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# PROSPECTING BIOSCIENCE FOR THE FUTURE OF NON-FOOD USES OF CROPS

A study for
The Government Industry Forum on
Non Food Uses of Crops

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Final Report
January 2004

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# EXECUTIVE SUMMARY

## Prospecting Bioscience for the Future of Non-Food uses of Crops

### The Report

This report was commissioned by DTI and DEFRA, for the Government Industry Forum on Non-Food uses of Crops. It considers the potential contributions of bioscience to non-food uses of crops and its principle objectives are to assist in:

- developing enhanced understanding amongst policy, academic and industry communities about these contributions.
- assessing their implications for future UK competitiveness and global sustainable development.

This study aims to increase understanding of the *additional* potential arising from bioscience applications to NFCs, drawing on current state of the art knowledge of the science and technology, and of the opportunities emerging from them. The key question is: *What difference can bioscience make – and how?*

### The Science and Technology Challenge

It cannot be over-emphasised that there is now a critical policy time-window, and for three reasons. Firstly, the depletion of petrochemical resources over the next 35-50 years and global climate change present a challenge to develop alternatives that has to be addressed now. In the 21st century, the bio-economy can provide a significant part of the solution. Secondly, the UK is already in a catch-up situation with respect to developments taking place in the US and elsewhere, and any further delay would be likely to increase the risks of UK economic dependency. Thirdly, there is an ever-increasing danger of a decline in the UK science base in this area.

Two main aspects of the challenge were identified, each requiring different solutions for the UK in a European and global context:

- the unavoidable shift towards a more sustainable development through bio-economy alternatives to petrochemical technologies
- the development of new bioscience products from non-food crops, especially pharmaceuticals and materials where plant-based technologies are the best or only option

### The potential contribution of GM and non-GM bioscience to NFCs

- Bioscience applications to NFCs derive especially from genomics and post-genomics, but do not necessarily involve the agricultural use of GM crops. There are important contributions that can be made to more conventional and currently less controversial agricultural practice.

- Even without GM, bioscience can achieve maximisation of those resources derived from the functionalities deliverable by a species genome, through genomics-based hybridisation. Greater understanding of plant metabolism and functionalities arising from genomic and post-genomic bioscience will enable greater use of existing and novel NFC plant properties for diverse applications.
- Excluding the GM route, however, will result in a significant reduction in potential across the whole range of applications and development of NFCs. Many of the key issues concerning environmental and agricultural sustainability from renewable resources will be at least very hard to address without adoption of GM technologies. This assessment applies to most products currently derived from petrochemicals: energy from biomass, plastics or adhesives from plants are prominent examples.
- Bioscience applications using GM need to be differentiated - between process and product, and between different types of NFC products. There are GM technologies that can be applied in bioprocessing, others used in agriculture, and others that can be used in combination for both phases of production. Many of these applications can lead to more ecologically sustainable production than pre-existing technologies.
- The key areas where GM technology achieve distinctive advantage are:
    - biocatalysis for renewable sources of energy (ethanol from biomass) and materials (e.g. plastics);
    - the development of plants with new output traits for feedstocks (e.g. starch, oils);
    - the development of plants with new output traits for enhanced consumer products (e.g. clothing, cosmetics) ;
    - the development of plants for producing therapeutic agents particularly antibodies (pharming for proteins)
    - the development of plant or microbe technologies for bioremediation, and leisure and amenity provision.

**Alternative futures**

The scenario workshop of experts considered four alternative visions of the future of UK bioscience technologies in NFCs.

- <u>“Go for it!”</u>. Extensive use of GM technologies for open-field agriculture as well as containment modes of cultivation, and the introduction of new non-GM crops, resulted in an unrestricted range of bioscience feedstocks, bio-processing and novel products.
- <u>“On the cusp”</u>. A critical point has been reached where either GM technologies could still be developed on a moderate scale, or UK capabilities would be irreversibly lost, leading to a decline in UK competitiveness and future quality of life.
- <u>“Contained but not constrained”</u>. Containment cultivation measures backed by extensive regulation confined the use of GM to closed environments, including for high-risk products or processes. A significant level of UK competitiveness for high value, low volume products could be achieved through this route.
- <u>“Not in”</u>. GM technologies were hardly developed, if at all, in the UK, and bioscience activities would take place elsewhere leading to technological and

import dependency including for pharmaceutical, renewable energy and materials applications.

To varying degrees, any of these scenarios were deemed to be possible, and much would depend on policy direction in the UK and Europe, and on global developments of these technologies and markets elsewhere.

**Opportunities and applications**

- Application of bioscience applications to Non-Food Crops presents tremendous opportunities to innovate new products and services that can contribute to UK competitiveness and quality of life.
- We are still at the early stage of these developments, and while many applications can be foreseen, there are bound to be innovations that will surprise us. Five major application areas can be discerned:
    - energy;
    - industrial processing;
    - plant, microbial, and fungal pharmaceuticals;
    - environmental amenity and bioremediation;
    - novel products of a wide variety.
- In each of these areas, developments in the USA have achieved commercialisation or are well advanced towards doing so. A considerable lag was identified in UK and European technology development, although there is a strong science base capable of achieving leading positions in certain areas.
- To address the two major challenges of the shift to sustainable development and development of new bioscience products in a UK/European context, the study and workshop process identified two corresponding areas on which to build UK bioscience capabilities:
    - The development of bio-refinery technology platforms to meet the challenges of producing new renewable resources of energy and materials to replace those based on petrochemicals.
    - The development of containment agronomies for the production of pharmaceuticals and novel specialist materials, with positive consumer or industrial benefits.

**Key policy recommendations**

In the conclusion, recommendations were presented that focus on two distinct challenges and with different but equally important responses relevant to each of them (A and B). There is also one general recommendation applicable to both challenges (C).

**A. The unavoidable shift towards sustainable development and the bio-economy.**

**Recommendation 1.** *Develop an integrated UK strategy for bio-economy solutions to Global Climate Change and the depletion of petrochemical resources for energy and materials*.

**Recommendation 2.** *Promote R&D investment and stimulate academic research in upstream, high IPR value, bio-refining technology platforms.*

**Recommendation 3.** *Stimulate collaborations across the range of biosciences in the NFC area for bio-processing and feedstocks to maximise technological and competitive synergies on a European scale.*

**B. Maximising the UK potential of bioscience for NFCs**

**Recommendation 4.** *Promote the development of high-value, low volume bioscience NFCs under containment agronomies, especially for pharmaceuticals and novel specialist materials, using UK comparative advantage.*

**Recommendation 5.** *Stimulate the development and application of venture capital to bio-science for NFCs, particularly in relation to the commercialisation of containment agronomies.*

**Recommendation 6.** *Levels of investment and support for UK basic plant bioscience in universities and public science institutes are sufficiently maintained to ensure continued world-class performance.*

**C. General recommendation**

**Recommendation 7.** *Develop statistical and other databases that adequately support biotechnology policy formation in the UK.*

# 1. Introduction

## *1.1 Objectives*

**1.1.1.** Bioscience is developing at a very rapid pace, with major advances in our knowledge of biological processes, and our capacities to study, measure and influence them. The ongoing evolution of this field has immense potential contributions to make to the future of non-food crops, and to the applications of such crops. The principal objectives of the present study are to assist in:

- developing enhanced understanding amongst policy, academic and industry communities about these contributions.
- assessing their implications for future UK competitiveness and global sustainable development[1].

**1.1.2.** Many opportunities are emerging in this area. There are opportunities to achieve specific *ends*, including doing familiar things more efficiently, and doing quite novel things. There are opportunities to use specific *means*, ranging from improving familiar techniques to introducing quite novel approaches. These opportunities span a vast range of applications. They include, for example, increased production of renewable raw materials and energy resources, so as to achieve more sustainable development; new biopharmaceutical products for healthcare; the introduction of new bio-processing techniques into industries of many kinds; and of new industrial feedstocks from renewable sources; environmental remediation, and the use of crops to produce novel materials with new functionalities for a diverse range of new markets. These examples suggest a range of possibilities capable of transforming the industrial and agricultural landscape.

**1.1.3.** There is already some awareness of the increasing scope for growth in non-food crops. In addition to the "push" from bioscience, there are "pull" factors, such as the projected decline in supply of petrochemical resources, significant changes in land-use in European agriculture, and the need to develop environmentally sustainable economic growth. Earlier reports have surveyed and assessed the possible growth of existing non-food uses of crops (NFCs) to meet this increased demand for sustainable development (ACTIN 2001; GIFNFC Annual Report; House of Lords Select Committee, 2000). The focus of this project is to develop an understanding of the *additional* potential arising from bioscience applications, based on current state of the art knowledge of the science and technology. The key question is:

***What difference can bioscience make – and how?***

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[1] When using the concept of 'sustainability' in this document we refer to economic, social and environmental sustainability in a broad sense.

## *1.2 The approach of the study*

**1.2.1.** The material in this report has been developed though three main strands of work:

- Desk-based study
- An accompanying programme of telephone interviews[2]; and
- A workshop involving various participants who are engaged with this subject (either in industry or in scientific research)[3]

**1.2.2.** The interview programme and desk-based research contributed to the production of a background document for the workshop, designed to stimulate discussion amongst the participants. The document also detailed four possible scenarios regarding the opportunities to cultivate GM crops in the UK. These were discussed and elaborated on by the participants. The scenarios presented in section 3 are the results of these discussions. A second task of the workshop was to consider areas of application for non-food crops, discussing, in light of the possible scenarios, the potential for UK participation in a global context.

## *1.3 Blurred Boundaries*

**1.3.1.** Radical technological change often results in blurring of established boundaries between what had seemed to be distinctive industries, products, techniques, and professions. This subject area is no exception.

**1.3.2.** First, what do we mean by the new bioscience? Understanding of biological processes at the molecular level has advanced dramatically, and influenced many other types of biological enquiry. Continuing movement in terms of understanding the functioning and properties of genetic material has been aided by the application of new Information Technology – under the umbrella of bioinformatics – itself undergoing very dramatic development. Bioscience is a much broader platform for technology development than genetic modification. Improved understanding of gene functionality is central to many other developments, in addition to genetic modification. It can be used to enhance "conventional" breeding and hybridisation, for example, and to develop new bio-crops and bio-processes. There are also, as we shall see, various innovations whose classification as involving genetic modification (or not) proves contentious.

**1.3.3.** Second, what is meant by "non-food crops"? Where it comes to the "non-food" element, some crops have both food and non-food outputs. For example, oilseed rape overlaps some food and non-food regulatory environments; may confront public reactions that do not discriminate between the two; and raises similar issues of crop management and co-existence measures. "Nutraceutical" and "food supplements" may be classified as food products or as health products. This study

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[2] See section 6 for a full list of interviewees from the UK and USA
[3] See section 7 for a full list of workshop participants

will need to be sensitive to interactions between market, regulatory, and policy environments covering food as well as non-food crops and products.

**1.3.4**. Where it comes to "crop", we could try to define the problem away by ruling that for our purposes, crops involve such conventional forms of agriculture as open field and greenhouse rearing of plants. However, genomics-based outputs have been developed from both plant- and non-plant-based (e.g. microbial) technologies. Plant and non-plant based applications of genomics may be developed to achieve the same outputs. They can potentially be in competition with each other. Crops – in the sense of plant-based methods - are often only one of a number of alternative approaches to production of non-food products. For instance, we could envisage microbial, fungal or other organic methods of production. In the event of serious regulatory hurdles in agriculture, we might find that non-crop alternatives become more relevant. Thus, while not the main focus of this study, they too need to be taken into account.

## *1.4 Structure of the report*

**1.4.1.** The next chapter of this report draws on interviews and desk research to discuss a number of issues that will shape the NFC future in the UK. Following this, Chapter 3 introduces a set of conceptual tools that have been used to structure thinking, and stimulate dialogue, in this study. These include the set of scenarios that were employed at a workshop in November 2002. Chapter 4 carries on the analysis by considering developments in a number of application areas, and Chapter 5 draws conclusions from the study.

# 2. Achievements and potentials in bioscience applications for non-food crops

**2.0.1.** Various factors are likely to influence, and be influenced by, greater use of non-food crops and the extent to which different areas of bioscience will be used for such applications. Five groups of factors - science and technology; institutional factors; the development of markets; the regulatory environment; and public acceptability - have been separated for the sake of clarity of discussion. But it is clear that they are interrelated and at least partly overlapping. This chapter outlines some of the debates around these factors, drawing on the results of desk research and interviews. It provides a context for the development of tools to consider future possibilities in the following chapter.

## *2.1 Science and technology*

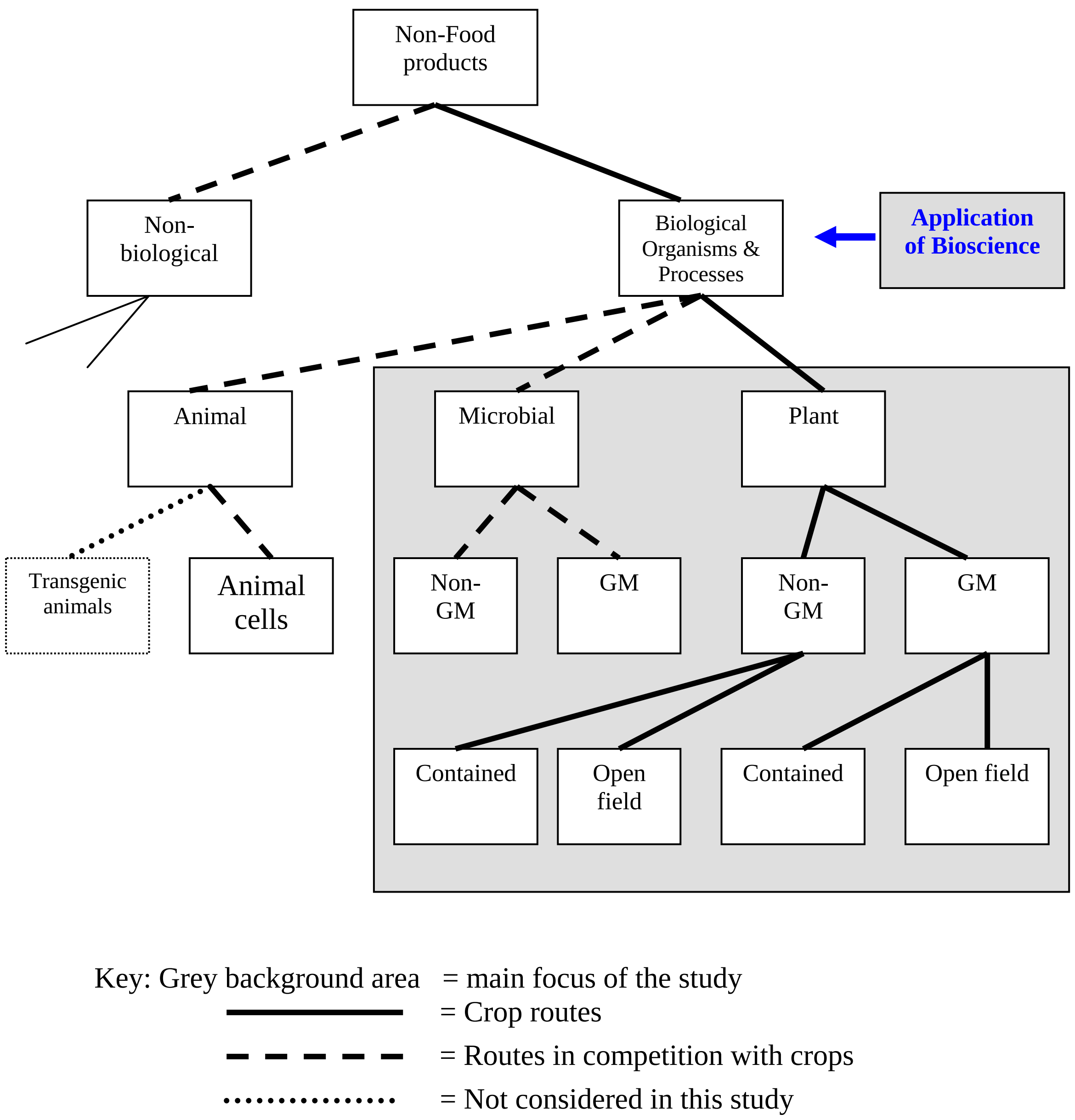
**2.1.1.** When considering bioscience applications for non-food crops simply from the standpoint of the science and technology, there is both enormous potential but a general recognition that, as with genomics and pharmaceuticals, time-scales are very long ones. We are at a very early stage of a long process. There are products already in the market, in some instances for quite a period, that are clearly identifiable as applications of non-food crop bioscience. GM canola and Bt cotton are the most significant in terms of global expansion, having been established on a large scale from the mid-1990s (James, 2001). Human growth hormone is exclusively produced by GM microbial fermentation, and insulin has also been widely produced by this technology (McKelvey, 2000). The use of bioscience is not limited to genetic modification. Much conventional hybridisation is now often using rDNA markers, gene silencing technologies for identifying functionalities of genes, or gene sequencing (British Society of Plant Breeders).

**2.1.2.** Chapter 4 will consider major areas for NFC applications of bioscience. Different reports have identified the different areas of non-food crops in different ways (BCPC Forum Report; Pew Initiative, 2001; House of Lords Select Committee on Science and Technology; IENICA report; GIFNFC Annual Report, 2002; AEBC Horizon scan, 2002). Few of these systematically differentiate between bioscience and non-bioscience applications. Many approach the issue from the standpoint of different crops (oil/chemical, fibre, specialty, carbohydrate), rather than from the science/technology perspective, asking the question, *what can the crops do?* rather than *what can the science and technology do?*

**2.1.3.** Figure 1 introduces a tree of alternative possibilities for applying bioscience to non-food uses of crops. It is presented as a device for showing how the application of bioscience to NFCs might compete with non-biological approaches; how biological approaches can be applied variously to plants, microbes or animal cells to produce competing products; that GM and non-GM approaches can be used to enhance the non-food uses of crops and that these can be grown in open fields or under containment.

**2.1.4.** First, products may be created through biological or non-biological means. The development of science and technology make it possible to create some products by biological means that previously could only have been manufactured through chemical processes; and conversely chemical routes become available for products previously created via biology. In thinking about the future for NFCs, we need to be aware that chemical engineering is also being transformed by new knowledge, for instance knowledge of novel approaches to making plastics.

**Figure 1. The application of bioscience to non-food crops.**



**2.1.5.** If the *biological* route is followed then options open up to utilise plants or microbes (or even animals and animal cells - for example, to produce complex products, tissues, organs). Microbial routes are not the central focus of this study, but they do need to be considered where they provide an alternative technology to plants. (The use of animal cells may also be considered as a competitor route to crops, but transgenic animals have not been considered.) In no cases of which we are aware is there head-to-head competition between these alternatives for the same product. But there appears to be no absolute scientific or technological reason why not – and thus we cannot rule out the scope for competition in the future. Plants are capable of producing large, complex, molecules, such as monoclonal antibodies, therapeutic proteins, or spider silk, in substantial quantities in a way that is certainly challenging for microbial technologies, because of the molecular constitution of bacteria. Conversely, microbial technologies offer opportunities from controlled industrial fermentation processes, suited to the production of some therapeutic proteins, polymers or polymer precursors, alcohol, or Vitamin B2. It should be noted here that most bioscience deployment of microbes has been developed using genetic modification technologies and, in many of these developments, a non-GM route appears scientifically impossible (therapeutic proteins, polymers, alcohol, etc.).

**2.1.6.** There are a number of potential problems with plant approaches. In particular, continuity of supply and the consistency and reliability of the product (the same plant grown in the same field in different years may produce a slightly different product) pose problems – such problems are lessened with a fermentation approach. But in contrast, the production of high yields through fermentation may be problematic. However, a significant issue here would be possible **combinations** between microbial technologies and non-food crop developments. They need not be seen only as alternative routes; for example, it may be that biological systems of microbe-plant interactions that can be developed on the basis of new bioscientific knowledge, in order to achieve enhanced nitrogen fixation. In the field of bioprocessing, GM microbial enzymes are already routinely used to process plant derived feedstocks, and it is plausible that the future will see simultaneous bioscience-based interventions across many stages of NFC product chains.

**2.1.7.** Once the *plant* route has been chosen, then decisions have to be made about whether a GM or non-GM plant is utilised, and whether these should be grown in open field agriculture, or cultivated in contained systems (e.g. glasshouses). It goes without saying that any functionality of a crop that is **not** expressed by a gene within the plant's genome can only be introduced through genetic modification technologies. Thus, many non-food bioscience applications - such as therapeutic proteins, mussel adhesives expressed in tobacco, fish oils for nutraceuticals - can only be achieved through genetic modification. Even enhanced expression of an already existing trait may also only be achieved through genetic modification in some cases.

**2.1.8.** Employing bioscience to better understand the function of crops can provide important information, information that allows for improved treatment of plants and important advances through more conventional breeding approaches. Conventional breeding may have advantages over genetic modification, in terms of the performance of the plant. For example, modifying a plant to increase the expression of a particular substance may upset the overall functioning of the plant leading to lower yields. Beyond conventional breeding, improved understanding of the plant may also allow for advances in processing technologies (e.g. better understanding of how fibres are held together) which may themselves employ bioscience techniques. However, whatever techniques are employed, large step change increases in materials produced by plants are not possible through conventional breeding.

**2.1.9.** Now, following the GM-NFC route, there are further branches corresponding to alternative agronomic methods for bioscience technologies. High value products, such as therapeutic proteins, cosmetics, fragrances or specialty oils may make capital-intensive containment cultivation a viable route. In some views, open field production of therapeutically active agents involves unacceptable risks, and irrespective of regulatory frameworks, favours the development of containment agronomy. GM mushrooms, with high per-hectare yields using containment agronomy methods for therapeutic proteins are an example of this technological route. Use of sealed glasshouse technologies or underground cultivation offer alternative possibilities, which would quite possibly benefit from the development of appropriate regulation. Conversely, high volume production of therapeutic agents is widely seen as a commercially viable alternative requiring open field cultivation. Certainly, for any relatively low value output traits where bulk production is essential, open field alternatives would seem to be the only commercially viable technological pathways. This too is an issue to explore systematically in terms of the scientific and technological constraints and opportunities presented.

## *2.2 Institutional capabilities*

**2.2.1.** Having outlined the range of alternative possible science and technology trajectories, we turn to a consideration of the emerging institutional organisation within which these developments are taking place. When new commercial opportunities arise from a quickly developing science base, it is common for new types of firm to emerge to exploit these opportunities, or to help other firms do so. This has been the case with some of the opportunities presented by modern bioscience to the non-food crop area. A variety of newly established dedicated biotechnology firms (DBFs) have been established, with some oriented towards the development of generic platform technologies (e.g Epicyte), and others with closer associations to particular application areas, such as health (e.g. Meristem) fragrances or new materials (e.g. Cambridge Biopolymers). While start-up for these small companies may be possible, and grants may be available to undertake initial development, there are continuing concerns about what is seen as the limited availablity of venture capital to continue development and potentially bring technologies to market. In some cases, funds may be provided by larger companies, for example, pharmaceutical companies, if unwilling to enter into the area themselves, may form alliances with small companies undertaking R&D in the use of crops for pharmaceutical production. Indeed the cost of developing GM technologies will mean that in many cases small companies cannot afford to commercialise products and, where they develop technologies with large potential, they will be absorbed by larger organisations.

**2.2.2.** By considering the tree presented in Figure 1 in institutional terms, it is also possible to think about a newly emerging industrial structure. For example, while Epicyte uses GM technology to modify plants to produce therapeutic proteins, Large Scale Biology Corporation (LSBC) produces vaccines using GM plant viral vectors on a non-GM tobacco variety. (A full consideration of the industry structure here would include firms persisting with the non-bio, chemistry-based alternatives at the top of the S&T tree, or those involved with microbial antibody production lower down).

**2.2.3.** The current industrial landscape is characterised by a number of large firms that are both producers and customers of bioscience-enabled non-food crops products. The most obvious examples in this category are the large chemical processing firms – leaving them with one foot in the biotechnology route and one in the non-biotechnology route. The involvement of these firms in the biotechnology route reflects both the potential that they may see for new potential products but also that they see the biotechnology route as providing strong competition to their traditional approaches. The innovation strategies of these organisations are differentiated by the extent to which they are pursuing in-house R&D for bioscience and NFCs, versus outsourcing or collaborating with DBFs. Dow, Cargill, Bayer, DuPont and BASF have been active in this area for some time, while ICI has more recently followed suit with strategic acquisitions of Uniqema and National Starch and Chemical Company. The opportunities for these companies concern both inputs (alternative feedstocks allowing for reductions in petrochemical use) and outputs (new materials with quality traits not hitherto achievable). The other major firms at the ‘supply/demand nexus’ are those involved with agribusiness, specifically the production of seeds and crop protection technologies. This is one of the key areas where UK activity is relatively low, and with the contraction of Syngenta’s, Dupont’s and Monsanto’s UK R&D, becoming smaller still.

**2.2.4.** The public science base in the UK, in contrast, is highly regarded. Despite difficulties emerging from the lack of ‘industry-pull’, it performs well on the global stage. The BBSRC is the primary source of funds for public science in the area of plant and crop sciences. It currently devotes about £60 million in this area, split approximately 50 / 50 between institutes and mainly responsive funding to universities. Much of the basic research in this area is, in a similar fashion to most other countries, focused at the molecular level. This focus for funding has perhaps led to certain other areas receiving less attention. Some of these, such as processing technology, may be harder to define as basic research, but are crucial to the efficient exploitation of crops. Another issue that has been raised in interviews is the lack of good interdisciplinary work in this area. Improved communication, such as between those concerned with processing and those with modification of plants, would be beneficial to the quality and utility of work.

**2.2.5.** To promote and facilitate commercialisation of the basic research, BBSRC has collaborated with DEFRA and the DTI in the ‘Competitive Industrial Materials from Non-Food Crops’ programme, under the LINK scheme. A large number of the projects funded under this programme concerned extraction technologies; of those that were more biology-based, at least one has already been commercially licensed. The project, managed through Rothamsted Research, developed a technology which enables plants to produce pheromones to attract biological agents to predate on aphids. This technology has been taken up by the US prune growers association. The durability and success of key university – industry linkages has been mixed. A 14 million Euro Framework 6 projects, LIPGEMS has successfully brought together BASF, Rothamsted Research and CNAP in a project aimed at producing dietary supplements in crops. However, the original collaboration between Syngenta and the John Innes Centre (JIC) for a wheat improvement programme, established to encourage knowledge flows across the public-private boundary has now been dismantled. Finally, the major research institutes supported by Research Councils in this area, including JIC, Rothamsted Research, Horticulture Research International (HRI), the Institute of Grassland and Environmental Research (IGER), the Scottish Crop Research Institute (SCRI) and CNAP do have institutional mechanisms for promoting the commercialisation of research and each has seen some success in creating new companies.

**2.2.6.** In terms of agricultural capability, through a combination of agronomic context and infrastructural path dependencies, the UK has strengths in a small number of open-field crops, particularly wheat and oilseed rape (Bullard et al., 2002). Through crop improvement programmes, it is possible that the UK could perform more competitively in other crops, including the mainstream cereals. However, in instances where high value products are achievable from small areas of cultivation, a UK comparative advantaged may be possible. So, while the UK will not compete in the cultivation of cotton for textile applications, it is quite plausible to imagine tobacco being grown under glass here to produce therapeutic agents.

**2.2.7.** It has been difficult to establish the extent to which the demand side organisations are actively involved in their own research and development to apply bioscience to NFCs. One plausible explanation is that the innovation pipeline is such that products are not yet available in many sectors. However, such research and development is being conducted. For example, ICI paints have been involved in two European collaborative projects aimed at trying to find new ways of utilising carbohydrates in polymers.

**2.2.8.** This brief and selective illustration of different institutional arrangements draws attention to the multiple possibilities for both new types of firm and new types of coordination between existing and new firms. As the science and technology of biology applied to NFCs develops, different forms of industrial organisation will emerge, which can be characterised with reference to the S&T tree presented earlier. Furthermore, a key question will be where the UK fits into these distributed production, cultivation and innovation arrangements. In this regard, and compared to the USA in particular, it appears that the UK has been considerably slower in generating new start-up companies and has a significant and widening gap in the agro-industry.

**2.2.9.** One area that the UK has been slow to develop, is the interface between plant science and medicine. "Molecular pharming" is identified as one of the key potential areas where plant biotechnology would make a positive and significant impact, by allowing the production of recombinant pharmaceuticals. Yet there are no institutes in the UK which promote this area, nor are there any public funding bodies that target this important area for cross-disciplinary research.

## *2.3 Market formation and demand*

**2.3.1.** In considering the potential for market formation and demand for bioscience applications to non-food crops, there is very little statistical or empirical research currently available on which to base assessments:

- In the first place, it is important to distinguish between market demand and public acceptability (dealt with in 2.5 below).
- Second, where there have been studies, they have largely focused on GM food (Food Standards Agency, 2003; Cabinet Office, 2002; Consumer Association, 2002). It is difficult to estimate the extent of the interaction between demand for food and non-food GM products, and it is certainly unwise to infer lack of demand from the former to lack of demand in the latter. The Cabinet Office market assessment of limited consumer demand for GM food crops, and hence limited economic benefits for this line of development, is not transferable to the NFC situation.
- Third, where there are already-existing well-established end-markets for GM products (from cotton clothing to human growth hormone or insulin), absence of labelling or segregation, and possibly widespread unawareness, mean that it is impossible to infer positive demand *for* GM products. There is no differentiation, in this case, between GM and non-GM markets.
- Fourth, where there are GM processes or products for intermediary markets, there has been little attempt to differentiate between demand (and its potential growth) in general for NFC products, and demand specifically for bioscience-enhanced (let alone GM) non-food crop products. Thus the ACTIN Scoping Report (2001) presents a number of prospective areas of substantial intermediate market growth for non-food crop products (oils, fibres, starches, specialty products), but gives no indication of any additional difference the application of bioscience might make to the growth of these markets. Likewise, Table 1 below projecting substantial growth in market and market share for bio-lubricants in Europe, only deals with non-GM products. There is no evidence concerning the application of either GM or non-GM bioscience to products in these intermediary markets. The Table is presented to illustrate existing market potential, without the possibilities for additional growth deliverable by bioscience applications.

**2.3.2.** The discussion in section 2.2 makes it clear that, depending on the product area, primary, intermediary, and end markets are highly interdependent. The development of new non-food crops in agricultural production often involves new organisation of intermediary processors, and a development of new end markets for novel products, making investment a big risk. As a counterpart to the industrial restructuring seen with ICI, Dow-Cargill, the development of Croda, or the emergence of companies like Cognis, the new value chains imply market re-alignments at each stage. The role of trade associations like ERRMA, or the DG Enterprise initiative on Renewable Raw Materials is significant in market formation, by facilitating new value chain collaborations. Likewise, the governmental support given to Novamont in Italy developing starch-based plastic materials, assisted the transitional phase in value chain re-alignment. In the UK, supported by the DTI and DEFRA, the recent launch of the National Non-Food Crop Centre in York can be anticipated to provide a significant contribution to bioscience applications, in addition to its general stimulation to the development of non-food uses of crops, including the introduction of novel NFC crops into UK agriculture.

**Table 1. EU NFC Market figures for 2000**

| Lubricants Market Sector | Total EU Market (‘000 tonnes) | Current EU Bio-Market (‘000 tonnes) | Current EU Bio-Market without further regulations (‘000 tonnes) | Bio-Market by 2010 with ongoing legislation (‘000 tonnes) | Bio-Market share by 2010 with ongoing legislation (%) |
|---|---|---|---|---|---|
| Hydraulic Fluids | 750 | 51 | 100 | 250 | 33 |
| Greases | 138 | 1 | 2 | 69 | 50 |
| Chainsaw Lubricants | 40 | 29 | 30 | 38 | 96 |
| Mould Release Agents | 82 | 10.5 | 20 | 41 | 50 |
| Motor & Gear Oils | 2408 | 4.5 | 20 | 482 | 20 |
| Metal Working Fluids | 338 | 4.5 | 20 | 170 | 50 |
| Other Applications | 486 | 0.5 | 10 | 240 | 50 |
| TOTAL | 4242 | 101 | 202 | 1290 | 30 |

Source: DG Enterprise, 2000

**2.3.3.** Given the risks involved in developing new products for new markets, it is unsurprising that much of the investment is towards substitution products for existing markets. While the use of non-food crops to produce materials to substitute for petroleum-derived substances may present less uncertainty than seeking to introduce new products in new markets, there are still big obstacles to developing the market. Primary amongst these is cost. Without either government intervention or price increases due to shortages of oil, the crop routes will struggle to compete on cost alone. This is problematic because, while ‘green’ issues may be important to customers, they do not in general override cost concerns (of course performance must be comparable with the plant-based products). Regarding the introduction of GM products, this cost issue is exacerbated, as companies will only push through a product where they expect very high returns. This creates problems in certain markets where the products are not high value, raising the question of whether the large bioscience investments can be justified.

**2.3.4.** There is also a critical geo-political dimension to the interdependency between primary, intermediary and end markets. For some high-value, low-volume, products it is possible to construct a value chain spanning UK bioscience, UK agriculture, UK intermediary production, and global end-markets (therapeutic proteins or pheromones would be possible candidates). For high-volume crops, or for crops whose agronomic characteristics are sub-optimal for UK cultivation, it is likely that primary, intermediary, and end markets will be globalised. Croda, for example, has developed global sourcing and production facilities in creating markets for specialty oils from non-food crops. But, as a company, it specifically restricts itself to supplying multiple intermediary markets: pharmaceutical companies, plastics and packaging, dietary, and food applications.

## *2.4 Regulatory and policy environments*[4]

**2.4.1.** We can usefully disaggregate the regulatory and policy environment into that which bears on bioscience and agricultural broadly and the more specific instances which are relevant for particular application areas. Regulations for $CO_2$ emissions and carbon taxes; effluent control regulations; pharmaceutical regulations; recyclability guidelines etc., all these amount to measures that might influence the potential take-up of bioscience NFCs products and processes. Another example of this is the European Union End of Life Vehicle Directive and the impacts this has on the automotive industry. This will require that 95% of vehicles by weight can be reused, and has the effect of pushing the industry towards recyclable plastics rather than renewable (crop) sources. We will examine some of these application specific regulations and policies in more detail later in this report, where they impact on likely developments in particular worked examples. This section will briefly review the main issues that apply to biotechnology and agriculture generally, by reviewing developments in the regulation of GMO releases and labelling, and the Common Agriculture Policy.

**2.4.2.** The key regulatory issue for biotechnology, in the broad sense, concerns the control of GMO releases into the environment. In February 2001, the European Parliament adopted Directive 2001/18/EC (repealing Directive 90/220/EEC) which presents a revised version of the previous directives. This directive entered into force on 17 October 2002 and aims to strengthen the safety assessment of GMOs, and to improve transparency and public consultation. As with the previous directive, decisions to approve GM crops are taken on a case-by-case basis, following a scientific assessment of any risks to human health and the environment. The directive distinguishes between releases related to R&D (i.e. field trials) and those associated with full commercialisation. While field trials have taken place, a *de facto* moratorium on commercial licensing of new GM products has been in place in the EU, since June 1999. (Nap et al, 2003)

**2.4.3.** The current Directive includes provisions for the labelling and traceability (possibility to prove the origin of GM organisms or their products and any stage and

[4] We would like to express our thanks to Sally Gee for providing background material for this section

at any time) of GM food, seed, feed and pharmaceuticals. New Traceability and Labelling proposals aim to build on the traceability requirements in Directive 2001/18/EC. They set out specific requirements for a harmonised EU system for tracing and identifying, through the production and distribution chains, GMOs as well as products derived from them, at all stages of their placing on the market. The significant issue for this current study is that the labelling and traceability Directives do not as yet cover the majority of other products based on GM technology and non-food crops. What are the expected future developments concerning these regulations in cases where GM technology has been used in industrial processes or at any point in the supply chain for non-food consumer markets (cotton and dyes for clothing, for example)?

**2.4.4.** The Common Agriculture Policy (CAP) has traditionally created an environment where non-food crops must compete for land with food crops. Food and feed production in the EU is aided through a range of support mechanisms and a wide variety of programmes. The market support mechanisms raise output prices above world market levels making production of food crops more attractive to farmers than the growing of other crops. These incentives for food farming have most probably meant, in effect, negative incentives for non-food crops. If there is a choice farmers will only grow non-food crops if the returns are at least comparable with those for supported food crops.

**2.4.5.** In 1992, in an attempt to alleviate this problem, and as part of the push towards creating greater diversification in agriculture, CAP reforms were introduced with the aim of reducing food production across the EU by taking a percentage of agricultural land out of food farming. This ‘set aside’ land attracted subsidies for the growing of non-food crops. The combination of different initiatives has led to piecemeal and complicated support for non-food crops, with suggested reductions in subsidy for “set aside” land (Royal Society, 1999; Select Committee on Science and Technology, 2000).

**2.4.6.** The uncertainty regarding how CAP incentivises NFC agriculture remains, particularly with EU expansion a close reality. There will be further changes through the steps to further disassociate subsidy from production that are currently under discussion. It is hard to predict the impact that these measures will have on incentives for the substitution of various non-food for food crops.

**2.4.7.** The existence of alternative regulatory and policy environments in different regions will have an impact on the level of financial support for different aspects of plant biology, on the decisions of large companies concerning where to locate R&D and production facilities, and the prospects for developing markets in different application areas. With issues such as labelling, the potential for trade barriers is high if different regions adopt markedly different policies. Furthermore, it is true in this field as in other fields of biotechnology, that developments in the science and technology will necessitate continuous evolution of regulatory frameworks (Konig, 2003)

**2.4.8.** Varying regulation regimes (particularly within the European Union) have been identified as having a major negative impact on innovation by small and medium size enterprises (Nap, 2003). The costs of meeting regulatory tests and registering GMOs, and the timescales of regulatory as opposed to innovation pipelines, provide a disincentive for investment in R&D that only large corporations may be able to overcome. While in principle there could be a large number of DBFs, they may be unable to bring products to market themselves, and would become more dependent on large corporations for commercialisation. Further, there is a considerable risk that even discovery or early phase innovation is undertaken by large corporations to a greater extent than would otherwise be the case. Thus, the effect of current regulation in this area provides a stimulus for greater concentration both in R&D and in commercialisation.

## *2.5 Public acceptability*

**2.5.1.** Shifts in the dynamics of public acceptability for different biotechnologies will impact the relative importance of different branches in the S&T tree, and perhaps most significantly, the balance between GM and non-GM applications of bioscience to NFCs. The fifth Eurobarometer survey (Gaskell, Allum and Stares, 2003) on biotechnology reports that optimism about the benefits of biotechnology in general is lower than for other technologies, including telecommunications, computers and IT. However, in general there has been a marked increase in optimism across the EU since the previous survey in 1999.

**2.5.2.** At the level of the individual countries (see Table 2 below) there is more (modest) support for GM crops than there is opposition. Focusing on the UK, while there is weak opposition to GM food there is weak support for GM crops. This suggests that opposition to GM in agriculture could be more to do with perceived health risks from food and the perceived usefulness of the applications rather than environmental concerns about the use of GMOs.

**2.5.3.** It is also very clear from these results that health-related applications are reported to have wide support. The notion that health applications could be produced from crops does not appear to have been explored. Indeed the definitions of categories used to survey public opinion reveal that only part of the variety of potential applications of bioscience to NFCs has been considered:

> 'GM crops: taking genes from plant species and transferring them into crop plants to increase resistance to insect pests;
> GM enzymes: using genetically modified organisms to produce enzymes as additives to soaps and detergents that are less damaging to the environment…' (Gaskell et al, 2003)

**2.5.4.** This restrictive definition concerns just input traits for crops and "eco-bonus" applications in industrial processing. This demonstrates that the potential range of applications is not yet on the public radar, nor on that of the Eurobarometer surveys. With the further development, and therefore increased visibility, of different biotechnology processes, the significance of the distinction between GM and non-GM might change. One example is the difference between closed GM-microbial processes versus open field GMOs. A recent study conducted by the US Biotechnology Industry Association, which used focus groups and involved dialogue with NGOs, found that the microbial route met with considerably less controversy because it is a closed-loop process.

**Table 2. National comparisons of support for biotechnology applications**

| | Genetic tests | Clone human cells | Enzymes | Xeno | Crops | Food |
|---|---|---|---|---|---|---|
| Spain | ++ | ++ | ++ | + | ++ | + |
| Portugal | ++ | ++ | + | + | + | + |
| Ireland | ++ | + | + | + | + | + |
| Belgium | ++ | + | + | + | + | - |
| Sweden | ++ | ++ | + | + | - | - |
| Denmark | ++ | + | + | + | - | - |
| UK | ++ | + | + | + | + | - |
| Finland | ++ | + | + | - | + | + |
| Luxembourg | ++ | ++ | + | + | - | -- |
| Germany | + | + | + | + | + | - |
| Italy | ++ | ++ | + | + | - | - |
| Netherlands | + | + | + | + | + | - |
| France | ++ | + | - | + | - | -- |
| Greece | ++ | + | + | - | - | -- |
| Austria | + | + | + | - | - | - |

++ Strong support
+ Weak support
- Weak opposition
-- Strong opposition

source: Gaskell et al, 2003, p.14

**2.5.5.** Another important dimension of public acceptability concerns variability in different countries. This Europe based survey already demonstrates different levels of support between countries, and these differences are replicated and perhaps magnified when the global context is considered. In each country, different actors and organisations (including the media) have different influences shaping the development of public acceptability. Therefore, the dynamics of public acceptability will have a marked impact on geopolitics, if differences in this regard between the UK and China, as one significant example, influence what is grown and what is sold in different places.

**2.5.6.** Research into the reason for public opposition to GM crops has identified a number of influences. Whether there are benefits, who will benefit, whether the public are given an effective choice and whether regulatory authorities can adequately control the operation of large corporations, emerged as primary reasons behind public opposition. The work also argues that there is, in general, ambivalence to GM food; people are not simply for or against but can recognise positives and negatives. On a more fundamental level, people were found to be ambivalent about notions of progress in agriculture and food, having doubts about further industrialisation of food production, with GMOs “possibly representing “a step too far” in an ongoing trajectory” (Marris et al, 2002, p.5). Hence, overcoming public opposition will require a broader approach than simply education. Positive images are sometimes less easy to muster and make stick than are negative ones, as research on trust has demonstrated (e.g. Solic, 1993). However, rebuilding the necessary trust in regulatory institutions, a crucial part of addressing public concerns, may prove to be a more complicated and drawn out process than some would hope.

## *2.6 Summary*

**2.6.1.** This chapter has reviewed a wide range of issues and factors that may shape the development of bioscience and its application to non-food crops.  These are a diverse set of potential influences, and a good deal of uncertainty surrounds most of them. There is both uncertainty as to how the factors may evolve, and uncertainty as to the precise influence that they would exert if they did evolve in one or other way. Reviewing these issues makes it clear that the approach of developing alternative scenarios is appropriate.  Decision-makers need to be aware of the very different paths of evolution that are possible. In the next chapter we introduce the tools developed to consider these alternative futures and for thinking about the role that UK bioscience and agriculture might play, in the global context.

# 3. Tools for considering the potential contribution of bioscience to the Non-food crops area

**3.0.1.** This study addresses two main questions:

- **How can bioscience help develop a sustainable use of non-food crops?**
- **In order to enhance this development, what are the optimal relationships between UK bioscience and UK agriculture in a global context?**

**3.0.2.** In order to consider these questions, this chapter presents a number of interrelated conceptual tools for thinking about the issues around the use of bioscience in the non-food crop area. The first of these is the tree of nested science and technology alternatives presented in section 2.1. Second, is a framework for consideration of the global context of UK developments. The third tool is a set of four scenarios are outlined, structured around different prospects for the cultivation of GM crops in the UK

**3.0.3.** These tools were developed during the course of the study, and used to inform the desk work, interviews, and – especially – the workshop held in London on November 17th 2003[5].

## *3.1 Moving towards non-food crops – a tree of alternatives*

**3.1.1.** The application of bioscience to non-food crops potentially involves major changes in the science base and in the industrial division of labour, and it implies the emergence of new markets and new regulatory challenges. The route to bioscience applications, whether for substitution (e.g. renewable materials substituting for petrochemicals) or for novel products (e.g. new therapeutic proteins), involves not only a multiple shift in product development, but also the construction of new supply chains, involving new industrial and retail partnerships.

**3.1.2.** The first tool is the nested tree introduced in Figure 1 earlier. It summarises a series of "science and technology choices" that are required if there is to be a move towards greater use of non-food crops. As we shall see, these are not simple options which we can pick and choose from at will. Choices are influenced by resources and capabilities, by perceived opportunities and risks, by the costs of decision making, as opposed to following routines.

**3.1.3.** This tool enables us to focus down on the particular objective of this study – namely, evaluation of the alternatives at the leading edge, in terms of bioscience, of the 'tree' of nested alternatives. As mentioned, this spans GM and non-GM applications of bioscience. Moreover, the tool highlights a particularly important element in this evaluation of alternatives. At each point in the diagram, the

[5] We would like to express our thanks to Helena Poldevaart and Lindsay Colbourne for their help in designing and implementing the workshop.

alternatives are potential competitors in current or future markets. They do represent "choices" in that, over time, specific routes are adopted to deliver particular products. At any one moment, there may be limited choice available to any one party – it is not simple for a chemical company to decide to begin producing a major product line by biological means, or source a new feedstock of NFC origin.

**3.1.4.** At each branch in this tree, many factors shape the decisions that are taken, and that generate the options available for economic agents. These factors include the scientific knowledge and technology itself; institutional arrangements; market demand; and regulatory issues. To pursue one branch of this tree will mean pursuing opportunities and overcoming barriers associated with a combination of these issues.

**3.1.5.** The tree has been used to differentiate between different future scenarios, but before we turn to that analysis, it might be helpful to provide an example to illustrate how the tool can be used. Consider the outcome that results from taking the right hand fork at each level: *biological- plant-GM-open field*. An example of this could be ethanol produced from genetically modified sugar-cane. The alternatives to this product at the first level of Figure 1 could be any of a range of possible non-biological alternatives: fossil fuels, solar and nuclear generation of energy, fuel cell and battery technology for mobile power supplies, and so on.

**3.1.6.** At the second level of Figure 1, it is more difficult to envisage any non-plant biological alternatives for substitute energy. Difficult, but not impossible: methane production at landfill sites is one possibility, and there are efforts underway in the USA to create bacteria that will be able to release hydrogen to power fuel cells. For other products, such as pharmaceuticals, significant alternatives might be envisaged at this level – indeed various health products are already manufactured in this was.

**3.1.7.** We can envisage competition for many products at all levels, up to and including closed cultivation or open field alternatives, and in either non-GM or GM. Several US companies, e.g. Epicyte and Prodigene, are pursuing the production of therapeutics through GM plants in open field cultivation. But there are possibilities for alternative non-GM routes, such as plant-derived substances discovered by explorations of biodiversity using comparative genomic analysis.

**3.1.8.** A tool of this kind involves necessary simplification, which we should not allow to constrain our imagination too much. The example of renewable energy illustrates this well. As will be discussed later, one important route for bio-fuels could be the production of fuel from biomass, through the use of enzymes produced from microbes. Such a combination of the plant and microbial routes is not readily represented on the diagram. This is because, in essence, the diagram emphasises the primary route for approaching production and not processing technology.

**3.1.9.** But this analytical tool does effectively demonstrate the extent to which bioscience applications to non-food products involve major or minor shifts from existing technologies, markets, or institutions. This depends on the depth and breadth of shift in technology required. It is highly relevant to the scope for change that an organisation can confront. For a major pharmaceutical company whose primary supply chains have been built around a portfolio of proprietary synthetic chemicals, the shift to biologically based pharmaceuticals would be a first radical step. The choice of crops rather than microbes would be another such step, and that of GM rather than non-GM yet another. It can be challenging to take such steps, since they require the acquisition of new competences. A high level of scientific/technological, institutional, and market "path dependency" may, in such cases, act as a significant constraint to a switch to a crop-based alternative. The analytical tool should be useful for thinking through the implications of the route to bioscience applications to non-food applications. Conversely, where non-food crops are already established technologies prior to the application of bioscience, bioscience applications can build on existing supply chains, markets, and technologies. The current production of renewable energy in the form of ethanol from conventional crops, or biomass for combustion, would be a case in point.

## *3.2 Placing UK bioscience and agriculture capabilities in global context*

**3.2.1.** Developments in bioscience applications to non-food crops are well advanced in the US (as confirmed in the interviews we conducted in that country in connection with this project, and as documented in such reports as Renewables Vision 2020, 1999). NFCs based on new bioscience, notably Bt cotton, are expanding on a global basis. The continuation of such a trend is implicit in our scenarios. UK capabilities and capacity in bioscience, and in agriculture related to non-food crops, need to be considered within the global context. The current capabilities of UK bioscience in this area are high: CNAP, SCRI, IGER, Rothamsted Research and the John Innes Centre are widely regarded as world-leading centres. Indeed, some see the strong research base in the UK as second only to the US. Equally, there are strengths in UK agriculture, in particular crops for example (e.g. wheat) – though in terms of providing host environments for NFC, the UK presents limitations to so with space, climate range, the local politics of land use, etc.

**3.2.2.** Earlier sections of this chapter have elaborated on the tree framework of Figure 1, and we now introduce a second conceptual tool to aid examination of these questions. This is another simple framework, this time taking the form of a matrix that illustrates how UK bioscience and agricultural capabilities may be aligned in a number of *different* ways, in terms of the global context within which they operate. Table 3 demonstrates the possibilities for invention, cultivation and sales of non-food crops, in terms of this matrix. Developments in UK bioscience applications to NFCs may overlap, but do no coincide, with developments of UK NFC agriculture. The extent to which they coincide or not is a key scenario question. At one extreme, UK NFCs are developed in agriculture through the introduction of novel crops, for example, without developing many bioscience technologies, whilst UK bioscience protected by IPR leads to technological innovation elsewhere. At the other extreme UK bioscience and new high-tech NFCs and bio-refining processes benefit strongly from mutual synergies.

**3.2.3.** Certain of the combinations implied in Table 3 are more likely than others. Different areas of bioscience, and different NFC products and application areas, may well display different patterns of relationship across this matrix. But how these relationships evolve into the long-term future is quite uncertain, depending upon strategic choices and contingencies that are hard to second-guess. Thus we need to introduce a third tool, a set of alternative scenarios for NFC development, that will help us think through these issues.

**Table 3 The geopolitics of bioscience applied to non-food crops**

| | Bioscience innovation | Agriculture | Product Market |
|---|---|---|---|
| UK | 1 | 2 | 3 |
| Continental Europe | 4 | 5 | 6 |
| Rest of World | 7 | 8 | 9 |

## *3.2 Possible scenarios for the development of non-food crops*

**3.2.1.** The aim of introducing scenario analysis is to provide a framework for considering the potential role that the biosciences can play with respect to non-food crops.

**3.2.2.** There are many ways of preparing scenarios. Many scenarios have been developed to tackle specific issues, and in principle it would be possible to make use of an "off the shelf" set. There have been several attempts to develop sets of scenarios explicitly bearing on the future of bioscience and technology, and the prospects for GMOs in UK agriculture, and also scenarios bearing on the potential for non-food crops (e.g. respectively, Justman et al., 2002; Cabinet Office, 2003; BCPC, 2002). But though these studies provide helpful insights, none of them provide sufficient focus on bioscience **and** NFCs, for our purposes. Scenarios specific to the focus of this study were necessary, and were generated in the first instance using the conceptual frameworks outlined in the previous sections. The scenarios represent different pathways for the application of biosciences in NFCs in UK agriculture.

**3.2.3.** Two underlying assumptions apply to all of the scenarios elaborated below. A **very** different world would be implied by a future in which these assumptions did not apply. The first is that, globally, bioscience will continue to develop rapidly. Understanding of the operation of biological processes will continue to expand, as will the scope for intervention into these processes, and, most dramatically, the range of applications of the knowledge developed in the biosciences. This seems to be a fairly safe assumption: both the challenges to scientific endeavour, and the potential social and economic benefits of understanding and controlling biological processes, will continue to drive efforts in these directions.

**3.2.4.** The second underlying assumption is that some of these applications of bioscience will be in place across all scenarios. In particular, we anticipate (a) more or less extensive use of non-GM agricultural biotechnology (e.g. enhanced crop breeding techniques using gene markers), and (b) more or less extensive use of microbial and other "industrial" NFC applications of bioscience, whether GM or otherwise. This assumption is based on the lack of spill-over of concerns about GM to other areas of biotechnology, and of concerns about food hazards to other types of agricultural and industrial activity.

**3.2.5.** What differentiates the scenarios, then, is not the pace of development of bioscience – though they may vary in terms of the orientation of UK bioscience. Nor is it the development of industrial and non-GM. Rather, they vary in terms of the extent and style of development, in the UK, of agricultural NFC applications of bioscience. Table 4 sets out major features of the four scenarios.

**Table 4. Four Scenarios for NFC Development**

| | **Agricultural NFC** | | | **"Industrial" NFC** | |
|---|---|---|---|---|---|
| | **GM-based** | | **Non-GM** | **GM-based** | **Non-GM** |
| | **"Open"** | **"Contained"** | | | |
| **Scenario A** | ++ | 0/+ | + | ++ | + |
| **Scenario B** | + | + | + | + | + |
| **Scenario C** | 0 | ++ | + | + | + |
| **Scenario D** | 0 | 0 | ++ | 0/+ | + |

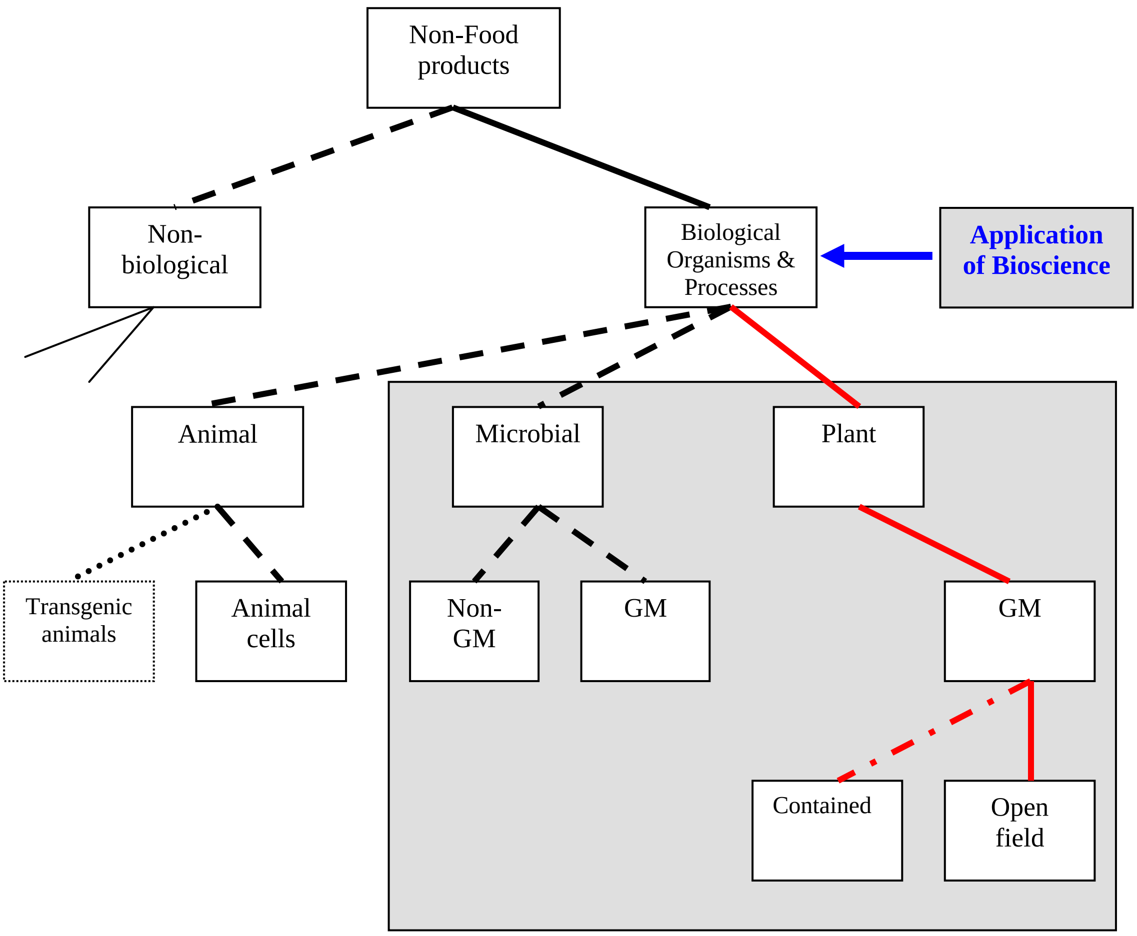
**3.2.6.** In **Scenario A**, NFCs are widely used in agriculture, with regulatory and other developments making it possible to exploit the new technologies on a wide scale in open fields and the like. In **Scenario C**, this route is ruled out, but various ways of practicing agriculture in contained environments are employed to enable NFC use. **Scenario B** lies between these: it sees limited development of "open" GM-based agriculture, with some development of these contained methods too. **Scenario D** sees practically no commercial use of GM in agriculture, though bioscience still generates novel applications in non-GM uses and industrial settings.

**3.2.7.** These scenarios are tools for thinking about issues that might arise in alternative futures. They are not predictions. The future that eventually arises is likely to be some combination of the scenarios. It is, of course, quite possible that we might move from a situation of, say, scenario D to scenario C to scenario A over time. This raises the question of what time horizon is being considered for this scenario analysis? For the workshop, we proposed a 15-20 years horizon: *looking back from 2023*, we could say that *one particular scenario has been firmly entrenched for most of the preceding decade* (even if it might now be being replaced).

**3.2.8.** In the workshop in November 2003, participants were divided into four groups that were each allocated one of these very elementary scenarios. The groups were asked to elaborate on the scenarios – to consider what a plausible and coherent picture of the future corresponding to the scenario might be, what factors would have "influenced" – i.e. led to – the development of the scenario, to outline what the situation of UK bioscience and NFC agriculture would look like within it. The further discussion of the four scenarios that now follows draws on the very rich discussions that emerged from the four groups. Inevitably, we have had to summarise the material that the groups produced, but hopefully enough flavour of the deliberations remains to show the usefulness of these tools in promoting stimulating dialogue. The names given to the scenarios below are those that the groups themselves determined. Each account is preceded by an attempt to visualise the scenario in terms of the tree framework introduced in the preceding section.

**Scenario A: "Go for it!"**

**Figure 2. Scenario A**



*Description of scenario A:*

***3.2.9.*** NFC use of GMOs in UK open-field agriculture in 2023 is fairly widespread, and no longer considered at all remarkable. Strong government leadership, along with the recognition of the many opportunities arising from the use of this technology, has led to regulatory arrangements that allow for more rapid and less costly approval. Political opposition to GMOs is low, as concern over environmental and health impacts of GMOs are diminished. This has probably been brought about by a combination of two factors. First is convincing evidence that the severe problems that had been the focus of earlier debate were strongly overstated. Many of the problems (e.g. effects on biodiversity) are seen as a product of conventional agriculture, and GM technology is seen as helping to offset some of the more damaging practices (such as excessive use of fertilisers and pesticides). Diminution of concern over food safety would also help allay worries about GMOs, and experience overseas could play a role here – if there are no evident health problems emerging in those countries which have gone down the GM route, then this would have an impact on public opinion. Second is wide recognition of significant benefits from using the new technology. This could involve several factors. One might be the successful introduction of attractive and healthy new foods using GM. Another might be more squarely to do with NFCs - environmental benefits through use of crops for remediation, or perhaps the use of genomics technologies to protect important features of the landscape from the effects of climate change or destructive insects.

**3.2.10.** As the use of GMOs has become more acceptable, there has been increasing recognition of the potential for the markets in these areas. This has lead to a big increase in private sector investment. Accompanying this, public funding of research has continued to increase. Bioscience has become an attractive career option, offering relatively secure funding and a chance to affect the world in positive ways.

**3.2.11.** “Contained” applications using GMOs do exist, but these are limited to niches where plants cannot be grown in open fields due to regulations and agronomic circumstances. These are likely to be high-value, if low-volume, crops. In general, GM technology is seen as yielding more effective solutions than non-GM routes, so these would rarely be competitive alternatives to GM crops. This is not to say that bioscience would only play a role through effecting genetic modification: better understanding of nitrogen fixation, of insect pests and their predators, of the operation of ecosystems and the effects of human action upon them, and so on, will continue to inform agricultural strategy.

*Influences on scenario A:*

**3.2.12.** Some of the factors affecting public attitudes to GM crops are hard to influence, but political action is crucial to this scenario. If the UK is to follow this route then this means that decisions will need to be taken in the near future – quite possibly in the face of large swathes of public opposition. It will be necessary to better understand public concerns and the dynamics of risk assessments concerning health, environmental, and other issues (which may be often conflated in practice at present, but which need to be distinguished for effective action). It will be necessary to address these concerns, for example by demonstrating tangible benefits and securing trust in the means that are put in place to avert hazards.

**3.2.13.** Coupled with this, there will then need to be increased investment in the UK, to initiate the process of catching up with the US in particular. Broad investment will be required, especially in underpinning areas of bioscience (not just in research itself, but also in building better links between research and its applications). But it will be important for the UK to identify priorities for strategic investment. These will be potential areas of competitive advantage, which may be based upon agronomic conditions, industrial strengths, or scientific knowledge.

*UK plant bioscience in scenario A:*

**3.2.14.** The more immediate implications of this scenario are the arrest of any decline in UK plant bioscience with respect to the US, and gains will be made compared with other European countries. The UK would become the Member State of choice for researchers in this area. In the longer-term, there will be sustained growth in a whole range of disciplines, professions, and organisations contributing to the underlying science and technology; the ability to transfer this knowledge into downstream applications will also improve continuously. The UK will be an active partner in the global research agenda.

**3.2.15.** In terms of the matrix of Table 3, the options presented in scenario A are potentially unlimited. Plant bioscience would benefit from increased investment, and linked to this, increased potential for taking products to market. In this situation, an *"invented here"* attitude could accompany the scientific-commercial links that constitute the *"invented here"* practice. This might lead to a virtuous circle of development - although of course the UK would still need to make efforts to catch up in many areas with the US. As discussed earlier, strategies intended to ensure the success of UK bioscience and agriculture should consider the areas where the UK may have an advantage over other countries, on account of particular scientific strengths or agronomic circumstances, or possibly on account of both and of such factors as social needs and market demands.

**3.2.16.** Indeed one could see a real success for the UK being represented by:

- *Invented here(1)– cultivated here(2) – sold everywhere( 3*/6/9)

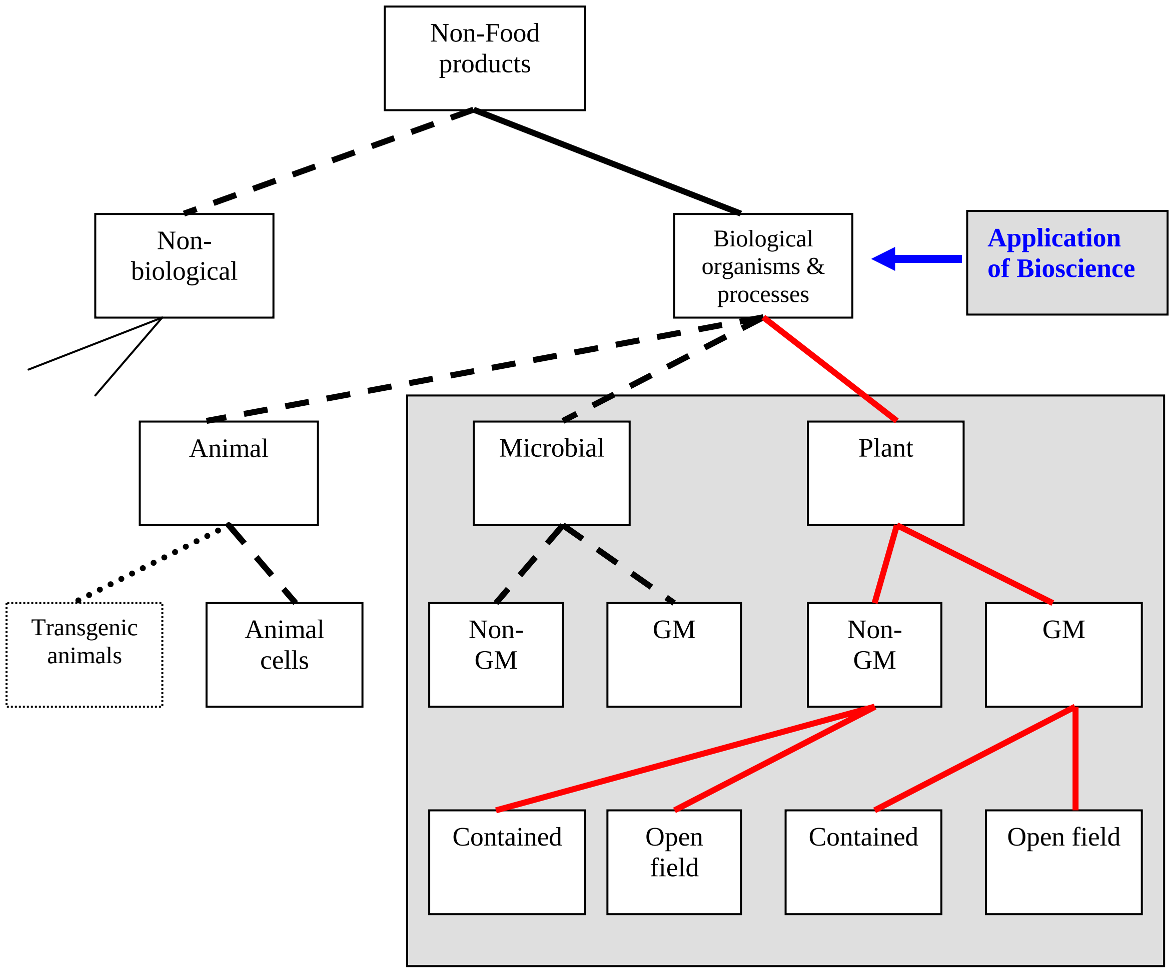
**3.2.17.** Equally in scenario A it is possible to imagine that UK bioscience would be utilised in other countries, even in areas where the UK may not have an agricultural strength, leading to a situation of:

- *Invented here(1) – cultivated elsewhere(8) – sold everywhere(3/6/9)*

**3.2.18.** In scenario A, GM crops can be cultivated in open fields in the UK. Thus it is likely that in many cases, crops developed elsewhere in the world would be cultivated here, too (*(6)-(2)-(9)* or *(7)-(2)-(9)*, for instance).

**Scenario B: "On the cusp"**

**Figure 3. Scenario B**




*Description of scenario B:*

**3.2.19.** In this scenario, NFC use of GMOs in UK open-field agriculture is emerging, but this is a slow process. This is being limited by several related factors - lengthy approval processes, slow development of markets, political opposition, uneven development of markets, the large costs involved, and so on.

**3.2.20.** The crops that are being exploited in this scenario are most likely to be those with the best combination of (a) high value (e.g. pharmaceuticals); (b) large markets (e.g. treatments for common diseases); and (c) least likely to give rise to environmental concerns (e.g. use of non-indigenous species to reduce risks of contaminating the native gene pool). The particular example of using crops for pharmaceuticals may not be such a good one here, however. It may raise concerns over biosafety that could (at least initially) offset the high value of such crops.

**3.2.21.** Open-field agriculture will be accompanied by contained agriculture in this scenario. It could be that in some cases containment will be an interim strategy while full regulatory approval is secure. Non-GM routes will also be pursued while uncertainty persists. The rules and market demand for GM imports may have a role to play in the viability of non-GM production of NFCs. In many cases, if these circumstances permit, GM-derived imports are liable to be cheaper (or in some cases to have greater functionality) than their non-GM local equivalents.

*Influences on scenario B:*

**3.2.22.** The label, 'On The Cusp', was chosen for this scenario since the group debating it at the workshop considered this to be an unstable state of affairs, with strong forces pushing in either direction. It is likely to evolve - either towards scenario A or towards scenarios C or D. The course of development will be shaped by changes in public acceptability for GM technology, in particular. Opposition could be hardened by increasingly effective lobbying or possibly by a 'GM catastrophe', whether this is real or perceived, strictly relevant or irrelevant, or in the UK or overseas. Vivid images of devastated landscapes or distressed humans or animals can be very telling, especially when they can be latched into an existing sense of threat. Greater acceptance could be gained through increasing recognition of benefits derived from the technology. This could be facilitated, too, by vivid images perhaps of restored or conserved landscapes or species, perhaps of attractive new products. Affecting the perception of benefits will be developments in the science and associated products, along with changes in the political environment, for example whether there is recognition of a positive role for NFCs in achieving targets of sustainability.

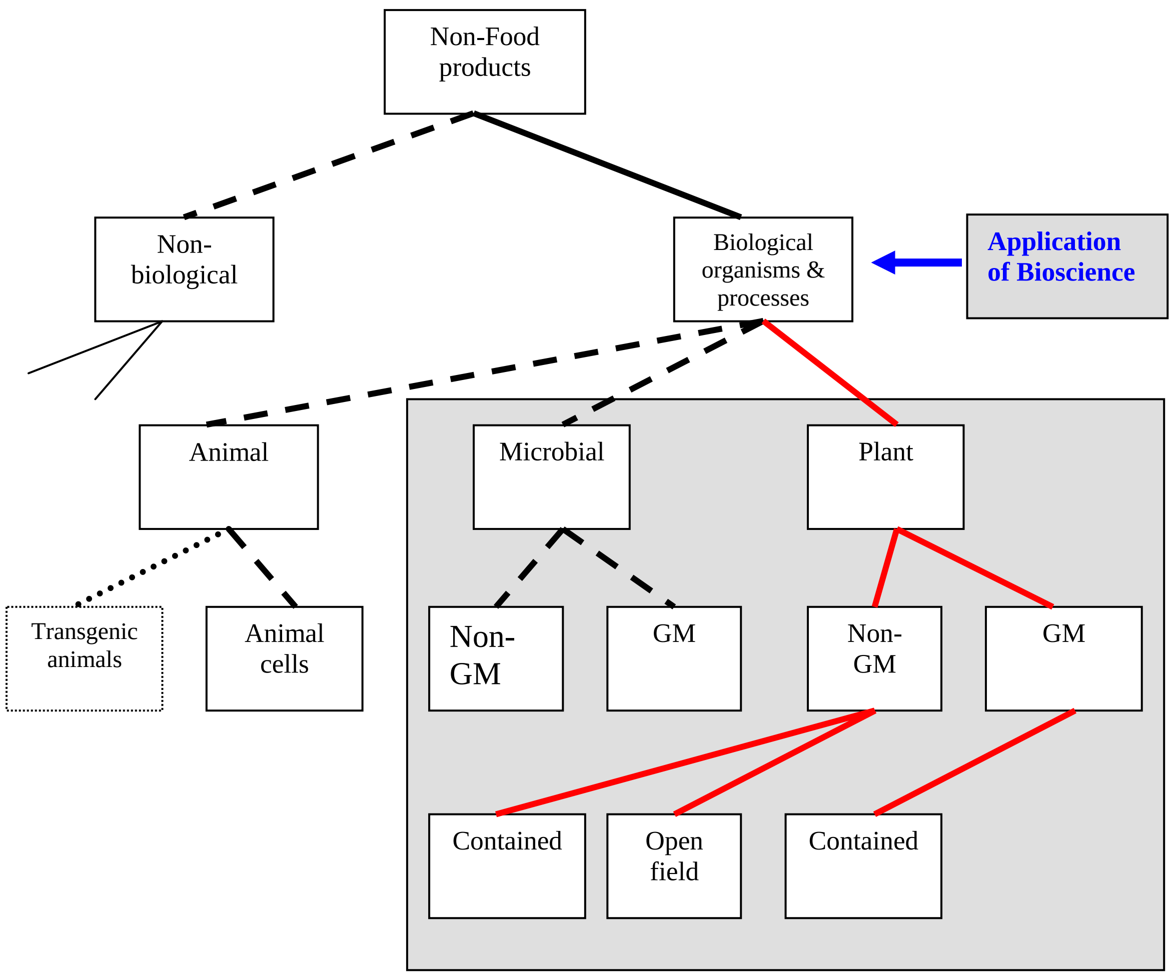
*UK plant bioscience in scenario B:*

**3.2.23.** While plant bioscience may remain relatively strong in the short-term, there might be a lesser degree of UK presence at the leading edge of strategic research on the world than in scenario A. How bioscience develops in the longer-term will be affected by the way the way that this scenario tips – towards scenario A or scenario D. It was anticipated that development would most probably be slower and less extensive than in scenario A, in either case.

**3.2.24.** Scenario B would see some open-field and contained cultivation of GM crops, and some parts of UK bioscience, in some parts of this area, would be expected to continue to achieve excellence. In terms of the framework presented in Table 3, for locating UK developments in their global context, how far does this leave open the *"invented here"* and *"cultivated here"* possibilities? In part this depends on how long this scenario persists (recall that it is considered to be unstable). Over longer periods, avenues may begin to be closed off – for instance, companies might choose not to go through difficult regulatory procedures if they could grow crops more easily elsewhere. This suggests that it may be that the *"invented here"* and *"cultivated here"* situation would be the most likely one, since operations would presumably be on a smaller scale, and usually require compelling reasons for growing the crop in the UK. These reasons could be as simple as a UK firm with strong links to local science and markets being behind the developments, or the UK presenting particularly favourable agricultural or social conditions for specific NFCs (possibly related to climate change or local environmental or even health concerns).

**Scenario C: “Contained but not constrained”**

**Figure 4. Scenario C**




*Description of scenario C:*

**3.2.25.** NFC use of GMOs in UK open-field agriculture is practically, if not entirely, non-existent in this scenario. But there has been extensive development of “contained” agriculture. Regulatory and technical developments allow for use of GM crops in greenhouses and similar built environments, and the opportunities are seized to a greater extent than many present-day commentators would have expected.

**3.2.26.** It is likely that building and other costs render “contained” agriculture considerably more expensive than open field cultivation of NFCs. However, some crops might be particularly suitable for contained cultivation. This could be for agronomic reasons - some products might best be grown in atmosphere and climate-controlled circumstances, of course. It could also be for bio-safety reasons, for example if pharmaceuticals (or more exotic new substances) are being produced, and possibly in some cases where toxic substances are being extracted from waste or contaminated land. In general, this would be expected to push the technology development in this scenario, further than was the case in scenarios A and even B, toward high value products. Whether these would always be large market crops is more of an open question. Market size would be restricted by the low yields that would be expected with contained cultivation – unless containment is on a huge scale such as is the case in the Spanish tomato and salads industry.

**3.2.27.** There may be some local political opposition in this scenario. This could well be aimed against the new buildings perhaps (as changing the rural landscape in unwanted ways), or against specific classes of "dangerous" crop (just as chemicals factories and waste incinerators are unpopular today). These issues might be as much as, if not more than, a source of concern as the GMOs themselves. On the other hand, there might be prospects for new job and rural economic development opportunities in this scenario that would offset political opposition to a greater or lesser extent, and again there are possibilities for very positive demonstrators of social and environmental benefits from such production.

**3.2.28.** The exploitation of non-GM routes for application of bioscience in agriculture would still be possible. It is plausible that technological and scientific developments associated with containment – better construction and clean-up methods, improved energy efficiency, new understanding of alternative cultivation systems and methods for intensive production of species that have so far proved difficult to commercialise - could benefit non-GM contained cultivation as well. But political objections to large-scale containment, on aesthetic or other grounds, might also spill over to non-GM agriculture.

*Influences on scenario C:*

**3.2.29.** The central question for this scenario is why the crop is being contained? Is it mainly being contained in the UK because of opposition to open field GM - or are there strong agronomic or economic reasons for containment?

**3.2.30.** Consider the first case. Would it be economically viable to produce NFCs in contained environments where they are grown in open fields elsewhere? This is unlikely unless there are regulatory or market forces that act against GM-based imports from overseas. Such a development might be conceivable, especially where a particular class of product was associated with unsustainable agricultural practices in the producing country. These unsustainable practices might be a result of the specific GM-using strategy being adopted (for example, increasing use of herbicides or pesticides by creating more tolerant crops). Or they might be a result of the more general agricultural practices in the producing country, for example if these are resulting in deforestation, damage to coastal ecologies, hardship for peasant farmers, and so on. While current directions in world trade agreements leave it a very open question as to how far social and environmental practices will be allowed to influence imports policy, there is certainly scope for user businesses to adopt strong stances here. This has already happened to some extent with NFCs, with the restrictions imposed by some big traders on the use of tropical hardwoods, for example. It would be interesting to explore how far such developments might take the form of general principles against specific agricultural practices and GMO use, or be themselves "contained" to individual products or classes of products.

**3.2.31.** The second case was felt to be a more likely pattern for the development of this scenario by workshop participants, though it was also the subject of some controversy. Two possibilities could coexist in this pattern, though quite possibly one or other might dominate. The first possibility is that the crops are grown in a contained environment because they perform better. This may be a feasible route for scenario C, and should be considered carefully in relation to possible trajectories of climate change. With considerable uncertainty about Europe's (and indeed the world's) future patterns of temperature, rainfall, and extreme weather, it is not at all unlikely that much received wisdom about what can be grown where will be overturned. Containment may be required to grow plants in a more hostile or more variable environment, and research into strategies and capabilities may prove to be an important insurance policy. The UK is seen as being rather well placed in these respects, with a history of innovative glass and plastic, and glasshouse, industries.

**3.2.32.** The other possibility, which the working group dealing with this scenario found to be particularly interesting, is that certain NFCs would be contained because they are too dangerous in one or other respects to be grown in open fields (at least, in a compact island like Britain). Whether this would be seen as acceptable, in a climate where opposition to GM was strong enough to prevent open field cultivation, is a moot point. A possible feature of this scenario could be one of "regulatory lag". Opposition to GMOs from environmental and other groups might actually fall away to a great extent, if these were seen as ways of protecting environments and rural economies from the effects of intensive agriculture or climate change, for example. However, regulations could have been put in place in an earlier period, and regulators could be "tuned in" to specific concerns dating from that period. Whether or not this element of the scenario does develop, regulatory change is essential for scenario C. Effective safety regulation governing standards for containment would need to be in place, and to be flexible enough to cope with rapid innovation in containment technology.

**3.2.33.** The controversy about this scenario was in part focused on the fear that GM would be seen as intrinsically associated with biohazards, making it more difficult to develop less problematic GM NFCs (and food crops). No standards are foolproof, furthermore, and accidents (and security breaches) are in effect inevitable, as the nuclear industry has demonstrated. Improved transparency may have to be balanced against security considerations, and even very low-probability risks with highly serious (or highly uncertain) consequences need to be confronted head on – even to the extent that a moratorium will need to be placed upon development of some beneficial applications. Unless these issues are confronted directly, with serious efforts to engage with (and not simply seek to minimise) public concerns from the outset, the management of biohazards will be tarred with the same brush as has been used on nuclear power.

*UK plant bioscience in scenario C:*

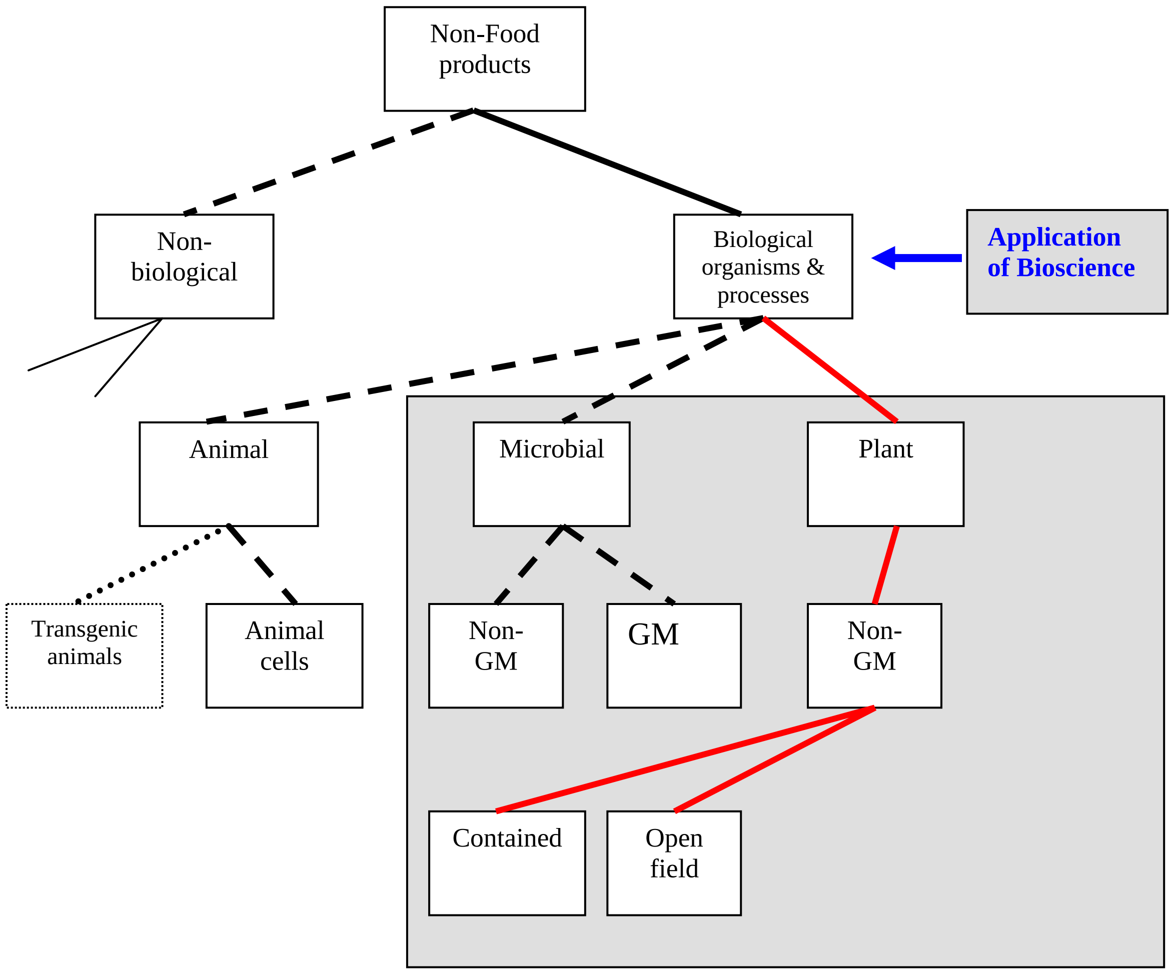
**3.2.34.** There could be possibilities for UK bioscience and UK industry to forge a specific niche in the production of contained crops. If these were high value crops that benefited from containment (and possibly where containment options need to be pursued in other countries), there could be chances for leadership in science and technology related to these NFC niches. (Note that this would extend beyond bioscience to include developments in such fields as glass and plastic technologies, sensor and climate management systems and industrial processing of crops). However, if containment was deployed in the UK, where similar NFC crops could be grown in open fields elsewhere, the situation is more complex. The question was raised as to whether contained growing would be competitive if the same crops could be cultivated in open fields elsewhere in the world.

**3.2.35.** Not all NFCs are likely to be grown in open fields (except perhaps in very remote areas of the USA and other large countries), however, and some other developmental possibilities were suggested in discussing this scenario earlier. It is not impossible that there would be possibilities for UK bioscience and industry to develop strengths in this niche of contained crops, though just how big the niche might be was the subject of some debate.

**3.2.36.** However, it is unlikely that plant bioscience in the UK would be limited to only these areas, hence, in terms of the matrix presented in Table 3, it would be important to pursue the "*invented here*", "*cultivated elsewhere*" situation. The international licensing of Intellectual Property would be an important factor in seeing returns from UK bioscience contributions that are not containment-specific. Such returns are dependent on improvements in the protection and exploitation of IP, which is a matter both of researcher and corporate strategies, and of the streamlining and implementation of effective IP systems. (Much of the IP generated in the UK in this area is already exported - with improved IP management this might be enhanced.) But this might be difficult to sustain. In these circumstances, however, the scholarly and commercial competitiveness of UK bioscience would be challenged. Researchers in other countries could in principle be linked more closely with those responsible for applying the new knowledge and techniques. Even with extensive collaboration and use of new Information Technologies to attain close contact over large distances, this lack of proximity and propinquity would constitute a disadvantage that would be hard to overcome consistently and repeatedly.

## Scenario D: "Not in"

**Figure 5. Scenario D**




*Description of scenario D:*

**3.2.37.** This is a scenario in which commercial NFC use of GMO crops in UK agriculture is practically, if not entirely, non-existent. In the workshop, it was thought unlikely that regulatory factors would completely exclude the possibility of GM approaches, but the costs of engaging in such applications outweigh the benefits by so much as to deter investors in even very high-value crops. These costs could include cumbersome regulations and long approval processes, but also the problems associated with political opposition (extending to various forms of disruptive protest), and associated market resistance (based on environmental or anti-corporate sentiment). Such market resistance would be expected to apply to imported products as well as UK-produced ones, which might cause problems for the sourcing – or final purchase – of some classes of product (e.g. cotton-based clothes). Safety, environmental and other ethical objections will have led companies to make decisions to avoid GM altogether, or to develop and commercialise their products elsewhere.

**3.2.38.** Some global markets may exist for non-GM crops, since anti-GM sentiment is unlikely to be contained solely in the UK. Whether these are major markets for NFC products is an open question – markets for food products might be more dynamic.

*Influences on scenario D:*

**3.2.39.** The strongest influence on this scenario is likely to be consumer demand and/or public opposition. Scenario D would seem quite a plausible outcome, should public attitudes remain frozen in their current forms. In the long term this is unlikely – attitudes change, often dramatically, over the course of decades, if not years.

**3.2.40.** But were events and political forces, aided by the mass media and public distrust of many authorities, to consolidate anti-GM attitudes, then the cultivation of GM non-food crops in the UK does not seem feasible. The import of products that are clearly beneficial to consumers may swing opinion somewhat, as would positive reaction to the use of GM in medical and other non-agricultural applications. But slight shifts in opinion need to be coupled with decisive political action to effect any movement away from scenario D.

**3.2.41.** This scenario does not necessarily require there to be specific political action to restrict the possibilities for GM cultivation. Inaction, or a fudging of decisions, would have the same effect. It was argued in the workshop that, such is the pace of change and the action being undertaken in other parts of the world, what happens in the next five years is crucially likely to affect any subsequent development. There may be opportunities to foster non-GM agriculture oriented to non-food crops, supported by the capabilities provided by the new bioscience. There may be opportunities to undertake important research relating to non-GM NFC agriculture. But such opportunities need to be carefully assessed, given doubts that NFC agriculture would continue to be competitive (especially where new products are concerned), and researchers' current perceptions of where the cutting edge of science lies. Assessment of future opportunities is difficult – for instance, it is hard to forecast whether there may be major opposition to the importation of some or all GM-based products, which would raise prospects for supplying a domestic market (and perhaps sympathetic markets or market segments overseas). What is clear is that in most instances these potential opportunities are more restricted than those made available by going down a more GM-oriented route. And in any case, these potential opportunities are not ruled out by taking a GM route, unless this was pursued to such an extent that there were no funds available for alternative lines of research, no land available for growing NFCs free of possible GM intrusion.

*UK plant bioscience in scenario D:*

**3.2.42.** In terms of the matrix of UK-global relationships featured in Table 3, Scenario D rules out "*cultivated here*" as an option for GM crops, even in contained environments. Given the likely public opposition to GM agriculture in this scenario, it may be that the possibilities for products to be *"sold here"* is also questionable. Incentives to engage in GM-oriented plant bioscience would thus be much diminished in this scenario. The option for cultivating non-GM NFCs is of course open. Plant bioscience could make important contributions here, in such applications as the use of genetic markers and screening methods, the use of information from genomics to inform classical plant breeding, and the like. This would probably limit applications to more low-tech ones, and provide a much less stimulating and rewarding bioscience research environment, with less incentive for industrial or government funding. For example, the introduction of NFC crops new to the UK, hybridised to maximise yield and utility in UK conditions, could become widespread.

**3.2.43.** In the near future there would still be a role for UK plant bioscience to contribute to GM-related developments that were being made elsewhere in the world. There could be significant contributions to make to agriculture and forestry in developing regions, for example, or to NFC production in Central Europe. However, workshop discussions suggested that it is unlikely that such a contribution could be sustained, on similar lines to the arguments noted for scenario C. UK plant bioscience would go into decline, with the most able people moving abroad to pursue better opportunities there, fewer people training in this area, and limited funds for research. Some niche interests might be productively pursued, but it is not easy to see how these could be sustained in the UK.

**3.2.44.** The likely competition from GM crops grown elsewhere might well mean that non-GM NFC markets would represent little more than a niche market in the UK (let alone in the wider world). The argument would break down if strong sentiment were to emerge, from consumer, retailer and/or other industrial users, against imported GM-derived non-food products. If this were to be the case, such sentiment would be unlikely to be restricted to the UK. It might, for instance, be triggered by events occasioning strong publicity against the use of GM applications for NFCs. It is probable that such events and publicity would reverberate around the world.

**3.2.45.** Such a future is one in which GM NFC production is postponed indefinitely, though it is rather difficult to imagine that all major agricultural producers can resist the opportunities offered by the new technologies. This scenario does not necessarily require legislation against GM crops, and it may be that other countries in the EU could pursue a different course. More likely versions of scenario D envisage positive attitudes to GM in much of the world, even if there is resistance in the UK and perhaps some other major markets. This then leaves the possibility of an "*invented here*", "*grown elsewhere*", "*sold elsewhere*" situation, in terms of Table 3, with the UK becoming an exporter of Intellectual Property. Such a prospect was felt to be even more contentious than the export of UK bioscience IP in scenarios B and C. The workshop development of scenario D stressed that the most likely outcome would be a decline in scientific capacity in this particular area. Trained scientists would move abroad, infrastructure would lag behind, fewer students would be recruited into plant bioscience. (A similar view was echoed in many of our interviews.) This would be particularly problematic, not just in terms of scientific and economic competitiveness, but also in terms of the UK's ability to contribute to solving the challenges of declining petrochemical supplies, the needs for renewable energy sources, and achievement of more environmentally sustainable development.

## *3.4 Summary*

**3.4.1.** The workshop examined our four scenarios, elaborating coherent and plausible accounts of what each might be like (though one of the four was felt to be particularly unstable). Various indications were given of the factors that might help shape each scenario, of the types of application that might be developed, and, of course, of the implications for the development and use of UK bioscience for NFCs.

**3.4.2.** This discussion should help decision-makers gain further insight into the factors that could lead to and influence the nature of each of the four scenarios – and, hopefully, help improve understanding of the underlying dynamics of change that will shape the future that we eventually do create. This future is unlikely to be precisely like any of the scenarios: the aim of the analysis is to help grasp the scope for change and choice, rather than to predict what **will** happen. The key factors emerging out the analysis, considered to be most important in terms of shifting the trajectory of development across the scenarios are:

- Strong government leadership, clearly recognising and articulating the commercial energy-related, and environmental case for application of bioscience to NFC agriculture.
- Shifting dynamics of consumer acceptability and demand, and the role that positive and negative "demonstrators" could play in influencing them in the direction of a more sophisticated appraisal of the issues surrounding bioscience, modern agricultural practices, and the challenges of sustainability.
- The ability of regulatory frameworks to keep pace with science and technology developments, and the need for improvements in regulatory design so as to allow for more effective, efficient, and relevant approval processes.
- The availability of infrastructural support, and of investment for nascent commercial activities that need to be to be consolidated and scaled up.
- Strong performance of the biological science base.

**3.4.3.** In all 4 scenarios, it was considered that the UK is at a critical stage, and that without a radical shift towards adoption of the full range of bioscience potential, the UK would be likely to lag further behind, to the detriment of competitiveness and quality of life.

**3.4.4.** The next chapter will go on to examine various types of NFC and NFC products, and their possible development, and consider the potential for UK participation in these application areas.

# 4. Bioscience Applications to NFCs, Global Developments and UK Capabilities.

**4.0.1.** This Chapter surveys the different areas of applications for bioscience and uses of NFCs. Drawing on a number of sources, it identifies some of the key developments, especially those that have already reached or are close to commercialisation. The Chapter then examines some of the particular UK capabilities that were highlighted in the Scenario workshop, as a result of placing applications in the context of the four scenarios. The aim was to explore some strengths and weaknesses of UK bioscience-related capabilities for five main different application areas:

- Energy
- Industrial processes
- Health
- Land-use, amenity and bioremediation
- New materials and novel products

**4.0.2.** It should be noted that there are few examples of applications that are close to being or already commercialised that can be taken from the UK. One of the early examples of UK production of plant-based vaccines has been held up as a representative casualty of the opposition to GM, resulting in a loss of investor confidence, namely Axis Genetics (Lomonossoff, 2001; The Times, 17 September, 1999).

**4.0.3.** As already remarked, developments especially in the US are well advanced, with firms already offering commercial products (some examples are given in the box below). A recent US survey of the use of biotechnology by US industry, undertaken by the Department of Commerce and Technology Management (2003) did not identify bioscience applications to NFCs as a separate category. Nonetheless, it emphasised that in all application areas (1,031 firms), over 30% were actively engaged in bioprocessing, and 14% of all sampled firms were engaged primarily in industrial and agricultural-derived processing. Overall, biotechnology development, even during this period of difficulty for high-tech firms in the US economy, was surprisingly vigorous, with an annual growth rate of employees of 12.5%, 2000-2002. A recent Critical I survey suggested that UK biotechnology was also exhibiting encouraging growth, but their statistics probably reflected the pharmaceutical sector, and did not separately identify agri-biotechnology or NFC biotechnology (Critical I, 2003).

**4.0.4. Bioscience and NFCs in the USA. Some examples of commercialisation from different application areas using GM technologies**.

**20 companies** are currently engaged in Plant-Made Pharmaceuticals cultivation, with 131 acres, 34 permits, and 3 clinical trials. Information, www.bio.org and http://aenews.wsu.edu

**Dow-Cargill –** produces ethanol fuel from biomass in a large scale facility.

**Dupont-Genencor** – produces biopolymers for plastics, marketed as Sorona.

**Metabolix** – produces plastics and chemicals from biomass using GM enzymes.

**Prodigene** – pioneers therapeutic proteins from transgenic plants

**Novozymes** – produces GM enzyme technologies for bioremediation of wastewater, agricultural land, and urban landscapes

**PureVision** – produces ethanol from biomass using GM enzymes, partly supported by USDA and DoE, with many industrial collaborations.

**Codexis** – develops GM enzyme catalysis and fermentation processes and products for high value chemical products, industrial and pharmaceutical.

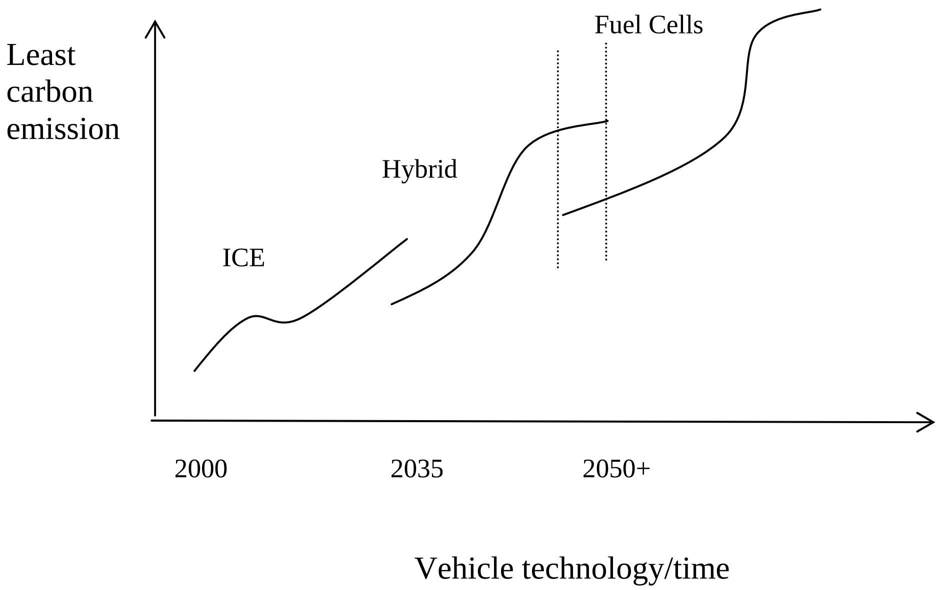
## *4.1 Energy*

**4.1.1.** *Global developments* Crop bioscience is being developed for energy applications, particularly in the United States (Hettenhaus, 2000). The drivers for this are the goals of fossil fuel replacement, energy security, environmental protection and rural economic development. From an economic standpoint, biofuels are some way from competing with gasoline and other fossil fuels. But policy contexts can be designed to promote such fuels, as in Brazil's use of "gasohol" in the 1980s, or in the biofuel-based power stations put up in the UK under the Non Fossil Fuels Obligation (NFFO) in the 1990s. A range of policy measures could be employed to promote the development of bio-alternatives, with or without use of GM technology.

**4.1.2.** Major petroleum companies are developing strategies to deal with a future of diminishing non-renewable resources. In BP's strategy for Alternative Fuels, it is estimated that biorenewables could be anticipated to meet 10% of energy needs by 2030. Moreover, as in other application areas, the interdependency between infrastructures (fuel distribution) and other technologies (internal combustion engines, ICEs), posed significant challenges in switching from fossil to bio-renewable fuels. The most probable scenario was for a fairly lengthy period of dual and hybrid fuel use, before the more radical switch to hydrogen cells, replacing infrastructures and

ICEs. Hydrogen can be produced from biomass for use in fuel cells, and currently this method is half the cost of producing hydrogen from electricity.

**Figure 6: Future Development of Energy Technologies for Transport**




**4.1.3.** The technology strategy needs to engineer a relatively *seamless* change to minimise costs to and resistances from consumers – coordinating vehicle technology/ design+distribution infrastructure with changes in energy. The critical switch from combustion engines using hybrid fuels to fuel cells is indicated in Figure 6.

**4.1.4.** The most prominent technological trajectory currently in place concerns the conversion of biomass into ethanol through the use of enzymes. It is the innovation in enzyme technology based on new bioscience that has enabled the necessary gains in conversion efficiency. The continued application of bioscience to improving these enzymes constitutes the major technological challenge in this area. It is expected that cost effectiveness / efficiency will increase 2% per year over the next five years. Full commercial scale-up is expected within the very near future (see Iogen box below).

**4.1.5.** From a sustainability perspective, compared with gasoline, ethanol derived from cellulose reduces carbon dioxide emissions by greater than 90%. In a climate of global negotiation surrounding greenhouse gas (GHG) emission regulation (the Kyoto Protocol), this potential for substitution is highly attractive. This has led to a number of different policy measures to promote the development of enzyme technology and biomass-to-ethanol plants. In the USA, the market for ethanol as a fuel only exists because of legislation which requires gasoline to contain oxygen (ethanol is 35% oxygen) and a federal $0.53/gallon excise tax exemption. In Europe, the Commission has a draft directive that will require Member States to have 2% biofuels by 2005, 5.75% by 2010 and 8% by 2010. But, a conflicting regulatory focus on tail-pipe emissions of $CO_2$ rather than on life cycle emissions runs the risk of promoting a next generation of engines designed to get the most out of petrol, rather than promoting a switch to biofuels. The regulatory frameworks are supplemented in the USA by large government sponsored programmes (DOE) and government procurement policies.

**4.1.6. Iogen**

Iogen is a Canadian based biofuel and enzyme producer. It has a demonstration plant in Canada, which produces ethanol. EcoEthanol is made from the non-food portion of renewable feedstocks such as corn stover and cereal straw, using Iogen's proprietary GM-enzyme technology. In May 2002, Shell invested $29million in Iogen to hold a 20% equity stake. The funds raised will be used to develop the world's first commercial scale biomass to ethanol plant. This forms part of Shell's sustainability strategy.

**4.1.7.** Further still into the future, there are international collaborative blue-sky research projects as illustrated by the Bio-X box below.

**4.1.8. Bio-X**

There are efforts within the international science community, through the International Energy Authority's Committee on Energy Research and Technology (CERT) to coordinate activities within basic research towards novel long term possibilities for step-change energy technologies:

> 'Bio-X involves many technical disciplines, including molecular biology, functional genomics, chemistry, engineering, materials sciences, nanosciences, and others. Its applications include novel approaches to the production of hydrogen and other clean fuels, energy carriers or storage media, the production of electricity from bio-sources (e.g., from conversions of sugars or other forms of biochemical energy storage), the production of bio-based alternatives for industrial processes and feedstocks and bio-processes for carbon-dioxide capture, fixation and permanent storage (sequestration).'(CERT, 2003)

**4.1.9.** *The UK future potential.* From an agricultural substitution perspective, it is clear that the UK is in a very different position to the USA, or other countries with large areas available for agriculture. 'The Midwest's access to biomass is analogous to being able to extract oil through sand at $3 per barrel, compared to other areas having to spend $25 per barrel drilling through oil shale', according to Cargill Dow (IOWA Industries of the Future, 2003). Recalling the open dilemma of volume versus value, the UK is possibly more likely to pursue higher value crops given the limited space availability and it appears that the UK has not participated very strongly in the relevant science, due to the unlikelihood of domestic exploitation. However, it is not clear why this should be the case, since the market for cellulose enzymes could be significant and need not rely on domestic application.

**4.1.10.** Given the eventual scale and implications of a switch to bio-renewable fuels, the least likely alternative, under any of the scenario conditions, was seen to be the development of large-scale biorefinery processing of UK biomass, either from agricultural residues or, as the better technological option, dedicated lignocellulose energy crops. Any widespread dedication of agricultural land in the UK was deemed unlikely, particularly if GM, even under the "Go for it" scenario. Logistical constraints suggest that UK biorefinery of crops grown elsewhere was also improbable for economic cost reasons. The best-case option for UK capabilities were judged to lie in the development of biorefinery technologies, especially biocatalysis, although there is already a technological lag with the US and Canada.

**4.1.11.** The implication of the scenarios for bio-renewable energy was that the most likely eventuality was that it would be developed and produced elsewhere, making the UK dependent on external energy resources, at least for transport purposes if not for power generation, where other renewable technologies may be more available and competitive.

## *4.2 Industrial processes.*

**4.2.1.** *Global developments* The development of bio-industrial processing, in its broadest sense biorefinery, normally also involves a switch to renewable bio-feedstocks. This is an area, therefore, that typically involves GM technologies in the processing phase (microbes, enzymes), and may or may not involve GM in the provision of feedstocks. Considerable gains are seen to arise from the development of GM feedstocks, and this affects competition with alternatives. In this application area, we are focusing on the inputs to processing and the bio-processing, rather than the novel materials that might be produced. But typically there is both substitution of non-renewable with renewable feedstocks for starch, oils, and fibres, and use of biological agents, especially enzymes and microbes, in industrial processing. Key drivers to consider are shared with other application areas, notably decreasing reliance on declining non-renewable resources, and increasing the use of sustainable industrial processes. Given that the aim is substitution, there is an advantage of employing existing industry value chains. The US Biotechnology Industry Organisation exemplified the gains to be made from the switch to bio-renewables plus bio-processing over traditional chemical production of nylon (see Table 5).

**Table 5: Bio vs. Chemo Fibres**

| Product | Traditional Chemistry | Bio-processing | Economic/environmental impact |
|---|---|---|---|
| Bio-plant produced monomer versus nylon | - Four synthesis steps<br><br>- Four isolation steps | - One synthesis step<br><br>-One isolation step | - 75% saving on capital equipment<br><br>- 50% operating cost reduction |

Source: Biotechnology Industry Organisation, 2003

**4.2.2.** Projections for the growth in the markets for renewable raw materials (RRMs) for industrial processes suggest 126% growth for vegetable oils, 46% for starch and 21% for Non-Wood fibres by the year 2010 (ACTIN Scoping Report, 2001). These projections are made on a basis that does not identify any anticipated gains from the application of bioscience. While the use of the biosciences may enable feedstocks to be produced through crop routes, it has to be born in mind that many feedstocks are low cost, raising the question of whether the investments needed would be seen as worthwhile. One major question arises from the fact that near-horizon relatively low-cost petroleum feedstocks are preventing the necessary investments in far-horizon substitution by renewable alternatives. Yet it is recognised that for a wide range of oils, bioscience applications, including genetic modification, could achieve much higher yields of specialty oils, providing an opportunity for greater expansion. Old firms are adapting to new potential sources of oils, and new firms are emerging to develop new markets.

**4.2.3.** Starch can be used in new ways to produce, for example, biodegradable plastic bags. Novamont, an Italian company has, through innovative chemistry, been producing plastics in this way since the late 1980s (more on this in section 4.5 below). From the perspective of the biosciences, the aim is to develop starch crops with high amylase contents to enable greater use in industrial processes. BASF have been working on the starch expression in potatoes, while work at the John Innes Centre on genetic modification of starch expression systems in various crops is directed towards genetic modification with starch molecular structure adapted to industrial needs points to future possible applications of bioscience. The work has been pursued at the John Innes Centre in an international collaboration supported by the BBSRC, the Arabidopsis Starch Metabolism Network. The National Starch and Chemical division of ICI is currently using natural mutants to this end. The development of gene expression systems for new polysaccharides in wheat could enhance the possibility of its source as a commercially viable feedstock.

**4.2.4.** In addition to exploiting the natural products found in crops, e.g. oils and starches, other opportunities arise through bioconversion systems for turning biomass into feedstocks. These systems utilise different combinations of enzymes, fermentation, fungi, and other organism and can produce a range of products. As discussed in section 4.1 above, ethanol can be produced in this way. Another important product is polylactic acids, although much IP for this appears to be held by Dow Cargill. Further possibilities include the production of hydrogen, synthesis gas, C5 fragments from the bio-catalysis of sugars and other oxidised products. A very different example of biocatalysis as an industrial process is evident in work being conducted on the use of microbes for production of therapeutic proteins, or indeed, other pharmaceutical products such as opiates.

**4.2.5. Microbes as biocatalysts**

The production of opiates through chemical synthesis has proved complex and environmentally costly, using metal catalysts. A bacterium (Pseudomonas putida) has been found by the Bruce Laboratory (CNAP), to metabolise morphine through enzyme catalysis, efficiently producing a number of morphine derivatives.

**4.2.6.** *UK future potential.* It was strongly argued that, as with energy applications, the long term technology strategy needs to ensure a 'seamless' switch from non-renewables to renewables. The UK advantage in chemical industries provides an opportunity especially in the medium term to exploit UK capabilities by combining biorefinery with the existing chemical industry capabilities, and in conjunction with petrochemical corporations such as BP and Shell. The development of generic biorefinery and bioconversion technologies, using combinations of bio-agents (GM enzymes, fermentation, fungal, and other organisms) could provide the UK with a strong comparative advantage in all of the four scenario conditions. The key question, however, was the extent to which these technologies might compete with other, including novel, chemical technology options. Discussion in the workshop highlighted that a key factor for the growth in the use of bio-refining in the UK is the need to facilitate the sharing of ideas between academic disciplines, and up and down the value chain, and across industry sectors.

## *4.3 Health*

**4.3.1.** *Global developments* Developments in modern biology and biotechnology are transforming healthcare by enhancing conventional drug discovery and offering the opportunity to use a range of biological entities as therapeutic agents (Fitzgerald, 2003). The availability of the human genome will provide the basis for much of this advance in the next 10-20 years. This application area only becomes a significant commercial possibility with the use of heterologous expression systems (bio manufacturing), such as GM bacterial or yeast systems used at present, and the potential for using transgenic crops for the future. Biotech medicines such as proteins, antibodies and enzymes now account for 20% of all marketed medicines and 50% of those in clinical trials (www.europabio.org). The new health products include new medicines, vaccines, diagnostics and emerging cell and gene therapies. Analysts at Wood MacKenzie predict that antibodies will be the largest growing section of the therapeutic proteins market. They forecast that the therapeutic antibodies market will reach $9bn by 2005, with a growth rate of 25% a year (Winder, 2003).

**4.3.2.** The introduction of microbial-based processes for the production of therapeutic entities in the 1980s (originally by Genentech) and the emerging possibilities for using plants, either in fields or under glass, is presenting a significant challenge to the incumbent chemical synthesis technology. The alternatives, which are at markedly different stages of scientific and technological advance, each present a distinctive range of potential benefits and stumbling blocks, some of which have been well demonstrated, others still predominantly conjecture. Recalling the tree in Figure 1 earlier, it is possible to schematically map the nature of this technological competition with reference to the main pros and cons.

**4.3.3.** The major pharmaceutical companies, with historical expertise in chemistry and fermentation as the dominant platforms have partially recognised the possibilities presented by crops, but the preferred route at the moment remains the fermentation-based technology. For example, GSK is now developing therapeutic proteins, antibodies and viral-based products by genetically engineering animal cells or microbes, but consider that the effectiveness of plant-based technologies is yet to be proven. In particular there may be problems associated with growing and harvesting crops in a way that meets the current manufacturing practices of the industry, while the problem of consistency of supply, in term of both quantity and quality, would also need to be overcome.

**4.3.4.** One of the key hurdles will be to establish the regulatory framework under which plant derived pharmaceuticals are manufactured. The current standard for pharmaceuticals is described under the terms of "Good Manufacturing Practice" (GMP), but these standards were developed with the existing production technologies in mind. The pharmaceutical industry rightly has reservations as to how to apply GMP standards to the production of a plant derived pharmaceutical. Nevertheless, these issues are not insurmountable, as demonstrated by companies who are active in the area, such as Dow, Monsanto (until recently), Prodigene and most notably Meristem Therapeutics who are on the verge of commercialising the first plant derived pharmaceutical product. Furthermore, in the USA at least, the regulatory authorities are starting to recognise the need for modifying the regulatory framework to keep up with new developments. Thus the introduction of new standards that recognise that some medicinal plant compounds contain mixtures of active ingredients, rather than a single pharmaceutical product is an important step. Another issue is that there is little agreement amongst companies promoting the use of plants as to which plants offer the best possibilities. To date, perhaps much of the work has been done with crops that are convenient as opposed to necessarily the best option.

**4.3.5.** The production of pharmaceuticals in crops can be seen as presenting a major biosafety issue, particularly if the crops that are used to express them are also food crops. Without the investment of the big pharmaceutical companies there will be continued difficulties in moving from the science to full scale commercialisation. One additional concern relates to the way proteins produced in plants are glycosylated, raising issues of immunogenicity and effectiveness (Winder, 2003). However, the latest science suggests that this might prove a temporary obstacle (Shah et al., 2003).

**4.3.6. Epicyte** (from Winder 2003)

Epicyte is a US company based in San Diego, holding key intellectual property in technologies for producing antibodies from plants 'for any antibody in any plant'. Epicyte has a two-pronged innovation strategy: 'next-to-market therapeutics' could be produced to compete with existing antibodies with sales of $700m-$1.2bn, on the basis of cost; novel therapeutics can be developed for well defined therapeutic targets on the basis on cost, scale and efficacy.

**4.3.7.** The compelling advantages of plant technology have economic and scientific bases. First, there are issues of scale and cost of production, where the large quantities of therapeutic agent required, for any chronic condition, have led to the conclusion that the plant route is the only economically viable option. Second, the capital investment and time required to establish production facilities for microbial technologies could be potentially undercut by plant based alternatives; estimates range from $250m to $500m for the microbial factories of Genentech and others compared to $10-15m for a plant extraction facility. Third, there are some therapeutic proteins for which production in plants represents the only practical means for manufacture. For example, monoclonal secretory antibody are highly complex multimers, that will not express efficiently in other systems such as *E. coli* or mammalian cells. One such therapeutic secretory antibody has been developed at Guy's Hospital, London against dental caries and is already being produced in plants. Other complex mammalian proteins are also being designed which are likely only to be amenable to the plant expression system.

**4.3.8.** *UK future potential* Although it has been noted that US companies are already well established in producing Plant-Made Pharmaceuticals (PMPs), it is important to recognise that there is considerable conflict between different stakeholders, between corn farmers, and between the food industry and pharming for fear of contaminated food supplies. Open-field cultivation of PMPs involves extensive governmental regulation and industry self-regulation (Biotechnology Industry Organisation, 2002). Buffer zones of non-cultivated ground, and extensive acreage of surrounding crops unrelated to the pharmed plants are many the times the area of actual pharma-crops. Monsanto, having invested heavily in early R&D has recently sold its business in this area to Dow (Mitchell, 2003), and there has been a shift of production to areas remote from food agricultural production. It is considered that for all these reasons, USA agronomies of pharming are unsuitable for UK and most European agricultural conditions.

**4.3.9.** This suggests a possible advantage in alternative containment agronomies, where the UK has an established leadership capability. The technology of using GM viruses to induce production of pharmaceutically important proteins in plants, although still some way from commercialisation, is a capability that was not lost with the collapse of Axis Genetics (Lomonossoff, 2001). It was considered that the development of this technology was well suited to containment agronomies, in contrast to Large Scale Biology Corporations use of the original technology in open-field cultivation. Containment provides advantages not only in security, but also in yield, quality, and ecology. This technology, whilst clearly requiring GM viruses to produce the protein expression in plants, does not involve GM plants: neither the output, nor the crop, are themselves GM. This is an example, discussed in other biotechnology contexts, where regulation lags behind developments in science and technology, so requiring an iterative upgrading of regulation to meet new challenges (König, 2003).

**4.3.10.** Also at a considerably earlier stage of development, but with promising signs, is the opportunity to produce therapeutic agents in mushrooms and this has formed the basis for collaboration between Horticultural Research International and Agarico, (itself a spin-out from HRI). Despite a general lack of understanding of the biology of mushroom cellular processes (there are only three global centres of excellence in this area), the project has succeeded in developing techniques for genetically modifying them. For the production of therapeutic agents, mushrooms would be grown in containment sheds. There are considerable advantages from the fact that they are not seasonal, and can produce very large yields (3-4000 tonnes/hectare/year, which is over 100 times plant based yields). To date, projects in this area have not received major support from large companies or venture capital investment.

**4.3.11.** The examples described represent different branches of the Figure 1 tree, where each presents different advantages according to a combination of economic, agronomic, scientific and public acceptability criteria, and different routes present more as less likely possibilities under different scenarios. The combination of containment agronomy, clear consumer benefit, new regulation, and potential global markets, however, placed this application potentially between the 'On the cusp' and 'containment but not confinement' scenarios. If some products were produced with widely recognised benefits (vaccines against the common cold virus), one possibility was that it would break the current mould. Much was seen to depend on the engagement of major pharmaceutical companies, currently reluctant to invest in such a radical shift in infrastructure and value chains. As in other application areas, new collaborations between different players, as well as interdisciplinarity in R&D, were seen to be important. Lack of investment and venture capital was seen to be an obstacle, but this could change especially if a clear policy lead was given.

## *4.4 Land use, amenity, and bioremediation*

**4.4.1.** *Global developments.* The Horticultural Research Institute has identified three areas of amenity and land use: ornamental flowers, potting and bedding plants, and shrubs. (It is possible to think of specific functions that are being pursued, that might give a slightly different categorisation. For instance, plants can be used for security purposes, to support sports and rambling, even as roof cover.) Although bioscience in terms of understanding interactions between gene expression and environmental conditions may lead to new products, genetically modified products appear to be unlikely in the foreseeable future in the UK, owing to high costs of development in what is a fragmented market with limited R&D budgets. The possibilities for GM products in the US seem to be much higher, with work being undertaken to control ethylene – the hormone that leads to flowers wilting. At the present time flowers are often sprayed with ethylene inhibitors, which contain silver, and these inhibitors are facing a likely ban in the Netherlands, which is a hub for the flower business. Perhaps the most immediate possibilities are in high value niche markets (orchids and tropical fish), where genetic modification has been developed to commercial ends.

**4.4.2. www.hybridorchid.com**

An internet auction was recently held for an orchid variety that glows in the dark, as a consequence of insertion of firefly genes. Prof. Chia Tet Fatt from the National Institute of Education in Singapore (NIE) created the bioluminescent orchid, from the *Dendrobium* genus using the firefly luciferase gene.

**4.4.3.** Other types of amenity land use might involve landscaping, golf courses, sporting venues, where new plants and grasses produced by genetic modification offer alternatives not available from conventional hybridisation. One possibility developed in the US is for herbicide resistant grass, while non-mow grasses, or 'stay green' are also emerging commercialised options. In terms of the UK, though grass is an evident target for bioscience applications, it also presents a big problem. Since it is widespread and because it is one of the biggest outcrossers, acceptable technology for restricting gene flow would have to be developed.

**4.4.4.** *UK future potential*. There are opportunities for UK bioscience in the amenity and land use areas. For research on grasses, the Institute for Grassland and Environmental research is regarded as perhaps the best place in Europe. In ornamentals, there are plants, such as roses and carnations, where the UK has particular strengths that could be exploited, although as was mentioned earlier, the industry is fragmented with little R&D spend.

**4.4.5.** Bioremediation has been defined as 'the use of biological systems such as micro-organisms and plants to decontaminate polluted land, water or air'. Plants could potentially be used for treating biocontamination, heavy metals, toxic organics, VOCs, explosives, nitrates, or oil. In addressing the potential deployment and markets for bioremediation technologies, the UK joint research councils (BBSRC, EPSRC and NERC, 1999) claimed that the value of bioremediation research to the owners of contaminated land in the UK, in terms of reduced remediation costs over the next 10 years, is conservatively estimated at £600 million. The report also recalled an earlier OECD prediction that the worldwide market in bioremediation estimated to be some £50 billion by the year 2000 (OECD, 1994) (These estimates will obviously need to be revised in the light of subsequent developments.)

**4.4.6. Plants for cleaning up contamination from explosives**

The Bruce laboratory at CNAP, with BBSRC funding, has been investigating the potential for plants to decontaminate land, which has been polluted by explosives. The research has demonstrated that the potential for phytoremediation can be greatly enhanced if the plant, tobacco in their experimental studies, is genetically modified – bacterial nitroreductase was expressed in the plants to combat the phytotoxic effects of TNT.

**4.4.7.** In the UK, efforts to commercialise research of this nature is being supported by the Bioremediation LINK Programme, launched in April 2001. £7.5 million has been made available to fund projects with industrial and academic partners, aimed at commercial exploitation of biotechnology for the clean up of contaminated land, air and water. Many of the technologies, both for amenities and bioremediation, were considered to be optimal using GM technologies. For this reason, they would become most widely developed only in Scenarios A and B. Containment conditions ruled out any potential, as of course did the restriction of development of the GM technological route.

## *4.5 New materials and novel products*

**4.5.1.** *Global developments* There are many naturally occurring materials that may be transformed by bioscience developments into commercially viable products as new markets. Almost by definition, this is an area of 'unknown unknowns', where genomics may discover new functionalities, new metabolic processes, and hence new 'products'. One of the key areas where there will be an increasing demand is the development of renewable alternatives to all petrochemical based materials (synthetic fibres, plastics, adhesives, coatings, surfactants). Unlike energy, where there are already competing technological alternatives for renewable energy, bio-renewables are likely to provide a major contribution to meet this challenge, even in the context of innovation in the chemical industry. In addition to the development of large-scale novel renewable material production, there is a potential for bioscience to create entirely new crops, or to use existing crops as vehicles for producing entirely new output traits. But this is still in its infancy. Many of these possibilities might be the basis of specialist intermediary or niche markets: advanced textiles with new properties, dyes, adhesives for extreme conditions, fragrances and cosmetics.

**4.5.2.** In this application area, the US, as in other areas, holds a significant lead in reaching commercialisation. Polylactic acids produced by GM plants, and the use of GM microbial fermentation for polymer production (such as DuPont/Genencor's 1,3 Propanediol, see box p.44) are already advanced.

**4.5.3.** In Europe, one area of particular interest is in the production of degradable bioplastics. There are competing ways of approaching this. One approach is via the use of starch, which is not a new product but a new way of applying a product. As mentioned earlier, the starch approach has been successfully applied by Novamont to produce 'Mater-Bi' products, whose physical and chemical properties are similar to those of traditional plastics and are used in plastic bags. The Novamont approach owes more to chemistry than to bioscience. However, if GM starch were available, then this could simplify the processes.

**4.5.4.** *UK future potential*. Though there are many possible lines of development here, there has not been time in this study to examine all of these in any depth. The Scenario Workshop chose to explore one particular application, in the production of bio-renewable plastics, in order to explore UK future potential in the four scenario contexts.

**4.5.5.** 'Green plastics' in general have been seen to have great potential (Poirier, 1999). For producing biodegradable plastics two primary routes were considered, the use of poly-3-hydroxybutrate (PHBs) from genetically modified plants, using GM processing biocatalysts, and the use of starch, optimally GM, but not necessarily so, with alternative processing technologies, traditional or biotechnological. PHBs are better for producing plastic bags than are plastics derived from starch (at least, at present) - but they are less good for plants, which currently produce low yields in consequence. In addition to potential problems with yields, there are other problems with producing plastics in plants. One major issue is what to do with the waste plant material once the plastic is extracted – conventional uses such as feeding animals could run into difficulties since it could be hard to ensure that no plastic is left over in the waste making it unusable. This issue led to Monsanto pulling out of a project to produce plastics from crops.

**4.5.6.** Biodegradable plastic bags will be a reality, but the way that they are produced will be largely dependent on the scenario for GM crops in the UK. For example, scenario D leaves only the option for non-GM starch production, while the scenarios involving emphasis on contained agriculture would seem to pose problems for producing PHBs in the volumes required – let alone at the prices that would be needed. It was considered that, even under Scenario A, the UK had already lost bioscience capability for the PHB route, and that it would be unlikely to be able to recover its position. For the starch route, the UK has both some IP and research capability, second to Germany, but under Scenario B, C, and D, the use of starch would be more likely to be via 'green chemistry' processing, rather than GM feedstock. In general, this example seems to demonstrate that the routes towards widespread substitution of large use bio-renewable plastics in the UK would be quite restricted in any of the scenario conditions. As with energy, unless major efforts are made to rebuild UK capability, the most likely future is one of import dependency. To assist such a recuperation, strong tax and regulatory incentives to create a market for biodegradable plastic products, and stimulus for investment in collaborative R&D across the new value chain, were deemed necessary.

**4.5.7.** As a counterpart to the large-use novel bio-renewable materials, the UK was recognised as having an expertise in specialist or niche products such as spider dragline silk and the use of mussel adhesives for potential surgical uses (The Mason-McQueen laboratory at CNAP). Both these applications rely on GM technologies, with low volume/high yield, that would make them viable in containment cultivation agronomies. This gives them commercialisation potential under Scenarios A, B, and C in the medium to long term.

## *4.6 Summary*

**4.6.1.** This section has reviewed some of the main global state of the art applications of bioscience to NFCs, with a focus on those which have been commercialised or close to it. The UK current and future potential was assessed, using the tools provided by the Scenario Workshop. The main points arising from this review are:

- **4.6.2.** Two main, large-use, application areas, energy and new materials, face a double imperative and opportunity, whether driven by concerns of global climate change, or by the necessity in the long term to find replacements for petrochemical products. In this area, the US is already advanced in commercialisation, with major investments by several government departments complemented by those of corporate finance. Much of the bioscience involves the use of GM technologies in processing or in feedstocks, or both. The UK is characterised by a considerable lag, if not absence of development in many of the developments in this area, with no major commercialisations currently in sight. The UK does however have strengths and potential in some smaller use, specialist or niche product areas.

- **4.6.3.** Health applications promise major benefits in the long term from plant-based pharmaceuticals, not only to substitute for chemical synthetic products, but also to develop entirely new therapeutic proteins. Nearly all developments in this area depend on the use of GM technologies. The US development of pharming, using open-field agronomies and mostly modified food crops, involves substantial containment regulation and procedures, and faces some corporate and agricultural industry controversy. These agronomies would be unsuitable for UK, and probably most European, adoption. The UK does have significant and leading-edge capabilities in this area, and is well placed technologically to develop them to commercialisation through use of containment agronomies.

- **4.6.4.** The potential for amenity, leisure and bioremediation applications of bioscience to develop sustainable land use is considerable, but has apparently not been investigated extensively in the UK as yet. Commercialisation of bioremediation and of some exotic leisure crops through use of GM technologies has been achieved, though on a small scale. While there are significant opportunities, the technologies are still in their early stages of development, and markets are a long way from being established. In the UK, many of these applications currently meet with regulatory and public opinion barriers, and there is little evidence of UK activity or capability in this field.

- **4.6.5.** In sum, across the broad spectrum of application areas, there is a small but critical time window for the UK to develop the bioscience technologies necessary to address the twin imperatives of finding alternative sources of energy and materials. In other application areas, UK capabilities are patchy and currently small scale. Without a major change in policy, regulatory, investment, and public opinion environments, there is a risk that the UK will slip further behind as developments forge ahead elsewhere in the world.

# 5. Conclusions: A critical policy time-window

**5.0.1.** The report has surveyed a wide range of possible benefits deriving from the application of bioscience to the non-food crops. In a factual way, the different potentials of GM and non-GM technology contributions arising from developments in genomics and post-genomics were assessed. We have signalled that the 21st century is likely to see a shift towards the bio-economy, a shift of major significance both in terms of replacing petro-chemical resources and in developing up entirely new products. Alternative future scenarios were explored, relating to the extent that GM technologies might be embraced, and under what conditions. The wealth of applications in the areas of bio-energy, industrial processing, health, bioremediation, leisure and the environment, and novel materials was demonstrated, including the advance towards commercialisation, especially in the USA. A significant gap is opening up between the USA and Europe, including the UK.

**5.0.2.** In this conclusion, we have decided to narrow the issues to focus on where the UK needs to make immediate progress, and where we believe the most practical possibilities exist. Solutions and applications that are viable in the European context, and give the UK comparative advantage in relation to the US and other global regions are identified. We suggest that these offer the strategic ways forward, at this point in time, and under current circumstances, without foreclosing on the many other opportunities that will no doubt arise with the development of bioscience.

**5.0.3.** Seven recommendations covering the key policy areas highlighted in the report have emerged from the study and discussions with GIFNFC. It cannot be over-emphasised that there is now a critical policy time-window. There are three major reasons for this urgency:

i) The depletion of petrochemical resources over the next 35-50 years and global climate change present a challenge to develop alternatives that has to be addressed now. In the 21st century, the bio-economy can provide a significant part of the solution.

ii) The UK is already in a catch-up situation with respect to developments taking place in the US and elsewhere, and any further delay would be likely to increase the risks of UK economic dependency.

iii) There is an ever-increasing danger of a decline in the UK plant bioscience base, if a positive, strategic view is not forthcoming soon.

**5.0.4.** Two main aspects of the challenge were identified, each requiring different solutions for the UK in a European and global context:

- the unavoidable shift towards a more sustainable development through bio-economy alternatives to petrochemical technologies
- the development of new bioscience products from non-food crops, especially pharmaceuticals and materials where plant-based technologies are the best or only option

**5.0.5.** The recommendations focus on these two distinct challenges (A and B), and we present different responses relevant to each of them. There is also one general recommendations applicable to both challenges (C).

**A. The unavoidable shift towards sustainable development and the bio-economy.**

**Recommendation 1.** *Develop a government-wide, integrated UK strategy for bio-economy solutions to global climate change and the depletion of petrochemical resources for energy and materials*.

**5.0.6.** The current petrochemical technology platform has been developed over a long period as an integrated industrial complex of interdependent processes providing energy and materials. The emergence of alternatives, including an important contribution from the bio-economy, will result in significant industrial restructuring as well as providing the basis for more sustainable development. The size of the challenge, and the timescale needed to construct from scratch an alternative base of science, technology, manufacturing and product supply should not be underestimated. Energy for power generation (domestic and industrial) and for mobility (air and terrestrial) is likely to develop from diverse technologies and different sources. The development of replacement materials from bio-refining is likely to be, at least in part, independent of the production of energy from biomass. An entirely different industrial landscape will emerge, for which there needs to be strategic vision to maintain a European and UK competitive position.

**5.0.7.** Further to this recommendation it is proposed that

- *a UK strategy task group be established to assist in the development of the government-wide, integrated UK strategy drawing upon industrial and academic expertise*
- *studies are undertaken to develop technology roadmaps for different application areas to highlight the specific needs of different sectors*
- *studies are undertaken on the consequences of restructuring of energy and materials industries for market and competition effects, employment and skills*

**Recommendation 2.** *Promote R&D investment and stimulate academic research in upstream, high IPR value, bio-refining technology platforms.*

**5.0.8.** For the immediate future, there seems little prospect of providing significant biomass for energy from bioscience crops or agricultural residues on the UK landmass. Bio-refineries need to be close to sources of energy feedstocks either from dedicated energy crops or from agricultural residues to be economically viable. The greatest opportunity for UK capabilities, therefore, resides in developing upstream technologies with high IPR values for bio-refining, building on existing petrochemical industry expertise. Development of GM enzyme technology for fermentation either for energy or materials, for example, is a key commercial area that could benefit from UK bioscience expertise.

**5.0.9.** Further to this recommendation, it is proposed that

- *a new R&D programme aimed at university and industry collaboration is established, focused on the development towards commercialisation of key bio-refinery technologies.*

**Recommendation 3.** *Stimulate collaborations across the range of biosciences in the NFC area for bio-processing and feedstocks to maximise technological and competitive synergies on a European scale.*

**5.0.10.** The first two recommendations are unlikely to be achieved within a UK context alone. For the development of a European bio-economy, whether for technologies or for production of new energy and materials feedstocks, European industrial and science-base collaborations will be essential. Interdependency between various new technologies will require collaborations between a new range of firms and organisations to maximise benefits and competitivity.

**5.0.11.** Further to this recommendation it is proposed that

- *there should be full UK involvement in the design and development of European initiatives in regulatory development, and research and industrial collaborations in this area.*

**B. Maximising the UK potential of bioscience for NFCs**

**Recommendation 4.** *Promote the development of high-value, low volume bioscience NFCs under containment agronomies, especially for pharmaceuticals and novel specialist materials, using UK comparative advantage.*

**5.0.12.** Glasshouse and other containment agronomies (e.g. fungi) present significant opportunities for the commercial production of GM and non-GM bioscience NFCs. First, this would take advantage of UK's strengths in technology and expertise in this area. Second, the open-field bio-pharming as practiced in the US is unlikely to be developed in European conditions. High and quality-consistent yields can be achieved in contained and totally controlled ecological conditions. Containment agronomies present an optimal technological NFC route for pharmaceuticals and high value specialist materials. This is not to foreclose on future bioscience developments and opportunities for mid-value, open field NFCs for bioeconomy materials. But, products with manifest consumer or industrial benefits and without many of the perceived risks associated with open-field production will provide significant commercial opportunities. It will be necessary to ensure that appropriate regulatory frameworks are developed in relation to containment agronomies that keep pace with science and technology, minimise risk and stimulate innovation.

**5.0.13.** Further to this recommendation it is proposed that

- *flagship projects to demonstrate containment agronomy and consumer benefits are invited and supported*
- *elevate awareness amongst containment agronomy community about the potential of bioscience NFCs*
- *economic and technological studies are undertaken for the exemplary applications, in terms of markets, science capabilities required, technological inputs, and cultivation procedures*

- *review and revise regulatory frameworks to optimise the UK economic environment for the development of bioscience NFC containment agronomies.*

**Recommendation 5.** *Stimulate the development and application of venture capital to bio-science for NFCs, particularly in relation to the commercialisation of containment agronomies.*

**5.0.13.** There is currently a comparative disadvantage for start-ups in the UK concerning lack of venture capital and a high-risk averseness. This needs to be addressed by giving clear policy leadership on the direction of change, creating market awareness of the significance of the bio-economy for the future, and demonstrating the potential for UK technological leadership in specific application areas.

**5.0.14.** Further to this recommendation it is proposed that

- *bioscience technology fairs and other forms of knowledge brokerage are promoted and supported*
- *encouragement of interchange between capital and product-market firms, e.g. through industrial placements*
- *interactions between university commercialisation organisations and venture capital are fostered*

**Recommendation 6** *Levels of investment and support for UK basic plant bioscience in universities and public science institutes are sufficiently maintained to ensure continued world-class performance.*

**5.0.15.** The UK has a world-class basic plant bioscience capability. It is vital that current levels of support are maintained to ensure future opportunities across the entire range of potential bioscience NFC applications remain open. UK participation in the future global bio-economy will require sustained expansion of both skills and research capacity.

**5.0.16.** Further to this recommendation it is proposed that:

- *the Office of Science and Technology urges BBSRC to explore the potential for cross research council initiatives with MRC, EPSRC and NERC*

**C. General recommendation**

**Recommendation 7.** *Develop statistical and other databases that adequately support biotechnology policy formation in the UK.*

**5.0.17.** From the study, it is clear that there is a paucity of the statistical and institutional data necessary to inform policy development in relation to the different areas of biotechnology activity across different sectors and application areas. There is a need to identify and track technology developments, companies, employment, and training in order to estimate strengths and weaknesses.

**5.0.18.** Further to this recommendation it is proposed that:

- *a review of existing statistical sources is undertaken to establish further potential value to policy development*
- *a statistical study is commissioned of UK industrial biotechnology activities differentiating between various application areas and sectors*
- *appropriate databases are created for secondary data relating to UK patents, publications and company reports in this area.*

# 6. References

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# 7. List of Interviewees

| Name | Organisation |
|---|---|
| **UK/Europe** | |
| Melvyn Askew | Central Science Laboratory |
| Richard Miller | Miller - Klein Associates |
| Ian Graham | CNAP |
| Colin Fitchett, Director | Cambridge Biopolymers Ltd |
| Peter Dunnill | Advanced Centre for Biochemical Engineering, UCL |
| Brian Thomas, Research Director | Horticulture Research International |
| Alf Game, head of Plants, Microbes and Genetics Branch, and Don Cheyene | BBSRC |
| Nigel Poole | Sekona Partnerships |
| David Buckeridge, Director | Advanta Seeds |
| Alistair Penman, recently retired, ex Director of R&D | Ex-Unilever R&D Laboratory |
| Charles Sell | Quest International |
| Steve Musgrave and Michelle Scott | GlaxoSmithKline |
| Andy Taylor, Director of Corporate Citizenship, Ford | Ford Motor Company |
| Roger Turner | British Plant Breeders Society |
| Jan Chojecki, Managing Director | Plant Bioscience Ltd |
| H. Bevinakatti | Uniqema |
| Ralf-Michael Schmidt | BASF |
| Andrew Cockburn | Monsanto (Europe/Africa) |
| Ian Bartle | ACTIN |
| **USA - CANADA** | |
| Ron Meeusen, Vice President, Research | Dow Agrosciences |
| Donald Erbach, Leader, National Programme of Environment and Energy | Agricultural Research Service, USDA |
| Harry Klee | University of Florida |
| Larry Grill, Senior Vice President | Large Scale Biology Corporation |
| Rick Keon, Manager, Planting Operations and Field Regulatory Affairs | SemBioSys |
| John Howard, Chief Technical Officer | Prodigene |
| John E. Ferrel, Director, National Biomass Coordination Office | US Department of Energy |
| Brent Erickson, Vice President | US Biotechnology Industry Organization |
| Bill Holmberg, Chair | New Uses Council |
| Dennis Schuetzle, Vice President | Technikon |
| James Hettenhaus, Consultant (ex Gist Brocades, Monsanto) | Chief Executives Assistance Inc. |
| Sivan Kartha, Senior Scientist | Tellus Institute |
| Mich Hein, President and CEO | Chromatin Inc. |

# 8. Invited Workshop Participants

Dr Martin Anthony, Bioscience Unit, DTI
Dr Sue Armfield, Bioscience Unit, DTI
Dr Gavin Bailey, Head of Technical Policy & Strategy, Safeway Stores plc
Dr Tina Barsby, Director Biogemma UK Ltd
Professor Dianna Bowles, Director, CNAP, University of York (GIFNFC)
Michael Brannan, Biotechnology Unit, Dept of Health
Dr Simon Bright, Manager of European Genomics, Syngenta
Dr David Buckeridge, Director (Europa and N America), Advanta Seeds
Dr Paul Burrows, Head of Science Strategy, Biotechnology and Biological Sciences Research Council (BBSRC)
Dr David Carmichael, Director, Battle and Pears Ltd (GIFNFC)
Mrs Pamela Castle, Chairman, Environmental Law Foundation (GIFNFC)
Dr Peter Cheetham, Chief Technical Officer, Zylepsis Ltd
Dr Andrew Chesson, Adviser on Renewable Industrial Materials Programme, DEFRA
Dr Ed Dart, retired (ex-Syngenta)
Ms Chris Dewey, Product Strategy Development, BP
Dr Colin Fitchett, Director, Cambridge Biopolymers
Dr Eli Keshavarz-Moore, The Advanced Centre for Biochemical Engineering, University College London
Professor Peter Lillford, Chairman, National Non Food Crops Centre (NNFCC)
Professor Julian Ma, Guy's Hospital (Medical Research Council - MRC)
Dr Colin Merritt, Biotechnology Development Manager, Monsanto UK Ltd
Dr Richard Miller, Miller-Klein Associates Ltd (GIFNFC)
Dr Rod Morrod, British Crop Protection Council (BCPC)
Dr Steven Musgrave, Biopharmaceutical Development, GlaxoSmithKline plc
Professor Nigel Poole, Managing Director, Sekona
Professor Alison M Smith, Department of Metabolic Biology, John Innes Centre (JIC)
Professor Uwe Sonnewald, Department of Molecular Cell Biology, Inst. fur Pflanzengenetik und Kulturpflanzenforschung
Andy Taylor, Director of Corporate Citizenship, Ford Motor Company Ltd (GIFNFC)
Robin Turner, Managing Director, Agrifusion Ltd
Martin Ward, Non Food Crops Strategy, DEFRA
Dr Mark Harvey, IOIR
Dr Andrew McMeekin, IOIR
Professor Ian Miles, IOIR
Professor Philip Vergragt, IOIR
Dr Steven Glynn, IOIR
Helena Poldervaart, Facilitator
Lindsay Colbourne, Facilitator
Natalia Davie, Bioscience Unit, DTI

# 9. Glossary

| | |
|---|---|
| BBSRC | Biotechnology and Biological Sciences Research Council |
| DBF | Dedicated Biotechnology Firm |
| EC | European Commission |
| EPSRC | Engineering and Physical Sciences Research Council |
| ESRC | Economic and Social Research Council |
| EU | European Union |
| GHG | Greenhouse Gases |
| GM | Genetic Modification |
| GMO | Genetically Modified Organism |
| IGER | Institute of Grassland and Environmental Research |
| IP | Intellectual Property |
| IT | Information Technology |
| JIC | John Innes Centre |
| NERC | natural environment Research Council |
| NFC | Non-Food (Use of) Crop |
| NNFCC | National Non-Food Crop Centre |
| PMP | Plant made pharmaceuticals |
| SCRI | Scottish Crop Research Institute |