as well as the short term opportunities in energy generation. The growth of the petrochemicals sector out of crude oil processing and the oleochemicals sector out of natural fats and oils processing provide analogues of this type of opportunity.
Given the competitive need for world scale commodity chemical plants and the production levels of UK biomass, it is likely that there will be limited opportunity for massive plants based purely on indigenous biomass. If required, by analogy with the current and planned bioethanol operations, feedstocks will need to be imported. This in itself is not seen as a problem if a downstream economic edge can be delivered from market, technology or incentives.

Hypothesis 3

Marine sources of biomass offer attractive opportunities for production of fine (and platform?) chemicals

Commentary:

The marine opportunity is some years in development terms behind the plant and microbe based opportunities and there are some fundamental issues of technology, processing and carbon footprint impact to be resolved. However at the top end of the product and effect spectrum there is undoubted long term potential justifying research and process development. The case for marine products (e.g. algae) purely for energy generation is seen as still highly speculative

Hypothesis 4

At least a level situation in terms of incentives or policies for UK land use should be given to low volume, high value feedstocks for manufacture of fine chemicals and pharmaceuticals

Commentary:

Incentives to promote the uses of specific feedstocks needed to be levelled (in terms of biofuels and bioenergy obligations) if emerging downstream opportunities are to be viable. A major issue which requires a significant degree of engagement is the essentially annual strategic horizon of the average farm and the ten year view of the product manufacturer. Appropriate incentives for continuous cultivation of the selected crops need to be considered.

Hypothesis 5

Sustainable Biofuel technologies will offer opportunities for by-product manufacture of platform chemicals.

Commentary:

The descriptor ‘Sustainable’ for Biofuels technologies has been added to convey what have previously been termed ‘advanced’ or ‘second and third generation’ technologies.

Current biofuels operations have significant co-product slates so the hypothesis has a reasonable basis. Once the strategic future directions for biofuels have been established opportunities for co-product production must be assessed. It is likely that a number of critical technology issues such as lignocellulose and C5-carbohydrate transformations will require resolution to allow significant value to be delivered in this area.

Hypothesis 6

Significant improvement in agricultural product yields will have a positive impact on the application of IB and the growth of IB based products. Similarly improved processability and content of desired products from plants will be significant benefits achievable from improved plant strains and varieties.

Commentary:

Improving product yield, processability and active content are seen as important areas in the competitive development of IB-based products and services. This can be achieved by GM modification and/ or conventional agriculture.

3 PROCESS TECHNOLOGY AND SCIENCE SECTOR

Hypothesis 1

The wider use of Industrial Biotechnology in the UK chemistry using industries is inhibited by the absence of access to medium and large scale development equipment particularly related to extraction, fermentation and biocatalysis scale up.

Commentary:

This is agreed to be a valid and important issue. It will be important to define the asset requirements in terms of scale and capability and also the potential business model for operation of such potentially ‘open access’ equipment.

Hypothesis 2

Wider use of biocatalysis in the chemistry using industries requires significant improvements in process intensity and catalyst life.

Commentary:

This is a significant limitation on application of IB in many sectors. Optimisation, scalability and demonstration of technology is more important than discovery of new systems. Economics of enzyme manufacture and supply lead to potential discontinuities in the supply chain.

Hypothesis 3

Production of fine chemicals (and pharmaceuticals) via expression in transgenic plants offers an economic route to high value products if concerns around use of GM plants can be resolved.

Commentary:

There are undoubted opportunities for chemicals and materials here but the case for widespread application of transgenic plants as 'chemical factories' set against genetically modified microbial systems has yet to be confirmed.
The stance of the IGT towards GM will need to be defined

Hypothesis 4

A multi feedstock 'Biorefinery' operation to yield platform chemicals (and fuels) is potentially technically and economically feasible.

Commentary:

This is likely to be a highly desirable way to reduce risks of feedstock pricing and availability but initial biorefineries are likely to be based on a simple feedstock proposition to minimise technical risk. Integration of biorefineries with conventional chemical operations to give more flexible downstream processing is attractive in theory but has yet to be proven practically. The IBTI initiative sponsored by BBSRC and Bioscience for Business KTN is a step in the right direction.

Hypothesis 5

'Local' processing of biomass followed by transportation of a more concentrated feedstock to a 'Central Biorefinery' is a technically and economically viable route to chemicals/ fuels.

Commentary:

This is a critical question requiring resolution ahead of any biomass processing strategy. Propositions need to be worked up for consideration.

The production of biofuel at increasing scales will drive the development of biomass densification strategies to relieve logistical constraints on lignocellulosic biorefinery size. Provided the focus of biofuel development remains biochemical in nature (i.e. based on fermentation of sugars, as is the current case in the USA) then the densification technology and infrastructure developed by the biofuel industry will be available for adoption by the chemical industry. The development of technology and its implementation should be monitored.

Annex B

POTENTIAL STEP OUT OPPORTUNITIES FOR IB TO MEET MAJOR SOCIETAL CHALLENGES

Anaerobic Digestion

The efficient conversion of waste to energy is an important societal requirement impacting resource availability and climate change. Anaerobic digestion is the leading candidate technology for organic waste conversion. It is strongly promoted in the UK Government's 2007 Waste Strategy because of its overall contribution to recycling as well as its carbon reduction impact: it "gets the energy out of food waste" (reduces carbon content) before the residue is used as fertiliser (using its enriched nitrogen and phosphate content).

- Current Anaerobic Digestion technologies are at an early stage of development maturity and significant opportunities exist to deliver major improvements in efficiency and productivity by combining UK skills in industrial biotechnology and chemical processing technologies.
- Success would result in improved capital productivity and conversion efficiency needed to enable more rapid introduction of anaerobic digestion technology with the concomitant positive environmental benefits.
- A further goal would be developing economically viable "local-scale" plants (c. 5-10,000 tpa) to reduce logistics by matching the process to the arisings of a typical municipal food waste collection, enabling sustainable communities.
- Technology licensing outside the UK would provide potential additional benefits.

Potential Recommendation:

The IB-IGT recommends government incentivises development of IB-enabled, "fit for purpose" Anaerobic Digestion as a key contribution to the UK's Waste Strategy through a research, development and deployment competition.

Carbon Capture and Re-use

Carbon Dioxide sequestration from combustion power generation units is a critical technological challenge for the delivery of long-term climate change targets. There is international recognition of the urgency of developing commercial scale Carbon Capture and Storage and it is a key plank of the UK Government's Climate Change Strategy. However, physical absorption and capture technologies under active development are likely to suffer kinetic and thermodynamic constraints that will limit their capital and revenue effectiveness. In addition, storage in geological reservoirs either constrains the applicability of CC&S to favourable locations or incurs additional capital costs and efficiency loss in pumping through long-distance pipelines.

An opportunity exists to develop carbon dioxide sequestration technologies using biological systems as the capture vector. If carbohydrates result, this would enable re-use of the carbon – a fundamental improvement over storage.

- Such technologies are at an early stage of development but combining UK skills in industrial biotechnology and chemical processing should significantly increase the success potential.
- Such a technology if it could be proved would yield major benefits in the cost and effectiveness of carbon dioxide sequestration over conventional physical systems.
- Further benefits could come through the symbiosis with other processes using the combination of waste heat from the combustion power generation process and the availability of bio-feedstocks.

Potential recommendation

The IB-IGT recommends that its CC&S programme prioritises solutions that enable economically productive re-use of the carbon, allocating 50% of the government's CC&S RD&D funding to IB-based technological solutions.