Sustainable Returns

Industrial Biotechnology Done Well

A Report for the Industrial BioTechnology Leadership Forum

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January 2013

forum for the future

Contents

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Executive Summary

Back in May 2009, the Industrial Biotechnology Innovation and Growth Team published its ground-breaking report on the potential for industrial biotechnology (IB) here in the UK. Three and a half years on, much progress has been made, and the Industrial Biotechnology Leadership Forum has been able to take forward many of the recommendations made in that original report.

It was also agreed at that time to set up a Stakeholder Council, of which I have been the Chair. Our discussions led to an agreement to produce a report examining what 'IB Done Well' might look like – from a full-on sustainability perspective. 'Sustainable Returns' is the end result of that process, which has involved a significant level of consultation with members of both the Stakeholder Council and the Leadership Forum.

The headline conclusion will hardly come as a surprise: that potential for the growth of IB applications here in the UK is indeed huge. We already have a significant research base, very active support from the Research Councils and the Technology Strategy Board, strong backing from Ministers, and a wide range of companies, both big and small, at the cutting edge of new development.

All of that is the minimum required for IB businesses (and users of IB processes and applications) to thrive in this country. This is a highly competitive sector, and the report highlights developments in other countries (including the US, Brazil, China and other European countries) where things seem to be moving forward even more purposefully.

In other words, there are still significant barriers to IB achieving its full potential here in the UK, and these are covered in some detail in Section 5, both from a public policy perspective and an investor perspective.

A big part of addressing those barriers is to ensure that IB, in all its many manifestations, meets the highest possible sustainability standards. That is where much of the debate about IB is still going on, particularly around key issues on biofuels, land use, GM, transparency and regulation.

Arising out of those debates, I have set out to consider a list of 'policy and industry mandates'. These will ensure that IB businesses in the UK are indeed driven by the kind of sustainability imperative that is now so critical in every sector of the global economy. From this kind of 'Done Well' perspective, IB businesses would:

1. Aim to achieve substantial societal and environmental benefits, as well as business benefits.

2. Support regulatory and governance structures that put public interest and private gain on equal footing, and promote extensive stakeholder engagement.

3. Avoid adverse impacts on food security and affordability.

4. Secure demonstrable, substantial reductions in greenhouse gas emissions.

5. Commit to production systems that optimise conditions for biodiversity and healthy ecosystems.

6. Commit to manufacturing processes that maximise the value of all feedstocks (eg closed-loop systems).

7. Place no additional burdens on the availability of scarce water supplies.

8. Avoid any risk of gene transfer in the open environment.

9. Pose no threat to human health.

10. Achieve the highest standards of health and safety both for workers and surrounding communities.

Such mandates cannot be delivered overnight. But they should steer the direction of travel for what is now a critical part of our economy – and one which depends on public support for its 'licence to grow' in the future.

In essence, this is all about responsible research and innovation. Both the Technology Strategy Board and the Research Councils have recently developed Frameworks to help define exactly what that means. They talk about "openness and transparency" as integral components of the research and innovation process, and put the strongest possible emphasis on "the consistent and ongoing involvement of society".

That is very much what this Report is all about, in the interests of stimulating a wider debate and consolidating the extensive common ground that already exists between all the different parties involved in growing the contribution of IB to the UK economy.

Jonathan Porritt

January 2013

Section 1 – Making the Case

The economic outlook for the next few years, following the crash of 2008, does not look good. And the worsening state of our environment (particularly in terms of accelerating climate change) is now a huge cause for concern. Wherever possible, it makes good sense to address these two crises in tandem.

By far the most intelligent way of addressing our environmental problems is by developing a new economic strategy: generating jobs and prosperity by massive new investments in what has been described as the Green Economy.

When people talk about the Green Economy, they usually limit themselves to energy efficiency, renewable energy and waste management. Both are indeed crucial, but they are not sufficient.

Waiting in the wings is a whole raft of technology breakthroughs that could have an equally dramatic impact on our lives – in the fields of agriculture, forestry, healthcare, manufacturing and industry in general. Welcome to the emerging world of Biotechnology.

I want to put my cards on the table right up front. After many years reading about these things, with endless discussions about the risks and the opportunities, the pros and the cons, I have come to the conclusion that our prospects for achieving a genuinely sustainable economy will be significantly enhanced by putting biotechnology at its heart.

Given that all of the wealth we create today is drawn from the natural world (whether we are talking about food, minerals, energy, fibre or whatever), you could say that ours is an economy already based entirely on biology. But modern biotechnology offers us something quite different: an opportunity to use those materials to produce the goods and services we need with far less impact on the natural world.

Of course, it is nothing like as simple as that. There is no guarantee that we'll put those technologies to <u>good</u> use.

Like all technologies of this kind, Biotech is neither good nor bad in and of itself. The good stuff or the bad stuff is all down to us – and people will not all agree where the dividing line between the two will fall. And there is no guarantee they'll make that big a difference in the limited amount of time we have still got to engineer <u>real</u> sustainability breakthroughs.

But all parties in this debate do need to start with a shared sense of purpose. Given the challenges we face today, both economic and environmental, we should enthusiastically embrace the potential of biotechnology to help us meet those challenges – and then work out how best to do that.

‘Biotechnology simply means making the best possible use of Nature’s raw materials, working with Nature to help meet human needs in ways that cause no harm to humankind.’

Section 2 – The Basics

For me, biotechnology simply means making the best possible use of Nature's raw materials, working with Nature to help meet human needs in ways that cause no harm to humankind.

We have been hard at work doing exactly that for thousands of years – ever since our primitive ancestors made life a little less primitive by learning how to convert the starch in certain grains into sugar in order to produce beer! Fermentation is still a critical part of the world of biotechnology today.

Come the Industrial Revolution, we started getting clever at this stuff. They first learned how to make plastics from plants back in the 1860s. In the early 20th Century, the earliest Model T Fords ran on ethanol from plants rather than petrol.

For almost as long, we have been using bacterial enzymes for all sorts of purposes, originally in the making of cheese and other foodstuffs. Enzymes are smart proteins that act as catalysts in kicking off chemical reactions, and are used today in many different industrial processes – we are probably most familiar with these in terms of enzyme-based detergents.

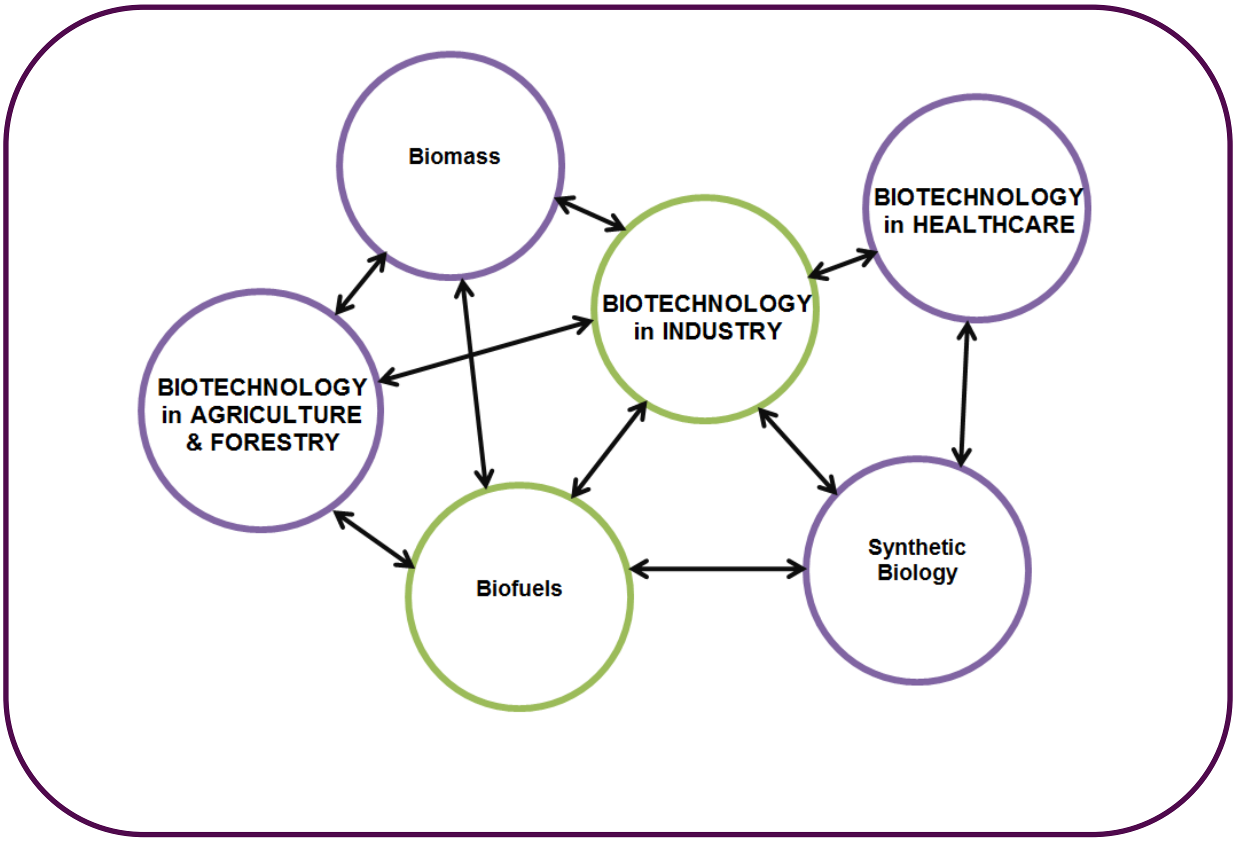
So biotechnology has been around for a long time. These days, people talk about different kinds of biotechnology cutting across three different sectors:

- For use in agriculture, aquaculture and forestry – sometimes called "green biotech".
- For use in healthcare and pharmaceuticals – sometimes called "red biotech".
- For use in industry and manufacturing – sometimes called 'white biotech'.

This report is focused on Industrial Biotechnology (IB), including the development of advanced biofuels. But as you can see from the diagram, all three families of biotech are closely connected, and all share the same set of research tools and basic platforms – which I will come back to.

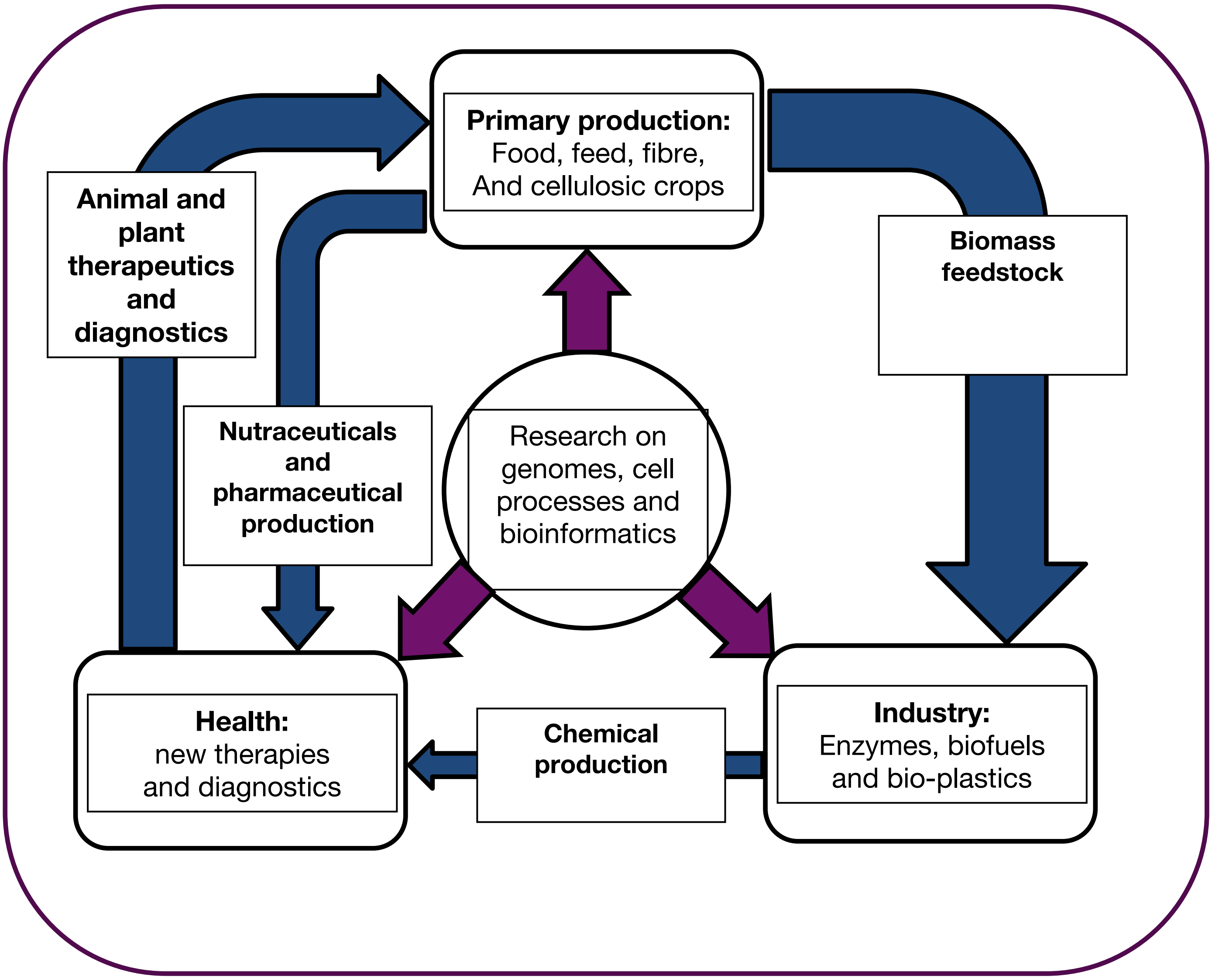
The prospect of integration somewhat obscures the lines between green, red and white biotech – and this has an important bearing on public attitudes. For instance, the value to society of new drugs involving the genetic modification of microbial and mammalian cells (manufactured in controlled industrial facilities) outweighs public concern about the genetics involved. And NGOs are perfectly comfortable about this. Moreover, this is a big area of economic development: it is reckoned that 7 of the top 10 best-selling drugs will be biotech-made by 2014, representing around 30% of a $0.6 trillion market. This healthcare model, based on strictly controlled uses of IB, provides the foundation for much of the rest of the IB world in the future.

The Bio-economy



The sum of all that (including the relatively new field of Synthetic Biology) is what is often referred to as **the bio-economy** – defined rather unimaginatively by the OECD as "the set of economic activities relating to the invention, development, production and use of biological products and processes….. to improve health outcomes, boost the productivity of agriculture and industrial processes, and enhance environmental sustainability".

And there is plenty of scope for cross-fertilising between the three main kinds of biotechnologies; new developments are increasing the level of integration all the time, as highlighted in this diagram.



Current and Expected Integration Across Biotechnology Applications[1]
(Note: Arrow width represents the relative importance of the integration)

By any standards, therefore, **the bio-economy** is already big, and will get to be a great deal bigger. That is what makes it such a strategically significant part of the overall Green Economy, as was eloquently highlighted in the National Bioeconomy Blueprint for the USA, published by the White House in April 2012[2].

Industrial Biotechnology

At its simplest, Industrial Biotechnology is all about transforming biomass into bio-based products – in sectors as diverse as chemicals, food, textiles, fuels, detergents, pulp and paper. That biomass can come from agricultural crops, other plants and grasses, agricultural and forestry residues, other sources of organic waste, and, last but not least, from algae and other marine sources.

Instead of using oil (from which we get the lion's share of all the transport fuel and chemicals that we use today), biotechnology allows us to use biomass to produce biofuels, bio-chemicals, bio-plastics and other materials. For the most part, those bio-based products are identical to products derived from oil, but some of the chemical building blocks generated from the use of micro-organisms like enzymes have specific capabilities that conventional petrochemical (oil-based) processes cannot provide.

But all of those things are still dwarfed by the use of biotechnology to produce biofuels – mostly in the form of ethanol from sugar, corn or wheat, or biodiesel from rapeseed. In Europe, these are blended with conventionally-derived petrol or diesel, in direct response to the EU's Renewable Transport Fuels Obligation. And that is where the controversies kick in, as I will cover in Sections 3 and 6.

The other big controversy is of course genetic modification, or GM. This debate is much more relevant to agricultural biotechnology (in terms of all the GM crops that have been developed over the last 15 years or so), but it is relevant to Industrial Biotechnology too.

Not least, as I said, because the same kind of research tools and basic technologies are used for some Industrial Biotechnology processes. Most people forget, for instance, that the man-made insulin that keeps countless diabetics alive today derives from a genetically modified form of *E.coli*, a bacteria normally viewed as a serious health risk, but in this modified form doing its stuff for us in huge fermentation tanks. Penicillin and other antibiotics depend on biotechnology processes.

The debate about GM (in the UK and the EU, if not in the USA) has been one of the most polarised and vexatious of recent times. This is not the place to revisit that broad debate, other than to reflect on those aspects of it that are relevant to the future growth of Industrial Biotechnology as a whole.

That means thinking about two principal aspects: the use of genetically modified feedstocks, as is the case, for instance, with the GM-corn grown in the USA for conversion into ethanol; and the use of genetically modified micro-organisms to act as bio-catalysts or other component parts in particular processes.

All the research into public perception of these issues tells us that most people are influenced by very different factors when weighing up the balance of benefits and disbenefits of GM. But three stand out:

1. Benefits

   People's perception of risk is strongly influenced by their perception of the benefits that might accrue from any GM development; the more direct the benefit, the greater the level of tolerance, as is clearly the case in the healthcare sector.

2. Trust

   By and large, most people in the UK tend not to trust reassurances either from Government or from those businesses that have a direct commercial interest in GM. Independent scientists and NGOs command much greater trust.

3. Containment

   GM products or processes that are contained within a laboratory or a controlled work environment are seen as much less risky than GM crops being deployed in the open environment.

All those considerations are directly relevant to IB, as I shall come back to later.

For the time being, all I want to suggest is that we keep this in perspective. The techniques involved in GM have moved on enormously over the last decade. Sequencing technologies have been dramatically speeded up, and the costs involved in generating valuable genetic data have been greatly reduced.

At the same time, selective breeding techniques that do not involve GM (such as Marker Assisted Selection (MAS) which uses biological or chemical markers to identify traits in plants) have greatly reduced the time required to develop new varieties based on conventional breeding techniques.

One thing I do know: it would be ridiculous for our whole approach to IB to focus narrowly on GM. There is so much more at stake here. Things have moved on so far over the last few years. The GM debate is still important, and it is foolish to think we can address IB issues without taking it properly into account; for many people, the mere mention of the word "biotechnology" triggers all sorts of GM-related connotations. But it should not be the principal determinant of how we feel about IB.

‘The big debate here is about land use. As food prices surged again towards the end of 2012, because of severe drought in the US and elsewhere, the food versus fuel debate has been reignited with a vengeance.’

Section 3 – What can IB contribute to a more sustainable world?

Many bold claims are made by those in the industry that IB brings with it significant benefits from a sustainability point of view. Some of these claims have been reviewed in an authoritative report by WWF and the Novozymes Foundation, *Assessing the Opportunities*[3]. For instance:

1. Improve efficiencies in the food industry.

   The use of enzymes and yeast in the food industry can certainly result in a much more efficient use of natural resources – and indeed in reduced energy consumption and reduced emissions of greenhouse gases. Enzyme-based systems can out-perform traditional manufacturing systems, using less energy, generating less waste, and avoiding the use of potentially hazardous chemicals.

   Such uses include enzymes added during the baking of bread, increasing yields for wine and fruit juices, improving cheese production systems, improving the digestibility of animal feeds, and so on. Enzymes can also be used to make existing processes such as the tanning of leather a great deal less polluting.

2. Reduce our dependence on oil – substitute oil with biofuels of different kinds.

   The biofuels market has essentially been driven by policy decisions taken in both the US and the EU to reduce our dependence on fossil fuels. The EU first set a substitution target of 5% (with different countries moving at different speeds in achieving this target), moving towards a 10% target by 2020. It was recently decided that the target will stay at 5%. The US has stipulated a minimum volume by 2022 (36 billion gallons - which is roughly 15% of the total liquid fuels market). China has also adopted a 15% target by 2020.

   However, it is Brazil that has really led the world on the production and use of bio-ethanol, going right back to the 1970s. Both sugar cane (in Brazil) and sugar beet (in Europe) have a high enough sugar content for ethanol to be produced by direct fermentation. Other crops (such as maize, wheat or cassava) have to be treated first to convert their starch content into sugar before fermentation can take place – and the same is true of other sources of biomass rich in cellulosic materials, though at much greater expense.

Bio-ethanol substitutes directly for petrol. Bio-diesel is produced through a completely different process, taking oil-rich plants (such as rapeseed, soy beans, oil palm, sunflower or jatropha) and converting those oils through a process called transesterification into bio-diesel.

We know these processes work. <u>But the big debate here is about land use.</u> As food prices surged again towards the end of 2012, because of severe drought in the US and elsewhere, the food versus fuel debate has been reignited with a vengeance.

Ethanol Production

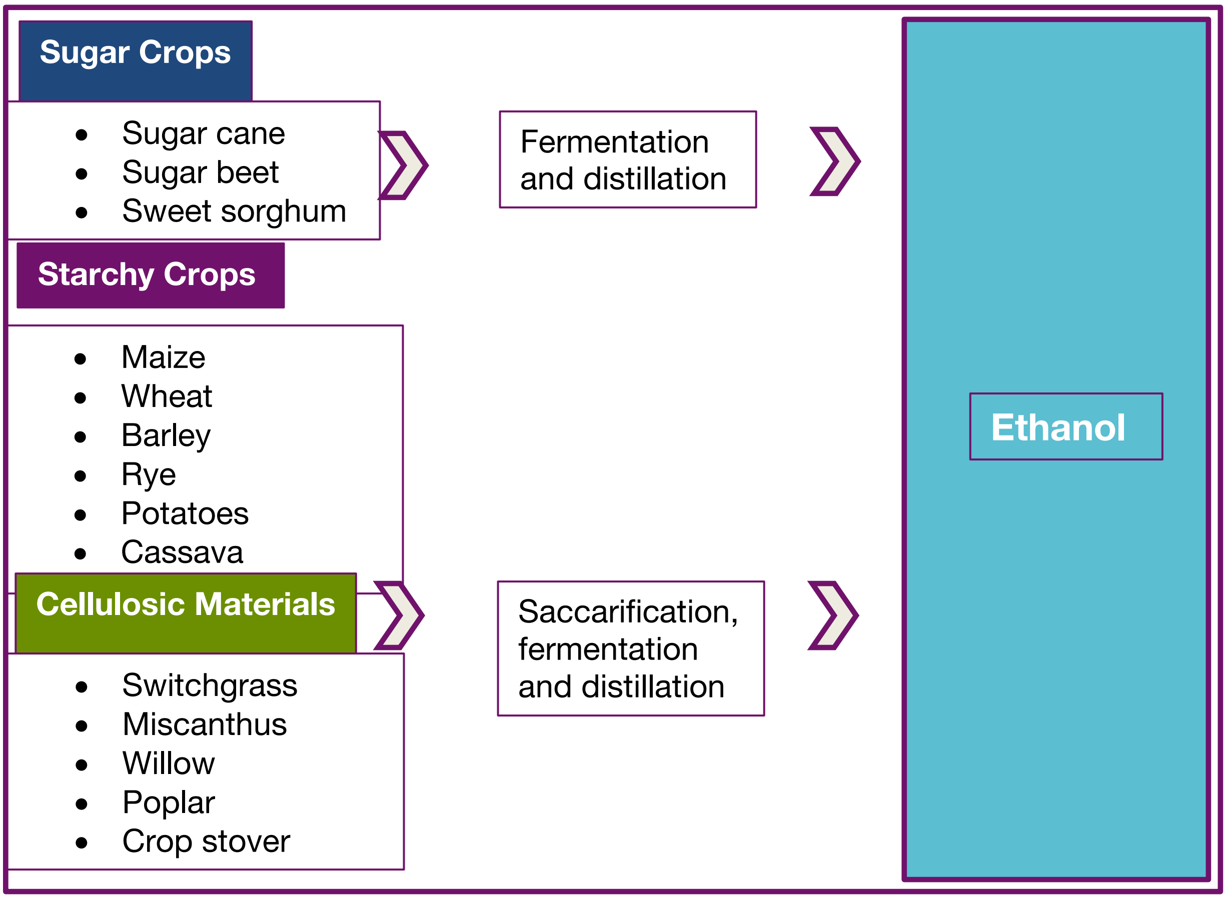


Figure taken from WWF/Novozymes Report[4]

Each hectare of land can only be used for one primary purpose: producing food for direct human consumption; producing feed for livestock systems; producing crops for use as fuel; producing crops for use as feedstocks for the chemical industry. Food campaigners have long argued that millions of people in some of the world's poorest countries are suffering directly because of valuable land (particularly in the US) being used to produce biofuels rather than food.

And environmentalists continue to point out that Nature has to be factored in here too – in terms of biodiversity and what are now referred to as "ecosystem services", including pollination, fertility-building in the soil, flood control and so on. We have already paid a very heavy price (in terms of soil erosion, over-abstraction of fresh water, climate regulation and so on) for down-playing or ignoring the fundamental importance of dependence on these services.

And it's not quite as simple as this anyway. There are all sorts of secondary value: agricultural residues that can be converted into biofuels; animals feeds that can be produced as a by-product of ethanol production. The food and fuel relationship is not a zero sum gain.

But it is of fundamental importance. There is little genuinely "spare land" in the world, and the word "marginal" often ignores the biological value of that land. Once we start to take climate change seriously, we will need to achieve dramatic reductions in greenhouse gas emissions from agriculture – and we will need as much if not more land for the agro-ecological farming systems that will become dominant. Reducing meat consumption is just about the only "system change" in modern agriculture that will free up a lot of land for biofuels or biofeedstocks – a double benefit from a more holistic sustainability perspective.

A final point here: ethanol is a perfectly efficient fuel (especially when engines are optimised for ethanol's high octane properties), but it is not a particularly dense fuel. For every litre of straight petrol, bio-ethanol provides only 65% of the equivalent energy. That is why there is growing interest in bio-butanol, which can be made from exactly the same feedstocks but is a much denser (i.e. more energy efficient) fuel. Vivergo (a joint venture between BP Biofuels, Du Pont and AB Sugar) is currently trialling bio-ethanol production systems at its new plant in Hull, with a view to extending to bio-butanol in the future.

Picture by www.simplespoonful.com

3. Reduce our dependence on oil by using bio-materials to produce the chemicals we need.

   IB can already be used to produce a variety of different molecules and compounds that are currently produced using oil as the basic feedstock – these are often referred to as bio-polymers or bio-plastics.

   The gains can be significant – particularly in terms of reduced emissions of greenhouse gases. More than five years ago, the EU-funded BREW project identified a large number of bio-based products that could be manufactured using biotechnology – with substantial greenhouse gas reductions per tonne of production.

   But we need to keep this in perspective. Less than 10% of the total volume of oil we use today goes into the chemicals industry – the rest is used for transport fuels or energy generation. And significant breakthroughs in biochemistry will still be needed to produce chemicals at lower cost than current petrochemicals – although the higher the price of oil, the easier this becomes.

   Much of the interest here is in so-called "fine chemicals" – high value but relatively low volume. Chemistry-using companies (in food or cosmetics, for instance) are keen to explore the opportunities of bio-based "active ingredients". Other companies involved in bio-plastics (such as Braskem in Brazil) are able to produce polyethylene derived from sugar cane ethanol, but remain dependent on customers being prepared to pay a premium price for the environmental benefits it delivers. (Paradoxically, however, the price of bio-feedstock often increases as oil prices increase – simply because the production processes for sugar and maize are dependent on the use of fossil fuels).

4. Reducing waste.

   In the pharmaceuticals sector, classical organic chemistry makes drugs through multi-step synthetic processes – with low yields and high costs. Selective enzymatic processes dramatically reduce the number of steps required, simultaneously reducing costs.

   The use of IB in the water and waste industries is already very well established, improving efficiencies in waste water treatment plants, anaerobic digesters and so on.

   But there is now growing interest in the idea of more integrated and sophisticated bio-refineries, capable of processing all sorts of different feedstocks (crops and organic waste, for instance) into different bio-based materials for use in different industries. The organic fraction in household waste can be converted into sugars and then fermented into either fuels or chemicals.

The whole idea here is to “close the loop” so that what would otherwise be a “waste problem” becomes a critical feedstock for a different industrial process.

Potentially, there are very exciting opportunities opening up here, and one of the great benefits would be the knock-on effects on land use. Instead of needing more and more land to produce IB’s raw materials, biorefineries will maximise the value of what would otherwise be problematic waste streams. Food companies today are increasingly keen to find ways of eliminating food waste problems. I will return to that in Section 7.

So what is the net effect of all that? Taking the long-term view, it is self-evident that we should be aiming to reduce our dependence on finite reserves of oil – and on petrochemical products derived from that oil. IB opens up that possibility. Even if you do not subscribe to Peak Oil theories (that we are very close to the point where we will have used up more than half of all available oil reserves), it makes sense for countries to improve their energy security by maximising the use of renewable resources.

In the near-term, if bio-based fuels and bio-based chemicals can indeed reduce our use of oil, and substantially reduce emissions of greenhouse gases (GHG) in the process, that is obviously a real sustainability win.

The WWF/Novozymes Report has carried out a detailed analysis of just how significant a “win” that might be. Whilst acknowledging that there are still all sorts of methodological issues involved with different kinds of Lifecycle Analysis, it nonetheless comes to the broad conclusion:

> “This report shows that IB can deliver significant GHG emission reductions, if focussed on achieving sustainability goals. A substitution of fossil fuels with biofuels can deliver global emission reductions estimated to be between 207 and 1,024 MtCO_2 by 2030. In addition, a critical number of petrochemical materials could be substituted by bio-based materials, achieving GHG emission reductions ranging between 282 and 668 MtCO_2 by 2030.”[5] (Author’s note: that puts the range at between 1.5% and 5% of total global emissions).

Given the scale of the reduction we now need to make in emissions of greenhouse gases, this would obviously represent a very material contribution to a massive problem – and demonstrate in the process that we really can wean ourselves off fossil fuels.

‘The World Economic Forum’s Report on the future of industrial biotechnology estimated that the business of converting biomass into fuels, pharmaceuticals and other chemicals has the potential to generate upwards of $230 billion by 2020.’

Section 4 - IB: the current state of play

IB is not seen as an economic sector in its own right; it comprises a set of tools and processes relevant to many different sectors. And that's what makes it so difficult to pin down!

As it happens, there has been quite a buzz about modern biotechnology for more than 20 years, and as we have seen, biotechnological applications have been around for a very long time. But as our knowledge of all the key elements in Biotech has deepened, the realisation of just how significant it could be has continued to move up the political agenda.

The Size of the Prize

The World Economic Forum's Report on the future of industrial biotechnology[6] estimated that the business of converting biomass into fuels, pharmaceuticals and other chemicals has the potential to generate upwards of $230 billion by 2020. But this figure is dwarfed by the total value of industries such as brewing which are driven by IB, contributing hundreds of billions of dollars to the global economy.

One of the reasons why the last UK Government set up its Industrial Biotechnology Innovation and Growth Team (IB-IGT) initiative was to assess what it called the "size of the prize" for the UK. It concluded that the global IB market in 2025 could be anywhere between £150 billion and £360 billion (depending on all sorts of variables), of which the UK's share could be between £4 billion and £12 billion.

The EU has taken a very active role in promoting the prospects for IB over the last few years. The European Commission set up an Advisory Group for Bio-based Products back in 2008, and the recommendations it made a year later (based on an assumption that <u>one third</u> of chemicals in 2030, including bio-polymers and bio-plastics, will be produced from biological rather than petro-chemical feedstocks) have informed the debate since then. The Commission's Lead Market Initiative for Bio-based Products has already had some impact in stimulating demand for innovative new products, through its Vision for Sustainable Growth.

Europe already holds the leading position in the development and production of enzymes (with Denmark out in front), and is strong in bio-chemicals and some bio-polymers. When it comes to biofuels, it is reasonably well-placed in terms of available feedstocks, with abundant supplies of straw from cereals providing a reliable source of cellulosic feedstock for advanced biofuels and other biotechnologies.

The emphasis in the UK has always been on innovation, skills and knowledge, with the ambition to lay claim to a larger share of IB's overall economic value than it would be able to do if that value was based on land area alone. UK research is already seen to be world-leading in many different aspects of biotechnology (particularly medical biotechnology), and there is a strong and highly experienced skills base in our chemistry-using industries. It is absolutely critical that this skills base is nurtured through a clear strategy for Higher Education.

The IB-IGT published its Report in May 2009[7], providing a powerful vision for the promotion of IB here in the UK (see below). Since then, its recommendations have been taken forward under the auspices of the Industrial Biotechnology Leadership Forum. One of those recommendations ("to establish an open access demonstrator facility particularly for fermentation-based innovations") led to the setting up of a £12 million demonstrator at Wilton, as well as the Technology Strategy Board's £2.5 million. The Centre for Process Innovation was also set up specifically to help build the IB base here in the UK.

> "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 the 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."

The UK's innovation agency, the Technology Strategy Board, has been actively supporting UK companies to develop new products, processes and services using Industrial Biotechnology. IB is one the strategic themes in its Biosciences Strategy, and it funds the Biosciences Knowledge Transfer Network (KTN) which supports networking in the area of renewable and sustainable bio-products. The Chemistry Innovation and Biosciences KTNs have a Special Interest Group in Industrial Biotechnology, which supports the work of the Industrial Biotechnology Leadership Forum as it takes forward the recommendations of the IB-IGT report – specifically to help chemistry-using industries reduce energy use and generally "green" their operations through the use of IB.

Academic research in the area is funded mostly by two Research Councils (the Biotechnology and Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC)) who collaborate on joint education and project funding, including the Bioprocessing Research Industry Club (BRIC). For instance, BBSRC is funding a big "cellulosic to ethanol" conversion project at Nottingham and Bath Universities.

So what's in it for us?

Apart from the biofuels story, what exactly are we talking about here in terms of real products making a difference in real people's lives?

Pharmaceuticals

Most drugs are complex molecules that have to go through many purification processes to make them fit for human use. I've already mentioned both insulin and penicillin, but many pharmaceuticals have benefitted from "leaner" IB processes. Viagra has for a long time been held up by Pfizer for its green credentials. A new reaction process radically reduced the amount of solvent required, cut out a number of hazardous and polluting materials and reduced waste by 75%.

BASF has greatly improved the manufacturing process for ibuprofen, using a three-step rather than a six-step process. As its literature now claims, 77% of the atoms used in the resulting synthesis end up in the final product rather than 40%.

Industrial enzymes

There are already umpteen different programmes pioneering different ways of using industrial enzymes in the food or drinks industry, in animal feeds, in textiles, in detergents, and in the pulp and paper industry. Many of these applications have already produced significant environmental benefits.

There are now a large number of new applications in the pipeline, many of which promise further environmental benefits in terms of increased energy efficiency, reduced water use and lower greenhouse gas emissions. Current research is aimed at expanding the range of useful enzymes through a number of different techniques including genetic manipulation, advanced selection techniques (including MAS) and different screening systems. It's a hot area – and is projected by everyone involved to keep on growing.

It makes particularly good sense to make better use of enzymatic catalysts in place of precious metal catalysts. These allow for inherently safer reactions to be carried out at ambient temperatures, thus reducing both energy use and waste.

Bio-plastics

Bio-plastics can be used for packaging, fabrics and some consumer durables (such as electronics casings and car components). Some of these bio-plastics are biodegradable; others are not. Some bio-plastics do not require particularly sophisticated processes; others do. There are already a number of big bio-polymer plants around the world – in the US (where a company called Natureworks produces polylactic acid using a fermentation route from starch), China, Italy, France and Brazil.

Braskem is the largest producer of thermoplastic resins in the Americas, with a 200,000 tonne Green Polyethylene plant in Triunfo. (Green PE has exactly the same characteristics as conventional PE – including recyclability – but with a reduced carbon footprint).

Copersuca, one of the biggest sugar companies in Brazil, has also led the way with a pilot-scale production plant for different polyesters. These natural polymers (synthesised by various bacteria strains) have properties very similar to petrochemical-based polymers such as polyethylene or polypropylene, and can be rapidly biodegraded by a large number of micro-organisms. (Research is also under way on producing these polyesters from GM switchgrass, but cost is still a huge issue.)

The US company Metabolix has been pioneering the production of PHA (an intermediate that can used to make a variety of different plastics) directly from switchgrass.

Other biochemicals

A number of chemicals and pharmaceuticals are already being manufactured by means of enzymes or fermentation, including vitamins, antibiotics and amino acids. A company called Excelsyn has pioneered low-cost ways of producing the amino acids that are used in so many different pharmaceutical processes.

A company called Croda has made major investments in new fermentation technologies at its Ditton site near Runcorn. This means they can move on from the very energy-intensive, multi-stage manufacturing processes that they used to depend on for their special chemicals, to single-stage processes that use much less energy. Sederma, one of Croda's subsidiaries, has developed a unique range of biochemical ingredients for skincare and beauty products.

As well as these fine chemicals, there are also opportunities to use bio-feedstocks to produce some high-volume commodity chemicals. A company called Green Biologics here in the UK is using advanced fermentation technology to convert agricultural residues and Municipal Solid Waste into Bio-n-butanol, a process that was first commercialised in the UK nearly 100 years ago! (n-butanol is an important chemical precursor of paints, plastics, coatings and polymers).

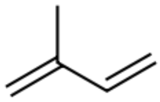
Companies like Myriant and Bioamber are constructing plants in the US to produce succinic acids. In Italy, a company called Genomatica is building a plant to produce butanediol. BASF has teamed up with Novozymes and Cargill to commercialise a process to produce bio-acrylic acid.

The tyre company Goodyear has teamed up with a company called Genencor to produce bio-isoprene (a key ingredient used in the manufacture of tyres) and they are hoping to produce partially recyclable tyres with a much lower climate impact.

Case studies: Bio-isoprene

Genencor/Goodyear – from switchgrass and sugar cane to tyres

Microbial strain development

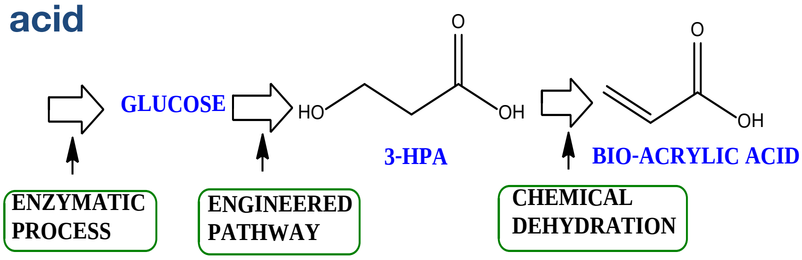


fermentation

recovery & purification

- Manufacturing a conventional tyre requires
  - 7 gallons of petroleum feedstock per tyre.
  - Using Bio-isoprene will reduce that down close to zero

Case studies: acrylic acid



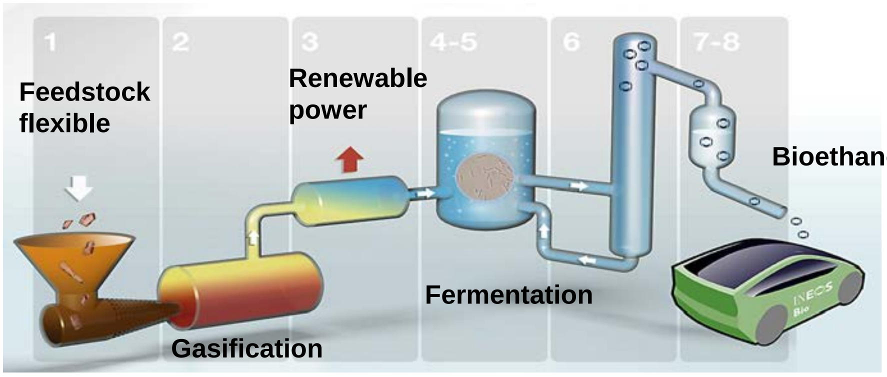
- petroleum-based acrylic acid & its esters: $8-11 billion global market

Case studies: 'Rubbish' to Bio-ethanol

INEOS Bio

- Convert low cost biomass & wastes (MSW) to clean fuel and energy
- Deliver a step change in greenhouse gas emissions
- Achieve both in a safe, reliable, cost effective & sustainable way

BIOMASS SYNGAS BIOETHANOL



Blue biotechnology

"Blue biotechnology" is sometimes used to categorise all IB innovations based on the marine environment, covering pharmaceuticals, chemicals and fuel. Apart from marine algae (which may or may not turn out to be the "wonder biofuel of the future"), the marine environment is already a rich source of new pharmaceutical compounds, natural biopolymers such as carrageenan and agar, and essential fatty acids. The cosmetics industry is particularly involved in new research here.

Bio-remediation and bio-sensors

Biotech is already widely used in the environmental services sector to clean up contaminated soils or sediments using a range of micro-organisms and these bio-remediation technologies have been at the heart of most sewage treatment plants for decades. Work is going on all the time to find ways of improving the efficacy of micro-organisms in neutralising harmful compounds, not least to improve their own resistance to toxins and heavy metal. Again, this is an area where both GM and MAS techniques are being used.

Bio-sensors are used in a variety of different contexts for monitoring the state of the environment, using enzymes to detect the presence of various chemical compounds.

So, there's already a lot going on beyond the world of biofuels, and a lot more in the pipeline.

However, a word of caution about what this currently amounts to in financial terms. The global chemicals sector has an annual value in excess of $1 trillion – and the IB contribution to that is still no more than 2%. Disruptive technology breakthroughs require a longer timeline than incremental innovation. This is particularly the case when dealing with complex living systems which is why it is sensible to look at some of the barriers confronting IB before getting too carried away.

‘IB is an area of business activity that has huge promise – both economically and environmentally. This has been recognised by politicians, policy-makers and investors going back more than two decades.’

Section 5 – Barriers

Whichever way you look at it, this is an area of business activity that has huge promise – both economically and environmentally. This has been recognised by politicians, policy-makers and investors going back more than two decades. You would probably have to say that progress has been rather slower than most anticipated, despite all the enthusiastic talking up that has been going on throughout that time.

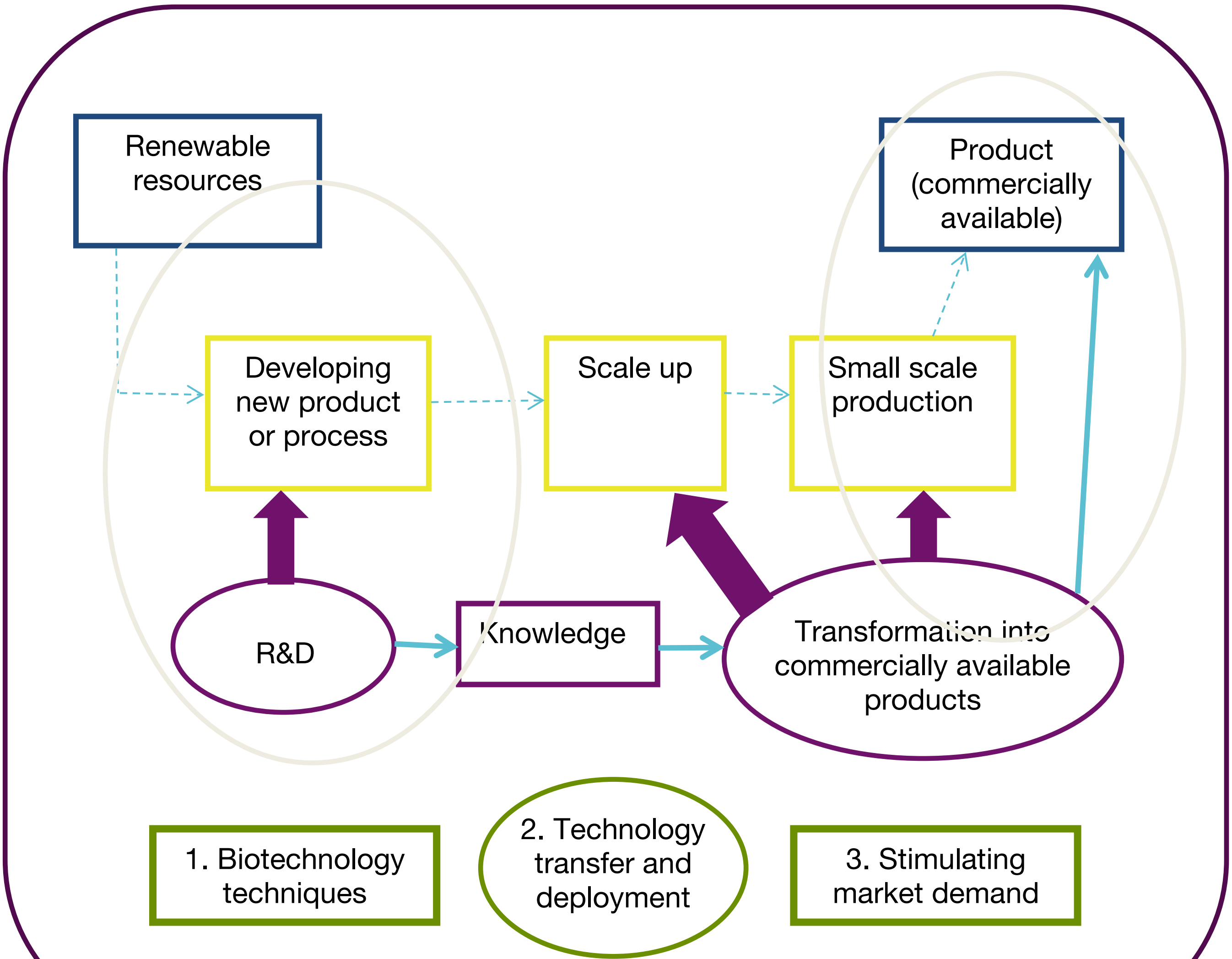
The IB Innovation and Growth Team summarised the situation in the UK as follows:

> "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 which would use 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."[8]

Other barriers have been identified:

- Poor understanding between academics and industry
- Too many gaps between R&D, pre-commercial demonstrators and prototype production plants
- Limited feedstock availability in the UK
- Bio-based products still not competitive with "conventional" products from the petrochemicals industry
- Complexity and inconsistency in the EU's regulatory approaches
- The lack of consistent political leadership in driving forward the low-carbon economy
- High levels of reputational risk based on limited understanding on the part of consumers as to the nature of IB
- And, in particular, relatively low levels of acceptance in the EU regarding GM.

All of these things contribute in one way or another to slowing down the kind of commercialisation strategy that the OECD has been actively encouraging for some time.



Taken from "A Framework for Biotechnology Statistics", OECD[9]

Public Policy Barriers

At one level, we have to distinguish here between policy frameworks that deal with biofuels, and policy frameworks that deal with all other bio-based materials. However, they are very closely linked and most industry experts agree that the wider IB field depends on the scaling up of biofuel production (particularly advanced biofuels) to open up new markets. A huge amount still depends on how well governments plan for, incentivise and regulate the future biofuels market.

Whatever their position, almost all protagonists would agree that developing a policy framework for biofuels has been a pretty messy business so far. As a consequence, large numbers of people remain confused about the potential benefits of biofuels, with smaller numbers still feeling very hostile. And there is by no means a consensus as far as the science itself is concerned.

For instance, there are still all sorts of wrangles going on over how best to define what is meant by sustainable biofuels, and even the notional clarity on the EU's greenhouse gas target (that biofuels must generate greenhouse gas savings of at least 35% in order to be considered as sustainable, with that target rising to 60% in the future) is still being called into question by the various disputes about Life Cycle Analysis that are raging out there.

These ongoing battles are important, but they clearly do not help much in reducing consumer confusion. The European Commission is under particular pressure regarding its estimates of the GHG savings from the production and use of rapeseed biodiesel – which it calculates as being between 38% and 45%. New research from the Friedrich Schiller University in Germany has argued that the savings amount to 25% at best.

Right now, there is even greater uncertainty than ever. The EU Commission is contemplating proposals to hold the target for crop-based biofuels at 5% (rather than increase it to 10%), and to remove all subsidy post-2020. This is being done because of growing concern about Indirect Land Use Change (ILUC) and is causing consternation in the industry. There is a realistic prospect that such a proposal will pretty much kill off all further investment in crop-based biofuels.

What is so bizarre here is that all agricultural activity is involved in ILUC, yet only land used for biofuels is being singled out. And no account has been taken of the Commission's calculations of the fact that ethanol plants can also produce valuable feeds for use in agriculture – what are called "Co-Products". This substantially reduces the overall carbon footprint of such plants.

However, the direction of travel in terms of overcoming those barriers remains reasonably clear: maximise the potential for co-products with first generation biofuels (see next section) and drive as fast as possible to scale up production of advanced biofuels, which have a much better sustainability profile.

In that regard, the EU's principal proposal here is to give advanced biofuels (using ligno-cellulosic materials from agricultural wastes) four times as much quota as first generation ethanol. That helps, but few people seem to think it's enough. There are very high additional costs associated with constructing "first-of-their-kind" plants for advanced biofuels and it will be pretty clear that technology providers will not commit at scale without substantial government support – especially given worrying levels of political risk as policy makers keep changing their minds.

Beyond biofuels, there is as yet no coherent policy framework in the EU to support IB and bio-based materials in general. Although the Advisory Group for the Lead Market Initiative for Bio-Based Products (which I referred to earlier) made a whole series of recommendations to provide incentives and stimulate market uptake, most of these have not yet been implemented.

There's a rather painful contrast here with other countries. The US Government is strongly supporting both biofuels and IB, and is spending nearly ten times as much on R&D as is the case in the EU. Through their BioPreferred programme, federal agencies in the US are required to give priority to bio-based products in their procurement processes.

One can't help but think that this made a big difference in the decision taken by INEOS Bio to site its BioEnergy Center at Indian River in Florida rather than here in the UK. This is a highly efficient, combined gasification and fermentation plant (using naturally occurring bacteria) that can process a wide range of feedstocks, including the putrescible element of household waste. On top of a substantial grant from the Department of Energy, INEOS-Bio also benefits from a $75 million loan from the United States Department of Agriculture.

It's not clear exactly what it would have taken to secure this investment for the UK. It is, however, encouraging that pharmaceuticals giant GSK has decided to invest around £500 million in a new bio-manufacturing facility in Ulverston in the North West of England.

Elsewhere, China is investing massively in new industrial parks with a strong emphasis on both biofuels and bio-based products – particularly for biodegradable plastics. India is not far behind and Japan and South Korea are already well out in front in certain key areas. Brazil's Bio-Ethanol Science and Technology Lab has set ambitious targets to ensure that Brazil keeps its lead on sugar-based IB developments.

This level of competition tells us a lot about how high the stakes are for IB globally. But specific Member States' public funding for IB R&D remains low, with the Dutch B-BASIC Consortium (which stands for "Bio-Based Ecologically Balanced Sustainable Industrial Chemistry), and Germany's CLIB2021 biotech cluster (including a cellulosic ethanol demonstrator at Straubing) making the running along with the UK, as detailed before. There are smaller programmes in France and Belgium. Much of this research is co-ordinated through the EU-wide ERA-NET for Industrial Biotechnology.

Investor barriers

It is of course perfectly true that private sector companies are <u>not</u> dependent on the public sector to raise the necessary funds from investors to take forward their own innovations and development opportunities. But those investors are more cautious than they might otherwise be for lack of a coherent, appropriately ambitious policy framework. These barriers are covered in some detail in NESTA's excellent report on "Financing Industrial Biotechnology in the UK"[10]:

"There are UK SMEs active in all relevant areas of IB, but in almost no cases are these recognised as world leaders. A dysfunctional financing base, which starves UK SMEs of capital, has played a critical role in limiting the development of the UK's IB companies.

While start-up companies can be established for a few hundreds of thousands of pounds, if they are to grow into cashflow-positive SMEs, they will typically need funding to orders of magnitude greater than this. Such sums are generally provided by VCs, but at present there is very little VC appetite for IB (or any other technology) investments in the UK."

In addition, there are few investment models for IB that VCs can point to in order to provide the assurance they need that they will get a good return on their investment.

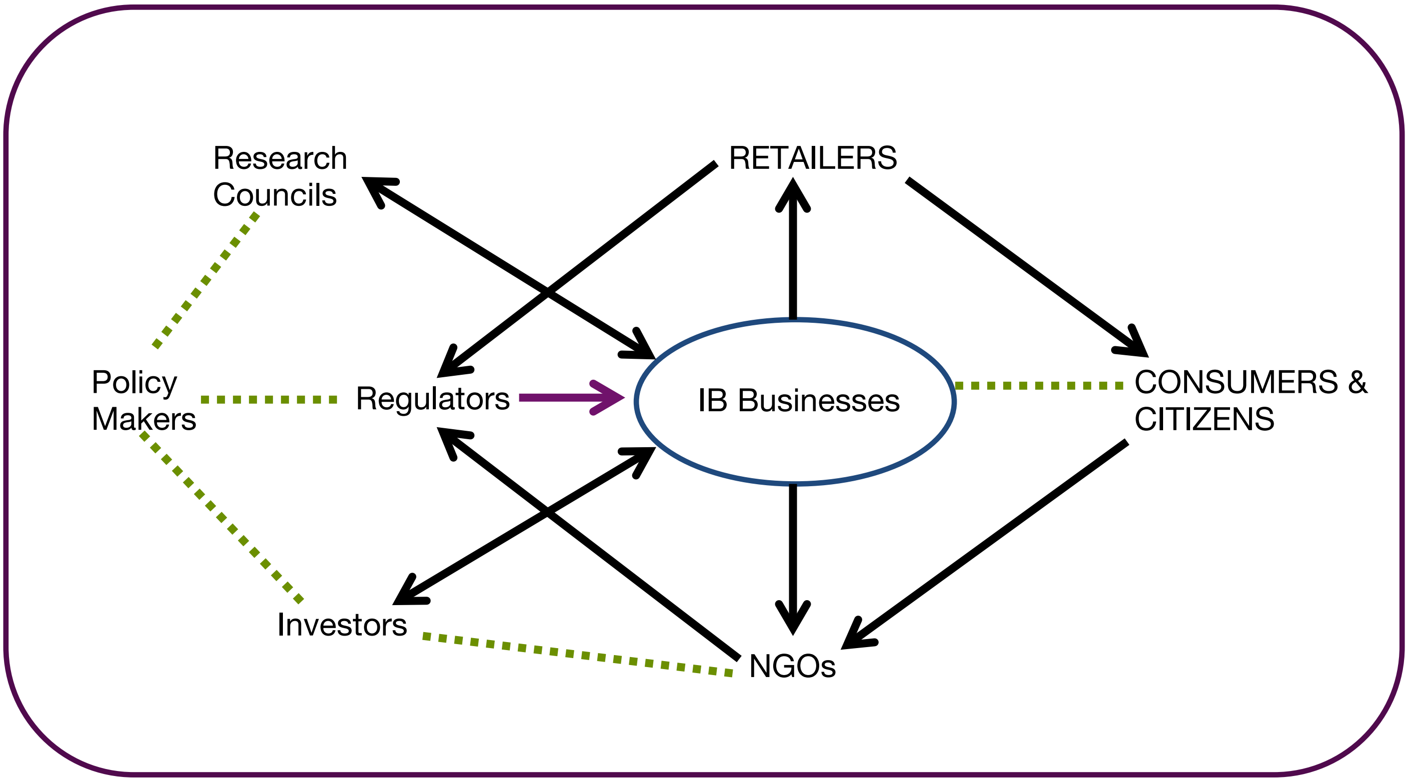
They may also be concerned about levels of public support, conscious of the carry-over that exists from the long-running, highly polarised debate about GM crops in the other area of biotech. In other words, is "white biotechnology" being contaminated by the fierce stand-offs around GM that still preoccupy the field of green biotechnology? The OECD report in 2009 was very clear about the possibility that some biotechnologies might not reach their full potential in the EU because of this unquantifiable and unpredictable factor.

It's here that the users of bio-based products (both retailers and consumers) have to be factored in – a critical dimension that the final report from the IB-IGT recognised very clearly, particularly the big retailers.

All this makes for a much more complex risk management matrix than is the case for many other industries, and puts a special onus on those NGOs involved in these debates. Retailers are reluctant to invest in innovative bio-based products if they think consumers are going to feel apprehensive or even hostile about them. Consumers often look – in a somewhat instinctive way – to NGOs actively involved in the debate to provide some kind of a steer on various acceptability factors; and this has a knock-on impact on investors themselves.

That can make things very frustrating for IB businesses. All the relationships on the left hand of the diagram opposite would look pretty much the same in any other industry, because they provide a relatively simple way of bringing new products to market – as in the OECD diagram on page 4. But the relationships on the right hand side of the diagram are much less predictable. This has huge implications regarding the governance of IB companies and the critical importance of transparency.

This is why the IB sector as a whole needs to be equally focussed on retailers, NGOs and consumers to ensure that the idea of "*IB Done Well*" commands equal enthusiasm across the whole value chain.


Research
Councils
RETAILERS
Policy
Makers
Regulators
IB Businesses
CONSUMERS &
CITIZENS
Investors
NGOs

‘It’s only possible to build trust if the sustainability dilemmas that are flagged up in this report are resolved. Trustworthiness builds trust. Trust builds confidence. Confidence builds markets.’

Section 6 – IB done well

The upshot of all this is clear: the promise of IB will only be delivered if those involved in the industry make every effort to put sustainability at the heart of their development promise. Every one of the scenarios that I have researched, mapping out different "futures" for IB, has flagged up the importance of "winning societal approval" – ensuring that people feel good and even excited about the contribution that IB can make to their lives as well as to the economy as a whole.

That means building trust – and it's only possible to build trust if the sustainability dilemmas that are flagged up in this report are resolved.

1. Land use

This is already a big deal, and it will become even more important as the world's population continues to grow and we struggle to provide enough food for everyone. I have already commented on the fact that there is very little "spare land" to bring into food production if land elsewhere is being lost to biofuel production.

The epicentre of the debate is currently in the US where 35% of the maize crop is currently turned into ethanol. It is also a very hot topic here in Europe, where campaigners are equally strongly opposed to more and more land going into bio-ethanol or into rapeseed production for biodiesel - and where large amounts of bio-ethanol are now being imported in order to comply with the Renewable Transport Fuel Obligation.

It will be impossible to avoid some competition between food and fuel over the next few years. But there are clearly a number of different ways in which this clash can be addressed.

1.1 Co-products

The graphic on page 8 indicates that each hectare of land can only be used for one primary purpose – be it food, animal feed, fuel, or feedstocks. In fact, that needs to be qualified. Ethanol plants can be configured in such a way as to produce not just ethanol but substantial amounts of valuable animal feed – usually referred to as "co-products".

This is already a strategic priority for many food and drink businesses, keen to reduce the amount of waste going to landfill, and to find value across the entire business. Indeed, it's estimated that the market for co-products in the UK is already around £500 million a year. Companies like British Sugar and Allied Bakeries (in partnership with AB Agri) have pioneered all sorts of valuable feeds for milk, beef and lamb producers.[11]

The biofuel industry is now doing the same. A company called Ensus already has an ethanol plant up and running that produces both animal feeds and ethanol. When Vivergo (the joint venture between BP Biofuels and British Sugar) opens its feed wheat ethanol plant on Humberside later this year, it will produce substantial volumes of both ethanol and co-products. Those co-products will be used by British farmers instead of having to import equivalent volumes of soymeal from Brazil and elsewhere. However, both Ensus and Vivergo have yet to demonstrate to both academics and NGOs that the projections they make on this front can actually be delivered in practice.

Co-production of animal feeds and other products from crops like sugarcane can have a very positive impact on net economic value. UNIDO (United Nations Industrial Development Organisation) has been keen to demonstrate just how important this could be for Brazil and other developing and emerging countries producing their own sugarcane. [12]

(Although this is not the place to debate the viability of today's livestock industries, it is worth pointing out that more and more people are beginning to question whether we can go on using so much land to produce feedstuffs for livestock instead of producing food for direct human consumption).

1.2 Advanced biofuels

This competition for land could be significantly reduced if biofuels are processed using forms of biomass that will never go into the food chain. For the last ten years or more, a huge amount of effort has been focussed on that very process, using grasses (switchgrass or miscanthus), agricultural residues such as wheat stalks or corn husks, or fast-growing trees like poplar or willow. (Collectively, these were once referred to as "second generation biofuels", with third generation biofuels focussed on algae, but these days the term "advanced biofuels" is used to cover everything apart from first generation ethanol or bio-diesel).

We need to be clear here: whilst biomass is, of course, a renewable resource, it is also a finite resource. These feedstocks still come from the land, and are therefore still "in competition" with other potential uses – including the potential importance of that land for biodiversity and other eco-system services. There will still be concerns about soil erosion and water use that have to be addressed. In principle, however, there need be no direct clash with land required for producing food, as these feedstocks should only be grown on land that is not suitable for primary food production.

Moreover, it is somewhat misleading to describe some of the biomass earmarked for advanced biofuels as "waste". Just as we are not producing more land, the total quantity of nutrients needed to grow crops has to be maintained in agricultural soils. This is achieved either by returning as much as possible to the soil (including any part of the crop that is not consumed by people or animals, and returning the waste products from humans and animals after they have eaten the bits of the crop used for human or animal food), or by using non-renewable fertilisers from elsewhere on the planet to replace organic matter, nutrients and micro-nutrients removed when crops are harvested.

Taking these critical caveats into account, I still believe that it is right that governments remain focussed on promoting advanced biofuels. Both the US and the EU are providing additional incentives to help promote both further R&D and fully-fledged industrial developments. BP Biofuels is hoping to be one of the first to go into scaled production with a new plant in the US using switchgrass as its principal feedstock.

As is the case with starchy crops like maize and wheat, both grasses and agricultural residues have to be processed to convert either the cellulosic material or the starch into sugar. Finding the enzymes that are capable of achieving that conversion, consistently and cost-effectively, remains one of the biggest challenges in the industry today.

Particular effort has gone into finding ways of removing lignin from the biomass feedstock to free up the cellulosic material for fermentation into ethanol – high levels of lignin impede the conversion process. One way of doing this is to modify both grasses and trees to reduce their lignin content – and that takes us right back into the debate about GM.

2. GM

There are some who would argue that GM and genuinely sustainable biofuels are mutually exclusive – and always will be. But is that any longer a tenable position?

As I mentioned before, it's clear that people are more concerned about some aspects of GM than others. There is still considerable anxiety across the EU about the potential roll-out of GM crops, albeit at a less intense level than was the case a few years ago. There may well be a readiness to differentiate between GM crops for direct human consumption, GM crops for producing animal feeds, and GM grasses or trees for use in biofuels or other IB developments.

There is already a lot of research going on into GM grasses and fast-growing GM trees. Protagonists acknowledge that rigorous regulatory conditions are be necessary to ensure that the low-lignin genes in these modified grasses or trees do not spread to wild plants and trees. So would it be acceptable to trial such GM strains in the open environment, given the substantial benefits that they may entail? Personally, I would be sympathetic to that under the right conditions.

It is clear, however, that the majority of people (including myself) would find it much more acceptable for any genetic modification to be carried out inside a contained environment, using genetically-manipulated micro-organisms to break down the lignin as part and parcel of the production process. This is where the R&D focus should be for the foreseeable future – not least because the likelihood of winning over the critics of trials in the open environment remains remote due to the potential risks of gene transfer in the wild.

These are not easy issues. Many campaigners are deeply concerned about the "food vs. fuel" debate. Other campaigners remain deeply concerned about GM field trials for low-lignin grasses and trees – the successful development of which could help accelerate the move away from those biofuels that are competing with food to those advanced biofuels that would not be directly competing.

The stakes are high. Work done by the World Business Council for Sustainable Development and the International Energy Agency has shown that the rapid adoption of advanced biofuels that guarantee reliable and sustainable supplies of biomass feedstocks is critical if we hope to reach a 20% substitution level for transport fuels by 2030. That would amount to about 1 billion tonnes of emission reductions every year. Without that rapid adoption of advanced biofuels, reductions would be almost 50% less.

3. Greenhouse gases

Right from the start, there has been intense controversy about the degree to which biofuels really do help reduce emissions of greenhouse gases, with constant hostile exchanges between protagonists, based on wildly diverging data from countless Life Cycle Analyses. As I have already stated, the EU Commission is currently embroiled in a fierce row about potential greenhouse gas savings from biofuel production systems in mainland Europe – and is not doing itself any favours by refusing to be completely transparent about the data it is using.

This takes us straight back to the question of trust. Consumers will remain sceptical about the potential benefits of biofuels in terms of reducing emissions of greenhouse gases if they don't have confidence in the data on which those claims are being made. This really should not be beyond the combined efforts of policy-makers, NGOs, the industry and independent scientists to resolve once and for all.

Beyond that, some NGOs are concerned that we may be so focussed on the biofuels debate that we are not thinking hard enough about the wider benefits of IB – as explored back in Section 4.

"The strong focus on biofuels, typical of current policies, may lead to the creation of highly specialized biotechnology solutions (in terms of feedstocks used, enzymes, fermentation processes, separation processes, etc) that are not applicable in the production of other bio-based materials, thus reducing or delaying their take up. Moreover, as investment resources are finite, strong investment in biofuels may crowd out investments in broad-spectrum biorefinery projects, which would be critical for the production of a large variety of the low-GHG bio-based materials."[1]

4. Transparency

Looking at the survey data about public perceptions of IB, it is clear that some people remain concerned about what they see as "the secretive nature" of the industry (over and above the usual commercial confidentiality) and a lack of transparency in the way businesses account for their impacts. At the heart of this is a feeling that the pursuit of "private gain" overrides the wider interests of society, and that society has an inadequate stake in the way decisions are taken.

This is problematic, and one can already detect the outline of a vicious circle at work here: companies and researchers are reluctant to talk about the work they are doing, for fear of it being misunderstood or even seized on by hostile critics, whilst some people get more suspicious and more inclined "to assume the worst" precisely because there seems to be so little that is openly shared and debated in the public domain.

The obvious conclusion – that the less a sector is trusted as a bona fide contributor to people's economic needs, the more transparent and accessible it has to be – is not unique to the world of IB. But it applies here as much as in any other sector of the economy.

In essence, that's what 'winning societal approval' comes down to. Although there are many other concerns that are raised by consumers' or citizens' groups (including concerns about human health and safety, water use and so on) the following four big issues keep cropping up: the need to ensure that IB does not impact on food production systems; the need to find some kind of consensus position on the role of GM for IB; the need to nail down the methodologies for ensuring that people could be absolutely confident about the benefits that IB offers in terms of reducing GHG emissions and the need to put in place the highest possible standards of transparency and accountability.

5. Policy and Industry Mandates

The implications of all this can be drawn together in a set of 'policy and industry mandates'. These will ensure that IB businesses in the UK are indeed driven by the kind of sustainability imperative that is now so critical in every sector of the global economy. From this kind of 'Done Well' perspective, IB businesses would:

1. Aim to achieve substantial societal and environmental benefits, as well as business benefits.
2. Support regulatory and governance structures that put public interest on an equal footing with private gain, and promote extensive engagement with stakeholders.
3. Avoid adverse impacts on food security and affordability.
4. Secure demonstrable and substantial reductions in emissions of greenhouse gases.
5. Commit to production systems that optimise conditions for biodiversity and healthy ecosystems.
6. Commit to manufacturing processes that maximise the value of all feedstocks (eg closed-loop systems).
7. Place no additional burdens on the availability of scarce water supplies.
8. Avoid any risk of gene transfer in the open environment.
9. Pose no threat to human health.
10. Achieve the highest standards of health and safety both for workers and surrounding communities.

‘Learn to walk before you run is always good advice. But it would be good to see us learning to walk a little bit faster than we seem prepared to do at the moment. Having to learn to run in the middle of the ‘perfect storm’ that is bearing down on us is not a happy prospect.’

Section 7 – IB done well NOW!

I have to admit that I sometimes think that scientists and NGOs are living in one world, and policy-makers and economists in a completely different one. If I were a policy-maker today, listening carefully to my Government's independent scientific advisers about the speed with which the climate is changing, the strong likelihood of severe food and water shortages within the next decade, the major challenges about both the availability and price of critical commodities and raw materials, let alone about the cumulative threats to biodiversity and the natural world (all of which Sir John Beddington, this Government's Chief Scientific Adviser, has described as an inevitable "perfect storm"), I would sit up straight, get rid of my ill-informed economists and put this whole story about sustainable wealth creation right at the top of my "to do" list.

Good things are happening, but not enough of them and nothing like urgently enough.

This backdrop is not helpful for IB in general – either for biofuels or for biochemicals and other bio-based products. The sad truth is that the world does not have forever to bring forward all the exciting technological alternatives on which our future prosperity will be built. Especially those with long lead-times.

So the principal thing to be said about IB Done Well is that it needs to be done well now, not at some distant point in the future.

In that context, I was struck by the fact that the two principal scenarios used by the OECD in its 2009 Report on *The Bio-economy to 2030: Designing a Policy Agenda* were respectively titled 'Muddling Through' and 'Uneven Development'. It would have been encouraging to see a third Scenario – perhaps called 'Go For It' – which would have been rather more helpful in today's hard-pressed circumstances. How are we to secure "the prize" that IB offers us (both an economic and environmental prize, as I have explained before) if we are so lacking in purpose that the best we can do is muddle through?

Bio-refineries

Take the whole question of integrated bio-refineries. Everyone seems to agree that the full range of potential benefits from IB can only be secured by moving as rapidly as possible towards a model of the integrated bio-refinery, combining different technologies to process renewable raw materials (for instance, multiple sources of cellulosic material), transform those feedstocks into various intermediate bio-chemicals from which to provide fuels, co-products and other bio-based products, and then "close the loop" by recycling any by-products back into new processes.

Until recently, models of this kind of multi-product bio-refinery were still pretty much stuck on the drawing board. Since 2009, however, through the American Recovery and Re-Investment Act, the US Department of Energy has committed more than $1.5 billion for commercial-scale bio-refinery demonstration projects. (Brazil and China have similar investment programmes, albeit at a much lower level). One of the principal reasons for the scale of public support in the US is the prospect of generating substantial numbers of “green jobs”, as emphasised by a recent report from the US Biotechnology Industry Organisation:

> “Bio-based products can offer significant growth to the US economy and confer a competitive advantage in the chemicals and plastics industry. The industry can create tens of thousands of green jobs and provide a range of additional societal benefits to the United States, including a reduction in CO_2 emissions and reduced dependence on foreign oil.”[1]

It is also worth dwelling a little on that notion of “closing the loop” through bio-refineries. This is one of the most important aspects of the WWF/Novozymes Report, *Assessing the Opportunities*, which highlights the degree to which versatile bio-refineries (those able to process a large variety of different feedstocks) will help dramatically reduce waste whilst easing the pressure on land use:

> “The establishment of a significant number of bio-refineries able to produce a large portfolio of end products, utilizing a large variety of feedstocks, provides the opportunity to directly transform any biobased material into a valuable feedstock for the production of other biobased materials (and biofuels). In principle, therefore, bio-refineries can ‘close the loop’ between waste and production, without requiring the use of extensive volumes of land to close the circle.” [1]

We already know enough from existing bio-refineries (mostly ethanol-based) how important it will be to establish a whole series of demonstrators if we are going to close the gap between where we are today and the kind of fully-fledged, bio-refining industry on which the future of the bio-economy depends. Without that scale of investment, bio-refineries will always be languishing in the shade of the petrochemical behemoths that we need to be moving away from as fast as we possibly can.

Today’s petrochemical industry first became viable in the early 20th Century when oil-based fuels (petrol, diesel, kerosene and so on) came to market <u>at scale</u>. It seems unlikely that a biofuel-derived chemicals industry will become truly viable until the same suite of biofuels come to market <u>at scale</u> – and that means in a way that is genuinely competitive with petrochemical products.

In the longer term, many believe it will not be possible to achieve dramatic reductions in emissions of greenhouse gases until we learn to produce biofuels much more efficiently, using algae or other genetically-engineered micro-organisms – but that lies way beyond the confines of this Report.

It has to be pointed out here (perhaps a little bit late in the day!) that there are many experts who do not subscribe to the idea that bio-substitutes for today's CO_2-intensive fossil fuels is necessarily the way to go. For them, all-electric vehicles, super-efficient hybrids or hydrogen-powered fuel cells offer a superior route to the radical decarbonisation of our ground-based transport systems. There is one thing we know for sure: even the most ardent advocate of biofuels would acknowledge that it is totally impossible to think of a 100% substitution between fossil fuels and biofuels. There will only ever be enough land available for a relatively small percentage share for biofuels.

Back in the world of EU biotechnology, getting enough access to public money for public-private demonstration projects remains highly problematic. That is not to say things are not happening already. There are several bio-refineries already up and running in Europe. Here in the UK, the BBSRC and the EPSRC have jointly set up the Integrated Bio-Refineries Technology Initiative to establish the economic potential of bio-refineries for sustainable production systems – and that includes research into where appropriate feedstocks will come from. High transport costs means that feedstocks will usually need to be sourced as close to a bio-refinery as possible – the so-called "proximity principle" – which will almost inevitably favour small or medium-sized bio-refineries rather than anything as large as today's petrochemical refineries. (That clearly isn't the case, however, with high-value speciality chemicals).

In the meantime, would it not be good for innovators and SMEs to have better access to relatively small amounts of finance, including easier finance for "proof-of-concept" studies for applications that offer real sustainability benefits? For new investors to be encouraged into the market by developing a database of companies that have already got an excellent track record? Or for government to find ways of working with the private equity industry to increase the availability of risk capital? These are all things that have been recommended by the European Commission's own Lead Market Initiative and by EuropaBio, the European Association for Bio-industries.

Learn to walk before you run is always good advice. But it would be good to see us learning to walk a little bit faster than we seem prepared to do at the moment. Having to learn to run in the middle of the "perfect storm" that is bearing down on us is not a happy prospect.

‘It is encouraging to see that the Industrial Biotechnology Leadership Forum has taken such a strong stance here – just as the IB Development Group has done in Scotland. The sustainability dimension is critical to their future success, and stakeholder engagement is a necessary and on-going responsibility in which they all have a part to play.’

Section 8 – The role of Government and the NGOs

Given the state of the economy; given the state of today's capital markets; given the ambiguous and rather febrile nature of public opinion; given the fact that much-needed media coverage of complex scientific and technical issues is often ill-informed and prone to sensationalism; given the fact that NGOs do not "see as one" on the potential for IB, and have their own precautionary way of not taking risks in this area; and given all the uncertainty of working in a part of the economy (chemicals and chemistry-using industries) that is undervalued and largely invisible to the vast majority of people – given all that, you've got to hand it to today's private sector IB champions for remaining so persistent and so doggedly optimistic!

I think they're right to be. As someone passionate about sustainability, I have learned that it is not possible to dig down into the IB "innovation pipeline" and come away anything other than excited and uplifted. The size of the sustainability prize (eventually!) could be very significant indeed.

So let me conclude with some thoughts on what this means for NGOs and for the Government.

In a way that makes many people quite uncomfortable (including many people in the NGOs themselves), the "general public" would appear to have more trust in what NGOs say about potentially high-risk technology issues than what business, let alone government, says. This imposes a significant burden of responsibility on NGOs, collectively and individually, to justify that trust, and the future role of IB depends, in this instance, on the way in which the NGO community chooses to play its cards on the future role of IB.

As I said above, NGOs are not as one on this. WWF, for instance, has done useful research into IB, and together with the Novozymes Foundation, has published an authoritative report on the potential for IB to help reduce emissions of greenhouse gases and substantially reduce waste – from which I have quoted on a number of occasions in this Report. Friends of the Earth and Greenpeace remain much more sceptical – suspicious even – that the sustainability claims made on behalf of IB can ever be lived up to. Many smaller NGOs remain hostile and would have zero sympathy for the idea that IB has a significant role to play in helping us navigate our way through to a more sustainable world.

Like it or not, much of this keeps coming back to two things: the protracted debate about GM and the various "lines in the sand" that were drawn in that debate more than a decade ago; and the lack of trust in "big business" and its readiness to prioritise "private gain" over public benefit.

Again, this can be very frustrating for those involved in IB research or commercial enterprises. Although I understand why some in the world of IB just want the whole GM story to go away (primarily for fear that it will stop people taking proper account of all the positive aspects of IB), I just don't think that's going to work.

Looking back on the excellent work done for the IB-IGT by the market research agency Opinion Leader on *Public Perceptions of Industrial Biotechnology* in February 2009[13], it is clear to me that large numbers of concerned citizens in the UK are not absolutely locked into immovable positions on GM, but are open to a debate on where those lines should now be drawn. Or redrawn, as many would see it.

At one end of the acceptability scale, in Europe at least, would be the idea of GM crops for direct human consumption grown in the open environment: that is still unacceptable to almost everybody I know concerned about GM. At the other end of the scale would be the use of GM micro-organisms in strictly regulated and contained manufacturing facilities to create new drugs, bio-based fuels or chemicals that would never come into direct contact with human beings or the open environment. That is clearly much more acceptable to very large numbers of people.

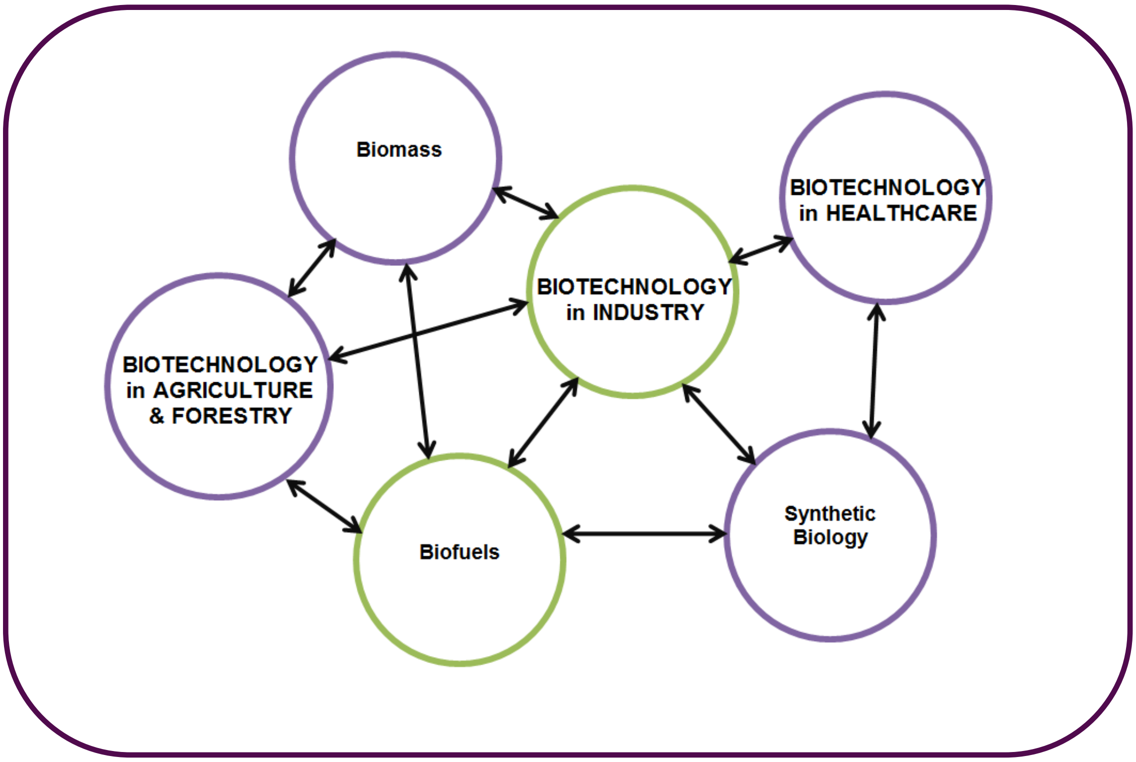
The very least that the industry is entitled to ask of the NGO community is to engage positively and open-mindedly in that debate. The quid pro quo, of course, is that the industry needs to do the same, without endlessly asserting the limitless benefits of GM as if this was now some "article of faith" to which they must profess allegiance whenever they are in the company of the undecided, the dissenters and the GM heretics.

In that pragmatic world of give-and-take, the easiest way for IB companies to develop common ground with anti-GM NGOs is not to get involved in the debate about transgenic crops and feedstocks, and focus instead on ensuring a positive debate about IB in properly regulated, industrial facilities.

And we need to engage in this debate soon before some of the even more complex (and, I suspect, even more controversial) debates surrounding the field of Synthetic Biology require our attention. (Synthetic Biology is included, as part of the diagram I used earlier, as an important part of the whole bio-economy.)

Synthetic Biology will enable many of today's GM techniques to be taken on to a different level, including the "synthesising" of organisms that do not exist in Nature, designed to improve productivity in all sorts of different fields. Friends of the Earth and other NGOs have already flagged up some of the ethical implications of this emerging field, as well as some of the new risk factors.

The Bio-economy



It is clear to me that the "governance story" around Synthetic Biology is going to demand a fundamental change in the way we currently regulate new and emerging technologies – not least around patents, intellectual property and the balance between private gain and public interest. This has already been recognised by the Technology Strategy Board, which has developed a highly innovative 'Responsible Innovation Framework' for use in all such areas of research.

So much for the NGOs. I do not want to over-state the role they play, but nor do I think it is helpful to ignore the burden of responsibility that they bear here.

But, as ever, it is governments that bear the heaviest responsibility – and I have already looked in some detail at what is going on here in the UK, in the EU and elsewhere in the world. This is not the place for a detailed set of recommendations for government (of which there are many in the various reports I refer to in the bibliography), but it is appropriate to reflect more broadly, in concluding the case for "IB Done Well", on the role of government in stimulating innovation.

The broad thrust (from this and every other government of modern times) is that governments can do little more than provide funding for R&D (through the Research Councils, for example), provide tax credits for private sector R&D, create some kind of skills infrastructure, ensure a strong legal framework and, where appropriate, help develop entrepreneurial clusters. Above all, of course, they feel they must not be seen to be "picking winners" (that is what the private sector does, with entrepreneurs, big companies and providers of capital working in harness to create the economy of tomorrow), although the recent announcements regarding funding for R&D in grapheme demonstrates a continuing readiness to put public money into the right kind of winners!

As the recent work of Mariana Mazzucato (Professor in the Economics of Innovation at the Open University) has demonstrated, that is what the debate about picking winners still looks like. But it is not necessarily how it works in practice. Analysing what is happened in the United States and elsewhere, she argues that:

> "The state can proactively create strategy around a new high-growth area before the potential is understood by the business community (from the internet to nanotechnology), funding the most uncertain phase of the research that the private sector is too risk-averse to engage in, seeking and commissioning further developments, and often even overseeing the commercialisation process. In this sense, it has played an important entrepreneurial role."[14]

She eloquently makes the case for a proactive, entrepreneurial state, able to take risks that the private sector is reluctant to engage with, creating a networked system of access, harnessing the best of the private sector for the national good.

It is that more entrepreneurial side of government that many in the world of Industrial Biotechnology are now looking for, with the UK Government taking on a new kind of market activism - as was picked up in the original report from the IB-IGT:

> "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 becomes 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." [15]

In many respects, the National Industrial Biotechnology Facility (NIBF), based at the Wilton site in the North East of England, provides an excellent example of what can be achieved here. The multi-purpose NIBF was commissioned back in 2010, and is open to any company wanting to take advantage of its biomass processing, fermentation, cell harvesting and product purification technologies. It works across many different sectors (including food, pharmaceuticals and chemicals), and puts a special emphasis on the kind of sustainability benefits discussed throughout this Report.

There are all sorts of additional ways in which that kind of proactive role can be taken forward by government, taking on responsibility for the adoption of internationally accepted principles and standards whether that is on high-profile definitions of what is meant by 'sustainable biofuels' and other bio-based products, or on the technical details regarding standards for Life Cycle Analysis, or taking a much more progressive line on green procurement, or in providing "proof-of-concept" funds (such as the SMART initiative), and more consistently creating incentives for companies coping with what is a very difficult set of economic conditions. Might it not be possible, for instance, to bring forward a series of "market stimulation" measures, including perhaps a *Renewable Chemicals Obligation* (along the lines of the BioPreferred Programme in the USA) to help grow the market over the next few years.

The UK Government would also be well-advised to take an active role in scoping existing markets to identify those areas where the most significant greenhouse gas emission reductions can be achieved, looking all the time for win-wins (on the economy and on the climate), rather than looking at each and every IB opportunity as being of equal value. As the OECD puts it:

> "Investment in many industrial biotechnologies requires market incentives. Over the short term, these incentives could increase costs for consumers. Higher prices would be difficult to justify without good evidence that such bio-products meet environmental sustainability goals. Developing performance standards for environmental sustainability, based on robust methodologies for Life Cycle Analysis that include global land use effects, will be essential. Performance standards should ensure that undesirable environmental impacts are not simply shifted from one region to another."[16]

And that is the final piece in this particular jigsaw. Government Ministers need to be as passionate about the "size of the sustainability prize" as they are about the size of the economic prize. IB will only become the dynamic, powerful driver of prosperity that it could be if sustainability is seen to be absolutely at its heart.

The same must be said, by the same token, for all those companies involved in IB. As I have highlighted in the report, some are absolutely on the button when it comes to sustainability, both in terms of understanding "the bigger picture" (around climate change, waste, land use and so on), and in terms of "walking the talk" in their own businesses. Others, it has to be said, are not really engaged at all.

It is therefore encouraging to see that the Industrial Biotechnology Leadership Forum has taken such a strong stance here – just as the IB Development Group has done in Scotland. Its members know that that whole sustainability dimension is critical to their future success, and they know that the kind of stakeholder engagement (of which this is just one small part) is a necessary and on-going responsibility in which they all have a part to play.

I have not touched much on the whole area of communications and stakeholder engagement in this Report, as work is already on-going on a separate outreach and communications strategy for the IBLF and associated organisations.

But given just how little understanding there is about IB and society today, let alone the prospects for IB Done Well in terms of the massive benefits this could secure for humankind, in a more sustainable and increasingly low-carbon world, it's fair to say that we now need all the 'stakeholder engagement' that we can get!

And I very much hope that this report will contribute to that process.

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