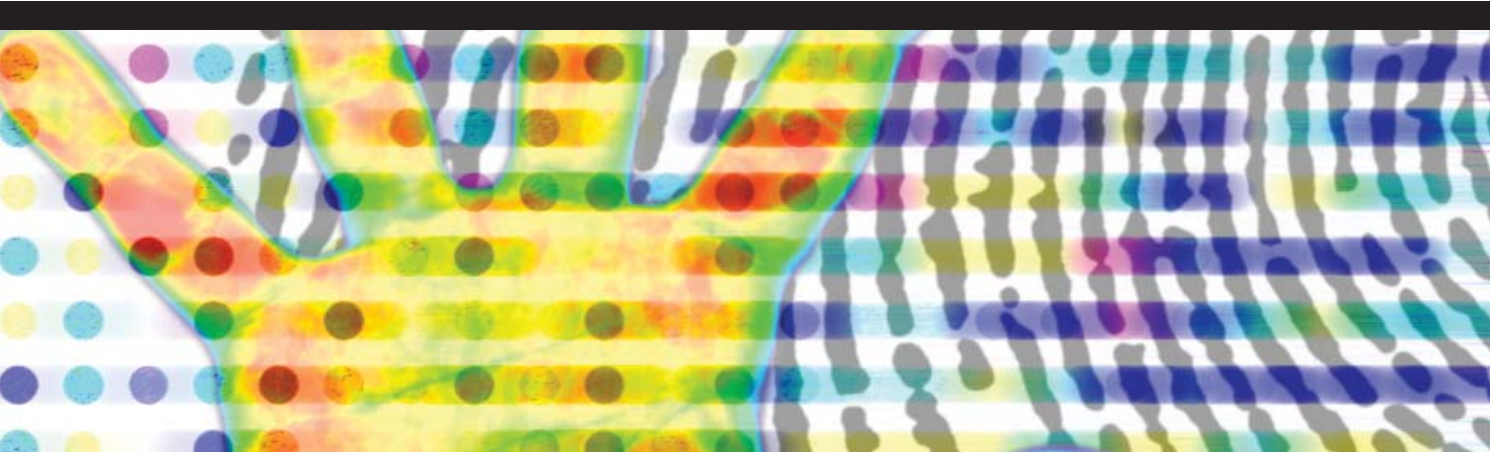


Bioscience and Healthcare



The potential for innovative technology in healthcare and the commercial applications of bioscience is huge: healthcare expenditure alone has been estimated as 7% of global GDP.

The bioscience and healthcare sectors in the UK generated over £23 billion in revenues during 2004, of which £12 billion was directly from the pharmaceutical industry and £11 billion from medical devices. These industries employ well over 400,000 people in the UK, and are second only to the US, with all the global top 10 pharmaceutical companies having significant activities in this country.

Some analysts consider the potential of other industrial applications of bioscience to be at least as great.

UK CAPABILITY

Our analysis revealed UK capability in four broad areas:

- **Medical devices** – developing, manufacturing, calibrating and sterilising non-pharmaceutical products for improved healthcare targeting, prevention, diagnosis (including medical imaging), treatment and rehabilitation.
- **Pharmaceuticals including radiopharmaceuticals** – discovery and development of drugs and vaccines.
- **Biopharmaceuticals** – discovery, development and manufacture of pharmaceuticals, vaccines and therapies developed from new biotechnologies such as monoclonal antibodies, recombinant proteins, gene, cell and tissue therapies.
- **Exploitation of bioscience by industry** – use of agricultural feedstocks and biocatalysis/biotransformation technology to develop more efficient, and more sustainable methods of obtaining a significant part of our energy, chemicals and materials needs. Development of novel bioproducts to improve health, energy and water usage, nutrition and efficient use of resources.

While the US is recognised as being the global leader, the UK has the largest and most mature bioscience industry in Europe, based on world leading research in life sciences and related measurement sciences.

GLOBAL MARKET OPPORTUNITY

The trends of an increasingly ageing population; increasing demand for – and costs of – healthcare provision; spiralling costs of drug development; and the challenge of climate change and the need for bio-renewable fuel and feedstocks are global and, as a result, offer UK organisations significant market opportunities.

With the largest healthcare market and cluster of biotechnology firms being located in the US, UK firms will wish to explore the best means of addressing that market. Participating actively in the European Framework Programme is a means for developing capability and establishing partnerships in key European markets. However, the growth of Western diseases in countries such as China suggests that there are wider opportunities to be explored.

PRIORITIES FOR ACTION

The analysis has indicated that we should prioritise our activities around three main themes, namely:

Medical Devices

- Converging technologies/ regenerative medicine (including bionanotechnology/nanomedicine)
- Assistive technologies
- Improved diagnostic and therapeutic equipment and techniques

Pharmaceuticals/ Biopharmaceuticals

- Delivery of therapeutics
- Therapeutic monitoring including the use of biomarkers
- Biopharmaceutical bioprocessing technology

Exploitation of Bioscience by Industry

- New, easy and fast tools to discover bioactives functionalities and novel structural biomaterials
- Integrated programmes in development of feedstock, innovative process and extraction technologies and fermentation to deliver multi-product processes
- Biocatalyst design and process optimisation

Consultation to date suggests we need to consider a broader set of measures to encourage uptake. This includes a systematic mapping of the regulatory landscape in healthcare and medical biotech to identify where new standardisation activity would promote more rapid technological development and product uptake. More work on metrology techniques is required to determine pharmaceutical product functionality and in-process purity, as well as in relation to diagnostic and therapeutic applications of ionising radiation and ultrasonic beams. Development and validation of measurement technologies is required to ensure that they improve product safety and activity. We also need to align with technology strategies at a European level, in particular the Innovative Medicines Initiative, to ensure the UK is in the best possible position to take advantage of opportunities under Framework Programme 7.

The consultation has highlighted the strength of the UK's capability in the areas above but, in a fast moving market, we need to improve our awareness of global developments and opportunities, and continue to improve our competitiveness by collaborating with the best in the world. Global Watch Missions and the International Technology Promoters provide a powerful vehicle for developing both awareness and contacts.

BACKGROUND

INTRODUCTION

The aim of this discussion paper is to outline priorities over the next three to five years, and to also consider where funding of technology enabling activities, such as standards and metrology, would significantly advance technology uptake.

In parallel with the development of the Bioscience and Healthcare strategy, consultation documents are also being developed in five other themes:

- Information and Communication Technologies
- Advanced Materials
- Electronics and Photonics
- Sustainable Production and Consumption
- Design Engineering and Advanced Manufacturing

Where technologies cut across themes, we will attempt to highlight them in each relevant strategy. A further strategy on 'Emerging Energy Technologies' is to be developed following the completion of the DTI Energy Review (<http://www.dti.gov.uk/energy/review/>). This will inform final decisions on technology priorities in the area of emerging energy technologies. This paper outlines our assessment of the key technology priorities in Bioscience and Healthcare, the capacity of UK industry to exploit these technologies, and their potential impact. The strategy is based largely on input from industry through our Knowledge Transfer Networks, and refined through further feedback from a group of opinion leaders.

Based on the evidence presented, and further internal analysis, a way forward is proposed for the Bioscience and Healthcare theme, but implementation of this will be subject to further prioritisation and endorsement by the Technology Strategy Board.

METHODOLOGY

To identify the main topics within the broad remit of 'Bioscience and Healthcare', we arranged for a patent analysis¹ to be carried out, to determine the principal areas of importance in new technology globally, the main UK companies, and the principal investigators in each company.

This showed that the most important areas globally are:

- Medical devices
- Pharmaceuticals
- Biopharmaceuticals

and that the most rapidly growing, from a small industry base, was:

- Exploitation of bioscience by industry

For each of these technology areas, we sought formal contributions from our Knowledge Transfer Networks (KTNs) (Bioscience for Business, Healthcare Technologies, bioProcess UK) where those covered the appropriate area. For pharmaceuticals, we sought input from a respected industry figure involved in the generation of the Strategic Research Agenda for the European Innovative Medicines Initiative.

THE BIOSCIENCE AND HEALTHCARE INDUSTRY

The four areas covered by this strategy are:

The medical device sector – developing and manufacturing products for improved healthcare targeting, prevention, diagnosis, treatment and rehabilitation. The sector provides products into a market subject to increasing demand in developed countries from an ageing population, from increased incidence of obesity in younger people, and demand for more efficient and affordable healthcare.

The pharmaceutical sector is responsible for the discovery and development of over 90% of all recently approved medicines worldwide. The sector is a vital contributor to the economy of the UK and to the health and wellbeing of its citizens, with a trade balance of £3.6 billion in 2003 and 83,000 direct employees in the UK. The sector increasingly seeks partnerships with the academic institutions and SME companies to source and develop new

ideas, new technologies (platforms), and new early stage molecules, including biologics.

The biopharmaceutical sector is a very important and fast growing part of a wider global pharmaceutical industry, developing products derived from new biotechnologies such as monoclonal antibodies, recombinant proteins, gene therapies, and advanced (cell and tissue) therapies. This sector is forecast to grow to around 30% of the total global pharmaceutical market by 2015.

The technologies that we have grouped together under the title **exploitation of bioscience by industry** offer the basis for creating a new dimension to our economy, in which the use of agricultural feedstocks and novel biocatalysis and biotransformation technology allow us to develop new, more efficient, and more sustainable methods of obtaining a significant part of our energy, chemicals and materials needs. Integrating plant and aquatic feedstocks with the power of microorganisms, will drive the development of novel bioproducts to improve health, energy and water usage, nutrition and efficient use of resources.

INDUSTRIAL AND SCIENTIFIC PERFORMANCE

During 2004, the Bioscience and Healthcare sector as a whole generated over £23bn in revenues³, of which £12bn was directly from the pharmaceutical industry and £11bn from medical devices (covering diagnostics, devices and service and supply industry²). Agriculture, marine, industrial, and marine biotechnology contributed approximately £700m during 2003⁴. The industry as a whole employs well over 400,000 people directly and in supporting companies^{3, 2}, second only to the US. While the UK lies third behind the US and Germany in company numbers, the increasingly mature UK Bioscience and Healthcare sector has a higher average number of employees per company compared to Germany, more finance raised, and more products in late stage development.

According to the Pharmaceuticals Industry Competitiveness Task Force (PICTF) Performance Indicators Report 2003, the UK has been a comparatively favoured location for R&D and the country has the fourth place internationally in research productivity. According to the 2005 DTI R&D Scoreboard, Pharmaceuticals and Healthcare

companies invested around £7.5 billion in R&D in the UK in 2004/2005. A number of the global top ten pharmaceuticals companies have significant activities in the UK, including GSK, AstraZeneca, and Pfizer. The UK has very important biotech clusters such as the Cambridge area, attracting research centres from larger biotech companies such as Genzyme. The sector is historically attracted to the UK by its high quality science and its significant life science sector that produces a pipeline of new product concepts. The high level of dependence on innovation, combined with a strong UK science base in the life sciences makes the sector attractive as a target for exploitation of new technologies. Competition from innovative competitor nations and low cost economies is challenging the success of the UK in this area.

In the context of patent applications, the UK showed a strong position, with both GSK and AstraZeneca appearing in the top five players in worldwide applications. For the medical device sector, the strength of the UK position varied dependent on potential technology applications. For example, only GSK appeared in the top ten patent applications for drug delivery, whereas the UK showed leadership in devices for internal medical examination. In the biopharmaceutical arena, it was again GSK that spearheaded the UK's position by being strongly represented in the top ten patent applicants in this area. When applying the patent application metric to the fast developing environmental and industrial biotechnology sector, the UK shows good overall performance relative to its major competitors, but no significant strength in any one particular area.

As well as patent applications, academic publications offer further evidence of the strength of UK bioscience and healthcare. During the period 1997-2001 the UK proved to be the strongest European nation in life science research, when measured on publications and citations, and second to the US in the top 100 most-cited papers⁶.

DRIVERS OF INNOVATION

Companies supplying products and services into the Bioscience and Healthcare sector face some daunting challenges, but also some significant opportunities.

Issues that have a positive effect on driving innovation in the sector:

- An increasingly ageing population in developed countries driving healthcare demand.
- Lifestyle-related diseases such as obesity and diabetes could stimulate research on nutrition and nutraceuticals.
- An increasingly well-informed and demanding public.
- The increasing cost of healthcare provision will drive the search for new approaches.
- The development of health technology assessment based on economics and on social values.
- The spiralling cost of drug development and declining pharmaceutical drug pipelines will accelerate attempts to find new approaches to drug discovery.
- The need for a move towards more targeted medicine.
- The challenge of climate change, depletion of fossil fuels, and the need for bio-renewable fuel sources.
- Consumer demand for industry to reduce its environmental footprint by adoption of more sustainable processes for chemicals, materials, and energy.

Issues that threaten company innovation in the UK in the sector include:

- Growth of India/China as centres for low-cost R&D with a drive towards innovative science.
- Migration of technology activity abroad, e.g. Singapore.
- In some cases, a poor return on successful medical products due to cost containment.
- Increasing safety requirements for medical products.
- Stagnation in company structure – why has the UK failed to develop large companies in biotechnology?
- Perceived higher risk aversion and shorter timescales of UK risk capital industry compared with the US, whilst being satisfied with lower returns.
- The speed of adaptation of public policies (including reimbursement policies) to the new challenges from a regulatory, technological and societal view.
- The difficulty many companies face in recruiting adequate numbers of skilled employees.

- Ignorance of potential benefits of technology amongst many business service providers, and some mistrust of science and technology by the general public.

Support from government in helping to reduce the uncertainties, and share some of the risks and costs, in adopting new technologies will help UK companies make the most of the opportunities available and reduce the influence of the negative factors. We intend to do this through a package of mechanisms, including support for R&D, technology networking, infrastructure support in standards and metrology, encouraging more innovative government and NHS procurement, and working more closely with the investment industry to support further development of technologies.

Recent developments, such as the reorganisation of the Department of Health's support for R&D, the announcement in the April 2006 Budget statement of the forthcoming review of DTI/DH medical research structure with £1bn funding, and increased joint DH/DTI working such as on Healthcare Technology Co-operatives, will contribute to much greater joined-up government in this area.

The Healthcare Technology Co-operatives, developed under the Healthcare Industries Task Force (HITF) report³⁶, demonstrate the use of the NHS as a centre for clinical development, a topic also raised in the Bioscience Innovation and Growth Team (BIGT) report²⁵ that could also be taken forward in the future.

METROLOGY

The importance of metrology for medical and biotechnologies is already recognised at national level, with the Measurements for Biotechnology Programme and the Measurement for Emerging Technologies Programme, including medical technologies⁷.

MEASUREMENT CHALLENGES

Nucleic acids: the ability to manipulate DNA is at the core of the biotechnology industry, and DNA analysis is the foundation of a large part of the bioscience and healthcare industries. DNA analytical methods are continuously evolving and there is typically a gap between the adoption of technique and the development of appropriate

reference materials to support comparison across techniques. Reference methods are required for the development. High profile applications include the use of DNA in forensic science and pharmacogenomics, the typing of individuals to determine their genetic response to particular drug treatments. Multiple measurements of different DNA sequences in parallel, using techniques such as microarrays, are being applied to fields such as toxicology, but these methods require further validation.

Proteins: proteins are the tools of biotechnology and there are a huge number of existing applications in addition to the emerging areas. Specific proteins are often used as markers of disease states or of the presence of contaminating microorganisms in food. The measurement challenges here are in experimental design of the sampling strategy to ensure that there is high confidence in the results of the detection method, handling and processing of the sample to ensure that specific proteins can be detected in a mixture of similar molecules (e.g. blood serum), and accurate detection and quantification of trace amounts of material. Protein activity measurement is essential for most applications but there are multiple methods for its measurement. There is clear need for consistency of method and the development of appropriate reference materials and methods. Industrial biotechnology manufactures bulk batches of particular proteins where purity, structure, function, activity, and quantity all present particular standardisation challenges, as does the control of the manufacturing process itself.

Cells: the move to reduce animal testing has increased the applications of cell-based assays for biological activity. Standardisation of these assays and validation of cell lines present a diverse range of measurement challenges that require multi-disciplinary approaches to solve. Cells are used to produce biological molecules and are an integral part of Bioprocessing. Cells have been used therapeutically for many years (blood transfusions and bone marrow transplants) but scientific developments, particularly around the potential of stem cells as therapeutic agents, has highlighted the need for better controls and to identify ways to improve the efficiency of these techniques, all requiring improved validated measurement methods.

Tissues and biologicals: an obvious extension of the use of cells as therapeutic agents is the use of multiple cells in organised structures as replacement tissues. This requires standardisation of measurement methods for the biomaterials and biocompatible materials that will be used to build these structures as well as the design of multi-parametric analysis to ensure that the surrogate tissue is functional. Biologicals are complex mixtures of biological molecules used as therapeutic agents (e.g. vaccines, artificial blood) that again require multiple analytical techniques and arrays of reference materials to validate their efficacy.

Whole organisms and systems biology: the growth in computing technology and scientific understanding has led to improved handling and analysis of life science data through bioinformatics and recently the ability to model cells, tissues and even organisms 'in silico' through the discipline of Systems Biology. This mathematical modelling approach will support a number of applications and will require data orientated standardisation activities in the areas of information capture, annotation and storage, data processing and image analysis, algorithm validation and data archiving.

Organic molecules and metabolites: the majority of pharmaceutical agents are small organic molecules that interact directly with biological systems. Chemical metrology will be required to validate their identification, manufacture and quantification. Where populations of small molecules are analysed, for instance in the measurement of metabolism, statistical modelling, data standardisation and method validation will be required.

Bionanotechnology and nanomedicine: nanotechnology and nanotechnology-inspired methods will increasingly be brought to bear on biological applications, for instance in the development of 'point-of-care' miniaturised diagnostic tests. Measurement at the nanoscale presents numerous new standardisation challenges which will have to be addressed to allow any nanomedical devices to meet both current and future regulatory guidelines. The DTI is funding the Centre of Excellence in Metrology for Micro and Nano Technologies CEMMNT).

Medical devices

- Drug delivery systems – measurement of the distribution of drug loading in polymer controlled release layer.
- Drug delivery systems – measurement of surface molecular engineering to correlate and design specific targeting.
- Tissue engineering and wound healing – the measurement of and spatial distribution of surface chemistries to promote cell attachment and growth.

Implants such as stents, catheters and pacemakers require measurement of the surface chemistry, the surface design, molecular orientation, and functionality for anti-microbial, anti-thrombogenic, and analgesic capabilities.

- Diagnostic arrays – the surface chemistry is critical and even for simpler DNA arrays is poorly characterised; new measurement challenges are in protein arrays and glycan-arrays.

Biomaterials

There are similar issues to medical devices and with additional concerns:

- Surface patterning and surface structures influence cell attachment and behaviour.
- Materials properties such as rigidity are important criteria.
- Tissue engineering – porosity and structure of scaffolds.
- Durability of implants such as hip-replacements.

Biopharmaceutical companies tend to maintain proprietary test methods to control their products. Generic products, such as blood products and traditional vaccines are standardised by National Institute for Biological Standards and Control (NIBSC) and the British Pharmacopoeia.

STANDARDS

In the biopharmaceutical industry, measurement, verification, and validation are often kept confidential during product development in order to support a company's competitive advantage.

Adoption of common standards is, however, a public good that can lead to further innovation and reduction in costs for the consumer (or healthcare provider), and can speed products to market through more streamlined approvals systems. The standardisation of biopharmaceuticals is coordinated by WHO, International Association for Biological Standardisation, and, in the UK, NIBSC, and the current arrangements work well in general. In emerging areas of bioscience and healthcare, where there may be few technical standards, those developing new products and services may find it useful to have guidance on relevant standardised methods and codes of practice and how these are integrated into the regulatory framework.

The British Standards Institution (BSI), the UK national standards body is mainly concerned with standards development associated with the implementation of the three European Directives on Medical Devices, *in vitro* Medical Devices, and Active Implantable Medical Devices. The work is directed towards compliance rather than competitiveness, and the BSI has not historically been involved in pharmaceuticals standardisation. Current mechanisms do not take full account of business or other high-level requirements. DTI has commissioned BSI to develop a Publicly Available Specification (PAS 83) document that will map and inform industry and researchers of the critical path requirements from research to clinical application for cell-based therapies, to be published in Autumn 2006. This activity could identify opportunities for technical standards and act as a pilot for similar guidance in other technology areas, such as nanomedicine.

The convergence of European and international standards bodies, including those not previously associated with healthcare standardisation (e.g. ETSI, the European Telecommunications Standards Institute) will be increasingly important to resolving standards conflicts or gaps.

There needs to be a paradigm change in the way that standards are drawn up and implemented in

the field of bioscience and healthcare. The current standards focus on the (US) medical device market, and a more holistic view is required if integration of devices with telecommunications and the built environment for patient monitoring and drug administration in the home are to make a significant impact on acute care loading. Such a view might be provided by the development of a Standards Architecture, drawing on value chains and roadmaps drawn up by industry. The current BSI standards programme review should be extended to provide an understanding of the relevance and role of the current standards portfolio, identify gaps, and provide background data.

In addition, consideration should be given towards developing new methods and standards for design and statistical interpretation of clinical trials, for medicines and for advanced therapies. The potential role of standards in developing the use and uptake of new bio-based products and processes is significant. Opportunities exist for identifying standards for biodegradability, for example in the use of biofuels and biolubricants when potential contamination of the environment is likely. Clear standards to identify those materials that can be broken down in the environment with minimal impact will enable the consumer to make purchases with maximum information.

Biofuels will also need to meet specific criteria and these must be clearly identified and be compatible with existing standards. This may be extended to cover the additional benefit of bioenergy production and its reduced environmental impact.

SUMMARY

UK Bioscience and Healthcare is in a strong international position both industrially and scientifically. Given this strength, there is significant potential for government support through the Technology Strategy to leverage our world-class science and technology base in biosciences and our major global presence in the pharmaceutical, biotechnology, and medical device sectors by stimulating the development of new technologies and consequent products and services.

This leverage will be most effective where DTI support for collaborative R&D is aligned with its investments in metrology, standards and technical regulation, as well as in public policy development, and where it is able to influence innovation in government procurement, or work with other investors and partners to develop a market sector. Initial priority areas relating to the technologies covered in this document are indicated in Section 6, and will be developed subject to prioritisation and endorsement by the Technology Strategy Board.

MEDICAL DEVICES

INTRODUCTION

Medical biotechnology and medical devices include technologies, devices, and combined systems to provide for improved healthcare targeting prevention, diagnosis, treatment, and rehabilitation. Such technologies increasingly need multi-disciplinary solutions encompassing biology, physics, materials, engineering, mechanics, and IT. Developed countries face increasing demands in providing cost-effective healthcare, including providing for an ageing population and addressing growing obesity in the young. New technologies can act as enablers to deliver novel medical device products, to support new treatments for specific disease morbidities and enable a higher quality of life for all, including those suffering from rare diseases.

The healthcare models across the world are changing with the traditional 'late' treatment of disease becoming unsustainable and greater emphasis now being on 'early health' aimed at disease prevention, where possible, early identification and diagnosis, and mediating disease and disability.

Increasingly, the emphasis will be on supporting chronic illness at home, rather than in acute care, to meet people's need for independence and enable them to have a normal life, and also to free beds in acute care. This will stimulate demand for assistive technologies.

The key technology areas that will offer the greatest impact are seen to be:

- **Converging technologies** – convergence of the physical with the biological leading to new and combined functionalities.
- **Diagnosis and screening technologies** together with the development and monitoring of more targeted therapies.
- **Regenerative medicine** – methods to induce the body to regenerate healthy functional tissue and to provide replacement parts.
- **Assistive technologies**¹² – devices and technologies that aid rehabilitation and support for independent life in the community.

It is increasingly important that researchers in different disciplines and different professions work together more effectively to resolve the forthcoming technological challenges associated with a different healthcare model and enhanced patient expectations. One new initiative under development (with industry, DH and DTI support) is the Healthcare Technology Co-operatives, announced as a result of the Healthcare Industry Task Force (HITF).

In parallel, the Nanomedicine European Technology Platform (ETP) will complete its Strategic Research Agenda in May 2006. This is likely to focus on imaging, targeted drug delivery, and regenerative medicine.

TECHNOLOGY PRIORITIES

Key technology priorities identified by the medical device industry include:

Short term (2-3 years)

- **Converging technologies:** bioactive implants (involving microsystems technologies in particular, requiring new approaches to bring electronic, mechanical and biological functionality into one integrated system); in vitro diagnostics and point-of-care testing; bio-physics/bio-photonics; reactive biomaterials coatings; nano-structured materials and surfaces; anti-microbial and anti-fouling coatings; controlled biomolecular interfaces and remote sensing.
- **Diagnosis and screening technologies** for targeted therapies in oncology and rare genetic diseases.
- **Regenerative medicine:** cell and molecular biology; tissue engineering (to optimise skin, bone, cartilage, pancreatic islet cell encapsulation etc.) and further development of autologous cell therapies (e.g. autologous chondrocyte implantation); tissue scaffolding technology; analytical cellular technologies for the tracking and monitoring of cells introduced into the body, by MRI, magnetic resonance spectroscopy, fluorescence, nuclear medical imaging, to support the required regulatory considerations governing regenerative medicines and bioactive implants.
- **Assistive technologies:** convergence of home platforms between health, social care and

housing, home-based activity monitoring systems to indicate the need for early intervention; open systems interoperability; increasing use of wireless technologies (Bluetooth, WiFi and broadband); body area networks for integrated monitoring; home diagnostics and sensors; miniaturised and wearable diagnostic tools.

Medium term (3-5 years)

- **Converging technologies:** intelligent/smart implants (with added active technology and combining analytical technology, diagnostics and therapy); *in vivo* sensors; continual monitoring; advanced *in vivo* diagnostics; guided *in vivo* biology and *in vivo* biological monitoring; functional imaging; smart wound dressings; patient specific therapies; high resolution endoscopy; improved biomaterials.
- **Diagnosis and screening technologies** for monitoring of more targeted therapies in oncology, rare genetic diseases.
- **Regenerative medicine:** tissue engineered scaffolds; *in vivo* tissue engineering; advanced bioreactors for tissue engineering; analytical cellular technologies for the tracking and monitoring of cells introduced into the body.
- **Assistive technologies:** integration of health data into low intrusion telecare systems using ICT for presentation to the wider clinical community technologies for preventative healthcare (lifestyle monitoring); home therapeutics & assistive technologies for chronic conditions; patient-specific devices; remote monitoring backed by response centre networks.

Long term (5 years and beyond)

- **Converging technologies:** molecular diagnostics; intracellular sensors; closed loop drug-device/biologic-device systems; custom devices; new imaging systems (e.g. photo-acoustics); robots that work independently or co-operatively in diagnosis and delivery of treatment options.
- **Diagnosis and screening technologies** along with targeted therapies, and for predictive and preventive medicine, and for monitoring compliance.
- **Regenerative medicine:** tissue engineered, cell-based and cell-biomaterial implants; *in vitro* engineered tissues; more complex replacement

therapy (organs – kidney, liver, pancreas; spinal injuries); xenotransplantation; analytical cellular technologies for the tracking and monitoring of cells introduced into the body.

- **Assistive technologies:** improved human/equipment interface technology to allow extension of use with impaired speech, hearing and vision; remote monitoring and feedback systems; systems to help close the loop between care assessment and care delivery.

UK CAPACITY TO DEVELOP AND EXPLOIT TECHNOLOGIES

The UK benefits from a broad base of academic scientific excellence in many of the technologies required for the above fields, example centres of expertise for illustrative purposes include:[‡]

- **Biomaterials**, (Cambridge, Nottingham, Sheffield, Leeds, Liverpool, Queen Mary, Bristol)
- **Biomedical engineering** (Imperial, Bath),
- **Bionanotechnology** (Nottingham, Oxford, Glasgow)
- **Tissue engineering** (Manchester, Liverpool, Nottingham, Loughborough, UCL)
- **Biosensors** (Imperial, Queen Mary, Cranfield)
- **Microsystems** (Newcastle, Imperial, Loughborough)
- **Manufacturing** (Loughborough, Warwick, Cranfield)
- **Regenerative medicines** (Sheffield, Leeds, Bath, Southampton)
- **Photonics** (Heriott-Watt, Cambridge)

There are growing demonstrations of multi-disciplinary activities across universities and others that lead to the step changes in technology needed to make an impact on the future clinical challenges, examples include:

- Imperial Institute for Bioengineering
- Bath Centre for Regenerative Medicine
- Nottingham 'emanate' Nanotechnology Centre,
- Yorkshire White Rose universities and Yorkshire Forward initiative; the Biomaterials & Tissue Engineering Centre for Industrial Collaboration (BITE CIC)
- Dstl and the Health Protection Agency on biosensors, biosecurity
- Royal Society – biomaterials and chemistry initiative

[‡] This list is not exhaustive and does not represent endorsement by government.

The UK is currently strong in the world market in orthopaedics and further support should go to maintain this leadership, whilst other areas are growth opportunities in newer fields. The UK has a strong medical device and diagnostics sector that benefits from world players that undertake R&D in the country (Smith & Nephew, Johnson & Johnson, GE Healthcare), world players that have activity in the UK (Guidant, Medtronic, Smiths Industries), medium size indigenous companies that are in growth areas of the market (Huntleigh Healthcare, Bspak) and a large number of innovative small companies that offer a route to de-risk new and exciting technologies, such as Oxford Biosensors. This innovative and entrepreneurial spirit is a strength of the UK and one that provides a route to start the important process of device exploitation.

To offset the ever-growing cost of development of new technologies through to proof of concept and clinical evaluation, it is necessary for companies to have the capability to exploit global markets. The greatest benefit for the UK economy occurs generally when exploitation is undertaken by a UK company with global reach. The UK industry does, however, include subsidiaries of large global players, such as GE Healthcare and J&J, that benefit from our academic/development expertise. The growing requirement for large-scale marketing and distribution expertise in NHS and other healthcare provider contracts makes life increasingly difficult for UK SMEs. This limits the ability of UK relative to US to fully exploit the technology currently emerging from academic centres.

Because of the increasing importance of convergence across medical devices, pharmaceuticals, and biopharmaceuticals, the strength of the UK in the biotechnology and pharmaceutical fields will be very important to the growth of the UK medical device and diagnostics sector, for example in devices that could support the tailored delivery of drugs to genomic targets.

The UK is perceived to have the most 'well-considered' legislative landscape, and one of the most trusted medicines control agencies globally. Given that the major hurdle to uptake of regenerative medicines is the need to assess the safety of living cells placed in the body, there is a real opportunity for the regenerative medicine industry in the UK to engage with the MHRA to

map out the requirements of these 21st century medicines. Innovative methods of tracking and monitoring cells in the human body, either directly or indirectly, will offer a significant advantage to the development of the industry.

Large-scale imaging equipment is not a big market for the UK, but the UK leads on areas of new imaging modalities such as photo-acoustics that could become mainstream, and innovative imaging solutions based on endoscopy approaches using, for example, ultrasound, miniaturised cameras, lasers. These would provide initial niche applications that could develop into larger markets.

SIZE OF THE GLOBAL MARKET OPPORTUNITY

The global market for medical devices is £120bn⁴ plus a further £23bn¹² for the diagnostics market. The UK is the 4th largest market in Europe¹³, with a turnover of US\$11bn in the diagnostics, devices, service, and supply industry, employing 100,000 people¹⁴.

Healthcare markets are growing at 7-12% per year and, excluding the commodities part of the market, are identified as high value added products with potential for good margins. It is also recognised that the size of the healthcare market is often under-represented as many companies supply into this field, but are not identified as healthcare companies in their own right. This will increasingly be the case as convergence of technologies occurs and e-health (combined computing, communications and medical technologies) comes into being.

Most countries in the developed and developing worlds¹⁴ place healthcare technologies as one of their priority targets which is stimulating considerable R&D expenditure in themes similar to those identified above. The UK is traditionally strong in a number of areas that can impact on the three themes, and can particularly benefit from the bringing together of different disciplines in a relatively simple geographical base, to deliver revolutionary and high impact solutions.

POTENTIAL FOR IMPACT AND TIMESCALES

The priority areas identified above particularly address known societal issues relating to an ageing population, and especially to realising

people's expectations of a higher quality of life through preventative healthcare, aids to restore or approach normal function of diseased tissue, and devices to support care in the community. Biomedical and medical device technologies have a key role in maintaining a satisfied productive workforce over an ever-increasing lifespan, and reducing the demand on the provision of public health services.

The UK medical device and diagnostic companies need to innovate and to collaborate to access the multi-disciplinary technologies needed for future generations of products. Even the UK's largest medical device company (Smith & Nephew) is small compared to the US giants, and such companies, together with the many small companies, need support and encouragement to allow them to make the bolder and longer-term investments needed to remain competitive in a fast-moving market.

There is a strong desire in the traditional medical devices industry in the UK to engage with the emerging technologies of regenerative medicine and tissue engineering. The mismatch of skill-sets, high investment requirements, and high technical risks are, however, major barriers to participation.

Government action could provide an intermediate step to allow industry to diversify into these new technologies by accessing relevant skills and sharing risk, and working with public procurement and the investment community to ensure product commercialisation.

PHARMACEUTICALS

INTRODUCTION

The pharmaceutical sector is a vital contributor to the economy of the UK and to the health and wellbeing of its citizens. The global industry is responsible for the discovery and development of over 90% of all recently approved medicines worldwide. In that endeavour, however, it works increasingly closely with academic institutes and SME companies for the provision of new ideas, new technologies, and new early stage molecules. In academe, the industry has frequently stressed the need for a thriving research base in the life sciences, and encouraged government initiatives to stimulate UK university research and training. The pharmaceutical sector itself contributes directly to this through the provision in the UK of over 700 PhD studentships at a cost of £70 million⁵.

The global industry has, however, its problems, and some of these are particularly acute in Europe. The industry worldwide has failed to contain the cost of drug discovery and development, which is now in excess of US\$1 billion per new chemical entity. The reasons for this are essentially twofold. First, cost is increasing through greater demand for assurance on safety and efficacy, and, second, despite massive investment in new technologies, the industry is failing to reduce attrition along the value chain of drug discovery and development. In an attempt to mitigate these trends, the global industry is seeking ways not only to improve its methods, but also to reduce its costs. This has involved a shift of R&D investment either to countries that have the greatest concentration of innovative life science research (such as the USA) or the most profitable markets (the USA again) or offer quality R&D at reduced cost (such as China, India, or Singapore). The effect on activity in the UK has been a decline in pharmaceutical R&D investment since its peak in 2003⁵.

Key areas to be addressed in this sector are:

- **Chemical space** (an improved understanding of the way chemical structures interact with biological target sites, coupled with the availability of novel structures of potential drug molecules from natural product chemistry and

molecular fabrication technology, yielding new classes of drugs).

- Novel and improved chemical processes in manufacturing.
- Drug delivery.
- Therapeutic monitoring including the use of biomarkers for safety and efficacy.

The response of the European industry and the European Commission has been to propose the Innovative Medicines Initiative (IMI), a consortium within the 7th Framework Programme to focus public and private resources on solving the generic problems that impede successful drug discovery and development. The key is the application of modern technologies to improve our ability to predict the safety and efficacy of new drugs (thereby reducing attrition) and to find innovative ways of testing and monitoring these in the clinic (thereby reducing both attrition and the length of time needed for drug approval). The IMI published its Strategic Research Agenda[§], which will influence the development of DTI strategy in this area, to help ensure that the UK is well placed to participate in the IMI programme of research in the event that it is funded in 2007.

TECHNOLOGY PRIORITIES

The challenges for the pharmaceutical industry are: to develop medicines with a higher probability of being safe and effective, and determining how technology can be used to improve clinical testing. A recent industry meeting proposed that specifying technologies for development would be unlikely to succeed in itself because of lack of timeliness and the limited opportunities for new players to get into an already identified field. On balance, the participants thought that identifying problems was likely to be more useful, and that Technology Programme competitions should be framed in such a way as to solicit ideas on how to solve them. The areas of greatest concern to the industry determined through consultation are:

Chemical space and chemical processes

(medium term) – the failure of very large random libraries to lead to success in drug discovery has led to a focus on smaller libraries designed to be more drug-like and therefore with improved probability of containing hits from drug screening. There are still many classes of drug target of great

§ http://europa.eu.int/comm/research/fp6/pdf/innovative_medicines_sra_final_draft_en.pdf

therapeutic significance that have not yielded to medicinal chemistry, however, in the way that, for example, the G protein-linked receptors have. This has been considered as one of the major drawbacks to the development of new antibiotics. Natural product chemistry and the use of phylogenetics, bioinformatics, and metagenomics could potentially also be a source of novel bioactive compounds.

The following areas should therefore be supported:

- [Developments in technology to access new chemical space](#)
- [Process improvements to improve yields, reduce complexity of synthesis, reduce environmental impact](#)

Drug delivery (medium to long term) – drug delivery encompasses a range of technologies to help ensure that drug molecules reach their targets within the body and are able to exert the required therapeutic effects. Challenges in this area include: overcoming biological barriers such as getting drugs across cell membranes and the blood-brain barrier, and issues with solubility for many small molecule drugs. Drug delivery solutions are especially important for biopharmaceuticals and vaccines, as larger molecules which mostly cannot be administered orally, are liable to be broken down or modified en route to their targets and face additional difficulties getting through biological barriers. Hence, the use of biological drugs (peptides, proteins, enzymes, monoclonal antibodies, siRNA) is restricted to those conditions for which injection is both therapeutically useful and acceptable to the patient. This excludes a large number of conditions where new biological products would struggle to gain market share against current oral small molecule therapies. The considerable clinical efficacy of some biologicals can overcome this inherent disadvantage, and work on stability, formulation, and injection devices could mitigate the poor acceptability of injection. Biopharmaceuticals are covered in more detail in Section 4.

Priority areas applicable to all drugs include:

- [Innovative approaches to access the brain without invasive and potentially risky surgery](#)

- [Miniaturised drug delivery devices, incorporating biosensors that monitor physiological status and release drug accordingly.](#)

The needs include methods for:

- [Delivery of biological drugs \(proteins, peptides, siRNAs\) to their target tissues.](#)
- [Introducing biological molecules across the blood brain barrier.](#)
- [Targeting drugs to their sites of action.](#)

Therapeutic monitoring (short to medium term) – the industry hopes that the traditional burdensome process of clinical trials will give way to a more flexible biology-driven process. The application of biomarkers to monitor efficacy and safety has the potential to transform clinical development and pharmacovigilance with far reaching implications for healthcare. This includes the use of safety biomarkers to give an early indication of toxic effects of drugs in development, which has great potential for reducing the high cost of ‘late stage attrition’ in drug development and increasing the safety of new medicines. For biomarkers to be maximally useful, they need not only to measure something real about the disease or treatment, but also to be convenient in use. The ideal of real- or near-real-time monitoring of therapeutic status has applications in early discovery, patient selection for clinical trials, the development of adaptive clinical trial protocols and post-marketing surveillance. Biomarkers can also be used to monitor disease status and/or drug efficacy. The needs are therefore to develop methods/devices:

- [For fast, simple, robust and sensitive therapeutic monitoring in accessible body fluids.](#)
- [Applicable to animals and man to aid early drug discovery and its translation to the clinic.](#)
- [For use in a home setting and capable of remote download of data to a clinical centre.](#)

UK CAPACITY TO DEVELOP AND EXPLOIT TECHNOLOGIES

The pharmaceutical sector is the leading industrial funder of the research base in the UK. The industry provides the third highest trade surplus of all sectors with a trade balance of £3.6 billion in 2003. The industry employed 83,000 direct employees in the

UK in 2002, GDP per employee being £80,843. The pharmaceutical sector is also a significant supporter of academic research, hosting nearly 700 PhD students in laboratories and funding over 400 separate collaborative research projects. This equates to funding over £70 million on collaborative research (excluding contract and clinical research) and provides access to new compounds, technologies and resources that students and universities would not otherwise have⁵.

According to the Pharmaceuticals Industry Competitiveness Task Force (PICTF) Performance Indicators Report 2003¹⁶, the UK has been a comparatively favoured location for R&D and the country has the fourth place internationally in research productivity. According to the 2005 DTI R&D Scoreboard¹⁷, pharmaceuticals and healthcare companies listed on the UK companies invested around £6.7 billion in 2004/2005. A number of the global top ten pharmaceuticals companies have significant activities in the UK, including GSK, AstraZeneca, and Pfizer. The sector is historically attracted to the UK by its high quality science and its significant life science sector that produces a pipeline of new product concepts. The high level of dependence on innovation, combined with a strong UK science base in the life sciences makes the sector attractive as a target for exploitation of new technologies. The DTI R&D Scoreboard indicates that the sector invested £6.5 billion in R&D in 2004/2005¹⁷.

The UK science base has a large number of leading centres in pharmacology and pharmacy, with illustrative examples such as University of London, University of Bath, Nottingham, Manchester and Strathclyde, and world leading medical schools, including examples such as London, Edinburgh, Nottingham, Bath, Cambridge, Oxford and Sheffield.

SIZE OF THE GLOBAL MARKET OPPORTUNITY

According to IMS World Review 2004¹⁸, the global pharmaceuticals market was US\$466.3 billion, and is quickly heading towards a milestone of US\$500 billion. North America, Europe, and Japan accounted for 88% of audited worldwide pharmaceutical sales in 2003. North America represented almost half of all global sales in 2003 (US\$229 billion), whilst Europe grew by 8%, to US\$115.4 billion. UK Pharmaceutical industry

exports were over £12 billion in 2004, generating a trade surplus of £3.75 billion that places it third in the UK industry rankings behind petroleum and power generating machinery.

POTENTIAL FOR IMPACT AND TIMESCALES

There are significant societal and economic benefits from innovation in the pharmaceutical industry. Investment in enabling tools that improve drug discovery and drug delivery processes will have significant potential benefits for:

- **The industry:**
 - More rapid time to market.
 - Developing drugs for more complex diseases.
 - More targeted, safer, efficacious drugs.
 - Reduced clinical trial burden.
 - Less attrition during the development lifecycle.
 - Greater opportunity to exploit libraries of drugs that have poor solubility.
- **Health provision and patient outcomes:**
 - More economic delivery of healthcare.
 - Improved quality and extension of life.
 - Integration of clinical diagnosis with treatment.
 - Economic value of a healthy population
 - Safer, more effective treatments (e.g. personalised medicines).
 - Improved quality of life for an ageing population.
 - Link between economic and social values for rare diseases.

BIOPHARMACEUTICALS

INTRODUCTION

Biopharmaceuticals are defined as large molecule medicines for human healthcare that are produced by biological means, rather than by chemical means. Included in this definition are traditional products extracted from animal and human tissue, such as blood and blood products and viral vaccines, and modern products derived from new biotechnologies, such as monoclonal antibodies, recombinant proteins, gene therapies, and cell and tissue therapies.

The biopharmaceutical part of the global pharmaceutical market is projected to rise to around 30% in 2015, based on the composition of the pipeline. If UK companies maintain their current 11% share of the world pharmaceutical market, this will equate to biopharmaceutical sales of US\$36 billion. In biopharmaceutical product development, the UK is currently in second place to the USA, and should aim to maintain this market share in the face of competition from USA, Canada and Germany. Key UK strengths lie in the discovery, development, and commercialisation of new products.

TECHNOLOGY PRIORITIES

The technology priorities in biopharmaceuticals are focused on a number of product types, each reliant on multiple basic science discoveries and technology developments. These technologies are all essential to discover, design, develop, and manufacture biopharmaceutical products of the following types:

- All biopharmaceutical products – genomics and proteomics – to determine causes of diseases and identify potential drug targets.
- Protein therapeutics – recombinant DNA technology, protein engineering, production, purification, formulation, delivery and analysis.
- Monoclonal antibodies – antibody engineering, antibody expression, technologies for therapeutic proteins.
- Vaccines – subunit vaccines, live vaccines, inactivated vaccines, DNA vaccines, antigen discovery, vaccine development and manufacture, adjuvants.

- Gene therapies – design of vectors, bioprocessing of vectors.
- Cell and tissue therapies – stem cell science, cell culture technology, matrix technology, scaffold technology.

UK CAPACITY TO DEVELOP AND EXPLOIT TECHNOLOGIES

The UK has a leading position in biopharmaceuticals, second only to the USA. The UK biotech sub-sector, as defined by Ernst & Young, includes over 400 companies, employing over 25,000 people, and generating revenues of £3 billion. The majority of these companies are small, young, privately held, and loss making. The broader bioscience/healthcare sector (which also encompasses diagnostic, device, service and supply companies, but excludes major pharmaceutical companies) includes over 1,100 companies, employs 100,000 people, and generates revenues of £11 billion.

The majority of companies are less than 15 years old, and only 8% are publicly traded. The sector is fast growing – taking the biotech sub-sector as a proxy of the broader bioscience/healthcare sector, employee numbers have grown at a CAGR of 35% and revenues by 48% between 1995 and 2002. The promise of the UK bioscience industry is clearly shown in its development pipeline: at least 194 drug candidates are in development, and 23 in Phase III clinical trials.

- The UK has a strong pipeline of biopharmaceutical products in development and marketed. For example, over 70 biopharmaceuticals are in clinical trials sponsored by UK companies, and one company, GSK, has vaccine sales of US\$1.8 billion worldwide.
- The UK has a strong biopharmaceutical manufacturing sector. For example at Speke, Eli Lilly manufactures human growth hormone and Chiron and Medimmune manufacture flu vaccines for global markets. In Haverhill, Genzyme manufactures polymers for pharmaceutical applications such as for renal disorders.
- The UK has a strong biopharmaceutical supply sector with total sales in the region of \$1 billion. Major contract manufacturers of biopharmaceutical operating in the UK include Lonza Biologics, Avecia, Angel, and Cobra

Biomanufacturing. Contract Research Organisations operating in the UK include Aptuit, Quintiles, Huntingdon, Charles River, Invitrogen Bioreliance, and there are specialist reagent suppliers such as Sigma, Serologicals, Invitrogen, and GE Healthcare.

- The UK has a strong and effective regulatory regime, and a flexible, but robust framework for managing research in novel areas such as stem cells. As well as the MHRA, the EMEA at the heart of Europe's biopharmaceuticals regulatory infrastructure is based in the UK.

The UK science and technology base has a number of internationally leading institutions in this area, including illustrative examples such as:

Sanger centre, University College London, Imperial College London, Birmingham Biochemical Engineering Dept, National Institute for Biological Standards and Control (NIBSC), Medical Research Council Laboratory of Molecular Biology, Cambridge, University of Cambridge, University of Kent, University of Cambridge, Institute of Pharmaceutical Innovation, Bradford, University of Nottingham, Jenner Institute, MRC National Institute for Medical Research, Stem Cell Research Institutes (Cambridge, Edinburgh, Newcastle), UK Centre for Tissue Engineering, Manchester & Liverpool. The Health Protection Agency (HPA) and Dstl have significant expertise in experimental vaccine and biodefence research.

Other small and medium size innovative companies in the biopharmaceutical sector in the UK include: Domantis, Haptogen, Genzyme, UCB Celltech, Cambridge Antibody Technology, Acambis. Onyvox, Chiron, Medimmune, Powdermed, Oxford Biomedica, Ark Therapeutics, Renovo, Reneuron, Axordia, CellCentric, Intercytex, Stem Cell Science, Ardana and Intercell.

SIZE OF THE GLOBAL MARKET OPPORTUNITY

The biopharmaceuticals sector is an attractive segment of the pharmaceuticals market for investment because:

- This is the next wave of innovation in medicines and could be 30% of the market within 10 years.¹⁹
- Potential to develop therapies for diseases with

no existing treatment. Examples include new treatments for rheumatoid arthritis, Crohn's disease, cancer, anaemia.

- There is a higher success rate through clinical trials.^{20,21}
- Potentially fewer side-effects.^{20, 22}

The global biopharmaceutical sales²³ were estimated at US\$71billion in 2005, with a compound annual growth rate of 16.5%. 1,771²³ candidates were in development in 2005, with 11% of these candidates being developed in the UK.

POTENTIAL IMPACT

The ability of the biopharmaceutical industry to innovate, with benefits to society is already in evidence. Over 70 biologics are on the market that treat many formerly untreatable diseases and use environmentally friendly manufacturing processes. A number of these previously untreatable diseases are very rare diseases called ultra-orphan diseases with less than 1000 patients affected in the UK. Over 250 million people worldwide have been treated with biopharmaceuticals.²⁴ Examples include²⁵:

- Genentech's Herceptin offers a significant advance over less specific chemotherapeutic and hormonal drugs, targeting cancerous tumours in women with a particular type of metastatic breast cancer.
- Cambridge Antibody Technology, in the UK, with the aid of Medical Research Council funded research, discovered Humira, a monoclonal antibody for treatment of rheumatoid arthritis and a potential blockbuster drug.
- Biogen's approved product for psoriasis, Amevive, is seen as a breakthrough use of a biopharmaceutical.
- Cerezyme, Genzyme's enzyme replacement therapy for Gaucher's disease, an ultra-orphan lysosomal storage disease caused by a defective enzyme was pioneering the area of orphan drugs.

Manufacturing of biopharmaceuticals poses particular technical challenges: the expansion of the global market for biopharmaceuticals is creating a significant opportunity for UK expertise in bioprocessing.

EXPLOITATION OF BIOSCIENCE BY INDUSTRY

INTRODUCTION

As the human population grows, and with changing customer demands, sustained economic development will depend upon a secure supply of raw materials as inputs for manufacturing. The majority of consumer goods are currently made from hydrocarbons from the petrochemical industry. These resources are limited, are depleting gradually, and need to be replaced by alternative renewable or bio-based resources.

Bioscience and bio-based technologies offer the basis for creating a new dimension to our economy, in which agricultural feedstocks supply a significant part of our energy, chemicals, and materials. Today, industrial bioscience already generates a number of products more cheaply and safely than conventional chemistry. In the future, combining plant and aquatic feedstocks and processes, and the integration of these with the power of micro-organisms, will drive the development of novel bioproducts and the creation of new bio-based businesses.

There is now clear recognition that bioscience and bio-based technologies will benefit our lives and our world. Bio-renewables will contribute to major industrial sectors such as those supporting our health, energy, water, food, and manufacturing requirements. Bio-renewables offer the means to achieve clean, sustainable, safe processes at affordable costs and with benefits for our environment and climate. Many of the technology areas described will be applied within and through the use of integrated and diversified bio-refineries that will increasingly replace existing oil refineries. In general, it is expected that petrochemical feedstocks and the carbon-based economy will evolve into biorenewable feedstocks and a sugar-based economy.

TECHNOLOGY PRIORITIES

Six generic technology areas will contribute to innovation and market opportunities for all of the business areas:

- Novel land and aquatic multi-cellular- and micro-organisms.
- Microbial and plant genomics, gene discovery and bio-informatics.
- Metabolic engineering, modelling and systems biology.
- Biocatalyst design and process optimisation
- Fast-track molecular breeding of feedstock species for improved raw material quality, consistency and yield.
- New, easy and fast tools to discover bioactivities, functionalities and novel structural biomaterials.
- Integrated programmes in development of feedstock, innovative process and extraction technologies and fermentation to deliver multi-product processes.

In some instances, work on these technology areas already exists but will need to be developed further and specifically to underpin each of the products and processes within the different business areas. In other instances, the technology areas are not yet highly developed and will require major new activity.

UK CAPACITY TO DEVELOP AND EXPLOIT TECHNOLOGIES

The UK has a world-class science base in plant and microbial sciences (with BBSRC spending approximately one third of its budget on plant/crop based science) and a number of centres of excellence with established links to industry. Notable illustrative examples include:**

- Centre of Excellence in Biocatalysis, Biotransformations and Biocatalytic Manufacture (CoEBio3)
- Centre for Process Innovation (CPI)
- University College London's Department of Biochemical Engineering
- University of Bath Centre for Extremophile Research
- University of York's Centre for Novel Agricultural Products
- Institute of Grassland and Environmental Research
- Biocomposites Centre Bangor
- John Innes centre of excellence in plant science and microbiology
- South West Marine centre in Plymouth
- North East of England cluster biofuels business

** It is recognised that this list is not exhaustive. Inclusion in this list does not represent endorsement by government.

The UK leads Europe in the industrial exploitation of biotechnology. UK biotechnology companies account for almost three-quarters of Europe's publicly quoted biotechnology companies. Below is a selection of these companies. Many of these have been shown to be active in this area in a recent patent mapping study funded by DTI⁹.

- **Speciality chemicals/pharmaceutical intermediates:**
 - Ciba Speciality Chemicals, GSK, AstraZeneca, Pfizer, Avecia, Unilever, Biotica Technology Ltd, Discerna Ltd, Baxenden Chemicals Ltd, Oxford Chemicals, Alphamerix Ltd, C-Tech Innovation, Syngenta
- **Healthcare and Food**
 - Botanix Ltd, Holland & Barrett, Bodyshop, Boots plc, Johnson & Johnson, Neals Yard Remedies, Unilever, Amano Pharmaceutical Co Ltd
- **Conversion of biomass to industrial feedstocks**
 - Bio-packaging /Bioplastics – Biopac, PotatoPak, Caledonian Ferguson Timpson, TMO Biotec Ltd, BPF, Packaging Group, The Box Shop, Packaging Federation, Cargill, British Sugar, Proctor and Gamble
- **Biofuels**
 - Shell, BP, Argent Energy, Brocklesby, Biofuels Corporation, D1 Oils, Ebony Solutions, Eurobiodiesel, Global Commodities, Greenergy, MK Biodiesel, Rix Biodiesel, British Sugar, Green Spirit Fuels

SIZE OF THE GLOBAL MARKET OPPORTUNITY

Health

Short to medium term opportunities include discovery and development of dietary supplements, functional foods, cosmeceuticals, pharmaceutical intermediates.

- The UK market alone for healthfood including dietary supplements grew to £513 million in 2004²⁶. The world market for functional foods is estimated at US\$10 to 30 billion, when this is restricted to include only food and beverages that make a specific health claim, the combined market value in Europe, Australia, Japan and the US in 1999 was estimated at more than US\$5.7 billion²⁷.
- The US market alone in cosmeceuticals is predicted to grow at a rate of 11% per annum

to 2008, with a market size in 2003 of US\$4.2 billion²⁸.

- Global markets for plant-derived small-molecule drugs alone are US\$13.7 billion (2002), rising to US\$19 billion in 2007; total over-the-counter sales of plant-derived drugs is US\$40 billion (2002)²⁹.

Energy

Short to medium term opportunities include development and use of biorenewable feedstocks and bioprocesses for example in bio-extractions, bio-conversions, added-value by-products, biofuel cells, bio-hydrogen production.

- The Energy Bill 2004 requires fuel companies to sell a given proportion of their annual fossil fuel sales as biofuels. EU Directive 2003/30/EU has set the target of 2% biofuel usage by end 2005 and 5.75% by end 2010 (& rising to 20% by 2020). For the UK, the first target would mean about 800,000 tonnes of biofuel.

Manufacturing

Short to medium term opportunities include the use of biorenewable feedstocks and bioprocesses for production of chemicals and materials such as platform chemicals, functional biomaterials, bionanostructures, biochemical scaffolds.

The market opportunities in this sector are amongst the most promising, reliable market data is, however, difficult to find. Examples of predictions for the global impact of bioprocesses in the manufacturing sector in 2010³⁵ are cited below.

- Fine chemicals US\$90 billion (bioprocess contribution 60%).
- Polymers \$370 billion (bioprocess contribution 10-15%).
- Bulk chemicals \$380 billion (bioprocess contribution 10-15%).
- Specialities \$560 billion (bioprocess contribution up to 50%).
- The overall predicted input from bioprocess in this sector is \$280 billion.

Although it is recognised that these predictions are unlikely to be realised in the timescales anticipated, this still presents a powerful indicator for the

potential impact of bio-based processes on the chemical sector in the future.

- In the UK alone, the plastics industry usage in 2005 was > 4 million tonnes; given bioplastics has a market penetration of only 0.15% at present, the potential is huge. The UK packaging market size is £9 billion, with food packaging representing 37% of the sector: Federation website: Packaging Federation UK Market Report No 4 (2005).
- The estimated market in 2015 for nanostructures is \$1 trillion (National Science Foundation, USA, from BIO report, US). This includes bio-based opportunities for the production of nanotubes, coating nanostructures with biocatalysts and use of switching mechanisms in computers facilitated using bioscience and recombinant DNA technology.

Water sector

In the water sector, opportunities are principally long-term, but include discovery and development of new bioprocesses for desalination, treatment, purification and recycling of water, improved drought resistance of plants and reduction in industrial usage.

- Opportunities are in desalination, treatment, purification and recycling, improved drought tolerance of crops, reduction in industrial usage. The desalination market 2005-2015 has been estimated as US\$95 billion, of which US\$48 billion will be derived from the increasingly urgent need for new capacity – this is manifested in the form of 31 million cubic meters per day already being commissioned in this period³⁰.
- BASF predict a total market growth for cold tolerance, drought tolerance, salinity tolerance, and yield increase for agronomic traits in crops to be US\$10 billion by 2025 – compared with less than US\$1 billion in 2004³¹.

(See also Sustainable Production and Consumption paper.)

Food and feed sectors

Short to medium term opportunities include discovery and development of new bioproducts

and bioprocesses, for example, to improve nutritional quality, improve safety, monitor composition, decrease spoilage.

- Opportunities are principally in improving nutritional quality, safety, monitoring composition, decreasing storage and spillage costs, and increasing utilisation of animal feeds. Replacing traditional foods (maize, sugar beet potatoes in EU) with corresponding biotech varieties crops could potentially be increased by nearly 8 billion kg and grower net income by EUR 1 billion pa. For the UK this translates to 336 000 hectares with a yield effect of 0.6 million tonnes and income effect of EUR 109 million³².

Environment

Medium to long term opportunities in the environment sector include discovery and development of bioprocesses, for example, to improve carbon dioxide entrapment, monitor genetic diversity, reduce waste from industry and agriculture, monitor environmental change.

- Opportunities are principally in improving carbon dioxide entrapment systems, monitor genetic biodiversity, designing new bio-safety systems, monitoring/reducing pollution from industry and agriculture. Examples of reported activity in this sector include those in Japan where environmental biotechnology accounted for 7.9 billion Yen in 2005³³, but is anticipated by the Japan Patent Office to grow by 2010 to 400 billion Yen (~£2 billion).
- The current UK technology based land remediation market is estimated to be worth £130 million and expected to grow to £350 million over the next 5 years³⁴.

Obtaining and defining the value of market opportunities for the technologies mentioned above is notoriously difficult. A clear area of future work will be to define these technology areas precisely and validate them against market size, capability, and capacity.

POTENTIAL IMPACT AND TIMESCALES

The Government is committed to sustainable development^{††}. Bioscience and bio-based

†† 'Securing the Future – the UK Government Sustainable Development Strategy' March 2005. <http://www.sustainable-development.gov.uk/publications/uk-strategy/index.htm>

technologies will play a vital role in delivering this commitment, and offer the basis for creating a new dimension to our national economy, in which renewable feedstocks supply a significant part of our energy, chemicals, and materials.

The exploitation of plant and microbial bioscience by industry is vital if the national economy is to retain competitiveness in the global context of declining fossil reserves and increasing costs of petrochemicals.

The use of renewable biomaterials as feedstocks for industry and biocatalysis and biotransformations for industrial synthesis can enhance the competitiveness of industry through development of new and improved products, while lowering costs through reduction in water and energy consumption and waste production. Integrating renewable feedstocks with the processing power of microorganisms and chemistry will lead to the development of new sustainable processes and competitive products that are applicable to a wide range of business sectors.

The development and exploitation of plant and microbial bioscience by industry is dependent on a multi- and inter-disciplinary approach to product and process design. Previous fragmentation and lack of cohesion of the relevant communities has held back development and exploitation of these technologies. Further Technology Programme support in this area is, however, timely to take advantage of the coherence, interest, and activity catalysed by the new Bioscience for Business KTN.

THE WAY FORWARD

The mechanisms for taking this vision forward were described in the Technology Strategy Board Annual Report and Call to Action. These will offer the opportunity of promoting innovation with the aim of stimulating multi-disciplinary approaches to developing products, potentially for government procurement.

In order to maximise the impact of its funding, the government will aim to combine its support for R&D activities with its support for other technology enablers, such as networking, metrology, standards, regulation, intellectual property policy, and broaden the interaction to include funding partners, work on innovative government procurement, and developing its relationship with the investment community. Our analysis suggests the need for a more 'challenge' oriented approach.

Early Priorities based on market opportunities:

The following priority areas are emerging from our internal analysis:

Delivery of novel therapeutics

This priority area will include a wide range of technologies to ensure that therapeutics (whether small molecule pharmaceuticals, large biological molecules, vaccines, or cell therapies) reach their targets in the body to exert the required therapeutic effects, and methods to determine the fate of the therapeutics introduced. This would include methods for delivery of biological drugs (proteins, peptides, siRNAs) to their target tissues, address introducing biological molecules across the blood-brain barrier, targeting therapeutics to their sites of action, and imaging and identifying the destination/metabolism of therapeutics.

Priority areas:

- Innovative approaches to access the brain without invasive and potentially risky surgery
- Miniaturised therapeutic delivery devices, incorporating biosensors that monitor physiological status and release drug accordingly

The priority area could lead to clinical trial support depending on interactions between other partners.

Converging technologies in medical devices

This priority area will stimulate the convergence of disparate technologies to make smarter devices, leading to new and combined functionalities. This could initially begin with smart sensors to prolong device life, but could ultimately lead to closed-loop drug-device/biologic-device systems that might identify demand for therapeutic and dispense it automatically, or, for example, robots that work independently or co-operatively in diagnosis and delivery of treatment options.

Other potential priorities

Further market-led priority areas based on the analysis in this paper under consideration could include: *Regenerative Medicine Technologies, Technologies for (Bio)Pharmaceutical Discovery, Development, Formulation, and Application, and Exploiting the Opportunities of a Bio-Based Economy.*

Early priorities based on societal challenges

In parallel with the 'bottom-up' industry/network consultation process to elicit priorities on market opportunity, we have conducted a similar process with Other Government Departments to identify where a joint technology support approach might be of benefit in leading to more innovative public procurement. Based on a these discussions, possible priority areas linked to societal challenges of relevance to this biotech / biomedical area are as follows:

Emerging priorities

- 1 Medical devices and networks for assisted living/telecare
- 2 Management of infection (special focus on HCAI and vaccines)
- 3 Imaging for medical applications

Future potential priority areas

Other priority areas addressing societal challenges with potential relevance for the Bioscience and Healthcare field include: *Virtual World: Simulation, Modelling and Training Purposes, Sustainable*

Water Supply, Resource Efficiency, Waste and Pollution, and Sustainable Food Chain.

Further work is now required to build the evidence base in the areas identified, particularly on industry analysis, work on value chains, and on roadmapping.

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ANNEX 2: GLOBAL WATCH ACTIVITIES

Missions:

- 1 Cancer Stem Cells – Scoping Mission to USA – June 2005
- 2 Cancer Biomarkers Mission to the USA – Oct 2005
- 3 Healthcare Technologies Mission to China – Oct 2005
- 4 Impact of regenerative Medicines and Converging Technologies on Medical Devices to USA – Oct 2005
- 5 Biosensing Technologies for Medical and Homeland Security Applications to US – Nov 2005
- 6 Central Nervous Systems and discovery technologies to Germany – Oct 2005
- 7 Functional Foods Mission to Japan and Singapore – Oct 2005

Future:

- 1 Biocatalysis to USA – Industrial Biotechnology – May 2006
- 2 Cellular Bio Processing Mission to USA – Sept 2006
- 3 The Assessment of Regenerative Medicine and Stem Cell Technologies to Australia – Nov 2006
- 4 White Biotechnology Mission – The Assessment of Industrial Biotechnology Capabilities in New Zealand – Sept 2006.

For more information on missions go to <http://www.globalwatchservice.com/missions>