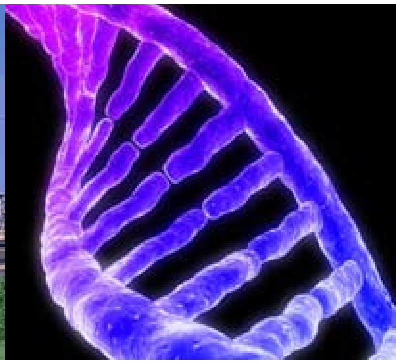
Technology Strategy Board

Driving Innovation



Biosciences

Technology Strategy 2009-2012

The vision of the Technology Strategy Board is for the UK to be a global leader in innovation and a magnet for innovative businesses, where technology is applied rapidly, effectively and sustainably to create wealth and enhance quality of life.

Our three-year organisational strategy is to drive innovation by **connecting** and **catalysing**. To achieve this we are focusing on three themes: challenge-led innovation, technology-inspired innovation and the innovation climate.

For more information on the overall strategy see **www.innovateuk.org.**

We have identified a number of application areas and technology areas on which to focus, and for which we are developing specific area strategies. This document presents our strategy for the **Biosciences** Technology Area.

Foreword

The Technology Strategy Board aims to make the UK a global leader in innovation. Our job is to help ensure that the UK is in the forefront of innovation enabled by technology.

Our task at the Technology Strategy Board is to *Connect and Catalyse*. As part of our challenge-led approach to innovation we treat societal and economic challenges of the future not just as threats but as opportunities for innovative solutions that enhance the quality of life and increase wealth.

The world is changing. Globalisation, digital communications and the growth of emerging economies present profound challenges to UK manufacturing sectors. Open access to global supply networks and emerging markets is easier than ever before; the highly skilled UK workforce, world class science base and open-market philosophy also put us in a strong position.

The biosciences underpin our understanding of life. Exploitation of the biosciences is most keenly demonstrated in biotechnology – an industry that has delivered solutions to challenges from novel medicines to sustainable routes to energy and materials, improving our quality of life while reducing our environmental footprint.

The UK, building on its strong base in the biosciences, is well positioned to exploit the business opportunities that will arise as we address the global challenges of a secure energy and food supply as well as affordable healthcare. We see opportunities for advanced biofuels, new crop varieties, bio-based materials, novel medicines and sustainable alternatives to petroleum-derived products.

The UK's strengths in food and agricultural sciences will be important in enhancing agricultural productivity, contributing to food security and providing important opportunities for wealth creation. The launch of our Innovation Platform in Sustainable Agrifood will play a key part in addressing these challenges through technological innovation.

This document closely aligns with our *Medicines and Healthcare Strategy*; both are part of our life sciences portfolio, and will provide the foundations for our work in this area over 2009-2012. We are looking forward to working in partnership with key players in innovative biosciences-inspired technology businesses and contributing to wealth creation in the UK.

Iain Gray
Chief Executive, Technology Strategy Board

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Executive summary

The biosciences underpin our understanding of life. They include biology, physiology and neuroscience, biochemistry and microbiology, as well as food, agricultural and environmental science. Exploitation of the biosciences is most keenly demonstrated in biotechnology, an industry that has delivered new applications ranging from novel medicines to sustainable routes to energy and materials, improving our quality of life while reducing our environmental footprint.

Yet the new opportunities remain enormous: for instance, we still have much to do in building the capability to develop mathematical models that will predict reactions in the human body.

The global challenges of climate, societal and demographic change are generating an ever-increasing need for more sustainable energy and industrial feedstocks that do not conflict with the food chain in their production. The challenges associated with ageing populations and the accelerating economies of developing countries present multiple opportunities for developers of lower cost medicines.

The UK, building on its strong base in the biosciences (in particular its world-leading science base in genomics, fermentation, biocatalysis, plant science, marine organisms and mycology), is well-positioned to exploit the business opportunities that will arise as we address these challenges.

The following are examples of this strong base:

- the UK is ranked third globally for citation impact in the biological sciences
- the overall UK science budget will increase to almost £4 billion each year by 2010-11, which will include almost £2 billion for medical research over three years to fund both basic and translational research
- a quarter of the entire research expenditure by the UK's manufacturing sector is funded or carried out by the pharmaceutical sector – equivalent to £10 million each day
- the biosciences sustain the economic wealth generation of 10 of the top 50 UK generators of value added operating in several sectors (pharmaceuticals and biotechnology, tobacco, beverages, food and drug retailers, food producers)
- in our analysis we found that industry sectors that benefit significantly from the biosciences (pharmaceuticals, biotechnology, chemicals and food) contribute 8% of the UK's Gross Value Added.

Priority areas

This Technology Strategy Board *Biosciences Technology Strategy* has been informed by extensive consultation with the industry and other organisations, and also draws on the output of the Department for Business, Innovation and Skills (BIS) Innovation and Growth Team's study on industrial biotechnology. We have then applied the Technology Strategy Board's four criteria for investment:

- the UK has the capability
- there is a large market opportunity
- the idea is ready for exploitation
- the Technology Strategy Board can make a difference.

Analysing this input has led us to build a UK strategy for biosciences around the following three priority areas:

- genomics
- industrial biotechnology
- agriculture and food (agrifood).

The UK has significant capabilities in these three interlinked areas and has opportunities for further commercial exploitation into large, growing global markets through innovation. Indeed a systems biology approach that brings together our increasing understanding of genomics and metabolic pathways will position us to develop breakthrough technologies that will have a significant impact on progress in medical biology, industrial biotechnology and agrifoods. The major applications for these three priority areas that emerged from our analysis include:

- new biological therapeutics and delivery systems, new vaccines, monoclonal antibodies and functional products (eg nutraceuticals), and gene and cell-based therapies (eg regenerative medicine, genotyping and gene therapy, and personalised medicine)
- efficient chemical and biological processes, including catalysis and biocatalysis, and chemical to bioprocesses
- sustainable energy and materials, eg waste treatment and recycling, biofuels, renewables and other biomaterials, and chemicals
- maximising the use of scarce land, water and resources to meet food and non-food needs, through advanced farming systems, efficient crop and livestock breeds and genetically-modified (GM) organisms.

Implementation

To implement this strategy, we will invest in UK businesses that can exploit biosciences-based technologies within our four criteria for investment. To bring these technologies to market we will be working with other organisations to ensure suitable tools are in place to do this.

Several of the research councils have supported research in the biosciences, in particular the Biotechnology and Biological Sciences Research Council (BBSRC), the Engineering and Physical Sciences Research Council (EPSRC) and the Medical Research Council (MRC), and we will work together to ensure that UK business can benefit. The BBSRC is the principal investor in biosciences research, spending £418 million in 2008-09, and has a number of ways in which it encourages scientists to work with business. The BBSRC intends to provide at least £34 million for complementary and collaborative activities with the Technology Strategy Board over 2008-12.

In addition, we will work with regional bodies and the knowledge transfer networks to ensure an aligned approach, and will use knowledge transfer activities to share best practice and increase collaborative working.

The Technology Strategy Board will invest to support and encourage:

- greater use of genomics-based technologies and knowledge sharing by UK companies, in particular those working in non-competitive, distinct sectors
- technologies that enable advanced generation biofuels
- next-generation biorefinery technologies
- UK chemicals and chemistry-using businesses to exploit the opportunities for bio-based processes
- UK companies working in crop, food and livestock protection

The Technology Strategy Board will ensure:

- that the biosciences play a part in current and future innovation platforms
- an increase in the number of knowledge transfer partnerships in the biosciences
- that businesses have opportunities to exploit BBSRC-funded research, with particular attention to their research industry clubs.

New discoveries and the applications of biosciences have had major impacts on politics and society in general (GM crops and stem cell research are two high-profile examples) and will continue to do so. It will therefore be important to consider the outcomes of investments in this wider context. In this respect, it will also be important to follow developments at BIS emerging from its ‘Consultation on Science and Society’, particularly in respect of ‘increasing public confidence in science, research and their application’.

The Seventh Framework Programme is the European Union’s main instrument for funding research in Europe, and recent themes have included food, agriculture and fisheries, and biotechnology, as well as biorefineries, nanosciences, nanotechnologies, materials and new production technologies. We will work to ensure that significant opportunities for research investment and knowledge transfer are available to organisations in the UK through participating in and influencing European Framework activities.

1. Background

1.1 Strategic context

The Technology Strategy Board's high level strategy *Connect and Catalyse* [1] featured the biosciences technology area.

The aims of this *Biosciences Technology Strategy* are to:

- identify the technology priorities for the next three to five years with the greatest potential for commercial growth through innovation
- set out the types of support that we will invest in to contribute to our business-led vision for sustainable, economic wealth generation and improvements in quality of life within the UK
- highlight areas for improvement and make proposals as appropriate, in the context of the Technology Strategy Board's wider remit to highlight barriers to innovation, and as a coordinating body.

Businesses inspired by the biosciences should use this document as a guide to consider the technologies that can best help them to create economic wealth.

We have already developed and published strategies in other complementary areas such as High Value Manufacturing [2] and Energy Generation and Supply [3]. In addition, several other strategy documents are being prepared that complement this one, such as the *Medicines and Healthcare Strategy*. Where biosciences-based technologies cut across other technology or application areas, we will refer to the complementary strategy (see Appendix 1).

1.2 Biosciences context

In developing this strategy we used as a baseline the former Department of Trade and Industry's (DTI's) Bioscience and Healthcare technology strategy, published in April 2006, and have sought input from industry through the knowledge transfer networks and through a road mapping exercise [4].This found that biosciences-inspired technologies are very broadly applicable across a range of sectors, and therefore responsive to a wide range of drivers. The major drivers identified were:

- increasing demand for healthcare, lifestyle products and food (driven themselves by changing demographics and limited availability) as well as personalisation of new treatments
- consumer expectations for quality of life
- the environmental challenges of global warming
- land and resource scarcity requiring renewable energy solutions.

The road mapping process identified the UK's pharmaceutical industry and research base as strengths, but skills shortages and risk aversion among consumers and regulators are potential barriers to progress, while the emergence of developing economies as technology powers is a clear threat.

In 2008, an Innovation and Growth Team sponsored by the former Department for Business, Enterprise and Regulatory Reform (BERR) began a study of the industrial biotechnology sector, and we remained close to the process throughout. The team's report to Government, and the Government response [5, 6] have now been published, and this strategy takes account of its analysis and recommendations.

We selected the technology priority areas for this strategy by assessing all of these inputs against the four Technology Strategy Board criteria for investment:

- the UK has the capability
- there is a large market opportunity
- the idea is ready for exploitation
- the Technology Strategy Board can make a difference.

We have developed a UK strategy for biosciences around the three following priority technology areas that have a strong biosciences component and where innovations in technology can generate significant economic benefit and improve quality of life:

- genomics
- industrial biotechnology, and
- agriculture and food (agrifood).

These areas represent broad, **overlapping** themes: for instance, modern genomic technologies employed within the industrial biotechnology and agrifood sectors can facilitate innovation.

Chapters 2, 3 and 4 of this strategy cover the three technology areas in turn. Chapter 5 explains how we will implement the strategy, and also highlights some opportunities that these technologies present as well as barriers to uptake.

Note: Market data is given in sterling (£) and converted, where necessary, for comparative purposes, using the factors £1 = $2 and £1 = €1.25.

2. Genomics

Genomics is the study of an organism's entire genome and the associated technologies required to achieve this. The field includes intensive efforts to determine the entire DNA sequence of organisms (human, animal, microbial and plant) and fine-scale genetic mapping. This area includes genome sequencing, function elucidation, regulation and evolution, gene expression, proteomics, metagenomics, glycomics, microarrays, diagnostics, computational biology and bioinformatics, plant and animal breeding, and the identification of genes involved in disease and complex traits, including responses to drugs and other xenobiotics.

2.1 Technology overview

A study of the sector revealed a number of technologies that are used regularly by businesses to generate innovations. The priority technologies relevant to this sector are:

- **Animal health technologies:** semen sexing, cloning, *in vitro* cell technologies, recombinant DNA technologies, siRNA (small interfering RNA) technology
- **Bioinformatics:** the integration of biology, computer science and information technology; a high level of skills is required to develop custom applications to integrate databases, simulations, molecular modelling and docking programs, etc
- **Gene-assisted selection (GAS):** selection for a trait of interest based on a single genetic marker linked to it. Common traits of interest include productivity, disease resistance, drought tolerance and quality
- **Genome-wide association (GWA):** used to identify the genetic variation across several similar genomes and identify genetic markers linked to observable traits. By comparing a control population with one demonstrating the trait, researchers can identify genetic markers that may be associated with the trait
- **Genome-wide selection (GWS):** selection based on a number of genomic markers identified by GWA studies as being associated with an observable trait. This has the potential to exploit all the genetic variance for a trait, without identifying which markers have significant effects. The markers are first estimated in a large reference population with observable trait information. In subsequent generations, only marker information is required to calculate the likelihood of that trait becoming visible.
- **High-throughput analytical technologies (HTAT):** hyper-parallel or next-generation DNA sequencing, DNA microarray, proteomics, transcriptomics, recombinant DNA and siRNA technologies, polymerase chain reaction (PCR), metagenomics, instrumentation and reagents, genome-wide methylation studies and ChIP-chip (identifies protein binding sites on a genome-wide basis).

2.2 Applications

Genomics-based technologies have applications in a variety of significant markets (see Table 1). These applications include:

- medicines and diagnostics
- livestock improvements
- bioenergy production
- environmental remediation
- enzymes
- new crop varieties and yield improvements.

The ways in which the genomics-based technologies underpin these applications are set out in Appendix 2.

Table 1 – Genomics-based technologies have applications in a variety of significant markets

Application	Market size	Technology
Medicines and diagnostics (human)	Global market for human medicines £356bn in 2007 [7], growing at 5% overall with the biologics component at 11-12% [8] Global market for therapeutic proteins £29bn in 2006 [9] Global market for antibiotics £10bn in 2006 [10] Global market for diagnostics £17-18bn in 2007 [11]	HTAT, GWA, bioinformatics
Medicines and diagnostics (animal)	Global market for animal therapeutics and diagnostics £11bn in 2007 [12]	HTAT, GWA, GAS, animal health technologies, bioinformatics
Livestock improvements	Global livestock gross production was worth more than I$600bn[1] in 2007 [13] Annual UK livestock output is £8bn, converted to £24bn at retail Global market for aquaculture production £39bn in 2006 [14]	HTAT, animal health technologies, GAS, GWA, GWS, bioinformatics
Bioenergy production	Global market for biofuels £17bn in 2005 [15] The European Commission (EC) has proposed that the UK should increase the share of renewables in its energy mix from around 1.5% in 2006 to 15% by 2020 [16]	HTAT, GAS, bioinformatics
Environmental remediation	Global remediation market £6-18bn in 2005 [17]	HTAT, GAS, bioinformatics
Enzymes	Global industrial enzyme market £1bn in 2007 [18]	HTAT, GWA, bioinformatics
New crop varieties and yield improvements	The global agricultural biotechnology market is projected to exceed £4bn by 2010 GM crops market is worth £3bn [19] and is growing at 10% per annum [20]	HTAT, GWA, GWS, GAS, bioinformatics

2.3. Industry and market overview

2.3.1 Background

The entire genomes of more than 70 organisms were sequenced by early 2002, including the first microorganism in 1995, the first plant genome in 2000, and the working draft of the human genome in 2001. By 2008 more than 850 genomes had been published, including the first cancer genome.

The Human Genome Project was completed in 2003 and successful sequencing was made possible, in part, by companies developing and using new technologies and processes to increase the speed and accuracy of mapping and sequencing. This endeavour created many new companies that sought to capitalise on the new sequences by identifying disease-causing genes and developing new therapeutic strategies.

Genomics-based companies can be loosely divided into seven major business types:

- large-scale sequencing companies
- gene mining companies
- functional genomics companies
- population-based genomics companies
- bioinformatics companies
- established pharmaceutical companies
- new biopharmaceutical companies.

A study in 2005 found that there were 300 firms specialising in genomics in the US and Europe, of which 30 were in the UK [21]. Most of the companies that offer a service-based model can apply their technologies to any organism; however, the potential applications can vary greatly (see Appendix 2). In addition, a number of companies such as plant and animal breeders are increasingly using these technologies in-house.

2.3.2 UK position

Although a third of the human genome was sequenced in the UK, no major genomics firms were created from this effort. However, there is still considerable potential for growth in most genomics-using sectors, and the UK is well placed due to its high-quality science base and its significant commercial life sciences sector. A Technology Strategy Board internal study found more than 50 companies that utilise genomics technologies – either in-house or as a service provider [22].

In May 2009, the MRC announced that it would invest more than £7m to support fundamental genetics research by creating three high-throughput sequencing hubs in Scotland, the north of England and the east of England.

1 The international dollar, I$, is a hypothetical unit of currency that has the same purchasing power that the US dollar had in the United States at a given point in time. It cannot be converted to another country's currency using current market exchange rates.

The Genome Analysis Centre was established by the BBSRC in partnership with regional economic development partners during 2009 – the centre represents an investment by all the partners of £13.5m in the capital infrastructure.

The BBSRC's Bioprocessing Research Industry Club has awarded £14m since its inception to support innovative bioprocessing-related research, under the direction of a consortium of UK companies. The BBSRC has a number of 'research and technology clubs' which support high-quality, innovative research in areas identified as strategically important by BBSRC and industry. The clubs are supported jointly by BBSRC, other funding bodies and consortia of companies, and fund research that addresses priorities in our technology strategy.

The House of Lords Select Committee on Science and Technology launched an inquiry into genomic medicine in 2008 and published its report in 2009 [23]. The inquiry provided an assessment of genome technologies and their actual and potential impact on clinical practice in the post-genome era and recommended that genomic science is adopted as a technology platform by the Technology Strategy Board.

The UK Biobank was set up by the Department of Health, MRC, Scottish Executive and the Wellcome Trust medical charity in 2006. This is a major UK medical research initiative with the aim of improving the prevention, diagnosis and treatment of a wide range of serious and life-threatening illnesses – including cancer, heart diseases, diabetes, arthritis and forms of dementia.

For more information about the UK's position in the Genomics sector see the following sections on 'Human genomics', 'Animal genomics', 'Microbial genomics' and 'Plant genomics'.

2.3.3 Human genomics

Human-targeted genomics technologies offer the potential for personalised medicines by enabling genetic variation to be correlated with disease phenomena – without the need to understand the physiological processes involved. Over 10 million DNA variants between people have now been characterised [24]. Recent genome-wide studies have discovered strong associations between inherited gene variants and common diseases, such as myocardial infarction, diabetes, age-related macular degeneration, asthma and several autoimmune conditions. The global market for diabetes therapeutics and diagnostics alone was worth over £100bn in 2007 [25].

Genomic approaches can complement other techniques in the development of new diagnostic tests based on proteins, single genes or other attributes. At the population level, these technologies could facilitate the identification of new diagnostic markers and potentially new targets for therapy. However, a number of challenges still exist: predictive accuracy will need to be improved, costs reduced and the ability to protect the intellectual property of novel genomic-based diagnostic tests. In particular, the value path that will link personalised genomics to healthcare is not clearly defined; for instance, each identified genomic marker will require an accompanying molecular diagnostic test.

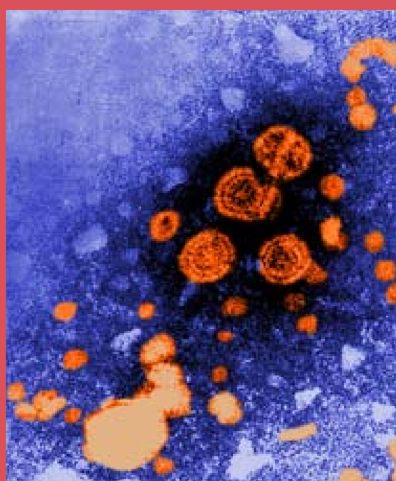
But validating genomic correlations with disease remains both expensive and high risk. Therefore, industry may not be willing to invest substantially until a clearer path to validation has been developed and a larger number of success stories achieved through the use of public funds. To realise the benefits of investing in genomic technologies, translational research to validate these correlations must be done [26]. This should be through the development of tools that would allow molecular diagnostics to be standardised and evaluated, and through increased cooperation with, and endeavour by, industry to demonstrate the utility of their developments. As well as this, unlike rare single-gene disorders such as diabetes

Commercial development of tandem-core based vaccines for hepatitis

In this collaborative R&D project part-funded by the Technology Strategy Board the consortum is developing a novel vaccine technology based on a genetic construct of tandem hepatitis B core antigens combined with antigens specific for hepatitis A and B. Such constructs are attractive since they dramatically increase the potency of the immune response generated to the specific target antigens.

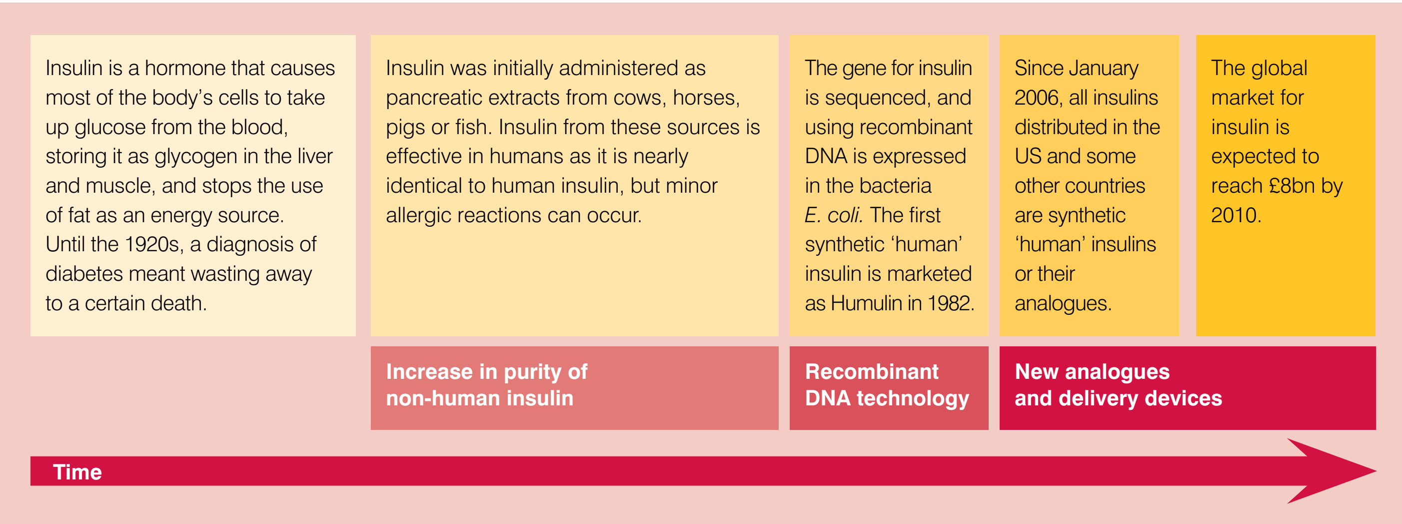
Partners: Arecor Ltd, iQur Ltd, Mologic Ltd, University of Leeds

Total project cost: £1m



Centers for Disease Control and Prevention / Dr Erskine Palmer

Figure 1 – History of insulin treatment for diabetes



(Figure 1), the complete causal pathway of common multifactorial diseases is likely to differ between individuals, and this inherent variability means that accurately predicting risk at an individual level may be difficult to achieve.

The last 30 years have seen significant growth in new medicines based on biological rather than chemical components. Biopharmaceuticals, which depend on recombinant DNA technologies, accounted for more than one-third of all drugs under development globally by pharmaceutical and biotechnology companies in 2007 [27]. The number of licensed biopharmaceuticals is forecast to grow at a rate of around 20% per annum, with antibody-based therapies being an important driver in which the UK has a strong track record of discovery [28]. There is significant longer-term potential for biopharmaceuticals developed in the UK to generate significant and profitable global sales (refer to our *Medicines and Healthcare Strategy*).

2.3.4 Animal genomics

Traditionally animal health companies have had limited interest in genomics but interest is now growing, with the use of genomics to identify targets (eg for immunomodulation, and identifying antigens or adjuvants) and to provide new insights into how certain pathogens evade an immune response. For instance, the British Livestock Genetics Consortium has over 80 members. Advances in molecular genetics have led to the identification of multiple genes or genetic markers associated with genes that affect traits of interest. This includes genes for single-gene traits, quantitative trait loci (stretches of DNA that are closely linked to the genes that underlie the trait in question) or genomic regions that affect quantitative traits. This has provided opportunities to enhance response to selection, in particular for traits that are difficult to improve by conventional selection.

With increasing disposable income in the developing world, the demand for meat, milk and eggs is growing [29]. Hundreds of thousands of global livestock farmers are potential customers of breeding companies. The UK is a world leader in animal breeding and has a number of world-leading companies which are well placed to exploit the increased understanding of the genetics of economically important traits and in several cases are already using genomics technologies. For instance, UK dairy farming is the single largest agricultural sector in the UK, valued at £2.8bn, and achieves yields above the EU average.

The publication of the draft genome sequences for the chicken and the cow, together with genome sequences of a range of key pathogens, provide good business opportunities. Other animal genomes are targets for sequencing but will require public funding.

Other animal biotechnologies, such as GM livestock bred for new traits, are very much in their commercial infancy. There is considerable technological and market potential (eg for GM poultry resistant to avian influenza as a strategy to reduce the risk of human influenza pandemics), provided that current nervousness about market acceptability can be overcome.

2.3.5 Microbial genomics

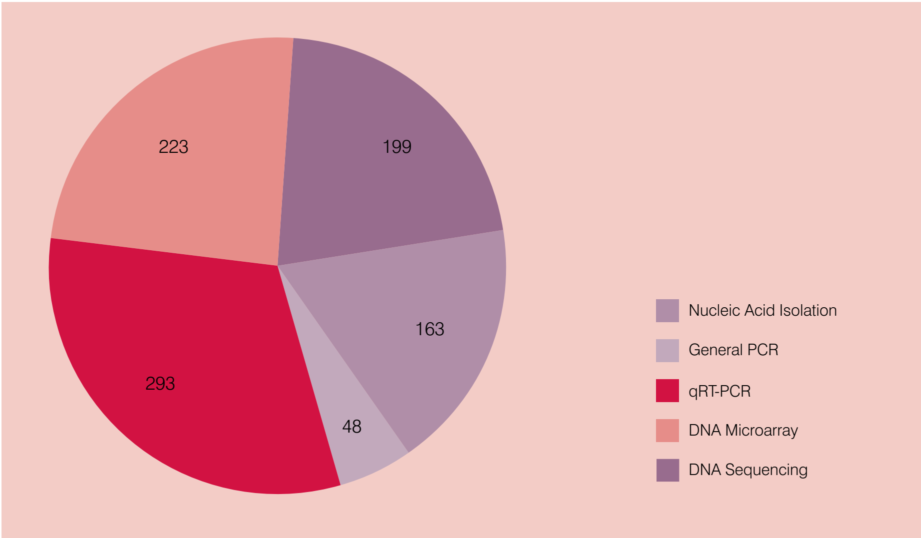
Microorganisms have been used in the manufacture of foods for over 8,000 years. They have a vital role in fermented foods such as beer and soy sauce as well as being a source of food additives: amino acid supplements, flavours, flavour enhancers and vitamins. In addition, microbial production of a wide range of therapeutically useful proteins (vaccines, cytokines and growth factors etc) is commonplace.

Microbial genomics offers opportunities to identify, detect, select and validate new antibacterial targets and vaccine candidates as well as to identify new medicines. A greater understanding of microbial metabolic pathways can elucidate potential means of controlling infection, inhibiting resistance to antibiotics, and accelerating the drug discovery process. In addition, microorganisms are a valuable resource as a 'biochemical factory', whether being used as a single species, a mixed community or a source of purified enzymes. For instance, the efficient breakdown of lignocelluloses is a key step in second-generation biofuels that can be achieved with the help of microorganisms or their enzymes.

The UK has a number of leading academic centres in microbial sciences that have a long history of using microorganisms for commercial applications. These economic uses of microorganisms are the earliest examples of biotechnology, used in food and agriculture. Beer is fermented from brewer's yeast and 90% of beer drunk in the UK is made here. The brewing and pub industry contribute over £28bn to the UK economy [30].

The UK's National Collection of Yeast Cultures has over 3,400 strains, and the rarity of some of the strains makes them important as reference material for research and potential applications.

Figure 2 – US markets (£m) of high-throughput analytical technologies in 2005 [34]



Half of BBSRC's Bioprocessing Research Industry Club members use microbial production systems for protein expression, mostly for human health applications.

2.3.6 Plant genomics

Plant genomics has had a very high public profile due to debates about genetic modification and its safety. This has been seen less in the US, where 300 million people have been eating GM ingredients for 15 years. In 2007 the global market value of GM crops was £3.5bn comprising soya beans, maize, cotton and canola [31]. The US is the global leader in GM crops, growing over 50 million hectares in 2006 [32]. In 2007, the global area of GM crops continued to climb for the twelfth consecutive year at a sustained double-digit growth rate of 12% [33]. Notably, 63% of GM maize, 78% of GM cotton, and 37% of all GM crops in the US in 2007 were stacked products (containing two or three traits that delivered multiple benefits) [31].

In the UK, if existing traditional crops were replaced with GM crops, yields could potentially be increased by nearly 0.6 million tonnes and generate income of £87m according to the National Centre for Food and Agricultural Policy. The UK has not planted any GM crops for commercial use, despite government support for the technology, although a number of research groups are active in this area.

However, genetic modification of plants is not the only technology in use, and applying all these technologies will substantially improve plant breeding, farming and food processing. Applications include new improvements to nutritional quality, increased yield or new varieties. Taking advantage of the genetic diversity of plants will not only give consumers a wider choice of food, it will also expand the range of plant-derived products, including novel forms of pharmaceuticals, biodegradable or bio-renewable plastics, bioenergy and paper.

There are a number of leading academic centres in plant sciences; the British Society of Plant Breeders represents more than 50 mostly commercial members. By 2010, the UK will have the largest biomass facility in the world.

2.3.7 Technology instrumentation and reagents

As well as the potential market applications from the use of genomics-based technologies, there is also a market for, and around, the technologies themselves. The US has by far the most successful and mature market, growing at about 3-5% each year [34]. The annual US market for goods and services supporting the genomics field is approximately £2-2.5bn, with the proteomics market less than half the size at about £0.5-1bn [34].

In 2005 the total US market for HTAT was £1bn (Figure 2). The fastest-growing segment of this market is for quantitative real-time reverse transcription polymerase chain reaction (qRT-PCR), including instrumentation and reagents. Other relevant technologies include nucleic acid isolation, general polymerase chain reaction (PCR), DNA microarray and DNA sequencing. The market is predicted to have a compound annual growth rate of 10.4% between 2005 and 2012, giving a US market of about £1.5bn in 2010.

2.4 Alignment with Technology Strategy Board investment criteria

Table 2 summarises the genomics theme according to the Technology Strategy Board's four criteria for support. The UK has a strong research base and a number of leading companies that are using genomics, both in human and non-human applications. The opportunity for genomics-based technologies to underpin a more bio-based economy is large and many opportunities are obtainable within a reasonable timeframe.

Table 2 – Technology Strategy Board criteria applied to the UK genomics sector

Fit against criteria for investment	
UK capability	Medium
Global opportunity	High
Timeliness & impact	High
Added value	High

3. Industrial biotechnology

Industrial biotechnology is the use of agricultural feedstocks and biotechnologies, such as novel biocatalysis and biotransformation, which may enable us to develop new, more efficient and more sustainable methods to help us meet our needs for energy, chemicals and materials. Integrating plant and aquatic feedstocks with the biocatalytic ability of microorganisms has the potential to drive the development of novel bioproducts that improve health, generate energy, or produce new chemicals or existing chemicals more cheaply. New technology could lead to using bio-based chemicals and materials to make products such as anti-freeze, plastics, packaging and coatings, and personal care items that are currently made from petroleum. In some cases these products may be completely biodegradable. Indeed some retailers are driving suppliers to meet sustainability criteria that require 'cradle to cradle' performance – that is, they are essentially waste free.

3.1 Technology overview

The priority technologies relevant to this sector are:

- **Biocatalysis:** using isolated enzymes or enzymes still residing inside living cells to perform chemical transformations on organic compounds, complemented by metabolic engineering and system modelling to optimise performance
- **Biorefining:** the design of new biorefineries including modelling and component technologies, plant and microbial matter bioprocessing, extraction and separation techniques, and fast-track molecular breeding of feedstock species for improved raw material quality, consistency and yield
- **Discovery tools:** microbial and gene screening, enzyme activity assays, cell-based bioassays such as those based on cell proliferation or cell death or that are specific for a particular drug's activity.

3.2 Applications

Industrial biotechnologies have applications in a variety of significant markets (see Table 3). These applications include:

- medicines
- biofuels
- enzymes
- bio-based chemicals
- food and feed ingredients
- carbon cycling and sequestration.

The ways in which biotechnologies underpin these applications are set out in Appendix 3.

Table 3 – Industrial biotechnologies have applications in a variety of significant markets

Application	Market size	Technologies
Medicines	Global market for medicines £356bn in 2007 [35]	Discovery tools, biocatalysis
Biofuels	Global market for biofuels £15bn in 2008 [36] The UK's demand for road transport fuels will increase by 14% between 2007 and 2010 [38]	Biocatalysis, biorefining, discovery tools
Enzymes	Global industrial enzyme market worth £1bn in 2007 [38]	Biocatalysis, discovery tools
Bio-based chemicals	Global market for bio-based chemicals £39bn in 2005 [38], expected to grow to £113bn by 2012	Biocatalysis, biorefining, discovery tools
Food and feed ingredients	Global market for food and feed ingredients £7-8bn in 2008 [39]	Biocatalysis, biorefining, discovery tools
Carbon cycling and sequestration	Likely to form part of an integrated biorefinery or as an addition to an existing facility	Biocatalysis, biorefining, discovery tools

3.3 Industry and market overview

3.3.1 Background

Large-scale manufacturing of industrial biotechnology products began through large-scale fermentation to produce animal feed, lactic acid and acetone nearly a century ago. However, it wasn't until the techniques of recombinant DNA technology emerged from medical biotechnology that it became possible to express some compounds previously only produced via synthetic routes.

Producers today use a variety of fermentation platforms and microbial strains to generate commercial biocatalysts for specific applications in the manufacture of a number of intermediates or final products. The biocatalysts are usually enzymes, either isolated or left inside the cells, for instance, during brewing where whole live yeast cells convert sugars to alcohol.

Industrial biotechnological processes (including biocatalysis) are having an increasing impact on the chemical sector, enabling both the conversion of renewable resources, such as sugars or vegetable oils, and the more efficient conversion of conventional raw materials into a variety of chemical substances, many of which cannot be made directly by synthetic routes. These substances include fine and bulk chemicals, pharmaceuticals, biocolourants, solvents, bioplastics, vitamins, food additives, biopesticides, and liquid biofuels such as bioethanol and biodiesel.

3.3.2 Europe

Europe has considerable capabilities in the field of industrial biotechnology: for instance 70% of the world enzyme industry is based there, and a high level of knowledge in the field of food technology and fine chemistry is located in Europe. Moreover, there is a strong political and public sentiment to improve industrial sustainability in Europe (Gothenburg objectives).

The economics of the industrial biotechnology sector are heavily influenced by fiscal incentives, often set by the European Parliament, to produce power and fuels from non-fossil sources, such as:

- Renewables Obligation Certificates
- Climate Change Levy Exemption Certificates
- Renewable Transport Fuel Obligation (RTFO)
- Energy Taxation Directive
- carbon pricing and trading.

3.3.3 UK position

The UK is committed to the multidisciplinary requirements of industrial biotechnology. In 2008, the UK's Engineering and Physical Sciences Research Council (EPSRC) selected 44 new centres to share a £250m injection into postgraduate science education that will provide 2,000 extra science and engineering PhDs over five years with a remit for collaboration across scientific disciplines.

The UK's status as a significant player in industrial biotechnology owes much to the underlying excellence of its chemicals, agricultural and marine sectors. For instance, the UK's maritime heritage, extensive coastline and easy access to diverse marine habitats have facilitated the establishment of several centres of excellence and support a number of companies.

The UK has a number of world-class culture collections of dairy organisms, food bacteria, industrial and marine bacteria, pathogenic fungi, plant pathogenic bacteria, algae and protozoa, wood-rotting fungi and yeast cultures. These national collections also offer associated services to identify and analyse microbial strains and support discovery research with a small but strong end user base. A strong industrial biotechnology cluster exists in the north of England and the UK Government recently announced an investment of £12.5m for a large-scale (10,000 litre) open-access industrial biotechnology demonstrator facility.

As part of the Government's recent study of the UK's biotechnology sector, we identified about 40 core users of industrial biotechnology in the UK. These include specialist companies, global chemicals and industrial biotechnology companies, companies with interests in industrial biotechnology for diagnostics and monitoring, and companies using bio-based feedstocks. The Government response to the BIS Innovation and Growth Team's study on industrial biotechnology has confirmed its view that industrial biotechnology has considerable potential in chemicals and chemistry-using industries that are themselves key UK sectors [6].

A survey by the Chemistry Innovation Knowledge Transfer Network confirmed that there is a strong and diverse base of activity in industrial biotechnology in the UK, operating throughout the chemicals and chemistry-using industries [40]. This sector has a turnover in excess of £50bn and is one of the UK's largest manufacturing industries. One-third of the respondents were current users of industrial biotechnology, with a further 13% of companies considering take-up of industrial biotechnology in the future.

The higher levels of take-up were concentrated in renewable energy (mainly biofuels), water and effluent treatment, brewing, and chemicals processing. Technologies underpinning the industrial biotechnology-based activity identified by the survey tended to centre on the action of enzymes as biocatalysts (eg fermentation processes).

In 2008, BBSRC launched its £5m Integrated Biorefinery Technologies Initiative Research and Technology Club aimed at developing biological processes and feedstocks to reduce UK dependence on fossil fuels as a source of chemicals, materials and fuel.

BBSRC has launched the Sustainable Bioenergy Centre, a £27m investment that increases UK bioenergy research capacity. The centre brings together six world-class research groups, creating a network with expertise and specialist resources that span the bioenergy pipeline from growing biomass to fermentation for biofuels. Fifteen leading industrial associates bring business expertise and perspectives, and support totalling around £7m.

For more information about the UK's position in the industrial biotechnology sector, see the following sections on 'Chemicals and chemistry-using sector' and 'Biofuels'.

3.3.4 Chemicals and chemistry-using sector

The market opportunities in the chemicals and chemistry-using sector are particularly promising due to their potential to take market share in existing, large petrochemical-based markets. In addition, there are many opportunities for existing chemical companies to further use the biosciences in their production processes. In 2005, bio-based products accounted for 7% of global sales and almost £39bn in value within the chemicals sector, with the EU industry accounting for approximately 30% of this latest value [38]. A breakdown of these markets is given in Table 4 with predictions for 2010; the total global market for 2020 is estimated to be £125bn. McKinsey and Company predict that biotechnology could be applied in the production of 10-20% of all chemicals sold by 2010 in sectors such as fine chemicals (total market size £45bn), polymers (£185bn), bulk chemicals (£190bn) and specialities (£280bn) [38].

Table 4 shows that in 2005 biofuels were the leading industrial biotechnology product by sales, generating £10.5bn. In Europe biodiesel is the principal biofuel produced, whereas bioethanol is the main output in the US and Brazil.

Plant extracts were the second largest by sales with £9.5bn, but they are predicted to have modest growth to 2010. These extracts have bioactive properties such as antifungal, antiviral, antibacterial or anti-inflammatory effects. More of these extracts are being discovered as the practical difficulties of natural products are being overcome by advances in separation technologies and in the speed and sensitivity of structure elucidation.

Table 4 shows that by 2010 the most significant growth is predicted to be in biofuels, pharmaceutical ingredients, bulk/polymers, food and feed ingredients, and enzymes. Enzymes have multiple uses including chemical conversion, preservation, ripening and clarification, which are employed in a number of industries such as chemicals, pharmaceuticals, food, textiles, starch, beverages and personal products. The most widely used enzymes available for commercial food and drink use are pectinases, hemicellulases, glucanases and glycosidases produced from GM fungi that are removed from the final product.

Table 4 – Global industrial biotechnology product sales in 2005 and predictions for 2010 [38]

Product	Sales in 2005 (£bn)	Predicted sales in 2010 (£bn)
Biofuels (bioethanol, biodiesel)	10.5	21
Plant extracts/botanicals (xanthans, essential oils, starch)	9.5	11.5
Pharmaceutical ingredients (including enzymes for chiral molecules)	5	10
Bulk/polymers (including rubber, propylene glycols)	5	7.5
Food and feed ingredients	3.5	5.5
Oleochemicals (surfactants)	3.5	4
Enzymes	1	2
Others (including R&D services)	0.5	1
Total	38.5	62.5

There is a large opportunity both in terms of the biological resources available and the size of existing global markets where bio-based products and processes can make an impact. For instance, only 5-15% of approximately 250,000 species of higher plants have been investigated for the presence of bioactive compounds. The global lubricants business was worth £18bn in 2006 and 90% of this could be replaced from biological sources such as vegetable oils [41,42].

Investment opportunities in the sector typically focus on a process rather than a finished product and tend to be defined not by markets *per se*, but by the deployment of biotechnologies to underpin multiple traditional markets. Products such as vitamins, amino acids, pharmaceutical intermediates, anti-infectives and bulk organic chemicals such as acetic acid or ethylene glycol, currently derived from chemical synthesis are increasingly being produced using biological routes. For example, vitamin B2 (or riboflavin) was produced from glucose through a complex and less sustainable multi-step chemical process, while today it can be produced in a one-step fermentation process which consumes less energy and is more efficient.

3.3.5 Biofuels

The market opportunities for novel biofuel technologies are large and the UK has a mature transport sector with a well established liquid fuel supply chain. The UK sold 264 million litres of biofuel during 2006, 95 million litres of which were ethanol [43]. UK production of biodiesel was 192,000 tonnes in 2008, an increase from 150,000 tonnes in 2007; the UK was the tenth-highest producer in Europe [44]. In 2006, Germany was the leading bioethanol producer in Europe, with 431 million litres per year [45].

If the current European and UK fiscal incentives to produce biofuels continue, then the conversion of crops to first-generation biofuels will persist. Two large, wheat-based bioethanol plants in the UK are due to come online in 2009-10. However, in the absence of subsidies, a biorefinery producing other chemicals is unlikely to be profitable as few bio-derived platform chemicals can compete with current petrochemical-derived ones. Therefore, any mixed-product biorefinery design may rely initially on the production of biofuels from crops to be commercially viable (see Figure 3, which represents a number of advanced biorefinery configurations, though it is not intended to be exhaustive).

Butafuel-advanced biofuels for transportation

Green Biologics Ltd is developing Butafuel, a sustainable transport fuel based on Butanol. Micro-organisms are used to convert waste plant material into the next-generation biofuel through high-temperature fermentation and enzyme processes, which are faster, more efficient and cheaper than conventional processes.

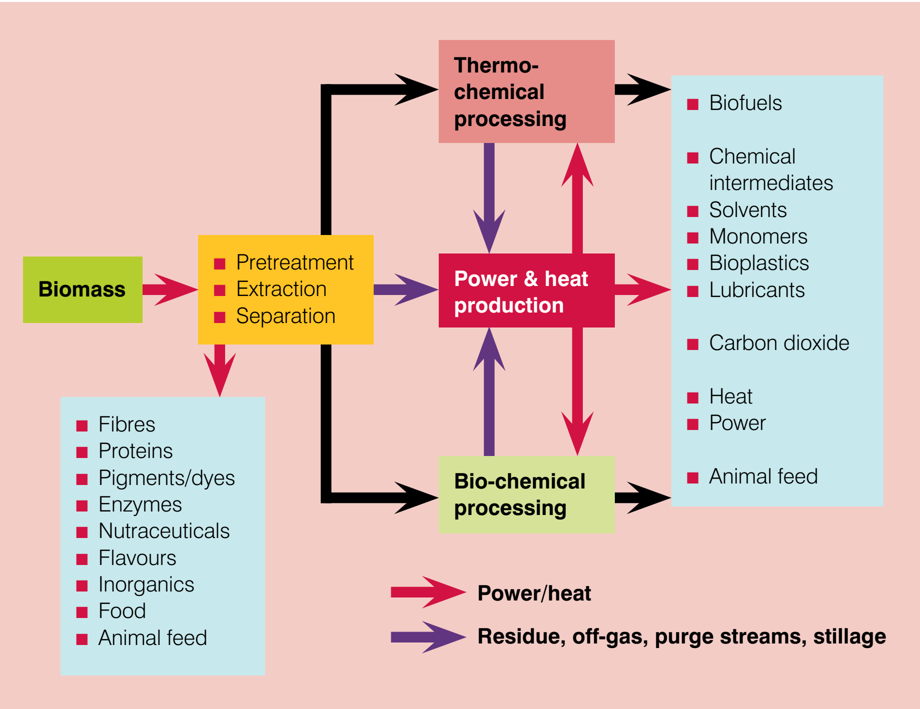
Partners: Green Biologics,
C-Tech Innovation,
EKB Technology Ltd

The total project cost: £567,000

Feedstock prices for first-generation fermentation routes (sugar and starch from the grain of the crop) will likely remain high and politically charged due to competition with the food chain. However, over time second-generation processes based on lignocellulosic feedstocks (from the non-food producing parts of crops or non-food crops) will become more efficient and drive the cost of bio-derived chemicals lower. Biochemical and thermochemical processes are constantly improving their conversion efficiencies. Third-generation biorefineries processing micro-algae may need to exploit existing markets for high-value products such as food and cosmetics or carbon cycling and sequestration until greater efficiencies can be achieved for biofuel production.

The UK's Carbon Trust has launched two initiatives to support the development of biofuels: the Pyrolysis Challenge in 2008 had the goal of producing oil with the properties needed for integration into the existing transport fuel supply chain, and the Advanced Algae Biofuels Challenge in 2009 supports the development and commercialisation of microalgae biofuel technologies. A number of energy companies and start-ups based in the UK are investing in bio-based methods of energy production. In fact, the UK's second largest sector by GVA is oil and gas. The UK has well-established ways to approve new suppliers of electricity or gas to connect to the electricity or gas transmission and distribution systems to receive an income.

Figure 3 – Schematic of a generic biorefinery complex



Source: National Non-Food Crops Centre

3.4 Innovation drivers

A number of themes are driving innovation in the industrial biotechnology sector. The most important of these are:

- the depletion of fossil fuels, security of fuel supplies, high crude oil prices and the need to dispose of wastes in a more environmentally friendly way. These factors will all drive the need for bio-renewable fuel sources. This is backed by UK and European targets related to energy security and climate change:
  - the UK aims to meet its share of the EU target to source 20% of the EU's energy from renewable sources by 2020
  - from April 2008, under the Government's RTFO, transport fuel suppliers have had to ensure that 2.5% of their total transport fuel sale in the UK comes from biofuels
  - the European Parliament's Committee on Industry, Research and Energy supports a transport fuel target of 10% by 2020
- the desire for the sustainable production of both biofuels and food will require the efficient use of land, water and nutrients
- consumers' ethical demands for industry and agriculture to reduce their environmental footprint by adopting more sustainable processes for food, chemicals, materials and energy production
- a move towards cleaner, more efficient manufacturing of chemicals, materials and active pharmaceutical ingredients in cost-driven markets
- the discovery and sustainable use of natural products as biologically active ingredients.

3.5 Alignment with Technology Strategy Board investment criteria

Table 5 summarises the industrial biotechnology theme according to the Technology Strategy Board's four criteria for support. The UK has a strong research base, many successful small and medium-sized enterprises (SMEs) as well as large chemical companies that can exploit the biosciences. There are still significant technical and investment challenges to overcome to fully realise the potential of second and third-generation biofuel production.

Table 5 – Technology Strategy Board criteria applied to the UK industrial biotechnology sector

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	High
Added value	High

4. Agriculture and food (agrifood)

Agrifood includes agriculture, horticulture and food and drink processing technologies. Agricultural and horticultural practice provides a number of outputs such as food ingredients, biomass and biofuel, and it also sustains our landscape. The path from agriculture through to food retailing is important as the route taken has an impact on food security, biofuel production, yield, quality and the landscape. The food processing sector, sitting between producer and retailer, forms a significant division of UK manufacturing where, apart from a small number of large companies, small companies, operating on low margins, dominate.

4.1 Technology overview

The priority technologies relevant to this sector are:

- **Diagnostics:** tests for nucleic acids (DNA and RNA), markers and antibodies; chip technology; multiplex detection; PCR; biosensors; automated sampling and rapid liquid chromatographic techniques
- **Physiological and phenotype screening:** responses to temperature and climatic zones; developmental responses to temperature, photoperiod, and light quality; photosynthetic rate comparisons; photorespiration; relative growth rate; imaging systems for root and foliage formation
- **Reproductive, cell and embryo technologies:** artificial insemination; tissue explants methods for studying host-pathogen interactions; cryopreservation (freezing) of gametes or embryos; induction of multiple ovulations; embryo transfer; *in vitro* fertilisation; nuclear transfer and cloning
- **Selection, preservation and processing:** encapsulation, nanotechnology, emulsification, irradiation, drying, controlled release, high-pressure processing and separations.

4.2 Applications

Agrifood-based technologies have applications in a variety of significant markets (see Table 6).
These applications include:

- crop improvement and protection
- livestock improvement and protection
- functional foods and novel food processes
- food safety, authenticity and traceability testing.

The ways in which the technologies underpin these applications is set out in Appendix 4.

Table 6 – Genomics-based technologies have applications in a variety of significant markets

Application	Market size	Technologies
Crop improvement and protection	The global crop biotechnology market in 2007 was valued at £3.5bn [19] and is growing at 10% each year [20]	Physiological and phenotype screening, diagnostics
Livestock improvement and protection	The global livestock gross production value in 2007 was over I$600bn[2] [46] A conservative estimate of the gain from animal breeding improvements in Europe is nearly £1.6bn each year [47] The cost of the foot and mouth outbreak in the UK in 2001 was £8bn [48]	Reproductive, cell and embryo technologies, diagnostics
Functional foods and novel food processes	The global functional food market is expected to reach a value of at least £45bn by 2013 [49]	Selection, preservation and processing
Food safety, authenticity and traceability testing	The global food microbiology testing market is expected to grow to £1.2bn in 2013, representing a projected annual growth rate of more than 8% since 2005 [50] The US market for food safety testing was valued at £1bn in 2006 and predicted to rise to £1.4bn by 2012 [51]	Diagnostics

2 The international dollar, I$, is a hypothetical unit of currency that has the same purchasing power that the US dollar had in the United States at a given point in time. It cannot be converted to another country's currency using current market exchange rates.

4.3 Industry and market overview

4.3.1 Background

The food processing industries are bound together with the agricultural food chain, extending from the production and processing of agricultural inputs through to food retailing and catering (Appendix 4). The composition of the global food industry is continually changing and evolving as food suppliers, manufacturers and retailers adjust to meet the wishes of the consumers, who are increasingly demanding a wider variety of higher-quality products and greater all-year-round choice.

Many foods have become commodities driven by price and delivered through sophisticated supply chains. However, food prices have risen over recent years due to a complex set of factors that include poor harvests, changing land use, increasing fuel costs for logistics and production, demand for first-generation biofuel feedstock, and the changing appetites of people in developing nations. The global demand for meat, milk and eggs is expected to grow rapidly, especially in the developing world. Another factor is the lack of applied activities in the sector, which has led to a stalling of increased crop productivity and food research.

Concerns about food security (availability, access, affordability, safety, resilience and public confidence in supply) have raised the potential for technology innovation to improve agricultural productivity and reduce wastage through the supply chain. The Technology Strategy Board announced a new innovation platform in sustainable agrifood in 2009, to meet such challenges. In the UK, the self-sufficiency ratio of domestic production to consumption has been in noticeable decline over the last decade. However, some consider this a misleading indicator of underlying food security and that many of the risks associated with food supply are likely to be adequately dealt with by the markets [61].

Products that can improve health, enhance appearance or improve mental or physical performance are important growth areas but, for authenticity, will rely on scientific evidence to support their claims. However, knowledge transfer of best practice will be equally important in increasing production and supply chain efficiencies.

4.3.2 UK position

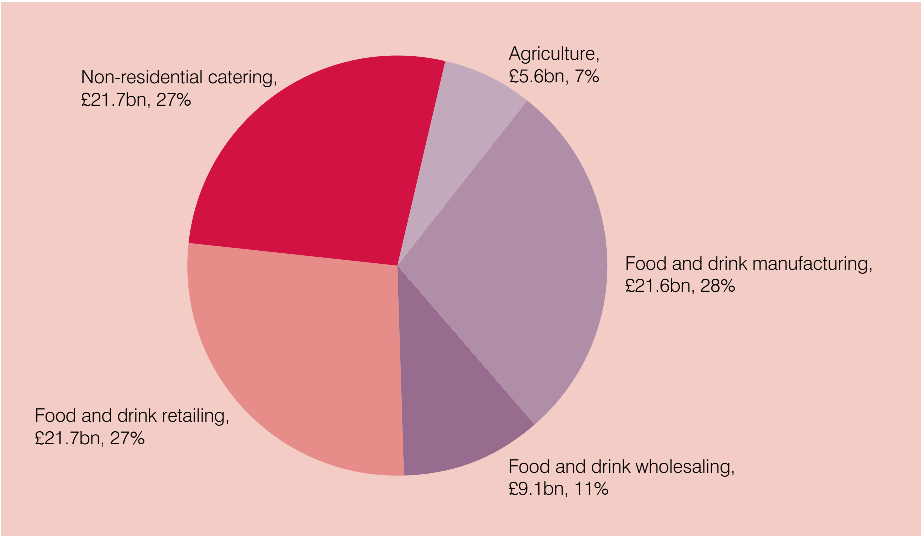
The UK is 60% self-sufficient for food, supplied by more than 300,000 farmers and primary producers. A further 6,000 enterprises process this food, adding significant value. The UK food processing sector is relatively fragmented: a few multinationals compete on the global market with global brands and a large range of products, while smaller enterprises serve local markets and concentrate on regional preferences. Due to the small size of most of the companies within the food processing sector, investment in research is limited. However, the high rate of product development, driven by market forces, results in a high capability for process flexibility and improvement.

The UK has high standards of food quality, safety and sustainability (there are more than 100 food safety testing centres), a strong ability to add value, good logistics (means of transportation and distribution) and technological sophistication.The sector's productivity and productivity growth are high relative to other UK manufacturing sectors and its R&D intensity is higher than in other EU countries, although the amount spent on research is low compared to other industries.

In the UK, groceries account for 12.8% of all household spending, making it the third largest area of expenditure accounting for 49p in every £1 of retail spending [52]. The UK agrifood sector (agriculture, food and drink manufacturing, food and drink wholesaling, food and drink retailing plus non-residential catering) was worth £80bn in 2007 (Figure 4); part of a £128bn grocery market [53].

For more information about the UK's position in the agrifood sector, see the following sections on 'Crops', 'Livestock' and 'Food technology and processing'.

Figure 4 – Gross Value Added to the UK by the agrifood sector in 2007 [53]



4.3.3 Crops

Recent global crop production (wheat, grain, rice, oilseeds and cotton) has increased 5% annually and stands at 2,500 million metric tonnes [66]. However, with an increasing demand for food (for humans and animals) and biofuel (corn, vegetable oils, wheat and sugarcane), global agricultural trade is projected to rise.

Wheat is the most widely grown cereal crop in the UK and is mostly milled for flour or used for animal feed. UK farmers are among the most productive and efficient in the world, accounting for 2.5% of global production. In 2008, the UK cereals harvest was 25 million tonnes, up 28% on 2007.

GM crops represent a small proportion of global crop production but represent a £3.5bn market [19]. In the first 10 years of commercial use, incomes from the 10 million farmers using GM technology increased by £14bn and pesticide use was 7% lower [54].

The effects of climate change and the desire to cut CO_2 emissions while maintaining a secure, competitive energy supply offer a number of challenges for the agrifood sector. An increase in UK temperatures will have some negative impacts on agriculture but might also allow the planting of new crops and an increase in others, such as vineyards. Longer growing seasons should allow extended supply and greater availability of home-grown produce, for example altered lambing and calving patterns that fit grass growth can enable longer market supply of meat or new non-food crops for bioenergy.

The forecast for world cereal production and use is expected to demonstrate a strong growth, which mainly reflects the rapid rise in the use of grains as raw material for the production of biofuels; for 2007-08 this was forecast to approach 100 million tonnes, mainly corn [55].

In 2007, US corn ethanol reduced greenhouse gas emissions by 19% compared with gasoline [56].

The UK Government's Rural Development Programme will be allocating £3.3bn to agri-environment and other land management schemes during 2007-2013. About £600m will be made available to make agriculture and forestry more competitive and sustainable, including grants to cover 40% of the establishment costs of several energy crops [57].

The British Society of Plant Breeders represents more than 50 members of which the majority are commercial organisations; the largest of these announced plans in 2008 to increase its investment in research and manufacturing in the UK by more than £100m.

4.3.4 Livestock

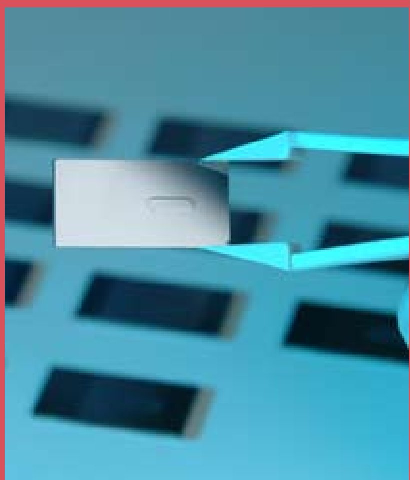
The UK has a rich and diverse population of livestock breeds, which use a significant proportion of agricultural land. There are over 160 native breeds of cattle, sheep, goats, pigs, poultry, horses and ponies. The UK has several world-leading livestock companies which provide more than half of the global genetics in meat and poultry. The UK livestock domestic market encompasses an estimated 200,000 livestock holdings and 500,000 related jobs, and annual outputs of £8bn at farm gate and about £24bn at retail [58].

The economic gain from animal breeding to the animal agricultural sector in Europe is worth almost £1.6bn each year and breeding organisations spend some £120m yearly on research, development and implementation [47].

The global veterinary diagnostics market in 2008 was worth between £500m and £1bn and is dominated by traditional immunoassay diagnostics, although the market for nucleic acid-based veterinary diagnostics is expected to grow [59]. The UK has a regional network of 16 veterinary laboratories as well as two surveillance centres which together can detect new and emerging diseases throughout the country.

Portable direct immunoassay diagnosis devices for animals and humans

Stratophase and its consortium partners are developing a direct immunoassay system to detect foot and mouth disease. The system will have higher sensitivity than the antibody-based lateral flow tests used at present. This will allow infection to be detected sooner and will avoid the need for time-consuming polymerase chain reaction lab tests.



Partners: Stratophase Ltd, University of Cambridge, Bristol Industrial and Research Associates Ltd, Chelsea Technologies Group.

The total project cost: £1m

4.3.5 Food technology and processing

Food technology enables food science to be applied to the selection, preservation, processing, packaging, distribution and use of safe, nutritious and wholesome food. Global processed food sales were worth £1.6tr in 2005 and accounted for about three-quarters of total world food sales [60]. In Europe, food and drink turnover reached £669bn in 2005 with the majority of companies being SMEs, which accounted for about half of the turnover [61].

Over a fifth of the UK's top 100 companies by GVA are in food manufacturing, and with over 6,700 food and drink enterprises in the UK alone, the UK is a world leader in added value food and drink production [62]. The UK is in the top five markets for industrial bakery enzymes, and the UK's leading food producer by Gross Value Added had UK sales of £67m and global sales of £437m from its cholesterol-lowering probiotic range in 2007 [63]. The industry is the UK's largest manufacturing sector, contributing 14.2% of manufacturing's GVA and employs 470,000 people [64].

4.4 Innovation drivers

A number of themes are driving innovation in the agrifood sector. The most important of these are:

- consumer demands for food variety, affordability, safety, quality and information, eg food miles, nutritional content and environmental impact
- consumer demands for healthy, convenient and indulgence foods, 'natural products', functional foods, sustainable and efficient production of authentic products
- matching diet to individual needs, eg those addressing obesity and diabetes
- increasing public awareness (and scientific evidence) of the link between food and health
- the effects of climate change and an increasing global population putting increasing pressure on available food sources.

4.5 Alignment with Technology Strategy Board investment criteria

UK capacity is good, built on a strong agricultural and food science academic base with translational activities encouraged by a number of world-class applied research organisations. There are a number of good opportunities which can be captured by accelerating the translation of agrifood science innovations to market, which can be achieved in relatively short time frames.

Table 7 – Technology Strategy Board criteria applied to the UK agrifood sector

Fit against criteria for investment	
UK capability	High
Global opportunity	High
Timeliness & impact	High
Added value	High

5. Technology strategy

5.1 Implementation

The Technology Strategy Board recognises the importance of the biosciences to the UK economy and will invest in relevant technologies aligned with the Biosciences Strategy, with a focus on genomics, industrial biotechnology and agrifood. This investment will be through business-led activities and therefore will implicitly have a market focus.

The priority applications identified in our analysis include:

- new biological therapeutics and delivery systems, new vaccines, monoclonal antibodies and functional products (eg nutraceuticals), and gene and cell-based therapies (eg regenerative medicine, genotyping and gene therapy, and personalised medicine)
- efficient chemical and biological processes, including catalysis and biocatalysis, and chemical to bioprocesses
- sustainable energy and materials (eg waste treatment and recycling, biofuels, renewables and other biomaterials)
- maximising the use of scarce land, water and resources to meet food and non-food needs, through advanced farming systems, efficient crop and livestock breeds, and GM organisms.

We will work with key stakeholders in the sector (including government departments, research councils, knowledge transfer networks, research and technology organisations, regional development agencies and the devolved administrations) to ensure that a coordinated approach to funding is achieved that provides businesses with a clear picture of investment opportunities. We will also explore opportunities with other stakeholders to co-fund future activities and to establish new collaborative initiatives. UK companies should make use of appropriate opportunities through the European Seventh Framework Programme. There are a number of themes which usually include support for R&D by companies that have capability in the biosciences. In addition, we will consider investment in relevant European programmes which can offer opportunities for UK companies to form collaborative projects with European partner companies or universities.

To implement this strategy we will invest to support and encourage:

- greater use of genomic-based technologies and knowledge sharing by UK companies, in particular those working in non-competitive, distinct sectors: for instance, the UK should exploit the business opportunities afforded by applying modern genomic techniques to commercial crop and livestock species
- technologies that support the production of second and third-generation biofuels through novel and/or improved processes: opportunities to increase productivity begin with the sustainable supply of high-yielding feedstocks and finish with the production of pure, high-value chemicals, including quality-tested biofuels
- next-generation multiproduct biorefinery technologies, building on the UK's strengths in chemistry, microbiology and engineering with attention to both upstream and downstream technologies
- UK chemicals and chemistry-using businesses to exploit the opportunities for bio-based processes: the UK should increase its use of sustainable, bioscience-inspired processes to produce products currently derived from petrochemicals, encouraged by knowledge transfer activities and financial incentives
- crop, food and livestock (agrifood) protection and improvement technologies: the UK government, in partnership with businesses, should invest in technologies to improve and monitor the yield, variety, safety, authenticity and traceability of its food supply; the diversification of our food supply should increase food security, increase consumer confidence and generate economic wealth
- the biosciences to play a part in current and future innovation platforms
- an increase in the number of knowledge transfer partnerships in the biosciences
- BBSRC and EPSRC to ensure that businesses have opportunities to exploit their funded research, with particular attention to the research industry clubs.

To implement the strategy more effectively we will also:

- interact with key industry bodies to facilitate engagement with business
- secure a strong input into European thinking on future Framework 7 themes through National Contact Points, to ensure that UK industry receives opportunities that match its interests and capabilities
- seek opportunities to help UK companies engage with their European counterparts
- communicate with UK Trade & Investment to ensure that an accurate picture of UK strengths is presented to current and future investors in the UK.

5.2 Technology opportunities

5.2.1 Genomics

Despite a lack of first-generation genomics companies, the UK's strong research base in the field combined with the variety of companies able to exploit the falling price of genomics technologies should offer several opportunities. In particular, more SMEs will be able to access these technologies as they become more affordable. All the larger companies, in particular those in the pharmaceutical sector, have in-house R&D capability and appropriate genetics expertise. These companies can generally access investment funds and have a proven record of innovation.

5.2.2 Industrial biotechnology

The development and exploitation by industry of plant, animal and microbial biosciences requires a multi and interdisciplinary approach to product and process design. The development of new biofuels markets in the UK represents an important strategic element of government policy in the transition to a future low-carbon economy [65]. Recent fiscal incentives have stimulated the biofuels sector although it is currently based on first-generation technologies where UK production capacity has been limited by cheaper foreign imports. However, developing a truly sustainable biofuels economy that can deliver environmentally beneficial transport fuels to customers at low cost while providing an attractive financial return to manufacturers and investors remains a challenging opportunity. The Technology Strategy Board, in partnership with other organisations, will aim to accelerate the development of advanced biofuels.

5.2.3 Agriculture and food

Opportunities in this sector include the development of diagnostic technologies for traceability and authenticity. There is also the potential for GM crops and animals to be part of the food chain but this will require public acceptance. In this respect, it will also be important to follow developments at BIS emerging from its 'Consultation on Science and Society', particularly in respect of 'increasing public confidence in science, research and their application'.

5.3 Barriers to uptake

5.3.1 Genomics

The increasing flow of data from high-throughput techniques (refer to our *Information and Communication Technology Strategy*) and the integration of genomic with other biological data are proving barriers to innovation. Several organisations are addressing these challenges using a systems biology approach, which could generate significant returns if methods become better targeted and more predictive. Other organisations are using cloud computing to provide a low-cost method of accessing sufficient amounts of computing power.

The stratification of patient populations is a route towards an ideal of personalised healthcare. Giving the right treatment, to the right person, in the right dose, avoids ineffective treatment and unwanted side effects. However, the ability to categorise patients into different subsets can require the validation of several genomic correlations with a particular disease. This requires the discovery of sufficient numbers of biomarkers through the collection of data from large numbers of patients. This is expensive and high risk as well as being a shift for pharmaceutical companies more used to the traditional business model of the 'blockbuster'. Therefore, private-public partnerships may be required to facilitate the transition.

5.3.2 Industrial biotechnology

The replacement of existing chemical-based processes with biological-based processes is hampered by a lack of awareness and understanding of the capabilities of industrial biotechnology and what benefits it has the potential to deliver. However, viable routes to market for bio-based products will require that they match existing petroleum-derived alternatives. Clearly, this is an area where knowledge transfer can play a key role in reducing barriers to uptake and in lowering perceptions of risk. To achieve a step-change in the economics of second and third-generation biofuel production requires a radically different manufacturing capability, such as that provided by the biorefinery concept. Large-scale process integration will maximise both energy and materials conversion efficiencies, and economies of scale can be exploited to deliver capital efficiencies and the cost-effective co-production of value-added chemicals. In addition, viable routes to market will often include the licensing of processes, which will require SMEs to think globally.

5.3.3 Food and agriculture

There are barriers to technology uptake in the food and drink industries due to the generally low margins and fast product turnover. The routes to market for traditional foods are well-established, but there is still some public resistance to the use of animal biotechnologies applied to food, animals and crops as well as the regulatory process being slow. In addition, foods that promise health benefits are required to demonstrate validity of their claims and few companies have successfully completed this process.

5.3.4 Other challenges

Other challenges include:

- the translation of basic BBSRC-type research into industrial applications
- the regulatory framework, particularly for some newer technologies (eg 'rationally attenuated' live vaccines are regulated for market approval).

5.4 Standards and metrology

Standards have a significant role to play in the uptake and use of new bio-based products and processes, and various agencies set and monitor those standards:

- biofuels will need to meet specific sustainability criteria; a European technical committee was established in 2008 to harmonise biofuel sustainability. In addition, standards may be required for permissible levels of biofuel components, and this may provide opportunities for businesses that produce diagnostics
- the European Chemicals Agency has identified a number of 'substances of very high concern' that could require formal authorisation under the Registration, Evaluation and Authorisation of Chemicals (REACH) [66]. REACH is a European Community Regulation on chemicals and their safe use which became law on 1 June 2007. It calls for the progressive substitution of the most dangerous chemicals when suitable alternatives have been identified which may provide opportunities for bio-based alternatives
- the European Food Safety Authority is responsible for risk assessment regarding food and feed safety, providing independent scientific advice and clear communication on existing and emerging risks that underpin new legislation
- the EC is responsible for approving GM organisms, taking scientific advice from the European Food Safety Authority; 110 crops have been approved to date. The release and marketing of GM organisms in the EU is governed by European Directive 90/220/EEC, and in the UK all applications are scrutinised by the Advisory Committee on Releases to the Environment.

Appendix 1 – How the biosciences relate to our other work

The biosciences underpin or overlap with other technology areas, application areas and innovation platforms that are supported by the Technology Strategy Board.

Technology areas	Areas of cross-over
Materials	■ Use of plant-based material to make bioplastics
Nanotechnology	■ Development of high-sensitivity diagnostics ■ Nanoporous zeolites for slow release of water and fertilisers for plants ■ Nanocapsules for herbicide or insecticide delivery ■ Nanosensors for monitoring soil quality and plant health ■ The use of nanocomposites and other advanced materials for food packaging to maintain freshness and avoid microbial contamination
High Value Manufacturing	■ Design and operation of biorefineries ■ Processes and logistics (automation, packaging, e-logistics, robotics and sensors)
Electronics, Photonics and Electrical Systems	■ Development of diagnostic systems to determine the results of biological assays
Information and Communication Technologies	■ Databases used to store genomic information ■ Global positioning systems for management of agricultural land ■ Software tools for data mining and analysis (bioinformatics)

Application areas	Areas of cross-over
Environmental Sustainability	■ Carbon dioxide reduction through reduction in use of fossil fuels to produce chemical insecticides and herbicides through better crop varieties and conservation tillage ■ Carbon capture using photosynthetic organisms ■ Diagnostic methods to monitor genetic biodiversity and biosafety ■ Monitoring/reducing pollution from industry and agriculture through plant and microbial remediation ■ New bioprocesses for desalination, treatment, purification and recycling of water ■ Improved drought resistance of plants and reduction in industrial usage ■ Technologies for reducing environmental impact, eg biodegradable packaging
Energy Generation and Supply	■ Energy generation from biomass, biofuel cells and biohydrogen ■ Development of second and third-generation biofuels

Application areas	Areas of cross-over
Medicines and Healthcare	■ Genetic and genomic assays ■ Discovery of potential gene or protein targets for new medicines and/or pharmaceutical intermediates ■ Greater understanding of mammalian, microbial and plant metabolic pathways to improve the production of medicines and/or pharmaceutical intermediates ■ Identifying host-pathogen interactions ■ Validating the links between diet and health
Transport	■ Biofuels
High Value Services	■ Industrial services: consultancy, research and development
Built Environment	■ Use of biomass in construction

Innovation platforms	Areas of cross-over
Network Security	■ Design of biometric security devices
Low Carbon Vehicles	■ Biofuels
Low Impact Buildings	■ Use of biomass in construction ■ Biomass-based heating systems
Detection and Identification of Infectious Agents	■ Livestock protection
Sustainable Agrifood	■ Livestock improvement and protection ■ Crop improvement and protection

Appendix 2 – Market applications of genomics technologies

Medicines and diagnostics

- HTATs are employed to elucidate an improved understanding of the genetic basis of disease, facilitating the development of new medicines. For instance, sequencing the genomes of microbial pathogens is used to identify new targets for antibiotics and vaccines or improve the synthesis of secreted proteins.
- GWA studies enable the identification of genetic variation across a genome, designed to identify genetic associations with observable traits. In human studies, people with the disease and similar people without have their genomes sequenced. Then bioinformatics is applied to compare the two sets and identify markers of genetic variation, which may contribute to the disease.
- Bioinformatics enables organisations to extract valuable information from the data generated from HTAT. Effective bioinformatics methods can be applied to diagnose cancer subtypes, predict the survival time of cancer patients or identify the mode of action of candidate drugs.

Livestock improvements

- Artificial insemination enables beef producers to gain access to superior genetics, through the use of males with high estimated breeding values – the genetic worth of animals. Embryo transfer can increase the conception rate further (5-10%) by using an already fertilised egg.
- A number of genetic tests are now available based on GAS. One of the first examples for a quantitative trait for livestock was the test for the oestrogen receptor, which has been used in several commercial lines to enhance selection for litter size.
- GWS can be used to screen male cows (bulls) for any traits that have been measured in a sample of superior bulls, including production, cow fertility, somatic cell and longevity. Bulls can be ranked for each trait and converted into an estimated breeding value. The technology reduces breeding time and enables bulls to be selected from a much wider genetic pool.

Bioenergy production

- By sequencing the genomes of novel microorganisms, new biochemical pathways can be identified that may be beneficial to bioenergy production.
- By sequencing the genomes of plants, researchers can identify the biochemical pathways that produce biomass and optimise the production of sugars, which can be converted to biofuels.

Environmental remediation

- By characterising naturally occurring microorganisms or plants using HTAT and bioinformatics, new species or biochemical pathways can be found that may be useful for treating soils and waters contaminated with toxic metals. High biomass metal-accumulating plants can concentrate metals from the soil into the above-ground shoots, which are harvested with conventional agricultural methods.

Enzymes

- Novel enzymes, in particular from bacteria or fungi, can be identified and characterised by HTAT. For instance, fungal enzymes can be used to digest the brown lignin in wood, leaving the white cellulose behind for use in making paper.

New crop varieties and yield improvements

- GAS enables users not to have to wait for a seedling to grow into a mature plant to determine whether it has a desirable trait, saving valuable time. A tissue sample is analysed for the appropriate gene, and if contained, the breeders can use that plant before the traits are observable.
- The increasing availability of plant genome sequences offers the potential for GWA studies that can expose evolutionary pathways and influence future breeding programmes, increasing yields.

Appendix 3 – Market applications of industrial biotechnology technologies

Medicines

- Discovery tools such as cell-based assays can be used to screen for therapeutic modulators of drug targets, such as kinases, from novel microorganisms. Kinase inhibitors are often used in the treatment of cancer and inflammation.

Biofuels

- Biocatalysis tools can be used to elucidate microbial sugar utilisation pathways, important for biofuel production. Metabolic flux analysis and system-wide mathematical/statistical tools can identify potential genetic and metabolic targets limiting efficient sugar metabolism.
- Biorefining technologies for pre-treatment of plant biomass are an important first step to releasing the sugars for conversion to biofuel as well as removing lignin.

Enzymes

- Discovery tools have been used to find new enzymes from microorganisms that are active at ambient temperatures. The increasing use of synthetic fibres and the desire to save energy has driven laundry washing temperatures lower. But in order to compensate for the lower washing efficiency, enzyme producers have had to look for new enzymes.
- To increase the yield of enzymes from microbial strains, different techniques such as metabolic engineering are used to engineer them to optimise enzyme expression before production.

Bio-based chemicals

- Polylactic acid is a biodegradable thermoplastic derived through bacterial fermentation (biocatalysis) of dextrose. It is used in woven shirts, containers and a number of biomedical applications.

Food and feed ingredients

- Discovery tools are used to identify and characterise microbial strains that might have therapeutic benefits, such as a probiotic, or that synthesise products that can be used as food ingredients, such as gums, amino acids and flavour compounds.
- Biorefining technologies can be used to produce multiple high-value products from a single feedstock. For instance, sugar beet can be converted to sugar for use in animal feed, molasses for bioethanol, and a co-product, lime, sold for soil conditioning.

Carbon cycling and sequestration

- Discovery tools are used to select the most appropriate algae species for capturing carbon from waste streams generated by industrial processes such as power plants, distilleries or breweries.

Appendix 4 – Market applications of agrifood technologies

Agrifood-based technologies underpin a number of applications.

Crop improvement and protection

- Screening techniques are used to identify resistance in wild plants, or those created through genetic breeding, to diseases, as well as to characterise host-pathogen interactions. This is done to better understand the processes that result in resistance or susceptibility as well as disease development.
- Diagnostic tests allow viral, fungal and bacterial testing of potato seed stocks during the multiplication process to improve integrated control systems. For instance, the detection of fungicide resistance enables early anti-resistance strategies to be used.

Livestock improvement and protection

- Improvements in methods to cryopreserve (freeze) and store semen have made artificial insemination accessible to more livestock producers; more than half of the dairy cattle in the United States were bred by artificial insemination in 2007 [58].
- Embryo freezing allows for the global commercialisation of animals with high genetic qualities. Animal breeders obtain multiple embryos from genetically superior females, which are then transferred to females of lesser genetic merit.

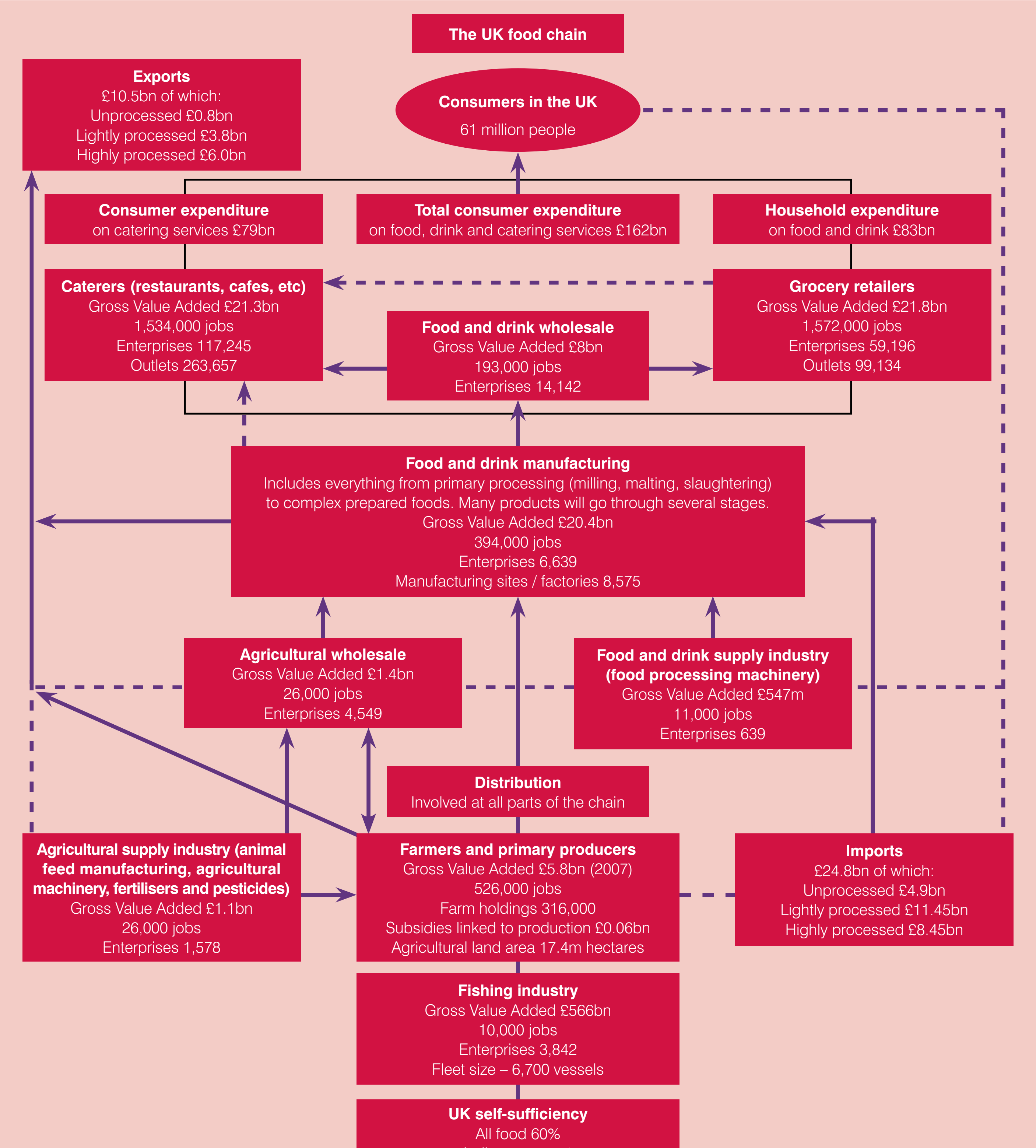
Functional foods and novel food processes

- Naturally derived colour additives isolated from fruits and vegetables can replace synthetic colourings. However, since they are often sensitive to pH changes, heat and light, novel processing methods are often required to stabilise them.

Food safety, authenticity and traceability testing

- DNA-based technologies provide a rapid, automated and highly discriminatory method for identifying the cause of food-borne diseases. By comparing the resulting data from different pathogens, they can be identified beyond the species level, which can help to identify the source of the outbreak.
- Biological markers (DNA, proteins or peptides) that are unique and survive food processing can be used to trace and authenticate food throughout the supply chain.

Appendix 5 – The UK food chain



Source: Defra [53]

Appendix 6 – Glossary

BBSRC	Biotechnology and Biological Sciences Research Council
BERR	Department for Business Enterprise and Regulatory Reform (formerly DTI)
BIS	Department for Business, Innovation and Skills (formed by merger between BERR and DIUS)
ChIP	chromatin immunoprecipitation
Defra	Department for Environment, Food and Rural Affairs
DIUS	Department for Innovation, Universities and Skills
DNA	deoxyribonucleic acid
DTI	Department for Trade and Industry
EC	European Commission
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
GAS	gene-assisted selection
GM	genetically modified
GVA	Gross Value Added
GWA	genome-wide association
GWS	genome-wide selection
HTAT	high-throughput analytical technologies
MRC	Medical Research Council
PCR	polymerase chain reaction
qRT-PCR	quantitative real-time reverse transcription polymerase chain reaction
RNA	ribonucleic acid
RNAi	ribonucleic acid interference
RTFO	Renewable Transport Fuel Obligation
SME	small or medium-sized enterprise

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