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AGRICULTURE AND ENVIRONMENT BIOTECHNOLOGY COMMISSION

LOOKING AHEAD

AN AEBC HORIZON SCAN

April 2002

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CONTENTS

INTRODUCTION

1. The AEBC set up a horizon scanning sub-group in 2000, and its terms of reference were as follows:

> To keep the AEBC well informed about current and future national and international developments that are relevant to fulfilling its strategic remit. This would include information on:
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> - trends in biotechnologies, in agricultural practice and policy, and in environmental issues;
> - trends in other technologies, where these may interact with biotechnologies;
> - relevant social, economic, legal and political trends i.e. those that will have a bearing on how biotechnology is shaped and how it is received by society.

2. This horizon scan is intended primarily as an internal tool, to make the AEBC aware of the wide range of work underway in biotechnology research, particularly genetic modification; and to highlight developments being mooted as of possible agricultural and environmental significance. It is a scan of work underway. It does not attempt to analyse particular strands in depth or tease out the full complexity of the issues they may raise. Some of the developments may in the future become subjects for studies in greater depth by the Commission. It is also hoped that the scan can be used to stimulate discussions with stakeholders and the public.

3. The scan has three main components. The first part looks at some of the major trends and factors that are likely to condition uptake of the technology, particularly in the UK. These have been compiled partly from literature and also draw on a series of meetings held by the sub-group with invited experts, the responses to the sub-group's consultation paper (at Annex D) on future scenarios for the uptake of GM technology in agriculture, AEBC public meetings held in Birmingham and Belfast, and a session with school students in Belfast. There are some further statistics on the biotechnology industry at Annex B. The second part looks at the implications of these trends for biotechnology in the United Kingdom as seen by the respondents to our consultation exercise. The third part contains an overview of current biotechnological developments, together with observations on potential benefits and risks, and some notes on what would need to be taken into account in a fuller technology assessment. This section is supported by detailed tables in Annex A listing specific applications of biotechnology to crops, animals, trees etc.

4. In this scan 'biotechnology' is understood to mean the suite of techniques developed over the last two decades or so to augment traditional plant and animal breeding techniques and traditional uses of micro-organisms such as brewing, baking and cheese-making. The most controversial of these techniques has been recombinant DNA, also referred to as genetic

modification, genetic manipulation, genetic engineering and transgenesis, and abbreviated to ‘GM’. The report is not confined to looking at the issues around recombinant DNA technology, although, in practice, this is where the most significant developments and the most vigorous public debates have arisen and accordingly is the focus of this report. Other techniques include marker-assisted breeding, mutation breeding and cloning. Together these techniques constitute what is often referred to as 'modern biotechnology'.

5. The scan is not designed to be an exhaustive account of all biotechnological developments and applications to date. It does give an account of the main applications of biotechnology, particularly genetic modification, which have implications for agriculture and the environment. It also highlights some of the issues which the technology and its applications are commonly felt to raise. For those who want to read further, we have included a short bibliography at Annex G, while Annexes C, F and H provide information on GM crop approvals in Europe, a list of AEBC members and a glossary.

6. The sub-group and Commission are very grateful to all those institutions, organisations, individuals and officials who took the trouble to give evidence to the sub-group, particularly all those who responded to the sub-group’s consultation exercise on future scenarios for the uptake of GM technology in agriculture (see Annex E).

7. The AEBC hopes that readers of this scan will comment on anything in the report or about issues they think are important which are not included and which the Commission should take account of in its work. The Commission plans to regularly review future developments and comments received. The aim is for the scan to become a living document which continues to inform the Commission’s thinking and helps stimulate and inform the public debate.

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PART 1 THE CONTEXT: MAJOR TRENDS AND FACTORS LIKELY TO CONDITION THE UPTAKE OF BIOTECHNOLOGIES

Trade liberalisation and globalisation

9. There is a trend towards an increasingly globalised economy, one where more and more goods and services are traded across borders. There is also strong international pressure to liberalise trade, i.e. to remove countries' various ways of protecting their own industries, so as to increase the overall flow of trade and to give more equal access to global markets. This trend is very relevant to agriculture, which is generally perceived as one of the most protected industries, with industrialised countries among the most protectionist, at the expense of less economically developed countries' access to new markets. By way of comparison, the volume of global trade in manufactured goods has increased by a factor of seventeen in the past fifty years; farm products by less than six times. Agricultural tariffs have remained higher than those in other sectors.[1]

10. The international political rhetoric of liberalisation, however, is not always matched by national political realities in relation to agriculture. The World Trade Organisation is now launching negotiations on liberalisation of agricultural trade. But despite the stated desire of the US Government to be part of and support trade liberalisation[2], the final farm bill at present going through the United States legislature may not match that aim. There is significant political pressure to increase rather than decrease Government support for U.S. agriculture.[3] It is also uncertain whether and to what extent Member States of the European Union will sign up to reform of the Common Agricultural Policy (CAP) when the time comes. And of course not everyone sees increased globalisation and trade liberalisation as an unqualified good.

Consolidation

11. The agriculture industry, like many other industries in more economically developed countries, is becoming increasingly consolidated. This effect is evident all the way through the food chain, from farm inputs such as seeds and pesticides, to farming itself, food processing and retailing. There is a concentration of agricultural goods and trade into a decreasing number of businesses. However, this consolidation reflects a series of mergers and acquisitions across all multinational businesses over the last two decades. Other business sectors (e.g. banking, pharmaceuticals, airlines, food retailing) all show similar patterns. An analysis[4] suggests that the seed

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[1] *Patches of Light*. The Economist, June 9 2001 (www.economist.com/library)
[2] See, for example, the US Agriculture Secretary’s closing statement in a meeting with broadcasters at www.usda.gov/special/fapradio.html
[3] See *Towards Efficient Farm Support*. The Economist, June 9 2001 (www.economist.com/library)
[4] *Agricultural Biotechnology and Industry Structure*, Fulton M & Giannakas K, Agbio Forum 4 (2), 2002

and chemical industry remains dynamic. Mergers and acquisitions are a key component of the new business relationships. Tables of major chemical and seeds business are included at Annex B. The peak of consolidation occurred in 1996 to1998 and activity has now fallen to the average rate for the last two decades (around 2 per year)[5]. In Europe the biotechnology industry is centred on medical and pharmaceutical end uses. It is difficult to unravel the agricultural industry statistics. One analysis[6] which concentrated on France estimated that 100 biotechnology firms were created between 1997 and 1999. It showed that around 24 per cent of biotechnology investment is directed towards agrifood, agriculture and environmental markets. The dynamics of the north American market have also been reviewed[7]. This analysis covers the major crop developments – cotton, soya and maize – and the major players (see Annex B).

12. The value of the global food business is projected to rise steeply. At the same time, farming is accounting for a decreasing proportion of the value of food, which means that food processors, traders and retailers will in future account for an increasing share of the final cost of food.[8] There is continual pressure on farmers to produce food more cheaply. In response to this pressure, agriculture in the industrialised world is increasingly looking for profits from non-food commodities, such as fuels and replacements for chemical feed-stocks. Farming in more economically developed countries is moving from a bulk commodity industry to one producing specialised goods, with bulk commodities coming from countries where there are economies of scale or where labour costs are still cheap.

Global population

13. The world's population is growing. Estimates vary as to exactly how fast, but the UN estimates that the global population, at present 6 billion people, will be more than 9 billion by 2050.[9] To date, growth in agricultural production has outstripped the growth in population: world output of food per head has gone up by some 25 percent over the past 40 or so years, during which time population has risen by some 90 percent.[10] At present there is, in theory, no absolute shortage of food. There are however huge disparities in access to that food, as famine in some less economically developed countries clearly shows.

14. Another important dimension of the population/living standards debate is that there is a widening global gulf between rich and poor, but standards of living are nonetheless rising in most countries. One effect of this is a shift in diet: when people become more affluent they tend to eat more meat. This in turn leads to increased demand for cereals for animal feed.

[5] Ibid
[6] *French Ag-Biotech SMEs: Development Prospects*, Mangemation V, Lemarie S & Caterien D, Agbio Forum 4 (2) 2002
[7] *Structural Change in the Biotech Seed and Chemical Industrial Complex*, Hayenga M, Agbio Forum 1 (2), 2002
[8] *Growing Pains.* The Economist, March 25, 2000 (www.economist.com/library)
[9] The UN estimates can be seen at: www.un.org/popin/wdtrends/6billion
[10] *Growing Pains*. The Economist, March 25, 2000 (www.economist.com/library)

15. Most commentators do not expect production to keep pace with population without the application of new agricultural technologies or without bringing much more land into agricultural production. The latter presents a danger of reduced global biological diversity, of which the felling of the Amazonian rainforest is one of the more well-known examples. Disparity of access to food means that environmental degradation tends to be worse in those regions where people are hungriest.

Environmental pressures

16. A highly important environmental trend is the likelihood of climate change. One effect of the accumulation of greenhouse gases is widely thought to be more variable weather patterns, including a greater incidence of 'extreme' weather events, both floods and droughts; and possible rises in sea levels leading to loss of agricultural land. The agricultural industry will have to cope with the physical effects of such changes, as well as with the effects of policies designed to mitigate them. These include measures to take-up or 'sequester' carbon, and may in future involve increased taxation of energy.

17. Availability of water will increasingly be a problem for agriculture, as rates of irrigation and thus abstraction go up, and if rainfall patterns change with climate change. Desertification is a growing problem in a number of places in the world.

18. Another global environmental trend is the loss of wild habitats to development, including agriculture. International agreements such as the Convention on Biological Diversity are the beginning of efforts to reverse this trend, making expansion of agriculture an international as well as a national issue.

19. The quality of agricultural soils is becoming a global issue, with many countries, both developed and developing, suffering problems of soil erosion, salination and accumulation of heavy metals and pesticide residues.

The growth in organic farming

20. The organic farming sector is growing rapidly in some countries. Although it represents a very small percentage of agricultural activity in the EU, it is growing rapidly. There were more than 100,000 organic farms, or farms converting to organic production operating in 1998, as compared with 6,300 in 1985, though inevitably the organic farming situation differs from one EU Member State to another[11]. In the UK, the amount of farmland under organic cultivation or being converted to organic cultivation was around 527,000 hectares at the end of 2000, about nine times the amount in 1996[12], and about 2.88 percent of agricultural land. International trade in organic produce is increasing as countries, including the United Kingdom, find it

[11] *Organic farming, Organic farming as part of sustainable agriculture in Europe*, European Commission, DG for Agriculture, 2002
[12] Source: DEFRA statistics: http://www.defra.gov.uk/farm/organic/stat.htm

impossible to meet demand from indigenous supplies. Anecdotal evidence appears to indicate that the reasons that consumers buy (and often pay more for) organic food are primarily to do with health (less pesticide residues) and secondarily about the environment. A debate is emerging, however, about the real meaning of organic standards, how well they are policed, and the benefits claimed for organic produce.[13]

21. A possible knock-on effect of the growth in demand for organic produce has been to make some food interests look at lower-input farming, as a way of meeting demand for more 'sustainable' produce.[14]

Public opinion

22. Increased awareness about the environment and concerns about food safety have also led to a vigorous debate about the nature of risk and governments' handling of it. A succession of events perceived as stemming from inadequate handling of risk have in some countries led to a crisis of confidence in both governmental and corporate ability to assess and manage the consequences of new technologies and practices. The BSE crisis in the United Kingdom is a prime example in the area of food safety. It focussed attention on the relationship between scientific advice and policy and highlighted crucial gaps in scientific knowledge about the long-term effects of certain agricultural practices (feeding animal products to herbivores) on animal and human health.

23. Alongside the pressure for liberalisation coming from individual governments and organisations like the World Trade Organisation (WTO) and the Organisation for Economic Co-operation and Development (OECD), there are in some countries anti-globalisation networks which object to what they see as a shift from accountable, if not always adequately so, national government to unaccountable transnational corporations and organisations. Future control of the food chain, and the consequences for individual consumers and farmers, is one of the subsidiary concerns of these networks, with an emerging theme of the need to 'localise' food production. On the other hand, many people see the pressure groups voicing this concern as themselves unaccountable and undemocratic.

24. The public response to those companies and authorities that have been responsible for the introduction (or attempted introduction) of the first generation of biotechnology products also forms an important part of the context for the introduction of any future technologies. In Europe, and particularly in the UK, early acceptance of GM tomato paste and vegetarian cheese was replaced by widespread public scepticism, accompanied by hostility directed at the companies, the regulatory authorities and farmers, and an unwillingness by major retailers to stock GM foods. The strands of opinion are analysed in more detail in the AEBC's first report, *Crops on Trial*.[15] The

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[13] See, for example, *Nature*, 16 August 2001, p. 666.
[14] See, for example, *Growing for the Future – Unilever Sustainable Agriculture*, and www.unilever.com
[15] Available at www.aebc.gov.uk

strong public reaction has led to the current political impasse in the EU on commercialisation of GM crops. A recent Eurobarometer survey shows similar reactions, although in different degrees, across Europe.[16] In the US there has apparently been more confidence in the regulatory authorities, greater acceptance of benefits, and overall less public resistance.

[16] *Eurobarometer 2001*, http://europa.eu.int/comm/public_opinion/archives/eb/eb56/eb56_en.htm

PART 2: IMPLICATIONS OF THESE TRENDS FOR BIOTECHNOLOGY IN THE UNITED KINGDOM AS SEEN RESPONDENTS TO OUR SCENARIO CONSULTATION

Trade liberalisation and globalisation; consolidation of the agriculture industry

25. Farming in the UK faces particular uncertainties at present, in addition to the effects of global trends. Farming in the UK is diverse and regional needs and practices differ, but there are some common themes. Consumer concerns over food scares such as BSE, and the effects of foot and mouth disease, have caused a drop in consumer confidence in UK farm products as well as loss of export markets. British farmers feel disadvantaged in the international market at present because of the strength of sterling. They have been hit hard in recent years by some extreme weather conditions and will feel further penalised if they are subject to new measures, for instance a mooted pesticide tax or energy tax in pursuit of global warming policies. The food processing and retail industries exercise increasing control over agricultural products and practices, while trying to drive down prices. Farm incomes are dropping (average incomes per farm dropped by 92% over the last four years in Northern Ireland)[17] and the average age of farmers is increasing, indicating the lack of opportunities in the business for young people.

26. United Kingdom Government policy is to press for reform of the European Union Common Agricultural Policy (CAP) in order to move away from price support for agricultural goods towards a free market, and to provide instead direct financial subsidy for the creation of environmental benefits from agriculture. The extent to which this becomes the position in the United Kingdom and Europe will not become clear unless and until CAP reform is agreed by European Member States. The UK also now has to take account of the effects of devolution, which has given Scotland, Wales and Northern Ireland strengthened powers to determine to some extent their own policies on agriculture and biotechnology. At the same time, the EU is planning for the accession of states which have large agricultural sectors and which may demand support for agriculture as a recompense for the effects of joining the EU on their less developed manufacturing industries.

27. The big retailers are in a position to satisfy demand for both low-cost food and premium ‘niche’ products such as organic food and, if UK production does not meet either price or quality criteria, increasingly source their products from outside the UK. Examples include cheap, intensively produced chicken from Thailand, organic beans from Egypt, and animal feed from Brazil. As well as continually driving down the prices paid to UK farmers, this exporting of agricultural production also means exporting environmental and social externalities to other, often developing, countries, beyond the control of UK

[17] Ulster Farmers Union at AEBC Belfast meeting on 13 September 2001

policies, and increasing 'food miles', the distance over which products travel from farm to plate.

28. A recent review[18] by Professor Sir John Marsh for the UK Government Foresight Programme presents one view of the dilemmas faced in Europe:

> 'In cultural and political terms the development and application of biotechnology is controversial. Some possibilities such as human cloning are widely regarded as unacceptable. Others, like genetic testing for predisposition for disease, raise acute questions for traditional ways of handling risk via insurance principles. For some groups the whole idea of manipulating genetic material by anything other than traditional means of plant and animal breeding is regarded as an immoral intervention in the processes of life. More generally there is caution about the potential but unproven negative impacts of using a new technology. These are commonly voiced in terms of environmental impacts but can extend into anxieties about the transfer of political and economic power to the large corporations who alone can afford the costly research from which new products emerge.
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> Communities vary in their reaction to these issues. In affluent and traditional societies including much of the EU negative voices tend to dominate the debate. There is a persistent questioning of the integrity of the scientist, of the objectivity of scientific committees that advise governments and a strong emphasis on possible but improbable catastrophic outcomes. Allied to a sense that 'things are alright as they are' governments are reluctant to confront such anxieties and readily succumb to the convenience of the precautionary principle. This avoids the need for decision now but does not take account of the long-term damage that may result from such inertia.
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> In competitive terms this can be considerable. Other communities, which feel more keenly the need to increase output or which are more ready to explore new technologies, will seek to make use of the new science. As they do so the real costs of production within their communities will tend to fall. The problems encountered will be assessed and appropriate response made and the biologically based industries move into a new era as different from contemporary production as today's methods

[18] *Agriculture in the UK – Its Role and Challenge*, a discussion paper by John Marsh, UK Government Food Chain and Crops for Industry Foresight Panel, September 2001.

are from those of the eighteenth century. For the UK and the EU this is a cumulative disadvantage. Ultimately it may prove so large that a major ‘catching up’ programme will be needed. However, that could prove structurally disruptive, costly and painful for the businesses that prove to be obsolete.’

29. The global trends of liberalisation and consolidation have to be seen against this background. Most of the respondents to our scenarios consultation paper (see Annex D) saw these trends as something to which UK farmers would continue to have to adapt, in particular the progressive dismantling of economic support linked to food production, which was likely to be the consequence of reforms of the CAP[19]. A common view was that only a minority (in one view, only 5-10%)[20] of the largest UK farmers would then be able to compete on world markets for bulk commodity crops (e.g. wheat, oilseed rape) leaving the rest to explore either internal markets for food, or to diversify away from food into ‘speciality’ non-food crops for both domestic and international markets.

30. For some respondents biotechnology was a means by which more UK farmers could hope to compete on world markets. For instance, the comment: ‘they [current GM crops and those close to commercialisation] could reduce costs and simplify cultivation techniques, increasing economic viability and international competitiveness’[21]. Similarly: ‘GM technology, if shown to be environmentally safe, may be a useful way to help reduce the costs of production (for large farmers).’[22] From the Northern Ireland perspective: ‘a recognition that GM crops were being grown widely in other parts of the world and a fear that Northern Ireland could be left behind and made uncompetitive if GM technology is not permitted here’, but at the same time awareness that, ‘if consumers did not want to buy GM products then there would be no market for farmers’ produce based on the technology’[23]. Overall, however, there was a feeling that the availability or non-availability of GM innovations would take some time to become crucial: ‘The effect of rejection of GM crops would not be significant in the short-term, but non-implementation of biotechnology could in medium to long-term see a major decline in the competitiveness of Scottish agriculture compared to elsewhere in Europe and world-wide’.[24]

31. Some saw GM as intensifying the trend towards larger farms, which was undesirable: ‘UK policy seems, without consultation, to be directed towards reducing levels to a very small number of even larger farmers, complemented by massive imports….The UK needs to produce food in the UK’.[25] Others saw higher food imports as the consequence of rejecting GM, if other countries accepted it: ‘Farming and all land-management for wildlife

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[19] For example, NFU, UFU, RSPB, Royal Society of Edinburgh, IACR submissions in response to AEBC Consultation Paper on Future Scenarios for the Uptake of GM in Agriculture, June 2001
[20] RSPB submission in response to AEBC Consultation Paper
[21] Royal Society of Edinburgh submission in response to AEBC Consultation Paper
[22] RSPB submission in response to AEBC Consultation Paper
[23] Minutes of AEBC Belfast evening meeting, 13 September 2001, Ulster Farmers Union presentation
[24] Royal Society of Edinburgh submission in response to AEBC Consultation Paper
[25] Five Year Freeze submission in response to AEBC Consultation Paper

conservation and amenity use would have to be heavily subsidised and would probably become unaffordable. UK would become almost totally reliant on imports of food and non-food agricultural products. Farming and food production in the UK would be a 'cottage industry' at best'.

32. There were several strong points made about the role of biotechnology in domestic markets. 'With 60 million of the richest consumers in Europe…on their doorsteps, UK farmers are likely to turn their attentions inward to national markets. They are likely to focus on quality, value-added products. With the current feeling of the public it is unlikely that GM crop products could be used to enhance quality aspects of food. Therefore, over the next 10-20 years GM crops are unlikely to provide a solution for the majority of UK farmers'.[26] Another went further: 'farmers in the island of Ireland should turn the issue of consumer choice into a competitive advantage by making their farms entirely GM-free'.[27] Similarly: 'Scotland might be able to become a niche supplier of non-GM products. However, in the longer term with an increasing market share, present premiums for non-GM crops could erode.'[28] Another view saw GM as creating a new niche market: 'There are likely to be strong pressures to minimise long distance transport and this could create high value niche markets in exotic crops (that are currently imported) modified to grow in UK conditions'.[29]

33. Several people commented that enforcing GM-free status for the UK would be impossible, possibly illegal under international agreements, and that contamination was almost inevitable. For example: 'As the use of biotechnology elsewhere in the world increases, there would begin to be a black market trade in seed. Growers striving to ensure that they stay market competitive would be tempted to ignore restrictions on approval of varieties. Brazil, where GM crops are not presently approved, is a good example of this as already some 30-40% of the soya and maize grown in the south of the country is GM'.[30]

34. GM crops were seen by some as having a role in the development of new, speciality crops such as: 'cereal and oil-seed products for industrial feed-stocks and other non-food uses; production of fine chemicals, energy crops, novel fibre-crops and even plant-based heavy chemical production….The production of high-value products from crops may mean that crop production for this purpose and/or systems of production based on fermentation technology may eclipse food production and processing in economic terms, thereby altering the economics of food production and possibility increasing dependency on exports'.[31] Others questioned the balance between food and non-food production: 'How does (industrial production) fit with the need to maintain and increase food production'?[32] and, 'Crops producing raw

[26] RSPB submission in response to AEBC Consultation Paper
[27] Brian Black at AEBC Belfast meeting, 13 September 2001
[28] Royal Society of Edinburgh submission in response to AEBC Consultation Paper
[29] IACR submission in response to AEBC Consultation Paper
[30] Royal Society of Edinburgh submission in response to AEBC Consultation Paper
[31] IACR submission in response to AEBC Consultation Paper
[32] Five Year Freeze submission in response to AEBC Consultation Paper

materials for industry should only be considered when food requirements are fulfilled'.[33]

35. Two comments about the acceptability of industrial crops which we received were: 'The use of GM technology in industrial crops is likely to be more acceptable to the public (because they do not have to eat them). Therefore we expect that the technology will develop faster in this sector than in others. However, from an environmental point of view, the same questions will need to be answered.'[34] But also: 'Please remember that a lot of crops which are used for non-food uses produce residues which are used with animal feeds as well, so there is not a total distinction, some part of non-food use output goes back into the food chain indirectly.'[35]

36. One respondent prefaced his response to the scenarios with a set of questions about the UK's role in global agriculture, that perhaps have added relevance following the events of September 11th: 'Does the UK have any agricultural future at all? Should the country not simply import all its food for the best price we can get? Or should we grow some products for domestic consumption, and if so, which ones? Does the UK still aspire to the possibility of food self-sufficiency in case of war?'[36] The events in the USA may well have a significant impact on agricultural production. Food self-sufficiency in the UK currently stands at 63% for all products, and around 75% for those products that could be grown here.[37]

Environmental pressures

37. As environmental awareness has increased, economists have begun to value the external costs of agriculture i.e. costs not included in the price of agricultural goods. One report has valued the external costs of agriculture in Europe, including the costs of cleaning up pollution, at a figure approaching the value of the industry's earnings.[38]

38. For some respondents, biotechnology was seen as key to addressing environmental problems, particularly the use of non-renewable sources of agricultural inputs (fertilizers and pesticides) and energy, and their implications for global warming. For instance: 'High priority must be placed on the development of sustainable technologies that substitute for the unsustainable reliance on non-renewable inputs….GM technology offers opportunities for increased resource capture efficiency by crops that are not

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33 Farm and Food Society submission in response to AEBC Consultation Paper
34 RSPB submission in response to AEBC Consultation Paper
35 Ian Gardiner, NFU, at AEBC Birmingham meeting, 18 July 2001
36 CropGen submission in response to AEBC Consultation Paper
37 Table 2.2, Agriculture and food in the national economy, *Agriculture in the United Kingdom 2001*, DEFRA 2002
38 Pretty J, Brett C, Gee D, Hine R E, Mason C F, Morison J I L, Raven H, Rayment M and van der Bijl G, 2000. An assessment of the total external costs of UK agriculture, *Agricultural Systems* 65(2), 113-36
Pretty J, Brett C, Gee D, Hine R E, Mason C F, Morison J I L, Rayment M, van der Bijl G and Dobbs T, 2001, Policy challenges and priorities for internalising the externalities of agriculture, *Journal of Environmental Planning and Management 44(2),* 263-283.

available through the conventional genetic improvement processes of hybridisation, recombination and selection based on natural genetic variation within a species and its close relatives.'[39] Similarly: 'the need for renewable raw materials (e.g. energy crops) is so great that we don't have the luxury of waiting for normal plant breeding techniques to become feasible to develop such crops, when new technologies may already offer methods. We shall be very short of land (though not food) and land will be needed to produce crops for industry, as well as food and environmental goods.'[40] One respondent identified three ways in which biotechnology could be relevant to global warming and climate change: 'first, …existing food crops such as wheat, oilseed rape and barley could be genetically modified to tolerate the wetter winters and springs, drier summers and overall increasing average temperatures that we expect in the UK…", second, "different crop varieties that are better suited to the prevailing climate will increasingly be used.. genetic modification may well have a role to play in this…", third, "…genetic modifications might be seen as having a role to play in the production of industrial (energy) crops.'[41]

39. Some respondents commented on the difference between market-led development of biotechnology and development somehow directed towards the goals of sustainable agriculture, accepting that there are no clear definitions (many people commented that the MAFF definition of sustainable agriculture quoted to provide a starting point was not adequate). 'Market led development could contribute to introduction of 'clean' technologies into UK agriculture, without specific Governmental policy guidance, and this would increase environmental sustainability. For example, growing crops with improved pest and disease resistance could reduce pesticide application rates and improve conservation value. However, there will be an unquantifiable effect on pest numbers and hence on their predators and benign insects, and so on further up the chain of predation. In addition, if farmers opted for totally 'clean' fields (without any weeds or pests) there would be little for wildlife to benefit from and this could lead to declining conservation value for agricultural land.'[42]

40. One respondent commented, however, that: 'under current legislation, GM products are more likely to promote sustainable agriculture than non-GM products. Under the newly-amended GMO deliberate release Directive, GM products may not be approved if their management system is shown to have a greater "indirect" impact on the environment than existing systems, whereas there is no provision for conventional crop varieties to be assessed in this way. Thus the new Directive is the first step towards guiding the development of new GM agricultural products.'[43] Similarly: 'I think it is unlikely given the high degree of regulation which surrounds the introduction of new crops that it would fail to increase sustainability in the environmental sense.'[44] Others

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[39] IACR submission in response to AEBC Consultation Paper
[40] Ben Gill, NFU, at 11th June 2001 Horizon Scanning Sub-group meeting
[41] RSPB submission in response to AEBC Consultation Paper
[42] Royal Society of Edinburgh submission in response to AEBC Consultation Paper
[43] English Nature submission in response to AEBC Consultation Paper
[44] Ian Gardiner, NFU, at AEBC Birmingham meeting, 18 July 2001

identified a policy led by 'sustainable agriculture' as involving different research priorities to a 'market led' policy: 'The focus will be on traits to reduce reliance on non-renewable inputs, to enhance resource-use efficiency and to allow the production in plants of industrial feed-stocks and other materials currently reliant on energy-demanding chemical synthesis. This is a genuine "green" agenda and one that will demand the appropriate financial framework to achieve because it cannot and will not be driven exclusively by the market.'[45]

41. Others saw no role for GM in environmental improvement. 'Environmental benefits all sound wonderful in theory, but there is no kind of proof that these dreams can be realised more rapidly than benefits that could arise through other means, e.g. reduction of consumption, no-till agriculture without herbicides or genetic engineering, variety mixes. And then there are so many unknowns to be factored in – unpredictable interactions and side effects, which cannot be foreseen or indeed tested for.[46] 'For agriculture to be truly sustainable quite specific guidelines need to be followed including commitments to a self-sustaining farm cycle in which external inputs are kept to a minimum; using resources which can be replenished within the economic and biological processes of a farm; ensuring that the economic and social well being of the immediately affected community is of primary consideration; maintaining inherited fertility of the land and providing for its improvement for future generations; recognising and valuing the integrity of all life forms, human, animal and plant. Given these criteria it is hard to imagine how biotechnology as it is currently understood can contribute to the development of sustainable agriculture.'[47] One respondent said that rather than looking at GM or non-GM, 'the fundamental question is whether the UK should have a strategy to encourage products and practices that support sustainable agriculture, and how this might be achieved. If the UK did choose to adopt a strategy to promote sustainable development and take-up of crop varieties consistent with the aims of 'sustainable agriculture' it would need to be a holistic strategy that took into account the needs of all stakeholders. Crops and animal species, varieties, rotations and management practices would all have to be considered in an integrated fashion to ensure a diversity of farming systems which can provide a range of desired outputs (food, fuel, biodiversity, groundwater protection, air quality, animal welfare, economic viability, social acceptability etc.)'[48] Several respondents cited mixed farming as potentially more sustainable[49] against a growing trend of specialisation.

42. A key component of sustainable agriculture was seen as locally-appropriate varieties. For instance 'the sustainability of soil fertility and structure was already an issue in the USA, eastern Europe and Australia, with some areas suffering severe soil degradation, because of adapting the land to the crop rather than the other way round. Marker-assisted breeding and genomics had scope for crops that are better adapted to soil conditions than

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[45] IACR submission in response to AEBC Consultation Paper
[46] Five Year Freeze submission in response to AEBC Consultation Paper
[47] Biodynamic Agriculture Association submission in response to AEBC Consultation Paper
[48] English Nature submission in response to AEBC Consultation Paper
[49] English Nature, NFU, Five Year Freeze submissions in response to AEBC Consultation paper

at present….Within the next 15 years there could be hybrid varieties especially designed for any particular areas, particularly if apomixis is introduced into crop plants.'[50] Similarly, 'since seed listing is national, varieties may not be well-matched to individual localities.'[51] A workshop in July 2001 convened by The Environment Council explored the potential of plant genomics to support organic and sustainable agriculture. Various issues were raised, including the need for locally-appropriate varieties, and varietal mixes (i.e. seed containing different strains to cope with a range of conditions) contrasted against the demands of the national seed listing system for distinctiveness, uniformity and stability, raising the question, 'Is the seed registration process facilitating or hindering plant breeding towards a more sustainable direction?'[52] Some of the issues raised at the July workshop were addressed at a follow-up meeting in February 2002. The February workshop reviewed and developed a crop specific research project (drafted by volunteers from the July workshop) to explore the potential for plant genomics to enable more sustainable forms of agriculture through non-transgenic applications.

Global population and development

43. The pressures exerted by a growing global population are relevant to the UK (whose own population is expected to continue to grow gradually from 60 million at present to some 64 million by 2025 and decline slowly thereafter[53]) in a number of indirect ways. There is UK development and aid policy, and the activities of the many development NGOs and agencies, which have implications for the way in which biotechnology is applied in less developed countries. There is the impact of biotechnology on countries that supply us with imports of food, and to whom we export. There is also the fact that when discussing the possible benefits of biotechnology, its potential to 'feed the world' or 'relieve famine' is often mentioned. The extent of this potential is not universally accepted.

44. Three recent issues illustrate the kind of tensions involved. The development of transgenic rice with added Vitamin A, aimed at reducing the blindness that results from severe Vitamin A deficiency, has been hailed as a major potential contribution to health in developing countries, and as an example of transnational companies donating their knowledge in the public good. Critics suggest that it is not yet clear how much Vitamin A the rice can provide, and that there may be environmental risks from using transgenics. The Department for International Development (DfID) has been criticised by some for funding the development of transgenic fish for use in less developed countries, where as there could be significant concerns about the potential environmental impact of transgenic fish if there were applications in the UK. Action Aid is campaigning against the development of GM coffee beans aimed at having coffee ripening uniformly, which the NGO suggests will favour larger

[50] Brian Johnson, English Nature, at 11th June 2001 Horizon Scanning Sub-group meeting
[51] Ben Gill, NFU, at 11th June 2001 Horizon Scanning Sub-group meeting
[52] The Environment Council – Exploring the potential for plant genomics to support organic and sustainable agriculture – Summary paper of a workshop held on 23rd and 24th July 2001
[53] *2000-based Population Projections*, Government Actuary's Department, November 2001.

coffee producers and damage the livelihoods of small-holders[54]. This scan has not attempted to look in detail at the issues facing individual countries but we have noted some generic concerns, from scenario respondents and from literature on the subject from the Department for International Development[55].

45. Despite increasing trends towards urbanisation, many people in developing countries are farmers, feeding themselves and trying to sell the remainder. A number of crop developments have been mooted as being of relevance to small farmers, for example virus-resistant papaya which is already having an impact on the Hawaiian papaya industry; Vitamin A rice; disease-resistant cassava, sweet potato and bananas; crops tolerant to saline soils and drought. However, the full potential of these developments, as well as attendant risks, is as yet unclear. These developments have relied on donation of intellectual property by private companies, rather than publicly-funded research efforts. One of our respondents noted that it was important that developing countries could make choices about what technology to employ: 'There is a need for increased yields to feed the growing world population. Need must always be given priority over profit. Individual countries should be given the necessary information and data to make their own choices on GM policy and its use. Pressure from global corporations or protest groups and enforced regulations from world organisations may not be helpful and can be counterproductive….GM is only one of the technologies available to help increase food production. The others should be given equal consideration and importance.'[56]

46. Some think that the stripping of developing countries' genetic inheritance of plants and animals appears to be a more likely prospect than benefit sharing between the developed world and developing countries. Developing countries do not always have the scientific or technical expertise to exploit this inheritance themselves.[57] One of our respondents noted that 'countries which are sources of wild germplasm, essential to deal with disease and climate change, feel themselves gravely threatened by GM. …We also need to consider the impact of proposed crop replacement using GM. If we destroy vanilla, banana, coconut industries through producing alternatives in the North, how do we address this as members of the international community?'[58] At the same time, there is a view that many developing countries actually benefit from the crops bred in the developed world both directly and by using them as breeding material.

47. Very sophisticated intellectual property regimes – see Part 3 on evolution of the biotechnology industry - would not be appropriate or possible for developing countries given their current levels of innovative capacity. In addition GM technology is mainly owned by the private sector in developing countries. There is thus an issue - access - about public/private research in

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[54] http://www.millennium-debate.org/ind17ma.htm
[55] *Trade, Development and Protecting the Environment*, DfID background briefing note, July 2001; *TRIPS and Development*, DfID background briefing note, October 2001
[56] National Council of Women submission in response to AEBC Consultation paper
[57] *Trade, Development and Protecting the Environment*, DfID background briefing note, July 2001
[58] Five Year Freeze submission in response to AEBC Consultation Paper

relation to the developed world which is additional to the main issue - public trust - in developed countries. DfID has set up an independent international commission on intellectual property rights to address these developing world concerns.[59]

Strengthened regulatory regimes in the developed world

48. Access to developed country markets is a key concern for developing countries. DfID note that moves towards labelling requirements based on environmental standards, application of the precautionary principle in developed countries and product discrimination based on process and production methods could lead to further barriers to developing countries' exports.[60] Extrapolating from these general concerns, a relevant example would seem to be EU proposals on GM traceability and labelling legislation: developing countries would seem likely to find it hard to meet the traceability standards being proposed. Separating out the market for GM and non-GM maize, for example, would be in many places impracticable due to the very small scale on which farms are run. Developing countries are not in a position to guarantee purity from GM, the labelling and traceability requirements, due to their less-sophisticated manufacturing and testing infrastructure. The implication would seem to be that stringent labelling and traceability requirements could effectively force developing countries to make a choice: either not to allow GM crops into their country so there is no risk of contamination, or forget about exporting to the EU. Some might argue that developed countries need to find ways of enabling developing countries to make their own decisions on whether or not to go down the GM route rather than effectively making the decision for them. Regulatory hurdles in agriculture particularly disadvantage many developing countries, where agricultural exports are particularly important.

The growth of organic farming

49. Perhaps not surprisingly, many commentators when asked to look to the future of biotechnology found it hard to look beyond the current issues around the co-existence of GM and organic agriculture. These issues are examined in detail in *Crops on Trial*, but the Commission is likely to return to the future practicalities of maintaining consumer choice between different types of products. This scanning exercise served mainly to highlight the urgency of doing so.

School student consultees

50. As noted above, public responses to GM in the context of the Farm Scale Evaluations were examined in detail for the AEBC's first report, *Crops on Trial*. Subsequently, the horizon-scanning sub-group hosted a session with Belfast school students, who further illustrated the diversity of views and responses to the technology and the factors that should be taken into account

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[59] *TRIPS and Development*, DfID background briefing note, October 2001
[60] *Trade, Development and Protecting the Environment*, DfID background briefing note, July 2001

when considering its potential.[61]

51. One group of students noted from their discussions that: 'about half the group thought it was justifiable to use the world as a manufacturing source, which involves manipulating the environment. The extent of this would depend on the science. It could be possible to have a model using ecological and biological techniques to find all the possible ramifications of a single change, and then assess whether the change was appropriate – the science gave a tool for making choices. Others in the group felt that it is the environment that manipulates people – the strongest survive, and people need to adapt, as evolution shows'.

52. The students saw concerns as being driven by for instance, fear of the unknown, long-term uncertainties, the idea of 'playing God', and the profit motive. At the same time, they saw a negative bias towards the technology in the media. One group reported that their general reactions were that 'there were obvious benefits and we don't know the long-term impacts'. One group said that 'we need to take account of farmers' views, and they need to stay competitive to survive.'

53. The students put a lot of emphasis on facilitating choice, and had strong views on decision-making, with comments such as: 'It is up to the ordinary person to make decisions, but how? We students couldn't affect the decision-making process and would have little say.' 'Everyone has their own opinion and there is a need for honesty, openness, communication and trust'. 'It is important to control, regulate and monitor development in the technology'. 'Public consultation might include focus groups, referendums and internet discussions'. They saw the internet as a potential tool for encouraging debate, but by no means the only one, and were aware of its limitations. These included that fact that there is not universal access, web-sites are not automatically interesting or trusted sources of information, and people may not interact with a web-site unless they have to, for instance as part of a syllabus.

[61] See minutes of the session on www.aebc.gov.uk/aebc/bel_discussion.htm

PART 3 THE TECHNOLOGY

BACKGROUND

54. This part outlines the most important trends in the development of biotechnologies for use in agriculture. More detailed data about the applications of modern biotechnology are set out at Annex A. The main focus of this outline of trends is on GM technologies, but some non-GM techniques which are aimed at similar outcomes are also covered, in paragraphs on 'Beyond GM'.

55. Applications are at different stages of development, but it is hard to pin down timescales due to a large number of variables. Not all of these developments will be successful in technical terms, or they might not meet criteria of commercial viability or public acceptance.

Which GM plants and animals are in, or close to, commercial agricultural production?

56. Globally, the main genetically modified crops in commercial production are cotton, soybeans, maize, oilseed rape (canola), and tobacco. Wheat and rice are also close to commercial production. Forestry trees, forage grasses, vegetables and fruit have also been genetically modified and a number of these are in development. Some, for example papaya, tomatoes, peppers and melons are in commercial production. Genetically modified animals in commercial production are sheep producing pharmaceuticals and those close to commercial production include fish. No commercial production of GM crops is underway in the UK, and approval in the UK for the commercial production of GM fish looks unlikely for some time to come because of concerns about the possible impact on the environment, but each application would be assessed on its individual merits.

How much commercial cultivation of GM crops is underway?

57. Thirteen countries grew GM crops commercially in 2001. Four countries account for 99% of current production of 52.6 million hectares (ha). In 2001 the biggest grower was the USA with 35.7 million ha (68% of the global total). Argentina had 11.8 million ha (22%), Canada had 3.2 million ha (6%) and China 1.5 million ha (3%). Of the principal countries China had the highest year-on-year growth with a tripling of its Bt cotton area between 2000 and 2001. The balance was grown in Australia, South Africa, Mexico, Bulgaria, Uruguay, Romania, Spain, Indonesia and Germany. In 2001, GM crop hectarage increased in South Africa and Australia by 33% and 37% respectively. [62]

Which crops?

[62] *Global Review of Commercialized Transgenic Crops: 2001*. C James, ISAAA Briefs No. 24: Preview. ISAAA, Ithaca, NY, 2001.

58. Of the total global area under commercial cultivation in 2001, GM soybean accounted for 63% of the total in 2001. The next most popular GM crop was GM maize, which occupied 19% of the total area of GM crops. The other crops are transgenic cotton (13%) and GM canola (5%). During the six-year period 1996-2001, herbicide tolerance has consistently been the most dominant trait, with insect resistance second.[63]

How quickly is commercial cultivation of GM crops expanding?

59. The rate of adoption since 1996 of commercial GM crops in the three principal growing countries, especially the US, is remarkable. From a standing start in 1996, globally an area twice the size of the United Kingdom's landmass is under commercial GM cultivation. During the six-year period 1996 to 2001, the global area of transgenic crops increased more than 30-fold, from 1.7 million hectares, in 1996 to 52.6 million hectares in 2001. GM crop cultivation is still increasing, but not as fast as at first. In 1999, there were 39.9 million hectares of land around the world under cultivation with GM crops. This represents an increase of 44% or 12.1 million hectares compared with 1998, when 27.8 million hectares were grown. The rate of increase between 1999 and 2000 slowed. In 2000, 44.2 million hectares were sown compared with 39.9 million hectares in 1999, an annual increase of 11% compared with 44% the previous year. The area rose 19% again however between 2000 and 2001, to 52.6m hectares, almost twice the corresponding increase between 2000 and 2001. [64]

60. Growth in the area of GM crops between 1998 and 1999 in more economically developed countries (MEDCs) was 3.5 times greater than in less economically developed countries (LEDCs), that is, 9.4 million hectares compared to 2.7 million hectares. In the following year the proportion reversed. Of the 4.3 million hectare increase between 1999 and 2000, 84% was in LEDCs – principally Argentina - compared with only 16% in the MEDCs (principally the USA and Canada). Thus, the area of GM crops in LEDCs grew by 51% from 7.1 million hectares in 1999 to 10.7 million in 2000, compared with only a 2% growth in MEDCs, from 32.8 million hectares in 1999 to 33.5 million hectares in 2000. However some 5.5million farmers are now using the technology, with three quarters of them from developing countries.[65]

61. Observers have posited a number of possibilities for the overall drop in the rate of growth, including relatively low prices for canola, a natural reduction in European Corn Borer numbers in the US in 1999 (leading farmers to expect similar low numbers in 2000 and to conclude that Bt resistance was at less of a premium) and a worry about markets for GM crops, particularly as a result of consumer concern in Europe.[66] One must be cautious in drawing

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[63] Ibid
[64] Ibid
[65] ISAAA Annual Report, quoted in Financial Times, 11 January 2002
[66] *Global Status of Commercialized Transgenic Crops: 2000*. ISAAA Briefs No. 21: Preview. ISAAA, Ithaca, NY, 2000; and *Global Status of Commercialized Transgenic Crops: 1999*. ISAAA Briefs No. 12: Preview. ISAAA: Ithaca, NY,1999.

general conclusions about GM cultivation in different countries because so few countries are engaged in significant levels of production.

62. It is expected that global area and the number of farmers planting GM crops will continue to grow in 2002 in the six principal countries that are already growing GM crops - USA, Argentina, Canada, China South Africa and Australia. The other seven countries growing transgenic crops in 2001 are expected to report modest growth in GM crop area in 2002.[67]

How is industry and research evolving?

63. The present configuration of the biotechnology industry has evolved from a series of mergers and demergers among companies concerned with the production of seeds, agrochemicals and pharmaceuticals as well as specific biotechnology start-up companies, often created to exploit the new genetic knowledge being acquired in academic institutions. This pattern of consolidation, together with the requirements of intellectual property rights, has led in some areas of agricultural production to control over genetic knowledge being concentrated in a relatively small number of corporations.

64. Research into plant breeding and biotechnology generally is increasingly in private hands, and the role of public research institutes is diminishing in some areas, with concerns that the role of public sector research may have diminished partly because of lack of investment and restrictions on exploitation of intellectual property. There is a view that the need for private interests to employ intellectual property regimes to protect their investments tends to restrict access to genetic knowledge and makes it difficult to have an early and open discussion of the goals and general direction of the technologies.

What kinds of modifications are being made to crops, trees, animals and insects?

65. This section sets out the main categories of development. Those already in or closer to commercial production are at the beginning of the lists. For each of 17 categories we have set out the aims of the application and some examples of possible benefits and risks, to signal some of the issues that would have to be addressed as part of a fuller technology assessment. A broader summary of work being carried out around the world on genetic modification can be found at Annex A. The AEBC would like to invite stakeholders to contribute to its ongoing development, which will help us to assess their possible impact on the UK.

66. There are a number of points we would like readers to bear particularly in mind, in reading this section and Annex A:

- We have tried to make the annex as comprehensive as we can and, where possible we give a timescale on which we might expect a

[67] See 62-65

particular development to be commercialised. However, much of the work listed is at a very early stage, and it is in the nature of scientific development that a significant number of these projects will not evolve into a marketable product.

- There are a large number of GM initiatives being taken around the world. Some are on the market, and some of those that follow, if marketable and proven safe to man and the environment, could impact strongly on UK competitiveness. For example, an increase in wool growth of 15% in sheep fed with GM sunflower would have a severe impact on UK farmers if others used this technology and the UK did not.
- A number of traits, particularly those that relate to pesticide reduction or a move to low tillage agriculture, could contribute to a more sustainable agriculture, and hence deserve a deeper study. A future AEBC study could usefully look at the environmental impacts of different agricultural methods.
- In later GM developments there will be many more crops which, now grown for food, will be grown for non-food applications - for chemicals, drugs and industrial feedstocks. The implications of such changes, for example in terms of separation distances, will need addressing. Although there are some crops now, like high erucic oil seed rape, which are grown solely for industrial use and grown at suitable distances from oil seed rape grown for food, the scale of such production could increase significantly over the next ten to twenty years.
- Many of the traits described here will be of interest in agriculture and will have been the subject of much original research. The patents will be owned by organisations both large and small. Ownership of germplasm and holding patents on technology concerns some people and is seen by others as an essential encouragement to investment in the development of technology. This is an area on which the Commission could, as a future task, help shed a little more light.
- If GM products continue to develop and expand around the world, trans-boundary issues will get more and more complex especially if the UK and Europe continues to be non-GM or if either has a segment of its population choosing non-GM options. The resulting problem of product segregation currently showing itself with GM maize and soya will become significantly amplified. In less developed countries the problem of possibly smuggled GM varieties is already evident, and in countries that might have different regulations from those of their neighbours, release of GM animals, fish and insects could pose particular problems. There is a clear need for internationally agreed regulations to deal with such issues.
- Commentators often point to the lack of consumer benefit in the early genetic modification traits that have been introduced to the market, but cost savings for the farmer and the production chain may find their way eventually to consumers in the form of cheaper food. A more efficient agriculture - with more effective weed and pest control - can also lead to a lower use of energy.
- For agricultural crops in development at the moment, the major species

with greatest frequency or likelihood of cross-pollination between GM and non-GM varieties are oil seed rape and to a lesser extent beet. However, if genetic modification is adopted in forage and amenity grasses and trees, for example, decision makers would need to think through the possible consequences of out-crossing in such species.

1. HERBICIDE TOLERANCE

67. **Aim**: Improved weed management and lower overall use of herbicide by allowing the application of a broad-spectrum herbicide that kills all weeds but not the crop. Tolerance has been engineered mainly to glyphosate and in some cases to glufosinate, in several crops of UK relevance: oilseed rape, beet and maize. It is being developed in wheat and barley too. There are other non-GM herbicide-tolerant crops especially those resistant to the imidazolinone class of herbicides. These have been on sale in the US since the early 1990s. In addition, certain crops have a natural resistance to herbicides. For example most grasses are resistant to the broad leaf weed-killer 2,4-D.

68. **Possible Benefits:** Lower costs for farmers, lower overall herbicide loading in the environment. The aim is to give farmers greater flexibility in weed management, because the herbicide can be applied at any time and can allow a period of biodiversity development in the field. Recent trials with GM sugar beet in the UK appear to support this[68]. The herbicide used is usually one which breaks down in the soil relatively easily and so does not accumulate in the soil to the same extent as would occur with some currently used herbicides. In the case of maize in the US the replacement of atrazine by glyphosate will result in the replacement of a persistent and soil mobile herbicide, which can cause groundwater problems with one that is readily degraded and non-toxic. In the case of soybeans the American Soybean Association (ASA) has released the findings of its first-ever conservation tillage study that shows how the availability of soybean seeds enhanced through biotechnology has allowed and encouraged farmers to implement reduced tillage practices that protect farmland from wind and rain erosion.[69] One result from the study is that 73% of the growers are leaving more crop residue on the soil surface than they did in 1996 when biotech-derived soybeans became available for commercial planting. Leaving crop residues on the soil allows for the increase in organic content within the soil, which is a critical element in reducing wind and water erosion of soil, and has the potential to reduce nutrient inputs to the crop. More than half the study group credited the introduction of biotechnology-derived Roundup Ready® soybeans as the factor that had the greatest impact on their adoption of reduced tillage practices in soybeans.

69. **Possible Risks**: Gene flow of the herbicide tolerance trait to other crops, to volunteers of the crops (which then may cause a weed problem in following crops) and to wild relatives of the crop. The latter is only relevant,

[68] *Weed Management for Agricultural and Environmental Benefits in GMHT Sugar Beet*, J.D.Pidgeon, A M Dewar, & M.J.May, BCPC Conference – Weeds 2001.

[69] *Tillage Study Findings Released by ASA*, News Release Nov 13, 2001.

however, where the crop has near relatives with which it can interbreed. In the UK this is relevant to GM oilseed rape and beets. Possible indirect effect on wildlife through changed weed management: less weedy fields could mean less food for insects, and thus less food for animals higher up the food chain, including birds. Some risk of run-off into water, although direct eco-toxicity is less likely than a contribution to overall pesticide loading which may trigger need for treatment of the water course if it is used for drinking water.[70] It is important that farmers using herbicide-tolerant crops rotate herbicide use to reduce the chances of resistant weeds appearing through sustained selection pressure, which would undermine the herbicide tolerance mechanism. The British Society of Plant Breeders has produced guidelines on this.[71] There is anecdotal evidence that this phenomenon may be emerging, for example, in Argentina, where repeated use of the herbicide may be resulting in resistant weeds.

70. **Further issues**: Tolerances other than glyphosate and glufosinate may emerge, raising their own questions about the impact of the herbicides being used. Herbicide tolerance needs to be seen in the context of biodiversity goals, how much diversity is desirable within farmland, as well as around it, and how might this be affected by widespread changes in weed management that might follow a rapid uptake in herbicide resistance, especially if it is used in several different crops. The same herbicide tolerance in different crops could have implications for rotations – glyphosate tolerant wheat and rape grown in the same rotation, for instance, could mean that the glyphosate tolerant rape volunteers would not be controllable by the glyphosate used on the wheat. This is an agronomic problem more than an environmental one, although if it means returning to selective herbicides it undermines the idea that herbicide tolerance is more environmentally friendly because of the lower impact herbicide being used. This suggests AEBC should be looking at research agendas to see if there is work on multiple crops for the same herbicide tolerance, and their likely markets, to see if it might compromise rotations.

71. Gene flow also needs to be looked at as a cumulative process, where there is the possibility of inadvertent 'stacking' of several different herbicide resistances in volunteers or wild relatives. An English Nature report[72] has already confirmed that this is happening in Canada, and AEBC should debate its implications, perhaps through the consumer choice group. Gene stacking would be of particular concern with grasses and trees because of the strong possibility of wild relatives - for instance herbicide tolerance has been engineered into apples and poplar, which have wild relatives in the UK, although no work is currently going on in the UK. Herbicide tolerance is being developed in the US for turf grasses. The UK regulatory system might well not give consent to GM grass where there was any possibility of crossing with wild relatives, but the possibility of grass seed arriving inadvertently with other crops or cargoes cannot be ruled out. This might be an area for further exploration by AEBC and links to other transboundary issues such as those

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[70] *The Environment Agency and Genetically Modified Organisms: Technical Report pp35-39*, Report by Environmental Resources Management and Green Alliance, August 2001 (ERM/GA report)

[71] BSPB guidelines

[72] *Gene-stacking in herbicide-tolerant oilseed rape: lessons from the North American experience*, English Nature research report Number 443, English Nature, February 2002

connected to insects and fish.

2. PEST RESISTANCE

72. **Aim:** To give crops in-built resistance to pests. Less relevant to UK than herbicide and fungal resistances, because UK climate means that there is less insect damage compared to that from weeds, and fungal and viral attack, although some insects do carry viruses and, through feeding, create wounds that open up sites for disease to take hold. Plants that are both insect-resistant and herbicide-tolerant therefore, could be sold at some future point in the UK. The main route has been through use of Bt genes, but other toxins are being explored. "Bt" is short for *Bacillus thuringiensis*, a soil bacterium whose spores contain a crystalline protein fatal to insects if ingested. Different versions of the Bt Crystalline (or 'cry') protein are toxic to different species of insect. Bt is used widely as a conventional insecticide on crops (including organic crops). What is new about the genetically modified Bt crops is that the crops have been modified to contain the part of the bacterium gene responsible for manufacturing the fatal, but highly insect specific, protein. It is important for future insect control that there are a variety of sources of insecticidal genes and candidates for these have now been identified. Three types are being investigated for GM strategies: the Bt family, Avidin and *Photorhabdus luminescens*.

73. **Possible Benefits:** Better control of pests, reduced chemical inputs. For instance, Bt cotton has allowed growers to reduce insecticide use and attain better control of these pests, which has resulted in increased yields. It is estimated that in 1999 cotton growers reduced insecticide use by 2.7 million lbs and made 15 million fewer insecticide applications per year since the introduction of Bt cotton. Cotton production has also increased, by 260 million lbs per year. Net revenues are estimated to have increased by US$99 million in 1999.[73] Bt genes have now been identified for the control of corn root worm which is the major maize insect pest in the USA. Again this should reduce the chemical load on the environment.[74]

74. **Possible Risks:** Impact on non-target species; development of resistance. There are concerns about the effect on species feeding on non-target species which have eaten insects which have themselves consumed a plant with Bt resistant genes, although a study undertaken in 1999 by Novartis found evidence that this was not a problem[75] and the US Environmental Protection Agency recently approved the continued commercial cultivation for a further seven years of Bt maize, concluding that it is environmentally safe.[76] A second concern was that pollen from Bt maize would harm the Monarch butterfly, which feeds on milkweed in and at the margins of maize fields. Extensive field studies have shown this not to be a problem.[77] Another

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[73] *Agricultural Biotechnology: Updated Benefit Estimates.* J E Carpenter and L P Gianessi, available at www.ncfap.org

[74] *Rootworm: A Biotech Boon? Corn designed to kill common pest stirs hope as pesticide alternative*, August 18, 2001, The Washington Post, Page A01, Marc Kaufman

[75] ERM/GA Report, p.44.

[76] See www.usinfo.state.gov/topical/global/biotech/01101701.htm

[77] *Bt corn good for growers and consumers*, October 30, 2001 Commentary from the Food Safety Network Krista Thomas and Douglas Powell.
See also: (www.pnas.org) & The EPA's registration action document

general concern with Bt is that insects will develop resistance to the cry proteins. To avoid this, farmers need to practice effective resistance management. The main suggested plank of this is providing refuge i.e. an area near the GM crop planted with a conventional variety of the crop. Only a few Bt-resistant insects would be likely to survive in the Bt field. The idea is that these resistant individuals would mate with the many non-resistant insects from the non-Bt refuge and the genes for resistance to Bt would be swamped by the non-resistance genes. There appears to be some evidence that a significant proportion of farmers in the US are not creating suitable refugia[78]. On the other hand, Bt resistance does not appear to have developed in to a major problem so far. As outlined above, providing farmers with different sources of insect resistance will be another way of offsetting the development of resistance.

75. **Further Issues:** Consideration is needed of the impact on organic farmers using Bt if resistances did develop. This is not likely to be a problem in UK since corn borer is not present, but could be if the climate continues to warm. A full technology assessment might take account of which pesticides are being replaced in which crops.

3. FUNGAL RESISTANCE

76. **Aim**: To enable crops to resist fungal attack.

77. **Possible Benefits**: Reduced crop loss from fungal attack; reduced use of fungicides, depending on the disease – there are different levels of efficacy of chemical treatments of different diseases. Fungicides cannot be readily used to control soil pathogenic fungi. GM resistance is therefore of great value. The International Potato Centre in Lima, Peru has been cited as estimating that late blight caused by the fungus *Phytophthora infestans*, costs potato growers worldwide about US$3 billion a year.[79] Another fungus causing early blight costs an estimated US$21 million to $44 million per year to control in the United States and Canada alone. Wheat is another crop that suffers significant fungal losses, including in the UK and resistance to *fusarium* (which produces carcinogenic mycotoxins on the crop and is thus a food safety issue) is under development. Chemical treatments for fusarium have low efficacy. In sunflowers, a potentially important crop in the UK, sclerotinia head rot (white mould) is a major problem and can be controlled using genes from wheat. Sclerotinia affects sunflower growers worldwide. For example, last year, it affected more than 80 percent of sunflower fields in eastern North Dakota, the leading sunflower producing state in the US. It has reached epidemic proportions not seen since 1986 with estimated losses of nearly $100m in 1999. Viable sclerotinia bodies can remain in the ground for eight years, and the disease has eliminated sunflower production in some areas such as Ohio. In strawberries, grey mould is being targeted with genes from pears, since no resistance genes are known from strawberries. The disease is of great economic significance for strawberry growers in the UK

(http://www.epa.gov/pesticides/biopesticides/reds/brad_bt_pip2.htm)

[78] See the Colorado University News Update at http://www.colostate.edu/programs/lifesciences/TransgenicCrops/janmar2001.html#breakrules, which refers to the report on this subject in January 2001 from the National Corn-Growers Association.

[79] *Engineered Potato*, Nov 29/00, Reuters, Maggie Fox, Health and Science Correspondent

and elsewhere in Europe. There is a suggestion that fungal resistance would mean healthier root systems, better able to take up water and nitrogen.[80] Fungal disease requires the application of regular high doses of fungicide to banana crops. Fungal resistance, by means of GM, could lead to reduced usage of chemicals in banana production.[81]

78. **Possible Risks:** Non target effects (perhaps affecting mycorrhizal associations with roots); spread of genes to wild relatives, perhaps affecting their susceptibility to fungal attack; development of resistance in the fungal pathogens.

79. **Further Issues:** If climate change makes the climate wetter, this could exacerbate fungal diseases. Reduction in soil-borne fungal diseases in a crop such as wheat may make it possible to grow wheat more frequently, which may have implications for rotations. Genetically modifying crops near to where they originate (e.g. potatoes in Peru) may carry risks of cross-pollinating land races (wild varieties) and complicating their use in future breeding programmes.

80. Work on fungal resistance is very difficult for a number of reasons, including the natural ability of the pathogen to change, the complexity of safety testing for the food product, and - most importantly – because resistance would involve polygenic (more than one gene) changes, since single genes do not provide sufficient protection. Substantial improvements in fungal resistance have been made by conventional plant breeding techniques which exploited resistance mechanisms in closely related species.

4. VIRAL RESISTANCE

81. **Aims:** to enable crops to resist viral attack.

82. **Possible Benefits:** There are no known chemical treatments for viral diseases – the pest carriers of the viruses are the targets. Benefits may be the elimination or reduction of the use of aphicides (to kill aphids, which spread many plant viruses) and which are particularly environmentally harmful in some contexts.[82] For instance, for potatoes, to avoid Potato Leaf Roll Virus (PLRV) farmers spray their crops with pesticides up to eight times between planting and harvest to control the aphids, in an attempt to prevent infection[83]. At least ten important viruses affect the potato: some are spread to the aerial parts of the plant and others dispersed by soil inhabiting organisms. In the UK, six viruses are particularly damaging in some regions and in some years. Combining resistances through traditional plant breeding is massively time-consuming, hence the interest in GM. Transgenic resistances have been developed against all of the major viruses of the potato crop and are being tested in Australia, Canada and the USA. In Hawaii, virus-resistant papaya has been commercialised and has reduced the threat of crop loss. In the UK context, a key target would be Barley Yellow Dwarf Virus.

83. **Possible Risks:** There is a general environmental concern around GM virus resistance technology, which is the possible creation of more virulent

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[80] ERM/GA report.42

[81] www.farmacule.com

[82] ERM/GA Report, p43

[83] Solomon-Blackburn, RM & Barker, H (2001) *Breeding virus resistant potatoes (Solanum tuberosum): a review of traditional and molecular approaches.* Heredity, pages 86, 17-35

viruses as a result of the re-combination of virus particles within the GM plants with wild viruses. The latter can be avoided by careful selection of coding sequences and should be watched carefully by expert regulators. Little is known about virus ecology. If pest resistance is the route to virus resistance, the same issues apply as cited under 'Pest resistance'.

5. BACTERIAL RESISTANCE

84. **Aim:** To enable crops to resist bacterial attack. Bacteria are associated with a wide range of disorders, particularly poor harvest. Very large losses are associated with bacterial rot of fruit and vegetables e.g. in storage, transport and on supermarket shelves.

85. **Possible Benefits:** For grapevine, resistance to Pierce's disease (caused by the bacterium, Xylella Fastidiosa) could increase production which would bring down the price of better quality Chardonnay and other grape varieties.

86. **Possible Risks:** Spread of genes to wild relatives, perhaps affecting their susceptibility to bacterial attack; development of resistance?

6. A-BIOTIC STRESS RESISTANCE

87. **Aim:** To make plants resistant or tolerant to stresses other than those caused by pests and weeds (biotic stress) for instance frost, heat, drought, water logging, salinity, heavy metal concentrations.

88. **Possible benefits**: Plants able to grow in areas where they previously could not could make a significant contribution to food production in some countries. One recent significant development is the insertion of a single gene from a relative of the cabbage into a tomato plant to create the first tomato crop able to grow in salty water and soil[84]. Further examples include work on aluminium tolerance in maize and salt tolerance in grass for sheep farming[85]. Stress resistance might enable new crops to be grown in the UK – for instance cold tolerance could enhance the growing of maize, sunflowers and soya.

89. **Possible risks**: Plants would become adapted to previously hostile environments and thus able to invade and colonise them, gene flow would still be an issue.

90. **Further issues**: It could be argued that the ability to adapt plants to polluted environments could mean less incentive to remove the pollutant. It could alter patterns of crop growing, enabling new crops to be grown in some areas, which may change landscape, patterns of labour use, and trade.

7. INCREASED YIELD

91. **Aim:** Significantly higher yields from staple crops. There are several pieces of work that offer this prospect. Rice yields, for example, may benefit from two approaches, one in which the more efficient maize photosynthetic machinery has been introduced to the rice plant, another which incorporates a

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[84] E Blumwald and Hong-Xia Zhang, *Nature Biotechnology*, August 2001
[85] CSIRO, Australia

dwarfing gene, which means that more of the crop's energy goes into grain yield rather than vegetative growth. Work on wheat is of high relevance to the UK.

92. **Possible benefits**: Increased yields of the order of 29% were found in trials of GM wheat[86]. More efficient use of inputs. Maintaining yields with lower inputs.

93. **Possible risks**: Increased yields means increased use of inputs, which if that means inorganic nutrients, could mean depleting the organic content of soils. Gene flow might be an issue if there is the possibility of altering the vigour of wild relatives of the crop.

94. **Further issues**: Consumer acceptability and preservation of consumer choice are major issues in relation to genetic modification of staple human food crops. On the other hand, substantially increased yields from GM crops could leave arable farmers not using GM crops at a severe competitive disadvantage. All the foregoing developments may have some effect on profitability either by increasing yield or reducing costs. This raises the general issue of competitiveness, which could merit a specific AEBC study.

8. FOOD PRODUCT QUALITY

95. **Aim:** A range of modifications aimed at changing the qualities of the crops, to improve the nutritional storage or processing qualities of the crop, and to offer benefits to the consumer.

96. **Possible Benefits:** Biochemical studies have uncovered the pathway by which plants make vitamins, pigments, phenolics and other phytochemicals. Plants are being created with enhanced levels of these chemicals to produce foods designed to offer health benefits to people in the developed and developing world. Two of the most notable examples have been vitamin A rice, designed to address widespread vitamin A deficiency in some developing countries, and high lycopene tomatoes. Lycopene, responsible for the red colour in tomatoes, has been shown to protect against colon cancer. These developments, together with advances in understanding of the human genome, might ultimately offer the prospect of diets designed according to individual human genetic profiles. With the increased knowledge of plant biochemistry there is now greater familiarity with the major biochemical pathways used by plants in making starches and oils. Oil and starch-producing plants can be genetically modified to produce more or different starch or oil. Products range from industrial starches and oils to healthier (higher oleic) oils in human food. A crop of possible high UK relevance is fructan-producing sugar beets. Fructans are fructose polymers of commercial interest as replacements for high calorie sweeteners and fats. Short chain fructans have the same sweet taste as sucrose, but provide no calories. Humans lack the fructan degrading enzymes necessary to digest them. Other avenues being explored include a range of fruit with extended storage or shelf life and non-browning potatoes. Such products could potentially make significant contributions to solving problems of food wastage. The ripening control technology used in the UK on tomatoes could be applied to bananas and pineapples. A global consortium of publicly funded institutes

[86] Smill, 1999

will supervise a five year project to identify the banana genome, the first edible fruit to receive this treatment.[87]

97. **Possible Risks:** In crops where out-crossing is possible, such as rape, beet and sunflower, the implications of any modifications getting into the food chain inadvertently would require consideration. Nutritionally-altered foods pose a challenge for the risk-assessment systems in trying to assess their risks, since boosting any particular nutrient could have risks as well as benefits.

98. **Further Issues:** There are issues of co-existence and segregation, since in this instance, producers would want to keep the streams separate because of their higher value. Gene flow is less of a worry in the bananas example because half the edible banana varieties in world production today are sterile and can only be propagated with cuttings. Ripening control could also be applied to coffee. At present picking is by hand because ripening is so random. But it has been argued that the converse of large-scale production of cheaper coffee threatens the livelihoods of many of the poorest smallholders in the developing world, whose production of this valuable cash crop is viable partly because of the variable ripening of coffee beans.[88] On a global level, biotechnology raises the prospect of product substitution, manufacturing products previously obtained or manufactured in other ways. Some of these products, such as vanillin and cocoa, have been key to the economies of particular less economically developed countries. This effect could be relevant to the UK, if biotechnology enables the growing of certain crops in different environments than is possible at present.

99. Food products and their safety are issues on which the Food Standards Agency and the Advisory Committee on Novel Foods and Processes (ACNFP) is in the lead.

9. ANIMAL FEED QUALITY

100. **Aims:** The vast majority of work to genetically modify broad acreage crops is directed at improving the quality of animal feed. Examples include grain with increased oil or protein content and the introduction into lupins of a gene which increases wool growth and live weight gain of livestock.

101. **Possible Benefits:** Economic gains for farmers and the food chain. A high proportion of crop production is currently used for animal feed and if efficiency increased, then more crop production would be available to feed people. Possible consumer benefits if animal feed translates into changes to particular products e.g. naturally spreadable butter produced by increasing the amount of oils in cattle feed. This is available as a non-GM product but illustrates the potential for manipulating feed. There may be animal welfare improvements from altered feed. For example, CSIRO scientists are working on a way to genetically modify clover and lucerne so that these pastures cannot cause bloat, which can kill livestock.

102. **Possible Risks:** Following the Starlink episode in the USA there is a need to ensure that products which are approved for animal feed use also meet standards and regulatory approval for consumption of the resulting

[87] *New Scientist*, 21 July 2001, p7.

[88] *Coffee is in crisis.* H Warwick, *The Ecologist*, July/August 2001.

products in human food.
103. For forage grasses and legumes, in the UK, there would be high relevance and major concerns about gene flow through cross-pollination with native species. Gene flow in conventional ryegrass is possible over a distance of a kilometre. Some GM varieties e.g. with disease resistance might be expected to be very successful in the wild.

10. PLANTS AS FACTORIES

104. **Aims:** To use plants as a source of chemicals and medicines. In Canada, for example, the biopharmaceutical, Hirudin, is now being commercially produced from plants. There is also a growing body of work attempting to create edible vaccines in a whole variety of cereal crops, fruit and vegetables.
105. **Possible Benefits:** Cheaper production of chemicals and medicines. Access to and delivery of cheaper vaccines especially in developing countries. Diversification for farmers.
106. **Possible Risks**: If using crops that can outcross, there is a risk that gene flow could result in chemicals inadvertently entering the food chain, making co-existence an issue here. There may also be effects on non-target species.
107. **Further issues**: Edible vaccine technology raises issues of choice: some people might not wish to consume a particular vaccine: how would they be guaranteed that, for example a banana they ate did not contain hepatitis vaccine. It raises issues of labelling, at the very least. Commentators have noted that the majority of research in this area in developing countries is being carried out by Government agencies and the US Department of Defence, rather than pharmaceutical companies.[89] There may a market for more reliable versions of plants already used for medicine and health products e.g. evening primrose.

11. OTHER NON-FOOD CROPS

108. **Aim**: Amenity grass is a large area of research; plants as feedstocks; flowers.
109. **Possible Benefits:** Grass that needs mowing less often, saving energy; grass that stays green, reducing need for fertilisers. Grass with improved disease resistance. Flowers with new decorative and improved keeping qualities.
110. **Possible Risks** Some people think commercialisation of this technology would need very careful thought. They would point out that cross-pollination could lead, for example, to unwanted patches of blue in the countryside, if different coloured grass was approved for commercial release. Cross-pollination is unlikely for the type of grass used on golf courses because it has no wild relatives and is in amenity uses - in theory at least -

[89] ERM/GA Report, p.54.

rarely allowed to run to seed.[90]

12. SMART PLANTS AND SIMILAR DEVELOPMENTS

111. **Aim:** Plants that could indicate their own needs for nutrients; and plants to make better use of nutrients.
112. **Possible Benefits:** Reduced use of fertilisers.
113. **Possible Risks**: Gene flow might be an issue, perhaps depending on what the signalling mechanism is based on. Early work has used fluorescence genes from jellyfish.
114. **Further Issues**: Such work might divert attention from other means of lowering inputs, such as organic approaches.

13. TREES

115. **Aim:** Agronomic traits like herbicide, disease or insect resistance; traits to change the quality of the wood, such as modified lignin trees.
116. **Possible Benefits:** Modified lignin could result in a more efficient and less environmentally damaging process for turning wood into paper. It could also result in improved wood quality and colour. There could be developments in producing biomass fuel. Herbicide disease and insect resistance could have similar pros and cons as with other crops. Work is going on in Scotland on introducing a gene for resistance to Dutch Elm disease into elm trees[91], to enable their re-introduction.
117. **Possible Risks:** For those species that can outcross, gene flow to wild relatives could be a major problem. However, sterile trees are a possibility, which would limit gene flow. There could be indirect impacts on biological diversity through changed management regimes, and through changes in land use patterns.
118. **Further Issues:** Developments with trees could be of major significance in the UK. In the UK the adoption of GM trees in forestry is likely to be reduced by the fact that the UK Woodland Assurance scheme does not at present certify a woodland scheme using GM trees. More critically, the price of timber is depressed at present and has been for some time and it seems unlikely that forestry managers would be willing to pay the cost premium for GM products[92].

14. FISH

119. **Aim:** Increased growth, greater cold tolerance.
120. **Possible Benefits:** Economic benefits from increased growth rates; amenity benefits from cold tolerance which could increase the range of particular fish.

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[90] ERM/GA Report, p.63.
[91] *Scientists modify elm disease to resist disease that killed millions of trees in Britain*, The Guardian, page 3, August 28, 2001, *GM elms 'immune to killer disease'*, The Times, page 7, 28 August 2001, *Scientists create a genetically modified tree to resist the ravages of Dutch elm disease*, The Independent, page 6, 28 August 2001
[92] ERM/GA Report, p.46.

121. **Possible Risks:** There is serious concern about the potential environmental consequence of commercial production of GM fish. The escape of farmed fish from net pens is inevitable, although perhaps not from land-based facilities, and would have more impact than the escape of farmed mammals. Experiments suggest that GM salmon, which grow fast, out-compete wild-type males in breeding activity but tend to be sterile. This has serious implications for wild fish populations. Laboratory research seems to indicate that GM salmon are less skilled at avoiding predators, so if they escaped those fertile few might breed with non-GM salmon to produce less well-adapted offspring[93]. The long-range migration of some fish means that this issue is particularly difficult to control across international borders. If GM fish escape or are released into the sea in one part of the globe, they could appear in many other places quickly. It seems unlikely at present that GM fish will prove acceptable for commercial production in the UK. The Royal Society of Canada has called for a moratorium on rearing GM fish in aquatic pens and said that any production should take place in land-locked facilities. The Royal Society has supported this recommendation.[94] Cold tolerance could alter the range of fish i.e. the areas in which they are found, with unpredictable consequences.

122. **Further Issues:** The welfare considerations here are similar to those for farm animals, although fish have less developed nervous systems so might be considered to suffer less.

15. INSECTS

123. **Aim:** Various modifications aimed at altering insects' abilities to be pests or vectors of disease, for instance malaria.

124. **Possible Benefits:** Reduced costs of predation, disease and pest and disease control.

125. **Possible Risks:** The risks which have been noted in connection with GM insects include the unpredictability of widespread release of GM insects into a wild population and the possibility that the beneficial genetic modification may mutate or undergo partial deletion. There might be undesirable unintended behavioural changes in modified insects (e.g. increased aggressiveness in biting insects). The use of 'gene drivers' to carry a beneficial (beneficial to humans, that is) genetic modification through the insect population, using autonomous transposable elements or *Wolbachia* (bacteria living in insect cells), would be an irreversible strategy with implications for whole populations and even species of insects. Clearly the environmental and ethical and biosafety issues are significant and such release could not be contemplated without very extensive justification and planning, which would need careful consideration.

126. **Further issues:** Work on malaria for instance may divert from other strategies.

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[93] ERM/GA Report, p.66.

[94] *The use of genetically modified animals,* Policy document 5/01, The Royal Society, May 2001, paragraph 105.

17. OTHER ANIMALS

127. **Aim:** Work with genetic modification of agricultural animals has not been taken as far as work with crops. The most advanced work relates to increasing the yield of animals for food. Other lines of inquiry are animals engineered to be resistant to disease, animals better adapted for farm conditions, and pets whose fur does not cause allergies. Genetically modified animals are, however, in widespread use in medical research and their numbers are likely to grow. The animals may be modified to express a human disease, to help enable better understanding of the nature of the disease and to research possible cures. Experimentation on genetically modified animals is used to better understand human gene functions. Mice are the creature predominantly used in this regard. Genetic modification of other animals, such as pigs, is also being researched with the aim of xenotransplantation (animal organs used in humans). GM animals are also used in laboratories to test toxicity: for example they can be genetically modified to be more sensitive to carcinogens, with the aim of speeding up the safety testing of new products. A recent report by the Royal Society gives further detail about the kinds of applications involving the use of animals underway at present[95].
Much of the current emphasis in the public debate about GM in agriculture is on plants because GM plants are already grown commercially. The debate about GM farm animals seems likely to come to the fore before long, however. The most difficult issues in relation to domesticated animals are likely to be around the ethical implications of changing the nature of animals, considerations of animal welfare, and consumer reactions to genetically modified farm animals used for food production.
128. **Possible Benefits and Risks:** The issues raised by biotechnology developments as they relate to animals will be the subject of a formal report by the AEBC in 2002[96].

17. BIOREMEDIATION AND PHYTOREMEDIATION

129. **Aim:** The use of GM micro-organisms in treatment of contaminated land, as sensors to detect pollution, or directly in soil to digest pollutants. Plants can also be used for such bioremediation of pollutants by being genetically modified to absorb and concentrate pollutants (phytoremediation). The plants are then harvested and destroyed. Four main areas which have seen research and development involving genetic modification include: biocontrols (to control the spread of contaminants); GMs for remediation (e.g. for analysis of natural bacterial and viral populations); and phytoremediation. Some of these methods are being used by commercial companies within the UK and further afield, to deal with land contamination issues. Proponents of these methods argue that, for many man-made compounds with high biological toxicity, microorganisms present one of the few ways of effectively identifying and degrading them. The majority of research in development

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[95] *The use of genetically modified animals.* The Royal Society, Policy Document 5/01, May 2001, (www.royalsoc.ac.uk).
[96] Draft report can be viewed on www.aebc.gov.uk

under the broad banner of bioremediation is currently focussed on improving performance capabilities. However, work involving the transfer of genes between species has taken place, primarily in the biosensor market.

130. **Possible Benefits:** The ability to break down pollutants that are not susceptible to non-GM remediants; ability to tackle lower concentrations of pollutants; faster and more efficient rates of degradation; greater resistance to toxic compounds formed during breakdown of pollutants. It may also be possible to employ sensors to detect polluters by showing more easily when contamination was occurring. Phytoremediation techniques are especially pertinent on soils which are contaminated with metals and organic compounds: in the UK this applies to 50% of contaminated soils.

131. **Possible Risks:** Gene flow from engineered microbes into native populations outside the site, perhaps resulting in degradation of non-target compounds. GM microbes may be harder to monitor than GM crops and animals. There are environmental implications of phytoremediants, for example, aspens in the US have been modified to grow on land contaminated with organic mercury. The trees absorb the mercury, however they do not fix the mercury, but release it as elemental mercury, which is less harmful, but will be eventually cycled back into organic mercury.

132. **Further issues:** With bioremediants acting in soil, there are general issues of lack of knowledge of soil ecology. With phytoremediation, there may be issues of final disposal of the GM plants and the pollutants they have sequestered – for instance if the plants are taking up heavy metals that cannot be extracted again. If the development of GM technology results in the increasing use of phytoremediants, these issues will increase in significance.[97]

BEYOND GM

Genomics

133. There is much talk of genomics as an alternative means of achieving the same results as genetic manipulation, without transgenesis. Genomics really only means enhanced knowledge of the genome, and has to be complemented by knowledge of what those genes actually do to be really useful. Genomics is important for two main reasons. First the additional knowledge could enable new, as yet unenvisaged types of genetic manipulation. Second, it could enable solutions to plant and animal breeding problems or goals without employing GM techniques, which may be more acceptable to a greater number of citizens and consumers. Although the techniques involved may be more acceptable, however, this is no guarantee that the products will be more acceptable. Already there are regulatory anomalies for products with identical effects, for instance herbicide tolerance, where GM versions are subject to regulatory scrutiny and non-GM versions exempt.

Apomixis

134. A related area of interest is apomixis. This is a process that occurs naturally in a handful of plants. It involves the plant reproducing itself

[97] ERM/GA report, pp 93-104

asexually, producing fertile seed without pollination. Apomixis occurs, for example, in dandelions, crab apples, blackberries and the grass used in many lawns. If staple crops, such as maize, could be coaxed into becoming apomictic, this could help farmers in LEDCs who save seed each year for planting the next and who consequently have to watch the vigour of their crop diminish year on year. A few institutions around the world are working on apomixis, trying to find the molecular switches to turn on the trait, which may be lying dormant in some plants.

135. There would be real concerns among seed companies about the intellectual property regime which accompanied any widespread use of apomixis, particularly if one company had exclusive control of apomictic technology. There could be potential benefits to the companies, however, if as expected apomixis sped up their production of new hybrid seed varieties and reduced the costs of development. Genetic modification of a particular plant may not be necessary to trigger apomixis. Equally, apomixis could be a means of eliminating gene flow from genetically modified varieties. Apomictic crops are thought to be at least some ten years from the market.

136. Apomixis could be one way of designing a genetically modified organism so that some of the perceived environmental risks associated with release into the environment are eliminated or reduced. Other design changes are achievable now. For example, there is concern about the presence of antibiotic 'marker' genes in GMOs. These marker genes are a useful tool in the creation of the GM organism. But in the environment it is possible that they could have adverse unintended effects, particularly the creation of antibiotic resistance in other organisms. These marker genes can be designed out of the final organism for release. The Advisory Committee on Releases to the Environment has recently issued guidance on best practice in this area.[98]

Mutation breeding

137. Mutation breeding is an example of a biotechnology technique which is not genetic modification, but is an interesting comparison, and which has been in use since the 1950s. Induced-mutation breeding involves exposing crop plants to ionising radiation or chemical mutagens to induce random genetic mutations. These treatments most often cause detrimental genetic changes and kill the plants (or seeds). But on rare occasions, the result is a desirable mutation. For example, a mutation might produce a new trait in the plant that is agronomically useful, such as altered height, more seeds or larger fruit. In these cases, breeders have knowledge of neither the exact nature of the genetic mutation that produced the useful trait, nor of what other mutations have occurred in the plant, including those that could alter the ability to cause allergic reactions.

138. The breeders will, on recognition of a desirable trait, backcross it into an elite line until the selected progeny have all of the desired elite characteristics including the desirable mutated trait. In this way they expect undesirable mutations to be eliminated. More than a thousand mutation-bred plant varieties from a range of different species have been marketed in Europe and the US over the last half-century and none have been subject to

[98] *Guidance on Best Practice in the Design of Genetically Modified Crops,* Advisory Committee on Releases to the Environment (ACRE) Guidance Note 13, DEFRA July 2001.

formal pre-market regulation. Several, including two varieties of squash and one each of potato and celery, were found to contain dangerous levels of endogenous toxins and were subsequently banned from commerce.[99]

139. As of 1995, the FAO/IAEA (Food and Agriculture Organization/ International Atomic Energy Agency) Mutant Varieties Database "included 1790 cultivars involving 154 plant species…in more than 50 countries, of which the `top six' were: China, India, the former USSR, the Netherlands, Japan and the USA" [100].

140. Examples include:

Effect	**Crop**	**Comments**
Dwarf Crops	Semi dwarf wheat was one of the contributors to the green revolution. It was probably a natural mutation	Dwarfing genes now identified and the trait is introducible in any appropriate crop.
Malting Quality	Golden Promise Barley	Golden Promise became the staple malting barley variety of the next 25 years. Beer and whisky made from it was drunk all over the world.
Herbicide Tolerance	Resistance to sulphonyl urea and imidazolinone herbicides created by mutation breeding or somaclonal variation Maize, Soybeans, Wheat, Canola	Mutated gene identified as aceto-lactate synthase. The same effect can be created by GM[101].
Starch Quality	Maize	Various mutations which affect chain length and branching in starch for food or industrial use

[99] Henry I. Miller and Gregory Conko, *The Wall Street Journal*, August 1, 2001

[100] *Engineering herbicide-resistant maize using chimeric rna/dna oligonucleotides*, Tong Zhu, Kathryn Mettenburg, David J. Peterson, Laura Tagliani & Chris L.Baszczynski, Nature Biotechnology, Volume 18, Number 5 pp 555 – 558, May 2000.

[101] *Engineering herbicide-resistant maize using chimeric rna/dna oligonucleotides*, Tong Zhu, Kathryn Mettenburg, David J. Peterson, Laura Tagliani & Chris L.Baszczynski, Nature Biotechnology, Volume 18, Number 5 pp 555 – 558, May 2000.

	Wheat	Durum wheat to make pasta has been produced by irradiation and hence mutation breeding
High Oil	Maize	Mutations for maize with higher than normal oil content. Of benefit in animal feed efficiency

GENERIC ISSUES ARISING FROM THE SCENARIOS AND THE ANALYSIS OF THE TECHNOLOGY

141. **Co-existence.** Whatever the future potential of the technology, many people seem to feel that the future is heavily conditioned by the outcomes of the present GM/non-GM debate. Several responses to the sub-group's scenarios consultation indicated that the idea of a GM-free UK or Europe might be considered simplistic and unrealistic. There is no doubt that there is a massive amount of effort around the world in institutions both public and private on crop and animal improvement both for production, processor and consumer benefits, and there is an increasing acreage devoted to the growing of approved species. There are also many consequences, both commercial and political, if the UK and, or, Europe chooses to turn its back on this technology. There is also a strong view that if other countries adopt the technology, given the global nature of trade in agricultural commodities and the opportunities for contamination all the way along the food chain, it will be impossible to maintain entirely GM-free sources of food or animal feed. Some respondents were more optimistic, seeing 'GM-free' as a good niche marketing tool for whole regions or countries, and an added boost to the already growing organic sector. The issues of co-existence, gene flow, contamination and consumer choice are therefore crucial areas for the Commission to examine, following on from the conclusions of *Crops on Trial*. They are forming a stream of work with the general heading of **consumer choice** – an area identified in 2001 for developmental work - now that the Commission's work on animals and biotechnology is nearing completion.

142. **Public attitudes.** It is clear that genetic modification enables developments in plants and animals not presently attainable through conventional breeding techniques. To those who are positive about the technology, this makes it a useful, perhaps essential, part of the toolkit for breeders seeking to improve agricultural and food production. For others it presents threatening uncertainties. It is equally clear, however, that advances in genomics, and the other techniques that lie outside GM, have the potential to bring forward developments we have not yet thought of, without using recombinant DNA techniques. This raises questions of where the dominant concern around GM really lies: is it with the fact of transgenesis itself, with the

kind of products to which the technology has been directed, with the ownership and control of the technology, or elsewhere? Understanding more about public attitudes to these aspects of the question will be crucial for the Commission in providing strategic advice to Government in terms of the acceptability of both products and techniques. The animals and biotechnology sub-group of the Commission has made a useful start on this kind of analysis of public attitudes in relation to biotechnology and animals. The Commission is working actively on exploring public attitudes, as the Government has asked for AEBC's advice in April 2002 on when and how to promote an effective debate on possible commercialisation of the GM crops in the FSEs.

143. **Research agendas.** Ownership and control of the technology were important themes in many of the submissions we received from the consultation on possible scenarios for agriculture. These included concerns over plant breeding and animal biotechnology applications being increasingly in the control of private rather than public institutions. The concern is frequently articulated, and formed one of the main recommendations from an OECD conference in Bangkok on New Biotechnology Food and Crops chaired by Lord Selborne in July 2001[102]. An AEBC study and/or a Commission-run public debate could look at biotechnology research agendas in both the public and private sectors, to consider for example where they are focussing at present, how they interrelate, what the dominant themes are, how they affect what is delivered, what commentators say, and how to ensure fruitful synergies between them.

144. **Comparative Impact of crop varieties and management systems.** As more than one respondent to our scenarios consultation pointed out, both GM and non-GM techniques could be directed towards the goals of 'sustainability', provided those goals were clearly articulated. Some commentators think that the market is already heading in the general direction of 'sustainability', with future GM developments in crops focussed on maximising yield and minimising inputs. Others thought that the massive investment required to develop new GM varieties would mean that product development would be confined to those varieties that could find a ready market, but would not necessarily be consistent with sustainability, construed as a more locally adapted, locally owned, flexible kind of agriculture. There was a fear that alternatives to GM would not be properly considered. An interesting observation was that in some ways GMOs are more likely to be environmentally sustainable than conventional crop varieties because regulatory requirements include assessment of both direct and indirect effects on the environment. Crops produced by conventional means are not subject to any such scrutiny. We were told that we urgently need a system for assessing the relative sustainability of all new crop varieties and the systems within which they are grown, and not just for GMOs[103]. This is a challenge the Commission, in association with other bodies, could fruitfully consider. A particular study for AEBC could be comparison of the **environmental**

[102] See http://www.OECD.org/agr
[103] As noted by English Nature in their evidence to the sub-group on future scenarios for the uptake of GM in agriculture (www.aebc.gov.uk/aebc/minutes_110601.htm).

'footprint' of different agricultural management regimes. This has synergies with the research work DEFRA are undertaking, following on from the AEBC's recommendation in 'Crops on Trial' on the need for baseline information. It could also pick up the issues such as whether herbicide tolerance introduced into several crops could affect rotations, as identified under the 'herbicide tolerance' heading earlier in this section. It might also provide a way of weighing up the very different benefits and risks around categories of development such as herbicide tolerance, as well as insect, fungal, bacterial, viral and stress resistance, and look at the emerging issues around embryonic developments such as 'smart' plants.

145. **Comparison of agricultural visions.** A useful context for the environmental 'footprint' study outlined above might be to compare the several published visions for the future of agriculture, including the Policy Commission on the Future of Food and Farming report, "Farming and Food – A Sustainable Future" (England), "A Forward Strategy for Scottish Agriculture", "Vision for the Future of the agri-food industry" (Northern Ireland) and "Farming for the Future" (Wales). Broad-ranging issues such as future uses of land and aspirations as to how much food is produced in the UK rather than imported are the province of these strategic visions and should provide the context within which the AEBC considers the future possible role of biotechnology.

146. **Competitiveness** of the United Kingdom agriculture and biotechnology industries was an issue highlighted from the scenarios consultation. The AEBC could consider the impact on the competitiveness of relevant UK industries (primarily farming and the rest of the food chain; biotechnology companies and associated research and development institutions) of the decisions made about the development and commercialisation of biotechnology in the UK. Such a study would consider competitiveness in the context of the World Trade Organisation and the European Union, flowing from decisions made about biotechnology in the UK.

147. **The impact of UK decisions internationally** UK and European Union decisions will affect development and implementation of agricultural biotechnology elsewhere in the world, as the scenarios discussions highlighted. A study could look at capacity building, management of developments, protocols and how they work in a range of contexts, how relevant developments are to other countries, who they benefit and how they are regulated. This could be primarily for AEBC or for organisations with an international focus.

148. **Trans-boundary regulation.** Many of the above issues bear on the big picture of how GM and biotechnology fit with agriculture both in the UK and globally. A more immediate issue may be around the ability to implement GM regulations as they stand at present. Other countries may release and commercialise GM plants and animals that might not be given consent under European regulations, but nonetheless have the ability to cross national boundaries. Fish and insects are the most obvious examples. Ideally, international regulations would deal with these eventualities, but may not yet

be sufficiently well-developed. The AEBC animals and biotechnology sub-group is examining the mechanisms for dealing with trans-boundary GMOs as part of its consideration of the present legal and regulatory framework. The whole area of trans-national boundaries is likely to be one of growing interest and concern.

149. Of these issues, co-existence and gene-flow are within the remit of the AEBC study on consumer choice. Public attitudes work is also active in the Commission.

150. It will be important for AEBC to prioritise between future studies. As an initial view - on which the Commission is consulting - research agendas and the comparative environmental impact of different agricultural regimes seem a high priority, followed by competitiveness and the impacts of UK decisions on other countries. The trans-boundary issues may need some clarification in terms of work by Government Departments before assigning them a priority.

ANNEX A

Table 1:
TABLE OF BIOTECHNOLOGY APPLICATIONS

Key: Where possible the table includes an indication of the stage of work:
C denotes commercialisation
F denotes field studies
G denotes greenhouse studies
L denotes research laboratory studies

Crop modification/ development	Aims
Herbicide tolerance	
This technology accounts for a large proportion of the GM crops in current commercial production. **(C)**	Herbicide-tolerant crops can allow farmers to apply a broad-spectrum herbicide (ie acts on a wide range of weeds) to control weeds without harm to the crop. This should mean reduced number of applications of herbicides to some crops. It gives farmers greater flexibility in weed management, because the herbicide application window is wide, the herbicides used break down in the soil relatively easily; this reduces risks of pesticide residues in soils. It also promotes minimal tillage, which could be of benefit to wildlife. Fuller discussion of the issues is in Part 3.
Maize (Corn) modified to be tolerant of the herbicides glufosinate (Liberty®) or glyphosate (Roundup®). (**C)** Bromoxynil in UK **(F)** for glufosinate and glyphosate	
Oil-seed rape (Canola**)** modified to be glufosinate or glyphosate tolerant **(C**). Bromoxynil in UK **(F)** for glufosinate and glyphosate	
Sugar beet modified to be glufosinate and glyphosate tolerant **(F)**	UK sugar beet trials suggest herbicide usage can be reduced by up to 30% [104]
Further possible commercial herbicide tolerant crops may include glyphosate tolerance in **wheat.**	
Soybeans tolerant of glyphosate. **(C)**	(Not a UK crop)
Cotton tolerant of bromoxynil, glyphosate or glufosinate. **(C)**	(Not a UK crop)
Rice tolerant of glufosinate.	(Not a UK crop.)
Amenity grass (Agrostis stoloniferia – Creeping Bent Grass) modified to be	Amenity grass as distinct from forage grass (pasture for animals). This is for use on golf

[104] M May, a Dewar and J Pidgeon, *'Herbicide Tolerant Crops'* in *GM Crops, Understanding the issues*, Agricultural Biotechnology Council booklet, 2001, 111pp

glyphosate tolerant.[105] **(F)** Kentucky Blue Grass and a number of other grasses have been transformed for herbicide tolerance for experimental purposes.[106]	courses – others may be developed for garden use. (Agrostis is not widely used in the UK – others might be.)
Trees – at least three species have been modified for herbicide tolerance.[107] **(F)**	Herbicide tolerance is considered to have particular importance for hardwoods, as these (unlike pine) face serious vegetative competition that cannot be addressed very effectively by traditional herbicides without harming the hardwood seedlings.

Pest resistance

General: 'Bt' strains of plants are genetically modified so that the plants themselves express a gene from a natural pesticide, derived from the bacterium *Bacillus thuriengensis* **(C)** Other insecticidal genes are now being identified, which, if successful when introduced into plants, will help alleviate concerns over resistance developing[108].	Pest control. When an insect starts to eat any part of the crop, it ingests the toxin and dies. Bt GM crops are in widespread commercial production. Bt protects crop yields without necessarily increasing them. Unlikely to make a large impact in the UK because the climate means insect pests are less of a problem than in warmer countries.
Bt **Rice** is in production in China. **(C)** The inserted gene protects Mediterranean rice against the striped stem borer[109].	Increased yield: up to 29% increase reported with no added pesticide.[110]
Cotton: Bollgard® Bt Insect-Protected **Cotton** is protected against cotton bollworms, pink bollworms and tobacco budworms. **(C)** Protection against bollworms, tobacco budworms and pink bollworms and of the armyworm and looper complexes, with a combination of Bt genes cry1F and cry 1Ac.	Reduced insecticide use, better pest control, protected yields.

[105] ERM/GA report
[106] see www.iger.bbsrc.ac.uk
[107] ERM/GA report
[108] Bowen, D., Rocheleau, T., Blackburn, M., Andreev, O, Golubeva, E., Bhartia, R. & French-Constant, R.H. (1998) *Cloning of a novel insecticidal toxin from the bacteria Photorhabdus luminescens*. *Science*, 280, 2129-2132
[109] J C Breitler, V. Marf, M. Royer, D. Meynard, J M Vassal, B Vercambre, R Frutos, J Messeguer, R Gabarra, E Guiderdoni, *Plant Cell Reports Abstract* Volume 19 Issue 12 (2000) pp.1195-1202.
[110] *Genetically Modified Rice Passes Key Chinese Test.* Agence France Presse English, September 29, 2000.
[111] *Agnet: Southeast Farm News via Newsedge Corporation*, February 15, 2002.

(F)[111]	
Maize: YieldGard™ Insect-Protected maize provides control of the European corn borer. **(C)** NatureGard®. These plants express a Bt protein toxic to European corn borer. **(C)** StarLink Corn. These plants express a Bt protein toxic to various lepidopteran pests. **(C)** Bt-based Rootworm resistance[112]. **(F)**	Increased yields in years of corn borer pressure. Reduced insecticide use. Improved yield. In 1999, it is estimated that 1.7 billion kg of maize were saved from the corn borer as a result of this technology.[113] Rootworm is a major US corn pest and is only treatable by soil active chemicals at present. It is becoming a problem in Europe. There are no known natural resistance genes in corn germplasm.
Potato: NewLeaf® Bt Insect-Protected Potato is resistant to the Colorado potato beetle. **(C)** Experimental work on using lectin genes for insect resistance in potatoes for industrial starch use (and rape for industrial use). **(L)** Greenhouse trials are underway to evaluate potatoes engineered to be resistant to nematodes, including potato cyst nematode[114]. **(G)**	Pesticides to control nematodes (nematicides) are not particularly effective and many are environmentally damaging. Objectives include environmental and economic benefit to developing countries.
Bt in **brassicas** including oilseed rape.	Protection against flea beetle.
Plants containing the **avidin** gene from chicken egg white. When present at levels of around 100ppm, avidin has been found to be toxic to, and to prevent development of, many internally and externally feeding insect pests that damage grains during storage.[115]	
Protease inhibitor genes for **rice**.	
In future, sunflower, soybeans, canola, wheat, tomatoes are all expected to be candidates for the creation of insect resistance through genetic modification.	

Fungal Resistance

A gene coding for a peptide from alfalfa introduced into **potato** has shown good resistance to Verticillium dahliae, which	Crop protection – fungal diseases cause large crops losses in potatoes.

112 *Rootworm: a biotech boon? Corn designed to kill common pest stirs hope as pesticide alternative, August 18, 2001, The Washington Post*, Page A01, Marc Kaufman

113 *Agricultural Biotechnology: Updated Benefit Estimates.* J E Carpenter and L P Gianessi, available at www.ncfap.org

114 ERM/GA Report, p.46.

115 *Commercial production of avidin from transgenic maize: Characterization of transformant, production, processing, extraction and purification. Molecular breeding 3:291-306, E E Hood et al, 1997.*

causes "Verticillium wilt" or potato early dying complex.[116] **(G)** Work is also underway on protection against phytopthera late blight.[117]	
Fusarium resistance in **wheat**[118]	Crop protection
Sunflower: Introduction of an oxalate oxidase gene from wheat for sclerotinia resistance.**(L)**	Crop protection. Sclerotinia causes large losses of sunflower crops worldwide.
Wheat and barley: development of transgenic spring wheat and barley plants carrying antifungal protein genes. **(G)** Work stimulating anti-fungal genes in cereals.	Crop protection. The antifungal market is one of the most important disease markets in Europe.
Grapevines: The introduction of disease resistance botryrtis without changing the essential quality of varieties is a target for research.**(L)**	Offers grape producers large potential gains.
Tomato: A variety resistant to powdery mildew. May approach market in around five years.[119]**(G)**	Crop protection
Strawberries: Resistance to grey mould. A gene from pears coding for an antifungal protein has been introduced into strawberries. Greenhouse trials show GM strawberries to be significantly more resistant than controls.[120] **(G)**	Crop protection
Banana: Insertion of genes conferring resistance to Black Sigatoka. The GM technologies are being tested in research fields and greenhouses[121].**(L/F)**	Crop protection and production – not a UK crop. This fungal disease requires regular high doses of fungicide. It is not possible to develop resistance to the disease by conventional breeding techniques. Current applications of fungicide place heavy loads on the environment and can impact on water run off in estuaries

Viral and bacterial resistance

Alternatives or adjuncts to pesticide sprays.	Objectives include reduced environmental impact from pesticides; cost reductions for the farmer and thus the consumer. There are no commercial antiviral chemicals. The only approach is to deal with the insect, fungus or other pest that carries them. Biotechnology offers a genetic approach to antivirals.

Bacterial resistance

[116] *Engineered Potato.* M Fox, Health and Science Correspondent, Reuters, Nov 29 2000.
[117] ERM/GA Report, p.41.
[118] www.scabusa.org
[119] ERM/GA Report, p.41.
[120] *Genetic Modification of Temperate Fruit Crops – why we do it and why it's necessary.* Paper given by Professor D J James for British Association Festival of Science, London, September 2000.
[121] www.farmacule.com

Vines: US scientists have inserted a silkworm gene, cecropin, into embryonic Thompson seedless grapes and are now working on Chardonnay grapes. **(F)**	Crop protection and to increase the quantities of wine produced. The modification does not affect the flavour, but protects vines against Pierce's disease, which kills the plant by attacking the xylem. Cecropin sticks to the cell membranes of Pierce's bacterium and punctures them, killing the cell.[122]
Rice: A gene from an African wild relative of rice, which imparts resistance to a severe bacterial blight disease, was transferred into highly susceptible breeding lines of Chinese rice. Transfer of this single gene has resulted in plants crossed with local Chinese varieties, which are highly resistant to the pathogen seven sexual generations after gene insertion. **(F)**	Benefits to producers. Not a UK crop.

Viral resistance	
There are many virus resistance trials in the USA and some in Europe.	
Wheat and oats: modification to increase wheat's resistance to barley yellow dwarf virus (BYDV), The virus, carried by aphids, infects wheat and other crops. The plant's natural "immune system" is activated against the virus by inserting a sequence of RNA (ribonucleic acid) from the pathogen into the plant's genome.[123]**(F)** Resistance to wheat streak mosaic potyvirus[124] **(FRP) (field release permit in USA)**	Crop protection. BYDV costs wheat growers billions of dollars a year. It replicates in plant cells, stunting growth and reducing grain yields. About 5 per cent of the world's wheat, barley and oats crops are lost to this virus.
White cabbage: Resistance to turnip mosaic virus. **(F)**	
Tomato: Field release permits in the USA include tomato (tomato yellow leaf curl virus); tomato tobamovirus; tomato spotted wilt tospovirus[125]. **(FRP) (field release permit in USA)**	Crop Protection
Melon: Resistances being worked on include cucumber mosaic cucumovirus, squash mosaic comovirus, watermelon mosaic potyvirus, zucchini yellow mosaic potyvirus[126]. **(FRP) (field release permit in USA)**	Crop protection.
Lettuce: Lettuce mosaic potyvirus above.[127] **(FRP) (field release permit in USA)**	Crop protection

[122] *The Standard* (St. Catharines - Niagara), May 24, 2001.
[123] Whitehouse et al., J. Molec. *Pathology*, 2001
[124] http://www.nbiap.vt.edu
[125] Ibid
[126] Ibid
[127] Ibid

Pepper: Resistance to Cucumber mosaic cucumovirus, tobacco etch potyvirus.[128] **(FRP) (field release permit in USA)**	Crop protection
Cucumber: Resistance to zucchini yellow mosaic virus.[129] **(FRP) (field release permit in USA)**	Crop protection
Papaya resistant to ringspot virus (PRSV). In commercial use in Hawaii since 1997, where it has led to a fourfold increase in yield. This disease devastated the papaya crop in Hawaii in the 1950s.[130] **(C)**	Reinstatement of crop. Not a UK crop.
Cassava plants engineered to have increased resistance to African cassava mosaic diseases. **(F)**	Crop protection. Not a UK crop. These are the most important diseases of a crop plant in Africa and responsible for the loss of up to 50 million tons of food each year.[131]
Potato There are at least ten important viruses in potato some that are spread to the aerial parts of the plant and others dispersed by soil inhabiting organisms. In the UK six viruses are particularly damaging in some regions and in some years. Combining resistances through traditional plant breeding is massively time consuming hence the interest in GM. Transgenic resistances have been developed against all of the major viruses of the potato crop and are being tested in Australia, Canada and the USA. One example is quoted below. Leaf Roll Virus (PLRV) resistance. **(F)** **New leaf potatoes (C)**	Crop protection. PLRV can reduce yields by half, and potatoes that are harvested have a dramatically reduced market value, due to brown 'splotches' caused by the virus, spread by aphids. PLRV is one of the most destructive diseases of potato crops[132]. Also benefits in reduction in the use of pesticides.
Squash: Genetic modification to produce yellow crookneck squash that are resistant to mosaic virus and other viruses. This product is commercially available[133]. **(C)**	Crop protection. Not a UK crop.
Sweet potato: Modification using viral coat protein resistance to combat sweet potato feathery mottle virus.[134] This is being tested in research fields at present. **(F)**	Crop protection. Not a UK crop, but a very important one in developing countries.

[128] Ibid
[129] Ibid
[130] *Harvest on the Horizon: Future Uses of Biotechnology*. Report prepared by the Pew Initiative on Food and Biotechnology, September 2001, p.21.
[131] *Forum for Applied Research and Public Policy*; Fall 2000 issue; http://www.forum.ra.utk.edu
[132] The Biotechnology Knowledge Centre, ref no:3413 May 16 2000 allAg.com
[133] The BIOIndustry Survey: www.bio.org/food&ag/transgenic products.html
[134] *Harvest on the Horizon: Future Uses of Biotechnology*. Report prepared by the Pew Initiative on Food and Biotechnology, September 2001, p21

Beet: resistance to beet necrotic yellow vein "benivirus".[135] **(FRP) (field release permit in USA)**	Crop protection
Sugar Cane: Resistance to sugar cane mosaic potyvirus.[136] **(FRP) (field release permit in USA)**	Crop protection

A-biotic stress resistance

Antifreeze genes from other plants show **cold** protective effects on canola[137], strawberries, maize and soybeans. **(F)**	The transfer of genes from adapted crops to non-adapted can extend their use by allowing cultivation in areas of the world where the climatic or soil conditions are too harsh for unadapted varieties.
Fructan-producing **sugar beets**, with an introduced bacterial fructosyl transferase gene performed significantly better under conditions of drought stress when compared to wild type plants[138]. Trials of **drought-resistant** crops are at a relatively early stage. The process of producing this characteristic is not simple because generally multiple genes are involved and need therefore to be transferred.**(L/G)**	
Researchers in the US and Canada have inserted a single gene from a relative of the cabbage into a **tomato** plant to create the first crop able to grow in **salty** water and soil.[139]**(L)** Chinese researchers are working on salt tolerant rice **(L)**	
Researchers in Canada are reported to have developed a GM flax tolerant to **herbicide residues** left behind when excessive herbicide has been used on a field.[140] **(F)**	
The production of a 'wide spectrum disease resistance' gene reportedly underway may have the side-effect of producing increased tolerance to **ozone** in crops.[141] **(L)**	

[135]See footnotes 120-5

[136] Ibid

[137] D Worrall, L Elias, D Ashford, M Smallwood, C Sidebottom, P Lillford, I Telford, C Holf and D Bowles. *Science* 1998, *282,* 115-117.

[138] *Enhanced drought resistance in fructan-producing sugar beet*. E A H Pilon-Smits, N Terry, T Sears and K van Dun, *Plant Physiology and Biochemistry* 37:313-317, 1999.

[139] E Blumwald and Hong-Xia Zhang, *Nature Biotechnology,* August, 2001.

[140] ERM/GA Report, p.50-51.

[141] ERM/GA Report, p.50.

Metal tolerance: The presence of aluminium can cause production losses of up to 80 percent in **maize, soybean, cotton and field beans.** Mexican researchers are reported to have isolated a gene that helps crops fight aluminium toxicity and are reported to be testing the gene in rice[142].**(L)**	

Increased yield

Various sorts of genetic modification are now being employed to seek the same result as conventional selective breeding.	Increased yield has long been a key goal in conventional selective breeding and is a key component of farmer choice.
Wheats with an introduced glutamate dehydrogenase gene yielded up to 29% more crop with the same amount of fertiliser than did the normal crop[143]. **(F/R)**	Highly relevant to UK.
Cultivars of **canola, chicory and maize** plants have been genetically modified to be 'male sterile'. The plants are commercialised in the United States and some are undergoing trials at present in the UK. **(C)**	The reason for making the cultivars male sterile is to produce F1 hybrid seed. Hybrid crops give an increased yield.[144] GM is being used to achieve male sterility instead of conventional means such as chemical treatment or manual detasselling (in maize) in pursuit of the same goal of ensuring hybrid production.
A Washington State University researcher recently announced biotech **rice** (spliced to a maize gene) with a higher rate of photosynthesis and 35% higher yields. Research is at an early stage. Rice modification on genes that alter inflorescence architecture. Dwarfing genes have been identified. **(L)**	By far the biggest rice yield gain in two decades[145] - not a UK crop. A significant increase on rice yields and those of other staple crops.
Tobacco: Haem gene inserted experimentally increased yield under lab conditions by 25%. Enables plant to grow in low oxygen (waterlogged) conditions.	

Food product quality
Bread making, flour and malting quality

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[142] Agricultural Research Service, USDA January 25, 2002
C S Prakash San Francisco Chronicle, March 30, 2000 www.sfgate.com/cgi-bin/article.cgl?file=/chronicle/archive/2000/03/30/ED64437.DTL
[143] Smill, 1999
[144] 'ERM/GA Report, p49.
[145] Dennis Avery, *Wall Street Journal*, July 5, 2000.

Wheat genetically-modified to produce starches for improved processing qualities[146]. Low gluten/ high starch for biscuits; high gluten/ low starch for bread.	Flour, bread and industrial starches produced more easily and cheaply. The possible wider use of starch as a material. Aimed at growing bread wheat in cool climates.
Barley: isolating genes from barley to allow brewers better fermentation and a trouble-free processing line, with consumer benefits from a better (and clearer) product. Isolating genes preventing barley from making tannins which are the major cause of haze. **(L)**	The genes control qualities of the barley grain itself, such as beta glucan which can lead to haziness in beer.
High oleic **soybean** flour[147]. **(L)**	Oleic acid lowers cholesterol and has higher cooking stability, and longer shelf life. Less wastage. Not a UK crop.

Designer oils

High oleic acid seed **sunflower**. Can be achieved by selection breeding or GM. **(F)**	Lowering cholesterol, higher stability, longer shelf life.
Oil seed rape: changes to fatty acid content to make better processing oils.	
Lunarium (honesty) changes to increase and modify oil content for **cosmetics.**	
Peanut plants modified by mutagenesis – rather than GM - to produce nuts high in oleic acid[148].	Longer shelf life for nuts, confectionery and peanut butter. Not a UK product.
High oleic **soybean** oil.[149]**(L)**	A cheaper alternative to olive oil. Not a UK product.
Low linoleic soybean oil, *w*ith less than 3.5 percent linoleic. Precise and localised gene expression may be required to reduce cold sensitivity.[150] **(R)**	Claimed health benefits through reduction of trans-fatty acids. This is an enhanced stability oil that will reduce the need for chemical hydrogenation, therefore reducing trans-fatty acids – not a UK crop.
Low-saturate soybean oil[151]. **(L)**	Claimed health benefits: this oil has 50 percent less saturated fat than commodity soybean oil (vegetable oil), or approximately 8 percent total saturated fat, the same as canola oil. Zero saturated fat can be reached in many formulations when a low-saturated soy is used in place of commodity soy. Not a UK crop.
Cotton: High oleic and high stearic cottonseed oil. The world's first cotton plants genetically modified to produce healthier cooking oils and margarines have been developed by CSIRO Plant Industry (Australia). By turning off the gene that produces polyunsaturates they have produced for the first time an inherently high-oleic cottonseed oil. No foreign genes have been added to the cotton to achieve this. A	Cottonseed oil already used extensively in margarines and cooking oils, particularly in the food service sector. Cooking oil from improved cottonseed does not need hydrogenation. Products made from these oils are claimed to be healthier because they will not contain trans-fatty acids. Polyunsaturates are nutritionally valuable, but break down under extreme heat, making them less suitable for cooking uses. About a

[146] .*Global Status of Commercialized Transgenic Crops: 1999*. ISAAA Briefs No. 12: Preview. ISAAA: Ithaca, NY,1999.
[147] Mazur, Krebbers and Tingey, Science, 285, 372, 1999
[148] Ibid
[149] Ibid
[150] Mazur, Krebbers and Tingey, *Science*, 285, 372, 1999.
[151] Ibid

very small amount of the cotton plant's own DNA has been reintroduced. In a related development, CSIRO has also altered the proportions of saturated fatty acids in cottonseed oil. Saturated fatty acids provide the solid properties that make cottonseed oil useful in margarine production.[152] **(C)**	quarter of cottonseed oil is made up of two saturated fatty acids, palmitate and stearate. Conventional cottonseed contains mostly palmitate, with small amounts of stearate. Nutritionists believe that stearate does not raise blood cholesterol, but palmitate does. Not a UK product.

Improved fruit and vegetables

Endless Summer® **Tomato**[153] is a GM low ethylene version of the FreshWorld Farms® tomato which has been on the market since April 1993. **(C)**	Greatly extended shelf life of more than 30 to 40 days after harvest.
Increased flavanol **tomatoes**. By inserting a gene that encodes for chalcone isomerase taken from petunia plants, which have high levels of flavonols in their reproductive structures, Unilever scientists produced tomatoes with skin that had up to a 78-fold increase in flavonol levels, an amount in line with that of onions. **(C)**	Antioxidant chemicals such as flavonols are thought to protect against heart disease, slow cellular ageing, help combat inflammation, and slow the growth of certain cancer cells. Although these compounds exist naturally in tomatoes, the levels are much lower than they are in such foods as onions and tea. The taste of the tomatoes was not affected and 65% of the beneficial compounds were retained when the tomatoes were processed into paste[154].
Increased pectin **tomatoes**. These tomatoes have been genetically modified to remain firm longer and retain pectin during processing into tomato paste.	A range of improved properties including taste, processing yield and cooking properties.
Ripening-controlled cherry **tomatoes. (C)**	Longer market life, improved flavour and better harvest traits through ripening.
Sweet **peppers** have been modified using Transwitch® technology and are currently undergoing field evaluations.**(F)**	Peppers remain firmer after harvest.
Sweeter **peppers**. Peppers have been modified to over-express a gene for sweetness. Plants are in early stages of field evaluations.**(F)**	Peppers designed to be sweeter and tastier.
Using the same ripening control technology as in its Endless Summer™ tomato, DNAP is developing **banana** and **pineapple** varieties with extended market life.**(F)**	Extended market life – not UK crops.
Again, the use of Transwitch® technology to keep **strawberries** firmer after harvest and adding genes to resist disease. **(C)**	Improved market life. Production benefits.
Longer-life Greensleeve **apples** have been modified to produce less ethylene, to slow decay of apples. **(F)**	Extended storage life.[155] It is hoped to apply this in the UK to apples such as Queen Cox, which has a farm gate value of around £60m. Increased availability of apples to the consumer during winter and reduced need for imports.

[152] *Heart health to benefit from GM oils*. CSIRO press release, May 28 2001 (http://www.csiro.au/)
[153] BIO Industry Survey. http://www.bio.org/food&ag/transgenic_products.html
[154] Nature Biotechnology, Volume 19 Number 5, May 2001
[155] *Genetic Modification of Temperate Fruit Crops – why we do it and why it's necessary*. Paper given by Professor D J James for British Association Festival of Science, London, September 2000.

Flowering control: 'Gene-switching' technology is where an organism has been genetically modified so that a particular characteristic such as the timing of when a plant flowers is controlled externally. The relevant gene is 'switched on' by, say, application of a chemical. This technology is being explored to control the flowering or sprouting process of crops like potato[156].**(L)**	This could allow growers an alternative to using chemicals to prevent sprouting; or control.
Dwarfing fruit trees: Demonstrated in Greensleeve apple variety by down-regulating a gene that controls shoot elongation.[157]**(F)**	Obviates the need for growers to apply chemical growth retardants, which can persist in soil.

Improved nutrition	
Increased **Vitamin C**. A potential development.**(F)**	Antioxidants of value in protecting against disease.[158].
Increases in the level of **Vitamin E** have been demonstrated in Arabidopsis seeds.**(F)**	
High **lycopene** tomatoes.**(F)**	
High-**glucosinolate** broccoli has also been selected using traditional breeding techniques. **(F)**	
Transgenic technology has been used to produce plants capable of synthesising their own **antifreeze.** This has been applied to tobacco, tomatoes, and potatoes.[159]**(F)**	To help protect crops from frost damage.
Rice rich in **Vitamin A** ('Golden Rice') was created in 2000. Now being crossed with other rice varieties with the prospect of field trials in the next year or two.**(L/G)**	Potential value in combating malnutrition in the developing world – not a UK crop.
Vitamin preservation: Vegetables which maintain their vitamin content in cooking.[160] Thought to be at least eight years from commercialisation. **(L)**	Improved nutrition.
Possible further developments: Protein-enhanced sweet potatoes and rice; high-vitamin-A canola oil; increased antioxidant levels in more fruits and vegetables; plants with increased levels of iron and folic acid.**(L)**	Possible benefits in combating malnutrition and in conferring other health benefits on consumers, particularly in the more economically developed world, for the latter.

[156] ERM/GA Report, p.51.
[157] *Genetic Modification of Temperate Fruit Crops – why we do it and why it's necessary.* Paper given by Professor D J James for British Association Festival of Science, London, September 2000.
[158] Dellapenna, Science, 285, 375, 1999.
[159] See: D Worrall, L Elias, D Ashford, M Smallwood, C Sidebottom, P Lillford, I Telford, C Holf and D Bowles. *Science* 1998, *282,* 115-117;
R Hightower, C Baden, E Penzes, P Lund and P Dunsmuir. *Plant Mol. Biol.* 1991, *17,* 1013-1021;
K D Kenward, M Altschuler, D Hildebrand and P L Davies. *Plant Mol. Biol.* 1993, *23,* 377-385; and
J G Wallis, H Wang and D J Guerra. *Plant Mol. Biol.* 1997, *35,* 323-330.
[160] *The Risks Associated with the Introduction of GM forage grasses and forage Legumes.* S Young, M O Humphreys, M T Abberton, M P Robbins, K J Webb Institute of Grassland and Environmental Research, 1999, MAFF Project RG0219.

Other effects on quality

When damaged, **potatoes**, along with many fruit and vegetables, release an enzyme called polyphenol oxidase (PPO). This causes blackspot bruising. CSIRO identified the gene that produces PPO, and switched off its PPO production so browning does not occur. **(L)** The team is now working on browning control in other crops such as dried grapes. CSIRO has already licensed the PPO technology in potatoes, lettuce, bananas and pomefruit for commercial development[161].	Non-browning potato: better appearance. Mechanical harvesting and transport often cause damage to the potato - brown or black spots appear in the flesh. Blackspot bruising does not affect the taste or nutritional value of potatoes, but is unappealing to consumers.
Researchers at Germany's Max Planck Institute for Molecular Plant Physiology reported a genetically modified potato that sprouts just 15 weeks after planting, seven weeks earlier than normal tubers. The novel potato exudes a bacterial enzyme that breaks down pyrophosphate, a compound that inhibits sprouting. The characteristics were also handed on to subsequent generations[162].**(L)**	Earlier sprouting. Obvious benefits to producers.
Modified starch content in potatoes. GM potatoes with up to 60% more starch than normal have been created and are being tested in research greenhouses. **(G)**	The extra starch reduces fat absorption during frying.
Fructan-producing beets. **Sugar beet**, which normally produces sucrose, has been modified so that 40% of the taproot dry weight was converted to short chain fructans without discernible impact on plant growth or phenotype[163].**(L)**	Possible replacements for high calorie sweeteners and fats. Short chain fructans have the same sweet taste as sucrose, but provide no calories.
Genetic modification of **sugar cane** for increased sucrose production and improved juice colour is at the laboratory stage.[164]**(L)**	Better appearance and higher yield – not a UK crop.

Animal feed quality

CSIRO Scientists are introducing an enzyme into **barley** endosperm to make it easier to digest in formulated animal feeds[165]. **(L)**	Faster weight gain for livestock.
Scientists at CSIRO are working on a way to genetically modify white **clover and lucerne** so that these pastures cannot cause bloat.	Avoiding bloat. Bloat can kill livestock so quickly that a farmer can lose a whole herd in a morning.

[161] www.csiro.au/index.asp?type=faq&id=potatoes
[162] *Nature Biotechnology*, March 2001.
[163] *High level fructan accumulation in transgenic sugar beet*. R Sevenier, R D Hall, I M van der Meer,H J C Hakkert, A J van Tunen and A J Koops, *Nature Biotechnology* 16:843-846, 1998.
[164] ERM/GA Report, p.48
[165]Dieter von Wettstein*, Galina Mikhaylenko*, John A. Froseth, and C. Gamini Kannangara* Proc. Natl. Acad. Sci. USA, Vol. 97, Issue 25, 13512-13517, Applied Biological Sciences, 5 December 2000

(L)	
Lupin seeds, with an introduced gene coding for a sulphur-rich protein from sunflower. **(L)**	Fed to sheep, the lupin produced 8% increase in wool growth and 7% live weight gain[166].
Maize: High lysine, methionine, tryptophan.[167] High oil maize (produced by mutation).[168] Low phytate. **(L)**	Improved nutritional profile of feed. Higher energy feed. Reduces the need for phosphate supplements to be given to livestock. Phytate is present in a wide range of cereals and legumes. It is indigestible to pigs and poultry. [169] Such supplements are reported to be a major pollutant in the US.[170]
Developmental work is being carried out to produce **forage grasses,** particularly ryegrass **and forage legumes** with enhanced feed properties such as lower lignin and enhanced fructan levels[171] **(L)**	Enhanced feed properties
Low phytate[172] **soybeans (L)**	Reduces the need for phosphate supplements to be given to livestock – not a UK crop.

Plants as factories

Biopharmaceutical/protein production factories: One transgenic plant-derived biopharmaceutical, **Hirudin**, is now being commercially produced in Canada for the first time.[173] **(C)** Rice producing **Hepatitis B antibody.[174] (F)** **Avidin** is commercially produced as a transgene in maize. It is used as a research chemical and diagnostic reagent[175]. It is	Significant potential cost savings in the ability to use easily harvested-plants to produce chemicals of benefit to human health, industry or livestock.

[166] CSIRO press release, November 22, 2000 http://www.csiro.au
[167] *Global Status of Commercialized Transgenic Crops: 1999*. ISAAA Briefs No. 12: Preview. ISAAA: Ithaca, NY,1999.
[168] *Global Status of Commercialized Transgenic Crops: 1999*. ISAAA Briefs No. 12: Preview. ISAAA: Ithaca, NY,1999.
[169] *Global Status of Commercialized Transgenic Crops: 1999*. ISAAA Briefs No. 12: Preview. ISAAA: Ithaca, NY,1999.
[170] ERM/GA Report, p.48
[171] ERM/GA Report, p.48, quoting…Young et al
[172] ISAAA Briefs. Global Status of Commercialised Transgenic Crops: 44, 1999.
[173] G Giddings, G Allison, D Brooks and A Carter, *Nature biotechnology*, Volume 18 Number 11, pp.1151-1155, November 2000.
[174] *Hepatitis antibody made from GM rice. Daily Yomiuru*, 1 November 2000.
[175] *Commercial production of avidin from transgenic maize: Characterization of transformant, production, processing, extraction and purification.* E E Hood et al, *Molecular Breeding* 3:291-306, 1997.
[176] See Prodigene press release at http://www.prodigene.com/news.html
[177] ERM/GA Report, p.53

produced in maize at a fraction of the cost that it can be produced in chicken eggs. **(C)** Production of industrial **enzymes.**[176] **(L)** Research is going on into the possibility of genetically modifying potatoes to produce **biodegradable plastics, paper, textiles and nappies.**[177] **(L)**	
Edible vaccines: A project is underway to insert in strawberries a gene coding for a peptide that controls dental caries [178].**(L)** Similarly, an edible vaccine in maize for Transmissible Gastroenteritis Virus, a swine disease, has been developed by ProdiGene.[179] **(L)** Scientists at Cornell University are developing a banana that contains a hepatitis vaccine. **(L)** Researchers are also developing plants that produce antibodies against measles, bacterial tooth decay and sexually transmitted diseases.[180] **(L)** Scientists have developed vaccine-carrying potatoes that, when fed to mice, immunised the mice against both rotavirus and enterogenic Escherichia coli.[181] **(L)** An edible vaccine for measles has been shown to work in tobacco. Work is now moving on to edible products: first lettuce[182] and then rice. **(L)**	For livestock, administering vaccines by means of a foodstuff potentially offers cost reductions and an easier method of administration. Similarly for human vaccines also. Possibly easier access to vaccines in less economically developed countries.

Other non-food crops	
Flowers: Chrysanthemums and roses with altered flower colours are undergoing trials at present. 'Moondust', the first mauve carnation was introduced in 1996 and is commercially available. Research is underway to examine the characteristics of flowering time, plant architecture and fragrance.[183] **(C)**	New decorative and improved keeping qualities
Amenity grass: There are a number of	These products would be marketed on the

[178] *Genetic Modification of Temperate Fruit Crops – why we do it and why it's necessary*. Paper given by Professor D J James for British Association Festival of Science, London, September 2000.
[179] See ProdiGene Press Notice at http://www.prodigene.com/news.html, July 20 1999.
[180] *Pro-Farm* Vol. 16, No. 2, March 2000.
[181] *Scientific American*, Kate Wong: http://www.sciam.com/news/060401/1.html
[182] *Australian scientists plan measles-modified food*, January 28, 2000, Reuters.
[183] *Harvest on the Horizon: Future Uses of Biotechnology*. Report prepared by the Pew Initiative on Food and Biotechnology, September 2001, p.51.

possibilities. Reduced growth rate grass; herbicide-tolerant and insect resistant grass; and grass that can survive on less water and with less fertiliser. One US company is developing GM grass for lawns and sports facilities e.g. golf courses.[184] Coloured grass is another possibility. **(F)**	grounds that the lawns would need mowing less frequently. This would reduce the energy costs associated with mowing, reduce the amount of water used and possibly allow the use of more environmentally friendly pesticides and herbicides.
Oilseed rape: plants with high (more than 35 percent) laurate in oil have been produced.**(F)**	Laurical®. A less expensive source of high-quality raw materials for soaps, detergents and cocoa butter replacement fats.
Canola oil used as petroleum substitute**.(L)**	Produced by conventional breeding but yield increases from GM varieties could significantly reduce costs and make this more viable as a fuel.
High erucic acid **canola. (F)**	Already in wide industrial use in detergents, produced by conventional selection breeding. GM varieties could enhance its value by increasing the proportion of erucic acid.
Soybeans: High oleic soybean oil. **(L)**	Usable as an industrial lubricant[185]. Not a UK product.
High palmitic soybean oil.**(L)**	Of value for the manufacture of soaps & detergents[186] - not a UK crop.
High ricinoleic and vernolic acid soybean oil. **(L)**	For use in plastics, paints and coatings[187] - not a UK crop.
Genetic modifications to improve **cotton** fibre and other qualities. Denim coloured cotton is undergoing testing also.[188] **(F)**	To enhance fibre performance, reduce dye-shop pollution and improve textile manufacturing efficiency – not a UK crop.

Smart plants and similar developments

Smart plants. Research is underway to produce 'sentinel' plants that can tell their grower when they need more food, water or other input by expression of a particular characteristic such as fluorescence. Smart plants are understood to be already in use in laboratory contexts as biosensors.[189] **(L)**	Having a few 'smart' plants in a field to let the farmer know visually when water or a nutrient was needed, with significant savings in irrigation.
Novartis, now Syngenta, has reported that work is underway to develop cereals which can **'fix' their own nitrogen** from the atmosphere rather than rely as heavily on fertilisers or the planting of nitrogen fixing crops like legumes.[190] **(L)**	Reduced fertiliser usage.

[184] ERM/GA Report, p.63.
[185] Mazur, Krebbers and Tingey, *Science*, 285, 372, 1999.
[186] Mazur, Krebbers and Tingey, *Science*, 285, 372, 1999.
[187] Mazur, Krebbers and Tingey, *Science*, 285, 372, 1999.
[188] ERM/GA Report, p.47
[189] ERM/GA Report, p.52.
[190] ERM/GA Report, p.53.

Decaffeinated tea and coffee Scientists have identified the genes that lead to the production of caffeine in coffee beans and tea leaves.[191] Genetic modification could lead to plants which yielded naturally decaffeinated products without having to go through the chemical processes used at present.**(L)**	Improved quality of the decaffeinated tea or coffee – not UK products.
Allergy free foods. Rice has already been modified to have reduced allergenicity. Gluten-free wheat is another candidate.[192]**(L)**	To reduce allergic reactions to foods
Research began a number of years ago into identifying the genes in barley responsible for some of the qualities of beers, with the possibility of using GM malting barley in **beer production**.[193] This is at the research stage. **(L)**	To improve the production process giving an improved fermentation and production process.

Trees - see also Table 2 at the end of this Annex

Research is underway to increase tree growth rates, modify wood structure, alter trees' reproductive cycles, improve tolerance to certain herbicides, and possibly store more of the so-called greenhouse gases associated with predictions about climate change – this is an area on which there is considerable scientific and general debate. A list of GM trees in field trials is shown in Table I below. These are not at the stage of commercialisation. **(F)**	Potential economic benefits for forestry and in some industries which use timber as a raw material.
Disease resistance: Insertion of a gene from the giant silk moth into apple trees is expected to make them more resistant to fire blight, a destructive bacterial disease. Bt genes have been used variously to try to make cottonwood trees resistant to the cottonwood leaf beetle and fruit trees resistant to the cottling moth larva, another pest. Genetic modification to engineer resistance to plum pox virus, which affects plum, peach, nectarine and apricot trees, is also a possibility.[194] Undergoing field trials.**(F)**	Crop protection
Resistance to the pathogen *agrobacterium,* which is tumour causing, in modified walnut tree roots.[195]	Crop protection
Paper pulping: Modifying lignin to make it	Potential benefits in energy saving and

[191] See www.colostate.edu/programs/lifesciences/TransgenicCrops/future.html for further details. This Colorado University site in general is a very useful source of information about developments in genetic modification.
[192] *Harvest on the Horizon: Future Uses of Biotechnology*. Report prepared by the Pew Initiative on Food and Biotechnology, September 2001, pp.37-38
[193] See CSIRO media release at www.csiro.au/communication/mediarel/mr96076.htm
[194] *Harvest on the Horizon: Future Uses of Biotechnology*. Report prepared by the Pew Initiative on Food and Biotechnology, September 2001, pp.46-47.
[195] *New Scientist*, 10 November 2001

easier to remove from cellulose – the primary ingredient in paper – papermakers can make high-quality paper using less energy and bleaching. **(F)**	environmental load.
Control of branching: Columnar apple trees are well known: produced by natural genetic mutation and subsequent selective breeding. The same effect could be produced more quickly by GM in other trees. **(F)**	Greater energy directed to fruit production.
Disease and pest resistance: Trials are underway of elm trees which have been genetically modified to make them resistant to Dutch Elm Disease. GM herbicide-tolerant and insect resistant (Bt) trees have also been created. **(F)**	A prospect of reversing the catastrophic decline since the 1970s of elms in Europe as a result of Dutch Elm disease.
Ripening control: Researchers at the University of Hawaii have genetically modified coffee to synchronise ripening. Growth stops just short of the point of maturity. When all the berries have reached this stage, they are sprayed with a chemical which initiates the final ripening process.[196] **(F)**	To enable mechanised bean picking and cheaper coffee – not a UK crop.
The objective of much of the GM research in relation to poplars has been to **increase tree growth rates**. One way of doing this is to produce sterile trees. An estimated 15-30% of a tree's energy resources are devoted to reproduction. Sterile trees can devote more of this energy to growth. **(F)**	Potential benefit for growers.
Faster flowering and fruiting trees Spanish researchers reported they had successfully taken two genes from thale cress, and inserted them into orange trees, creating trees that produced fertile blossom and fruit within the first year instead of the normal five or six years[197]. **(F)**	Fast-track growth is a potential benefit for growers, as some species of fruit and nut trees, such as the almond, take more than two decades before their first harvest.

Fish

Many fish species have been genetically modified in the lab to produce a wide variety of traits. One US company has developed a GM salmon known as AquaAdvantage® It has not yet been approved for commercial production. The company is reported to plan that the fish will reach US supermarkets within the next few years.[198] This GM salmon grows at two to three times the rate of unmodified salmon. Other GM fish are also in development. **(L)**	Increase production at fish farms

[196] *The Independent*, 17 May 2001, p.3.
[197] Reported in the March 2001 issue of *Nature Biotechnology*.
[198] See the *Editors and Reporters Guide to Biotechnology: Products on the Market* (www.bio.org/aboutbio/guide2000/guide_agproducts.html)

Insects	
Techniques under development include genetic manipulation to make sterile insects (currently done by irradiation) and boosting mosquito immune systems to make them more resistant to Plasmodium. Another possibility could be modification of the malaria parasite. **(L)**	Improved insect and insect-borne disease control – of limited relevance to UK. .

Other animals	
Pharming: The production of valuable pharmaceutical products in animal milk using transgenic techniques. **(F)**	To produce drugs.
Models for human disease Mice and other animals can be genetically modified to have a human genetic disease so that the disease pathways can be better understood and possible cures tried out on them. **(L)**	Medical advances.
Animals such as mice share a great number of genes with humans. Although the human genome has been mapped it is unclear what many of our genes do. GM experiments on a particular gene that is shared by an animal and humans, such a as 'knocking out' the gene in the animal, are being carried out to enhance **understanding of the functions of individual human genes.(L)**	Better understanding of human genome.
Xenotransplantation The use of GM techniques to try to make animal organs more tolerated by the human immune system. **(L)**	Increase availability of donor organs.
GM animals are used to aid the **testing of toxicity** of chemicals and drugs, particularly in relation to whether they cause cancer. Some rodents have been genetically modified so that if a mutation in a gene occurs, the change can be easily detected (e.g. by the mutated genes changing colour when removed from the animal and introduced into yeast cells. Other rodents have been modified to have much greater sensitivity to carcinogens than their non-GM relatives, so that they will develop cancer much faster if a carcinogen is present in a test substance. **(L)**	Speeding up the testing process; and using fewer animals to achieve the same result.
GM could be used to engineer **resistance to specific infectious diseases** within the animal population itself. It might be possible to make animals resistant to infectious diseases that are also human health risks such as salmonella in poultry. The problem of maintaining high value strains of cows successfully in sub-Saharan Africa could, it is claimed, be overcome by the introduction	Improved performance of agricultural livestock.

of disease resistance genes from local cattle.**(L)**	
Food production The addition of genes for various growth factors and hormones can increase food yield from agriculturally important animals e.g. chickens with extra breast-meat. Many other examples are also being experimented with. Work is also going on to manipulate the rumen micro-flora which break down poor quality or potentially toxic feed so that ruminants could derive greater nutritional value from poor quality feed. **(L)**	Faster production of livestock.
GM techniques could be used to alleviate some of the instances of poor **animal welfare** that have been caused by current farming methods. This could be by specific modification to correct a problem, or by substituting a beneficial new procedure, based on GM, for a current procedure.**(L)**	Improved animal welfare
In principle, it would be possible to modify **pet animals** to make novelty animals or just to modify or improve current strains. The creation of cats and dogs that do not provoke a human allergic reaction has recently received publicity.[199] Genetic modification could possibly be used to help correct some severe welfare problems in pets e.g. hydrocephalus in bulldogs, dislocated hips in German shepherds, and so on, which have arisen as a result of conventional selective breeding.**(L)**	Modifying strains of pets.
It might be possible to produce enhanced **racehorses** by GM.**(L)**	Faster race horses.

Technology aids

Cheese manufacture Chymogen® - Chymogen is the biotechnology-produced version of an enzyme (chymosin) found in calves that makes milk curdle to produce cheese. **(C)**	A purer, more plentiful and consistent quality product which eliminates variability in the quality and availability of calves' stomachs. Chymogen is used in approximately 60 percent of all hard cheese products made today.
Terminator/Traitor genes Genes to produce sterile seeds in the next generation as a germplasm protection system. **(F)**	Aims include reducing pre- and post-harvest sprouting in cereals and potatoes. This technology could be a possible route to limiting the unwanted spread of GM crops.
Plastid transformation Transformation of chloroplasts or mitochondria (plastids such as these are maternally inherited) by transgenes.**(L)**	A way of limiting gene flow, by ensuring that the resulting pollen does not contain the transgene.

199 See, for example, *Designer Cat Controversy*, BBC News Online, at http://news.bbc.co.uk/hi/english/sci/tech/newsid_1411000/1411802.stm

Selectable markers Allowing the selection of genetically transformed cells from untransformed ones in the course of a genetic modification process.**(C)**	Eliminates the use of alternative markers to antibiotic resistance markers.[200]

Bioremediation and phytoremediation

GM lux **biosensors** have been developed to show by their degree of luminescence the toxicity of a particular environment. Another product using baker's yeast modified with jellyfish fluorescent genes has been developed to detect the presence of toxins which cause damage to DNA. Other GM biosensors designed to detect the presence of an individual chemical are also in development.[201] **(L)**	There are obvious benefits in being able to detect the presence of toxins more easily.
Bioremediation is the cleaning up of a polluted environment by micro-organisms. Genetic modification of micro-organisms which are used to do this is underway to improve their performance in degrading contaminants. **(F)**	Improved performance.
Phytoremediation is the cleaning up of a polluted environment by plants or trees. Plants and trees have been genetically modified by transferring to them genes from bioremediant micro-organisms that allow the latter to degrade or absorb and accumulate toxins in contaminated soil such as heavy metals or explosives. **(F)**	Improved performance.

[200] *Guidance on Best Practice in the Design of Genetically Modified Crops*, Advisory Committee on Releases to the Environment (ACRE) Guidance Note 13, DEFRA July 2001.
[201] ERM/GA Report, pp.96-97.

Table 2:

ALPHABETICAL LIST OF GM TREE SPECIES THAT HAVE BEEN RELEASED INTO THE ENVIRONMENT (1988-2000)[202]

Key to abbreviations:

*: herbicide resistance

^: insect resistance

#: virus resistance

Scientific Name & Usage	Common Name and Year of Release if available	HT*	IR^	VR#	Lignin	Markers	Others	Total
Acacia magnium	Acacia (1997)							
Betula pendula (timber)	Birch (1996)				1	1		2
Castanea sativa (timber and nuts)	European Sweet Chestnut (1991)	1						1
Corica papaya (food)	Papaya (1991)			10		2		12
Citrus spp.	Sweet orange (1996)							
Eucalyptus (timber)	Eucalyptus (1993)	4		1	2	3	2	12
Juglans nigra (food and timber)	Walnut (1989)		7	1			7	15
Liquidambar styraciflua	Sweetgum (1994)	3						3
Malus domestica (food)	Apple (1991)	4	5			2	12	24
Malus pumila	Apple	1	1				3	5

202 Rather, M., 2001*: Biotech and Development Monitor*, 44/45 p2-7, Amsterdam. Other sources have reported more extensive lists of transgenic tree species, including almond (*Prunus amygdalus*), cocoa (*Theobroma cocoa*), coffee (*Coffea arabica*), elm (*Ulmus spp.*), larch *(Larix spp.*) and pear (*Pyrus communis*). However, no independent verification of field trials for these species could be obtained, and it is likely that some of these additional reports refer only to greenhouse trials.

(food)								
Olea European (food & oil)	Olive					2	2	4
Picea abies (timber & paper)	Spruce (1996)		3				3	6
Pinus sylvestis (timber & paper)	Pine (1996)	1	1			11	2	15
Populus tremula (fuel, timber & paper)	Poplar (1988)	39	35		4	5	39	122
Populus hybridus (fuel & timber)	Poplar	2	1		6	9	3	21
Prunus avium (model sp.)	Plum					3		3
Prunus domestica (food)	Plum (1992)			3			1	4
Pyrus spp. (food)	Pear						3	3
Tectona grandis	Teak (1997)							
TOTAL		55	53	15	13	38	77	252

ANNEX B

BIOTECHNOLOGY INDUSTRY STATISTICS

Table 1: Some major international agrochemical/seeds businesses and their turnover

Company	Annual Turnover (million $ USA)	
	1997	2000*
Monsanto	3126	5493
Syngenta	4199	4876**
Aventis	4554	4606
Dupont	2518	4318
Bayer	2254	3455
Dow Elanco	2200	2550
BASF	1855	2428
Total	**20706**	**27726**

* includes business acquisitions made in 1998.
** of which seeds, US$947million
Information from Annual Reports and footnotes 4 & 5.

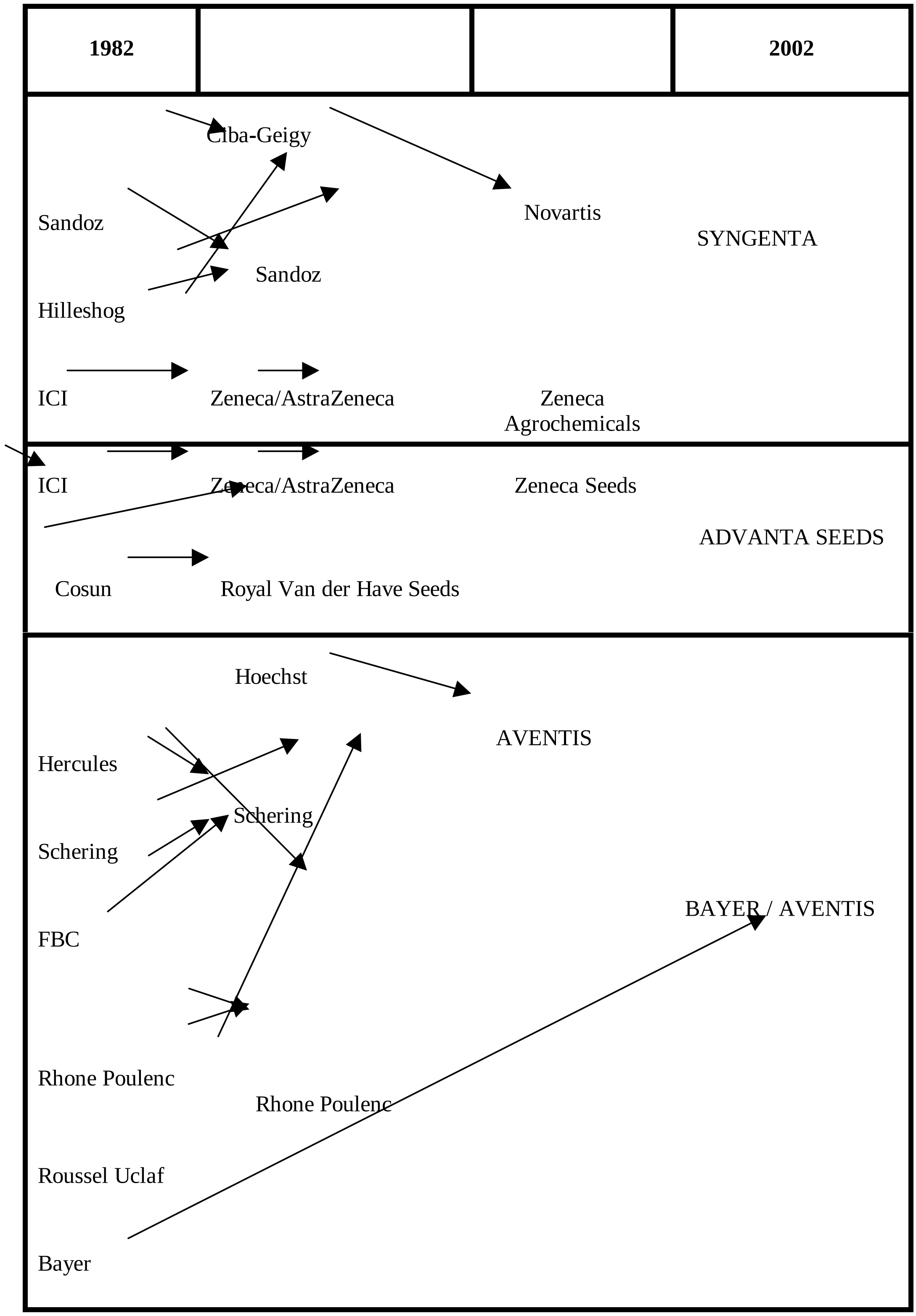
Table 2: Some major international seed businesses and their annual turnover*

Company	Home Country	Turnover (m $)	
		1997	1999
Pioneer(Dupont)	USA	1800	1850
Groupe Limagrain	France	686	700
Grupo Pulsar (Seminis)	Mexico	375	531
Advanta	Netherlands	437	416
Sakata	Japan	349	396
KWS	Germany	329	355
Total		**3976**	**4248**

* Apart from Pioneer, these businesses are not affiliated to agrochemical companies.

Information from footnotes 4 & 5.

Table 3 : Examples of Agrochemical Business Evolution – a comparison between 1982 and 2002 of agrochemical businesses



Monsanto Holdens Foundation Seeds DeKalb Delta Pine & Land Seeds Plant Breeding International Calgene	MONSANTO →	PHARMACIA →	MONSANTO (Agriculture)

ANNEX C

LISTS OF GMOS APPROVED FOR IMPORTATION, PROCESSING OR COMMERCIAL PRODUCTION IN THE EU[203]

For similar information with regard to US, see www.cfscan.fda.gov/lrd/bicon.html

Table 1:
GM crops with Part C product approval for importation and processing only - *not to be grown in the EU*

Date submitted	Lead CA	Company	Crop/Modification	Consent issued
Dec 94	UK	Monsanto	Soybeans/herbicide tolerance	May 96
March 96	UK	Aventis	Oilseed rape/ herbicide tolerance	June 98
June 96	UK	Northrup King	Maize/insect and herbicide tolerance	June 98

Table 2:
GM crops holding part C consents for cultivation in the EU*

Date submitted/Lead CA	Company	Crop/Modification	Scope	Consent issued
Nov 93 France	SNETA	Tobacco/herbicide tolerance [e]	Cultivation	June 94
Feb 94 UK	PGS/Aventis	Oilseed rape/ herbicide tolerance [f]	Seed Production	Feb 96
March 95 France	Ciba-Geigy/Novartis	Maize/insect and herbicide tolerance	Import and cultivation	Feb 97
April 95 Netherlands	Bejo Zaden BV	Chicory/herbicide tolerance [f]	Seed Production	Aug 96
June 96 France	Monsanto	Maize/insect resistance	Import and cultivation	Aug 98
June 96 France	AgrEvo/Aventis	Maize/herbicide tolerance	Import and cultivation	Aug 98
Sept 96 Netherlands	Florigene	Carnation/flower colour [g]	Cultivation	Dec 97
Aug 98 Netherlands	Florigene	Carnation/increased vase-life [g]	Cultivation	Oct 98

***-** In the UK no agricultural crops can yet be grown commercially because none have yet satisfied all the other relevant legislation and approvals e.g. the seed certification and pesticide legislation.
[e] - Only grown in France
[f] - Only grown for seed production-not for general cultivation
[g] - To be grown mainly by Dutch cut flower producers

[203] Source: http://www.defra.gov.uk

Table3:
Applications for Part C approval for placing on the EU market for GM crops for cultivation in the EU under consideration in Europe in Autumn 1998

GM Crop	Applicant	Lead Competent Authority	Stage in the regulatory process
Herbicide tolerant maize (GA21)	Monsanto	Spain	5
Insect and herbicide tolerant maize (T25+MON810)	Pioneer	Netherlands	4
Insect resistant Maize	Novartis	France	4
Herbicide tolerant fodder beet	Monsanto	Denmark	5
Herbicide tolerant oilseed rape	Aventis	Germany	5
Industrial Starch potato	Amylogene HB	Sweden	4
Herbicide tolerant oilseed rape	Aventis	Belgium	5
Below this line awaiting final consents			
Delayed ripening tomato	Zeneca	Spain	6
Insect tolerant cotton	Monsanto	Spain	6
Herbicide tolerant cotton	Monsanto	Spain	6
Insect tolerant Maize	Pioneer	France	6
Herbicide tolerant oilseed rape	Aventis	France	7

Table 4:
Stages in the evaluation process for obtaining part C marketing consent for GM crops under directive 90/220/EEC

Stage 1 Part C application to place GM crops on the market in the European Community are first submitted to any one of the 15 Member States which then becomes the lead Competent Authority (CA). The lead CA has 90 days in which to complete its evaluation.

In the UK this involves a thorough review of the application dossier by scientists in the UK Joint Regulatory Authority (DEFRA, MAFF, Scottish Executive, National Assembly for Wales and Northern Ireland LA) English Nature are statutory consultees on all applications to market GM Crops and independent expert advice is given by the Advisory Committee on Releases to the Environment (ACRE).

Stage 1A *– early applications which have not yet gone to ACRE for Ministerial advice;*

Stage 1B *– applications which ACRE have reviewed and given advice to Ministers.*

⇩

Stage 2 Following the 90 day evaluations period, the lead CA submits the application dossier to the European Commission with either a favourable opinion that the product should be place on the market or, it rejects the dossier.

⇩

Stage 3 If the lead CA submits the dossier with a favourable opinion the Commission circulates it to the other 14 Member States who have 60 days to comment.

⇩ (left branch) If all Members States approve the marketing application then the lead CA issues the Part C marketing consent which applies across all Member States

⇩ (right branch) If one or more Member States objects (which is normal) then the Commission will attempt to resolve the objections.

⇩

Stage 4 This usually involves seeking an opinion from its Scientific Committee on Plants (SCP) which is a committee of experts rather like ACRE.

⇩

Stage 5 Following consultation of the SCP, if the Commission judges that the GM crop should receive marketing approval it will ask the Members States to vote again, this time by the Qualified Majority Voting (QMV) procedure. Once the Members States receive the call to vote they have 28 days in which to respond on whether or not to accept the Commission's proposals. If there is a QMV in favour the lead Member State will issue consent.

⇩

Stage 6 If there is no QMV in favour the Commission will refer the decision to the Council of Ministers who have 90 days to respond. At this stage the Council of Ministers can reject the Commission's proposal (that the GM crop should receive marketing consent) but only by unanimous decision. If the Council of Ministers fails to act or to reach a unanimous decision the GM crop will be approved and the lead CA issues consent.

⇩

Stage 7 The Commission instructs the lead competent authority to grant consent.

ANNEX D

AEBC CONSULTATION PAPER ON FUTURE SCENARIOS FOR THE UPTAKE OF GM IN AGRICULTURE: JUNE 2001

The aim of this consultation is to help the AEBC understand a range of perspectives on how agriculture and the environment might be affected by the use, or non-use, of biotechnology in the UK and in Europe. We are conscious that biotechnology embraces techniques and products other than GM, and although GM is the focus of the current controversy, we want to look beyond this to developments in genomics and other applications of biotechnology. The sub-group is forming its own views about possible future developments in biotechnology, but we are keen to augment these with an understanding of how people with different interests and standpoints envisage the future with or without it, and how GM in particular fits or does not fit with wider aspirations for agriculture and for environmental protection.

We urge respondents to look beyond the usual 2-3 year time horizon to 10, 20 or even 50 years hence, and to think through the consequences of the different directions outlined below in as much detail as possible. It would also be helpful if respondents could set out clearly the differences between what they think **might** happen and what they would **like** to happen.

The scenarios we are proposing for debate are as follows:

A. The UK aims for market-led development and take-up of biotechnology (GM and/or other technologies) i.e. there is no policy guidance or regulatory constraint (that go beyond current policies and regulation) on what kind of products are brought forward by technology providers.

B. The UK aims for development and take-up of biotechnology consistent with the aims of 'sustainable agriculture' i.e. technology providers are given incentives, guidance or regulatory requirements to produce certain types of products (accepting that a definition of sustainable agriculture would be needed - the February 2000 MAFF definition is quoted below for discussion*).

C. The UK, or any of the regions within the UK, rejects biotechnology while the rest of Europe and the rest of the world accepts.

D. All of Europe rejects biotechnology, while rest of the world accepts.

We are aware that these scenarios are very simple in their construction and that they are not the only ones available. However, we feel that these are a reasonable starting point for debate. We would like respondents to comment on what each of these scenarios might mean in terms of:

1. What kind of products will be given priority, in terms of what kind of crops or animals, and what kind of traits? This should cover the applications likely to be brought forward in the short to medium term, and those targeted for development in the longer term. For instance, under a

scenario that aims for 'sustainable agriculture' the priority crop/trait combinations might be those that mean less use of inputs such as energy and chemicals. Crops include non-food crops such as forestry, or plants used to produce raw materials for industry, and may include consumer as well as environmental benefits.

2. The effects on agricultural trends, including patterns of land use; the mix of farming systems from conventional through to organic; the price of agricultural products; and agricultural trade and transport.

3. The effects on environmental trends, for instance the conservation value of agricultural land; efforts to reduce emissions of greenhouse gases, efforts to reduce quantities of inputs such as water, energy, pesticides and fertilisers, efforts to reduce 'food miles' i.e. distances over which agricultural goods are transported.

4. The conditions (regulatory and/or voluntary) that might be put on the use of biotechnology-derived crops or animals in agriculture, where these are different to what is already in place. For instance, how a GM-free UK (or part of the UK, or Europe as a whole) might be enforced; or how any voluntary codes of conduct or protocols for producers (for example refuge strategies or separation distances) might work.

5. The ways in which decisions are made, in particular how relative risks and benefits are assessed, how ethical considerations are factored in, and how people at large are involved in those decisions. For instance, how the contribution to 'sustainable agriculture' might be judged, who should be involved in such a judgement and through what mechanism.

6. Any other consequences on which respondents wish to comment.

To ease our analysis of the responses, it would be helpful if respondents could structure their notes by using the headings A1, A2 … A5, B1, B2 …B5 etc. to reflect the different considerations for each scenario. However, we would not wish this structure to constrain your reflections, so only use it where you are happy with this presentation.

How responses will be used

We are asking people from a range of viewpoints to respond to this consultation in writing by the end of July. At the Commission meeting in Birmingham in July, the evening of 18th July has been set aside for public debate on responses from three organisations (CropGen, UK NFU, RSPB). The Sub-Group on Horizon-scanning will then use the written responses, the results of the public debate, and our own research, to draft a report for discussion by the Commission at its meeting in Belfast on September 13th-14th. We are also exploring the possibility of using these scenarios as the basis of an internet-based discussion.

* February 2000 MAFF definition of **sustainable agriculture** (from ‘Towards Sustainable Agriculture, A Pilot set of Indicators’):

Sustainable agriculture means:

- Ensuring the continuing availability to the consumer of adequate supplies of wholesome, varied and reasonably-priced food, produced in accordance with generally accepted environmental and social standards;
- Maintaining a competitive and flexible industry which contributes to an economically viable rural society;
- Ensuring effective protection of the environment and prudent use of natural resources;
- Conserving and enhancing the landscape, wildlife, cultural and archaeological value of agricultural land; and
- Respecting a high level of animal welfare.

ANNEX E

WHO WE MET AND WHO RESPONDED TO OUR CONSULTATION

AEBC is very grateful for all the input from a range of people and organisations to its work on this horizon scanning study.

The horizon scanning sub-group's meetings included discussions with:

- Society, Religion and Technology Project: Dr Donald Bruce, Dr Mike Appleby, Professor John Eldridge, Ann Bruce, Rev Dr Michael Northcott, Prof Joyce Tait, in April 2001
- English Nature: Dr Brian Johnson, and National Farmers Union: Ben Gill, in June 2001
- DEFRA: Henry Derwent, Dr Linda Smith, Dr Paul Burrows (ACRE Secretary), in September 2001
- DTI: Dr Monica Darnbrough, Ian Shaw, Dr Sue Armfield, in September 2001

The Commission had two discussions at its public meetings. In July 2001 in Birmingham AEBC discussed scenarios on take-up of GM in agriculture with:

- CropGen: Professor Vivian Moses
- National Farmers Union: Ian Gardiner
- Royal Society for the Protection of Birds: Dr Mark Avery

In September 2001 in Belfast AEBC discussed the future of biotechnology in Northern Ireland with:

- Journalist, Brian Black
- Ulster Farmers Union: John Gilliland (also AEBC and sub-group member)
- Centre for Innovation in Biotechnology: Dr Jeremy Carmichael
- Bioresearch Ireland: Dr Jim Ryan:

The Commission also had discussions with senior school students from schools in Belfast in September 2001.

The minutes of all these meetings are on the AEBC website: www.aebc.gov.uk

AEBC had further, written, responses to the consultation paper on possible scenarios on take-up of GM in agriculture from:

- Farm and Food Society
- National Council for Women of Great Britain
- 5 Year Freeze
- Biodynamic Agricultural Association
- Royal Society of Edinburgh
- Royal Society for the Protection of Birds
- Statutory Conservation Agencies
- Institute of Arable Crops Research

- CropGen

ANNEX F

WHO WE ARE

Professor Malcolm Grant (Chair):
Pro Vice Chancellor at the University of Cambridge

Ms Julie Hill MBE (Deputy Chair) #
Programme Adviser and former Director of Green Alliance

Reverend Professor Michael Banner
Professor of moral and social theology at Kings College, London

Ms Anna Bradley
Director of the National Consumer Council

Ms Helen Browning OBE
Tenant Farmer, Eastbrook Farm; Founder and Director of Eastbrook Farm Organic Meats Ltd

Dr David Carmichael
Arable farmer concentrating on seed production from combinable crops

Professor Philip Dale
Leader of the Genetic Modification and Biosafety Research Group at the John Innes Centre, Norwich

Dr Ed Dart CBE #
Chairman of Plant Bioscience Ltd

Dr Matthew Freeman
Senior Researcher at the Medical Research Council Laboratory of Molecular Biology, Cambridge

Mr John Gilliland #
Arable farmer with a particular interest in sustainable production systems and the pioneering of non food crops.

Professor Robin Grove-White
Professor of Environment & Society, and Director of the Centre for the Study of Environmental Change, Lancaster University

Dr Rosemary Hails MBE
Ecologist, and Principal Scientific Officer, Centre for Ecology and Hydrology, Oxford and lecturer at St Anne's College Oxford

Ms Judith Hann
Freelance Broadcaster and Writer who presented Tomorrow's World for 20 years.

Ms Chi Chi Iweajunwa #
Member of executive evaluation group for NHS Direct and member of Partners Council for NICE (National Institute for Clinical Excellence)

Dr Derek Langslow CBE #
Scientist specialising in nature conservation/biodiversity and former Chief Executive of English Nature

Professor Jeff Maxwell OBE
Former Director, Macaulay Land Use Research Institute

Dr Sue Mayer
Executive Director of GeneWatch UK

Professor Ben Mepham
Director of the Centre for Applied Bioethics at the University of Nottingham and Executive Director of the Food Ethics Council

Ms Justine Thornton
Barrister specialising in environmental law

Dr Roger Turner #
Chief Executive Officer, British Society of Plant Breeders

# denotes horizon scanning sub-group members

ANNEX G

SHORT BIBLIOGRAPHY AND SOME INTERNET RESOURCES

Below is a selection of papers and articles considered by the sub-group in the course of this study. The sub-group also took evidence from a number of organisations and individuals (see Annex G). Minutes of those meetings can be found on the AEBC web-site (**www.aebc.gov.uk)**. Several web-sites where general information may be obtained on biotechnology are also listed at the end of this bibliography.

Genetic Modification of Temperate Fruit Crops – why we do it and why it's necessary. Paper given by Professor D J James for British Association Festival of Science, London, September 2000.

Consumer Benefits from GM Foods. Response from British Society of Plant Breeders to Food Standards Agency, September 2000.

The Risks Associated with the Introduction of GM forage grasses and forage Legumes. S Young, M O Humphreys, M T Abberton, M P Robbins, K J Webb Institute of Grassland and Environmental Research, MAFF Project RG0219, 1999.

Transgenic Crops: An Environmental Assessment. Henry A Wallace Center for Agricultural and Environmental Policy at Winrock International, November 2000.

Global Status of Commercialized Transgenic Crops: 1999, ISAAA Briefs No. 12: Preview. ISAAA: Ithaca, NY, 1999.

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Safety aspects of genetically modified foods of plant origin. World Health Organisation, 2000.

Preparing for the Future. Food Chain and Crops for Industry Panel report, Foresight, December 2000.

Foresight for agriculture, horticulture and forestry – crop production. Dr R Turner, May 1998.

A review of the role of agriculture, horticulture and forestry in the UK economy. J S Marsh, Foresight, 1997.

Why US farmers are adopting genetically modified crops. J E Carpenter and L P Gianessi, National Center for Food and Agriculture Policy, October 1999.

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Response to World Wildlife Fund Background Paper 'Transgenic Cotton: Are There Benefits for Conservation?' J E Carpenter and L P Gianessi, National Center for Food and Agriculture Policy, 25 September 2000.

Feeding the World with Sustainable Agriculture: A Summary of New Evidence. Executive Summary, J Pretty and R Hine, University of Essex, for Department for International Development, December 2000.

Briefing on horizon scanning in biotechnology R+D – what are the prospects and the potential risks to the environment? Evidence given by English Nature (B Johnson, A Hope) March 2001.

GMOs: Review and Forward Look. Paper (GC POO 71) for English Nature by B Johnson and A Hope. December 2000.

EU-US Biotechnology Consultative Forum Report. December 2000.

Elements of Precaution: Recommendations for the Regulation of Food Biotechnology in Canada. Report by the Royal Society of Canada [insert date]. (www.rsc.ca/foodbiotechnology)

Report by the New Zealand Royal Commission on Genetic Modification. 30 July 2001. (www.gmcommission.govt.nz)

Genetically Modified Food. Report to the Church of Scotland General Assembly by the Society, Religion and Technology Project. 1999.

Ethical Concerns about Patenting in relation to Living Organisms. Report to the 1997 General Assembly of the Church of Scotland by the Society, Religion and Technology Project. May 1997.

GM Animals, Humans and the Future of Genetics. Appendix to the Board of National Mission Report to the 2001 Church of Scotland General Assembly

The Environment Agency and Genetically Modified Organisms: Technical Report. Report by Environmental Resources Management/Green Alliance, H Livesey, J Hill, J Geddes, August 2001.

Towards Sustainable Agriculture A Pilot Set of Indicators. Ministry of Agriculture, Fisheries and Food, February 2000.

Harvest on the Horizon: Future Uses of Biotechnology. Report prepared by the Pew Initiative on Food and Biotechnology, September 2001.

The use of genetically modified animals. The Royal Society, Policy Document 5/01, May 2001, (www.royalsoc.ac.uk)

Global GM Market starts to wilt. John Vidal, The Guardian, 28 August 2001.

Organic Farming and Gene Transfer from Genetically Modified Crops. C L Moyes and P J Dale, published by John Innes Centre, Norwich, May 1999.

New Era, new Challenges, New Solutions. Paper presented by Dr David A Evans of Zeneca Agrochemicals, Fernhurst, UK and presented as the twenty-seventh Bawden Memorial lecture at the British Crop Protection Council Conference Pest and Diseases 2000, held at Brighton UK in November 2000.

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Report on the Future of the Biotechnology Industry. The Committee on Industry, External Trade, Research and Energy of the European Parliament, 28 February 2001.

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Farming and Food – A Sustainable Future, Policy Commission on the Future

of Food and Farming report, 2002

A Forward Strategy for Scottish Agriculture, 2002

Vision for the Future of the agri-food industry, (Northern Ireland), 2002

Farming for the Future, (Wales), 2002

Some internet resources

For general information on biotechnology:

Agriculture and Environment Biotechnology Commission: www.aebc.gov.uk

Society, Religion and Technology Project: www.srtp.org.uk

GeneWatch: www.genewatch.org.uk

English Nature: www.english-nature.org.uk

The New Scientist: www.newscientist.com

Natural Environment Council: www.nerc.ac.uk/publications/gmo

Biotechnology and Biological Sciences Research Council: www.bbsrc.ac.uk

The Royal Society: www.royalsociety.ac.uk

National Farmers Union: www.nfu.org.uk

Biotechnology Industry Association: www.bio.org

Organisation for Economic Cooperation and Development: www.oecd.org/agr

Department for Environment, Food and Rural Affairs: www.defra.gov.uk

Foresight e.g. Food Chain and Crops for Industry: www.foresight.gov.uk

Department of Trade and Industry, biotechnology in the UK: www.dti.gov.uk/bioguide

Office of Science and Technology: www.ost.gov.uk

US Food and Drug Administration, Center for food Safety & Applied Nutrition, Office of Food Additive Safety: www.cfscan.fda.gov/~lrd/bicon.html

Agricultural Biotechnology Council: www.abcinformation.org

ANNEX H

GLOSSARY

WHAT THE WORDS MEAN

This glossary gives definitions applicable in the context of this study; some terms may of course have different meanings in other contexts.
Items in italics are defined elsewhere in the glossary.

A-biotic stress resistance	Resistance to stresses arsing from non-biological sources e.g. drought, water logging, salinity and heavy metal concentrations
Abstraction	In the context of availability of water: the taking of water from the water table
Apomixis	A process that occurs naturally in a handful of plants. It involves the plant reproducing itself asexually, producing seed but no pollen
ACP	Advisory Committee on Pesticides: statutory body established under the Food and Environment Protection Act 1985 which advises on all matters relating to the control of pesticides (including herbicides)
ACRE	Advisory Committee on Releases to the Environment: statutory body established under Part VI of the Environment Protection Act 1990, consisting of independent experts with a secretariat provided by *DEFRA*; advises the Government on the safety of proposed releases and marketing of *GMOs* and non-native species, and on related issues
AEBC	Agriculture and Environment Biotechnology Commission: established in June 2000 following a review in May 1999 by Government of the regulatory and advisory framework for biotechnology with a remit to give Ministers independent, strategic advice on developments in biotechnology and their implications for agriculture and the environment
Autonomous transposable elements	Small sections of DNA carrying a gene and other information, and capable of integrating with the genome
Avidin®	Commercially produced as a *transgene* in corn and used as a research chemical and diagnostic reagent
Bacterial resistance	To give plants in-built resistance to specific bacteria

Biodiversity	The number and diversity of plants and animals
Biomass	The total mass of living matter within a given area
Bioremediation	The use of *GM micro-organisms* in treatment of contaminated land, as sensors to detect pollution, or directly in soil to digest pollutants.
Biotechnology	Modern biotechnology is understood to mean the suite of techniques developed over the last two decades or so to augment traditional uses of *micro-organisms* such as brewing, baking, cheese-making. The most controversial of these techniques has been *recombinant DNA*, also referred to as *genetic modification, genetic manipulation, genetic engineering* and *transgenesis* and abbreviated to *GM*. Other techniques include *marker-assisted breeding, mutation breeding* and *cloning*. Together these techniques constitute what is known as modern biotechnology
Broadacre agriculture	Large scale agricultural practice
Broad spectrum herbicide	Weed killer which controls a wide range of annual and biannual weeds
BSE	Bovine Spongiform Encephalopathy
Bt	Bacillus thuringiensis: a soil bacterium that produces toxins that are deadly to some insects
CAP	EU Common Agricultural Policy
Cartagena Protocol	Protocol to the *CBD* on biosafety (signed in Montreal, January 2000)
CBD	Convention on Biological Diversity: Signed by over 150 governments at the 1992 Earth Summit in Rio de Janeiro, its principal objectives are the conservation, sustainable use and equitable sharing of the benefits of the use of biological diversity
Carcinogen	Cancer causing
Chloroplast	The green part of a cell that converts sunlight into energy
Clean technologies	For example, growing crops with improved *pest resistance* could reduce pesticide application rates and improve conservation value
Cloning	Molecular cloning is the process of replication of a single

	gene sequence, and may enable the production of genetically identical plants or animals
Co-existence	Capacity for differing farming systems to be sustained alongside one another
Commercialisation	Growing crops on a commercial scale, for the market
Commission, the	*AEBC*
Conventional agriculture	Commonly used in two different senses, to mean either agriculture not involving *GM* crops or non-organic agriculture
Cry proteins	Crystalline protein which is fatal to insects if ingested
Cultivar	International equivalent of *variety* (see below)
DEFRA	Department for Environment, Food and Rural Affairs (from June 2001)
DETR	Department of the Environment, Transport and the Regions (until June 2001)
DfID	Department for International Development
Diagnostics	The use of *biotechnology* to diagnose the presence of disease agents
DNA	Deoxyribonucleic acid, a molecule which comprises the genetic material of most living organisms
DTI	Department for Trade and Industry
EU	European Union
EPA 1990	Environmental Protection Act 1990
Edible vaccine technology	Technology aimed at the production of cereal crops, fruit and vegetables containing vaccines
Environmental degradation	Deterioration of the environment in terms of quality of soil etc
Environmental 'footprint'	Comparative impacts on the environment of different *GM* and non-GM management regimes
Eurobarometer®	Survey of public opinion in the EU undertaken and published on behalf of the European Commission
Expression	As in gene expression: not all genes are active. The gene is

	expressed when the offspring show the character e.g. red flowers, blue eyes, of the parents
Fermentation technology	Technology to develop processes involving the growth of *micro-organisms* in liquid under a wide range of conditions. Fermentation usually refers to the growth of *micro-organisms* in the absence of air
Field trial	Tests of the ability of a new crop variety to perform under normal cultivation conditions
Fitness	The genetic contribution of an individual to the next generation: the fundamental measure of evolutionary success
Food chain	The transfer of energy from green plants (the primary producers) through a sequence of organisms in which each eats the one below it in the chain and is eaten by the one above
Fructan	A plant sugar
FSA	Food Standards Agency: established by Act of Parliament on 1 April 2000 with key functions including the provision of advice and information to the public and Government on food safety and protection of consumers through enforcement and monitoring
FSE(s)	Farm-Scale Evaluations of *GMHT* crops
Gene	The basic unit of *heredity*; an ordered sequence of nucleotide bases, comprising of a segment of *DNA*
Gene flow	The movement of genes from one population to another
Gene stacking	Simultaneous presence of more than one *transgene* in an organism, usually a *GM* organism. Stacking may be induced deliberately, but can will occur as a result of natural geneflow
Genetic engineering	See *recombinant DNA*
Genetic manipulation	See *recombinant DNA*
Genetic modification	See *recombinant DNA*
Genome	The total set of *genes* carried by an individual or cell

Genomics	The study of *genomes*
Germplasm	A general term for the available pool of different *genomes* in a species or hereditary material
Global biological diversity	The variability among living organisms from all sources including, among other things, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes diversity within species, between species and of ecosystems
Glyphosate	*Broad spectrum herbicide* to which certain crops (including the *GM* beet in the *FSE*) are tolerant
Glufosinate ammonium	*Broad spectrum herbicide*, to which certain crops (including the *GM* maize and *GM* oilseed rape in the FSE) are tolerant
GM	*Genetically modified:* see recombinant DNA and GMO
GM Bt crop	*Crops modified to contain the part of the bacterium gene responsible for manufacturing the fatal, but highly insect specific, protein,* Bt [see Bt]
GMHT crop	Genetically modified, herbicide-tolerant *crop*
GM foods	Foods containing ingredients produced using *recombinant DNA technology or genetic modification*
GMO	Genetically modified organism: defined as an organism in which the genetic material has been altered by the direct introduction of *DNA* (specifically defined in EU legislation)
Greenhouse gases	Gases in the atmosphere which allow short-wave solar radiation to pass through and warm the earth's surface, but at the same time trap some of the long-wave infrared radiation emitted by the ground, and keep the earth warmer than it would otherwise be. Human activities are increasing the concentration of greenhouse gases, particularly carbon dioxide and methane, with implications for global warming and the environment
Greenhouse trials	Tests of the ability of a new crop variety to perform under greenhouse conditions (contained environment)
Heredity	The passage of characteristics from parents to offspring
Herbicide	A substance which kills plants and is used to control weeds. Different herbicides are toxic to different varieties of plants and some can kill a wider variety of plant than others

Herbicide-tolerant	In the context of *genetic modification*, herbicide tolerance introduced by the insertion of a gene or genes capable of producing a gene product which inhibits or changes the effect of a herbicide on the plant. All crops are to some extent herbicide tolerant.
HGC	Human Genetics Commission: established following a review in May 1999 by Government of the regulatory and advisory framework for biotechnology with a remit to give Ministers strategic advice on the "big picture" of human genetics, with a particular focus on social and ethical issues
Horizontal transfer	Asexual movement of genes
HT	*Herbicide-tolerant*
Hybrid	An individual plant or animal that results from a cross between two genetically unlike parents (i.e. mule)
Hybridisation	Process by which hybrids are produced
IACR	
IPR	Intellectual property rights: the legal rights associated with inventions, artistic expressions and other products of the imagination (patent, copyright and trade-mark law)
Landraces	Pre-scientific local cultivars which are products of natural selection over time in domestication
LEDCs	Less economically developed countries
Lepidopteran pest	Type of insect: butterfly and moth
Lower-input farming	Farm system based on lower usage of fertilisers, chemicals etc.
Lycopene	Natural material found in tomatoes
MAFF	Ministry of Agriculture, Fisheries and Food (until June 2001)
Marker assisted breeding	Use of *marker genes* to enhance the conventional breeding of crops and livestock
Marker gene	A *gene* or short sequence of *DNA* that acts as a tag for another, closely linked, *gene*
MEDCs	More economically developed countries

Micro-organism	Usually a single-celled organism e.g. bacteria, yeasts, moulds and simple animals and plants
Mitochondria	Parts of cells responsible for energy metabolism
Mutation breeding	Selection of plants with natural or artificially induced (using irradiation or chemicals) mutations to produce novel varieties.
NFU	National Farmers Union
NGOs	Non-governmental organisations
NIAB®	National Institute for Agricultural Botany
No-till agriculture	System that reduces mechanical cultivation of soil
OECD	Organisation for Economic Co-operation and Development
Organic farming	Farming which produces food using feed or fertiliser of plant or animal origin without the employment of chemically formulated fertilisers and growth stimulants. Antibiotics and pesticides are permitted under some circumstances
Organism	An individual animal, plant, or single-celled life form
Out-crossing	Mating between different species
PCR	Polymerase Chain Reaction: technique used to replicate a fragment of *DNA* so as to produce many copies of a particular *DNA* sequence; commonly employed as an alternative to *gene* cloning as a means of amplifying genetic material for *gene* sequencing
Pathogen	A bacterium, virus or other *micro-organism* that can cause disease
Peptide	Biologically important class of molecules that can exist separately or be part of a protein
Phenolics	Organic chemicals
Photorabus luminescens	A soil-borne bacterium
Photosynthetic	Process in plants by which carbon dioxide is converted into organic compounds
Phytochemicals	Bioactive chemicals, other than vitamins and minerals, found in plants.

Phytoremediation	The cleaning up of a polluted environment by plants or trees which have been *genetically modified* specifically for that purpose
Precautionary principle	An approach to the management of risk when scientific knowledge is incomplete
PSD	Pesticides Safety Directorate: an Executive Agency of *DEFRA*, which administers the regulation of agricultural, horticultural, forestry, food storage and home garden pesticides
RNA	Ribonucleic acid; similar in structure to *DNA*, plays an important role in protein synthesis and other chemical activities of the cell. Many viruses are composed entirely of *RNA*
RSPB	Royal Society for the Protection of Birds
Recombination	The rearrangement, for example by crossing over, of nucleic acid molecules to produce new sequences
Recombinant DNA technology	Deliberate insertion of genes into a *DNA* molecule using the techniques of modern molecular biology
Refugia	An area providing a safe haven for species in which chemicals are not used
Risk assessment	A tool for extrapolating from statistical and scientific data a value which people will accept as an estimate of the risk attached to a particular activity or event
Roundup®	A broad spectrum herbicide which can kill a wide variety of plants, including soybeans which have not been genetically modified to tolerate it
Roundup Ready®	'Roundup Ready' is the proprietary name given to crops which have been modified to contain resistance genes to the herbicide *glyphosate (Roundup)*
Sclerotinia	Parasitic fungi
SEERAD	Scottish Executive Environment & Rural Affairs Department
Selective breeding	The use of organisms exhibiting desired characteristics to produce offspring which also bear these characteristics
Sentinel plants	Plants with the ability to indicate to their grower when they need more food, water or input by expression of a particular

	characteristic such as florescence
Small-holders	People who work holdings which are smaller than normal farms
Soil Association®	A registered charity with a Council elected by its members, which sets standards for the certification of organic food allowing no *genetically modified* ingredients in its production systems
Soil erosion	Loss of soil by wind and water
Soil salination	Build up of salt in soil
Splice	In the biological sense, to join or insert a gene or gene fragment
Substantial equivalence (principle of)	A comparative approach, focusing on the determination of similarities and differences between *genetically modified food* and its conventional counterpart, which aids in the identification of potential safety and nutritional issues
Sustainable agriculture	A system of agriculture aimed at: ensuring the continuing availability of adequate supplies of wholesome, varied and reasonably-priced food, produced in accordance with generally accepted environmental and social standards; maintaining a competitive and flexible industry which contributes to an economically viable rural society; ensuring effective protection of the environment and prudent use of natural resources; conserving and enhancing the landscape, wildlife, cultural and archaeological land; and, respecting a high level of animal welfare
Staple crop	Crops providing the principal components of an individual's or a community's diet
Strains of plants	Varieties of plants developed in breeding
'Take-all' resistant wheat	Varieties of wheat resistant to plant pathogen 'Take All'
Threshold levels	A quantity set by weight or number to define the maximum or minimum presence of one material in another (for example, the presence of *GM* seed in a batch of non-*GM* seed)
Transgenesis	See *recombinant DNA*
Transgene/ transgenic	Genes inserted by the direct incorporation of *DNA*, as opposed to endogenous genes

UFU	Ulster Farmers Union
Varietal associations	A crop *variety*, containing more than one plant type (usually two, of which one acts as the pollinator, the other the pollinated)
Variety	A subdivision of a species. An agricultural variety is a group of similar plants that by structural features and performance can be identified from other varieties within the same species
Virus-resistance	In-built resistance to a viral carrier
WTO	World Trade Organisation
Wolbachia	Bacteria living in insect cells
Xeno-transplantation	The surgical removal of an organ or tissue from one species and transplantation into a member of a different species