Non-Food GM Crops: New Dawn or False Hope?

Part 2: Grasses, Flowers, Trees, Fibre Crops and Industrial Uses

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Whilst GM foods have been intensely controversial, there is little awareness of the production of GM plants for non-food uses

Whilst GM foods have been intensely controversial, there is little awareness of the production of GM plants for non-food uses. The biotechnology industry hopes that these will attract less adverse attention and allow use of the technology, but there are still important questions for society to address. Part 1 of this report considered the use of GM crops to produce drugs. Part 2 reviews developments in the genetic modification of non-food plants: grasses, flowers, trees, crops such as cotton used for fibre production, and the range of different crops being modified to provide the raw materials for industrial production of oils, starches and plastics. It considers how they are being modified, how successful the modifications have been and what environmental and health issues are raised. It makes recommendations for policy and research.

Grasses

The main economic impetus for GM grasses is the amenity market golf courses, sports fields, municipal parks and private gardens and the desire to create the perfect green or lawn. Most GM grass research is taking place in the USA, led by Monsanto and Scotts with their herbicide tolerant, Roundup Ready bent grass, which may be the first GM grass to be grown commercially. However, an application to market the grass in the US has recently been withdrawn. Other research is investigating making grasses male sterile, disease resistant, or tolerant to drought or salinity. None of these are well advanced.

GM grasses raise serious environmental concerns because they are perennial, freely wind pollinating and often spread via underground shoots

GM grasses raise serious environmental concerns because they are perennial, freely wind pollinating and often spread via underground shoots (tillering) so gene flow to related plants is inevitable. Many of the grasses being genetically modified are also weeds in crops. The potential for more troublesome weeds to emerge is very real and it is unlikely that GM grass seeds will be easily contained. They can be easily spread internationally as contaminants on wool, in imported grass seed and in bird seed, for example.

The UK has considered the potential environmental impacts of the introduction of GM forage grasses but has not considered GM amenity grasses. There is an urgent need to consider the problems of containment on an international level as such grasses, like many grasses in the past, are likely to spread widely.

Industrial uses

Being able to use plants as chemical factories utilising the sun's energy, rather than fossil fuels, is one dream of biotechnologists genetically modifying crops to produce industrial feedstocks. They hope these will be environmentally friendly solutions to the demands for biodegradable plastics and the production of designer oils and starches. The use of GM potatoes with a modified starch profile is the most advanced application of GM in the field. The Swedish company involved, Amylogene, is applying for consent to grow these potatoes in Europe, and this could be granted in 2004. These are unlikely to be grown in the UK as starch potatoes are grown in Eastern Europe, the Nordic countries, Germany, Belgium and France. The high amylopectin starch extracted will be used in the pulp and paper industry.

Other applications - to use GM crops to produce specialised oils, other starches and plastics - are proving more difficult because of the complex or novel biochemical pathways involved. Unintended effects such as stunting of plant growth and reduced reproductive capabilities are often encountered. It has also proved difficult to achieve high enough levels of the compound to make it financially viable because the profit margins for industrial raw material production are much tighter than for the production of high value pharmaceuticals. There are also likely to be limitations on the amount of a plant's resources that can be diverted without affecting its growth and performance in other ways.

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GM crops could also be used as biofuels. GM sugar beet may be used for bioethanol production or the oil from oilseed crops used in biodiesel, not a food or feed. In these cases, the modifications are likely to be for agronomic purposes, such as herbicide tolerance, rather than to improve biofuel characteristics.

There are also important environmental and health issues that will need to be considered, particularly if crops are used which can hybridise with neighbouring food crops or wild species. The changed nature of lipids or the presence of new precursor compounds for plastics, not naturally produced in the plant kingdom, may have ecological impacts, but little attention appears to have been paid to such dangers. Depending on the crop involved and the scale of production, contamination of non-GM crops and resulting economic damage is also a factor that will have to be addressed.

Trees

The pulp and paper industry is a global, multimillion dollar industry and has therefore attracted the attention of the biotechnology industry as an important market. Multinational forestry corporations, such as Macmillin Blodel and Westvaco, are teaming up with companies like Monsanto or funding research in universities. There are no GM trees available commercially but the main application of GM to trees, as with many crops for food or non-food use, has been to produce herbicide tolerance or insect resistance. These are intended for use in intensive plantations of forestry trees, including poplars and eucalyptus. Pine and spruce trees are much more difficult to modify.

Establishing agreement about the environmental safety of releasing GM trees to the environment will pose more challenges than for GM food crops. The data considered necessary to determine genetic stability, the extent and rate of gene flow, and the persistence and invasiveness of a GM food crop typically involves experiments lasting over several generations of the plant, conducted under different environmental conditions. The long generation times and slow growth of trees mean that collecting similar data about their environmental performance will require much longer periods if it is to match that considered acceptable for GM crops.

Fibre crops

Like the pulp and paper industry, fibre production - particularly from cotton - is a multimillion dollar, global industry which has also attracted the attention of the biotechnology industry. GM cotton is being grown commercially on approximately 6.8 million hectares in the USA, Mexico, Argentina, China, India, Indonesia, Australia and South Africa, and constitutes around 12% of the global cotton crop. GM cotton has been modified to contain an insecticidal toxin, *Bt*, *The use of Bt cotton in the USA and Australia has brought some advantages in terms of increased yield and a reduction in the use of some classes of insecticide*

from a soil micro-organism, and to be herbicide tolerant. Other, less successful, research has attempted to introduce disease resistance, colour modifications and improved fibre qualities. Monsanto dominates GM cotton production. Conventional cotton production uses large amounts of insecticide because of problems with caterpillar pests such as the bollworm. The use of *Bt* cotton in the USA and Australia has brought some advantages in terms of increased yield and a reduction in the use of some classes of insecticide. However, the reductions are not uniform and may not be maintained and, in India, it is claimed that *Bt* cotton has not been successful. With *Bt* cotton, the pattern of insect pests is changing as sucking pests (which are not killed by *Bt toxins)* become more important and require additional insecticide treatments. The potential for the emergence of resistance to *Bt* among pests also threatens the long term viability of *Bt* cotton. GM cotton with two *Bt* genes is being introduced to try and delay the emergence of resistance. If resistance does arise, the use of GM *Bt* cotton may also compromise the usefulness of *Bt* as an organic insecticide.

In the countries where it is grown, there may be issues of cross-pollination of wild cottons and this has led to restrictions in the USA and Australia. The benefits (or otherwise) for small farmers are bitterly disputed. Monsanto is now targeting South-east Asia and Africa to increase its sales.

Flowers

The demands of the cut flower industry and the desire for ever more exotic colours and shapes have been behind the use of GM techniques in flower production. GM mauve and violet carnations are sold in Australia and Japan by the companies Florigene and Suntory respectively. These may also have been modified to have extended vase life. GM carnations have regulatory approval in Europe but are not sold here.

Ongoing research includes the search for the elusive blue rose, and disease and heat resistance

Ongoing research includes the search for the elusive blue rose, and disease and heat resistance. Wider environmental concerns about this work may arise if GM becomes more widely used in horticulture as the escape of exotics from gardens has already led to considerable ecological disturbance.

Conclusions and recommendations

For non-food crops, GM cotton and flowers are the first to have been commercialised. GM potatoes with modified starch may be grown commercially in Europe soon and possibly GM Roundup Ready grass in the USA. Overall, as with GM food crops, it is the agronomic traits of herbicide tolerance and insect resistance which are attracting most interest and proving the easiest to achieve.

Whilst there are aspirations to produce designer starches, oils and feedstocks for plastics, these have not been successful at product levels that are economically viable. Understanding of biochemical synthetic pathways is limited and the production of a particular oil or other compound can often damage plant growth. For industrial oils, a better strategy may be to improve the performance of plants which naturally produce specialised oils. Physiological limitations may ultimately hamper the economic viability of GM plants for industrial use they may simply be unable to produce enough of the required compound to compete with other sources, such as petrochemicals, without damage to themselves.

The environmental questions raised by some of these developments have been poorly addressed, and the potential harm arising from the use of GM grasses and trees demands urgent attention at an international level. Basic research is needed to understand how the production of new oils or other industrial molecules affects the ecological performance of a plant. There is little evidence of any such research at present.

Because non-food crops could cross-pollinate food crops, attention is needed to ensure that GM contamination of non-GM farmers' products does not occur.

Consideration of this issue should be included in the development of GM crop policy.

Arising from the research carried out for this report, GeneWatch UK makes the following recommendations:

The potential harm arising from the use of GM grasses and trees demands urgent attention at an international level

1. A review of the problems of national containment of GM trees and grasses must be conducted under the auspices of the Cartagena Protocol, which regulates the trade in GMOs and encompasses the issue of unintended transboundary movement. The UK government should press the EU to take this issue forward at Protocol discussions and consider its own position. There are good grounds for an international moratorium on the production of GM grasses and trees if these issues cannot be resolved.

2. A review of the various methods of producing designer oils and starches in plants should be conducted. In particular, it should consider the relative merits of GM compared to improving agronomic performance of plants making the products naturally. This should be used to inform research and investment priorities in this area.

3. In considering future UK policy in relation to GM crops, the interaction between GM crops intended for non-food applications and non-GM food crops should be evaluated. Contamination of non-GM foods by any GM crop, whether intended for food or non-food use, could have equally damaging economic consequences.

4. Basic research should be commissioned which investigates the impacts of introducing the production of new compounds into plants and altering levels of naturally occurring compounds. This should focus on the environmental performance and human health implications of the plant itself and other plants acquiring the gene(s). This would include considering toxicity for fauna and allergenicity for humans; seed survival and dormancy; disease resistance and susceptibility; and soil composition.

2. Introduction

One area of GM crop development attractive to the biotechnology industry is the production of plants which are not intended for food use

GM crops for food use have proved controversial for a variety or reasons including whether they are safe to eat. Therefore, one area of GM crop development which has been increasingly attractive to the biotechnology industry is the use of the technology to produce plants which are not intended for food use. This would allow companies to recoup their investment and make use of their patent portfolios to best effect.

In Part 1 of this report on non-food GM crops, we considered the issues surrounding their use to produce drugs, including vaccines, antibodies and therapeutic proteins. In Part 2, we consider other non-food GM crops. These include grasses for amenity use (rather than as fodder for animals); crops as industrial feedstocks; plantation and other trees; fibre crops (such as cotton and flax); and flowers.

For each of these applications, the report reviews who is conducting the research, what is taking place and how successful it has been. It addresses the question of whether this is likely to be a productive approach or is driven by the technology rather than need. The report also considers whether there are environmental or health questions to be answered, even though the products are not intended for consumption.

3. Grasses for gardens and golf courses

The amenity grass industry is growing. The US turf seed market is worth $1 billion annually, much of this being directed at golf courses and their maintenance. There is a pressure to create the 'perfect lawn' - one which is low maintenance, weed-free, uniform and, often, one that can survive stressful environments such as prolonged periods of drought. The prospect that GM techniques could help in this goal has stimulated research in this area. Research into the use of GM for forage grasses intended as animal fodder is not included in this report.

There is a pressure to create the 'perfect lawn'

3.1 What's under development

The main economic impetus to develop GM grasses is for the amenity market - golf courses, sports fields, municipal parks and private gardens. There are three main applications of GM to turf grasses:

- herbicide tolerance to simplify weed control;
- drought/salinity tolerance;
- disease resistance, especially fungal diseases.

Three species of grass, widely used in golf course and lawn mixtures because of their particular characteristics, are the dominant target of GM:

- creeping bent grass (*Agrostis stolonifera*) - the main species being modified. It is a perennial, wind pollinated grass, which can be a weed in crops. However, its fine leaves, tight sward and low growing habit make it perfect for golf courses;
- Bermuda grass (*Cynodon dactylon*) - used extensively in the southern United States for lawns and golf courses, it requires high temperatures and light to survive[1]. Bermuda grass is also an important weed species;
- Kentucky bluegrass (*Poa pratensis*) - a valuable meadow and pasture grass in Europe and central United States, having tall stalks and slender bright green leaves. It is often a chief constituent in lawn grass mixtures.

Other grasses being modified include perennial ryegrass (*Lolium perenne*), Russian wildrye (*Elymus junceus*), St Augustine grass (*Stenotaphrum secundatum)*, velvet bent grass (*Agrostis canina*), zoysiagrass (*Zoysia* spp.), and a hybrid of Kentucky bluegrass (*Poa pratensis*) and Texas bluegrass (*Poa arachnifera*).

The development of GM turf grasses is predominantly taking place in the USA, but research has been carried out in Japan (Japan Turfgrass), Canada (University of Guelph) and in Europe (Advanta Seeds). The GeneWatch web site gives details of the field trials with GM turf grass species which have been undertaken. There have been 171 notifications and release permits for field trials of GM grasses in the USA since 1993. Most of the research is being conducted by universities and other academic institutions. The commercial sector, which works closely with the public sector, consists of two main companies which are involved in developing GM turf grasses - Scotts and HybriGene LLC (part of Turf-Seed). Table 1 gives details of the work being conducted by these companies.

Of the three ways in which grasses are being modified, only herbicide tolerance is showing real progress

Table 1: Companies developing GM turf grasses

Company	Location and partners	Applications being developed	Notes
Scotts www.scotts.com	Based in Ohio. In 1999, Scotts gained exclusive Marketing rights to Monsanto's consumer Roundup herbicide Products in the US, Canada, UK, France, Germany and Australia.	Roundup Ready bent grass.	The largest turf and Horcultural products company in the world. Withdrew application for commercial licence for Roundup Ready bent grass in 2002.
HybriGene www.turf-seed.com	Based in Rhode Island. Part of the Turf-Seed Inc. Group. Owned by Bill L Rose, President Of Pure Seed Testing - also part of Turf-Seed. Research and Collaboration Agreement with University of Rhode Island[2].	Male sterile, glufosinate tolerant bent grass.	Bill Rose also owns Pure Seed Testing, Roselawn Seeds and Turf-Seed. The four companies together aim to pdevelop GM Grasses, create commercially viable lines and market the seed throughout the World. Turf-Seed also Produce a non-Transgenic fescue Grass that is tolerant To Roundup, called Aurora Gold[3].

3.1.1 Herbicide tolerance

Of the three ways in which grasses are being modified, only herbicide tolerance is showing real progress. Roundup Ready bent grass utilises the same gene constructs used in other Roundup Ready GM crops a version of the EPSPS gene which is not affected by glyphosate (Roundup), so the plant is not susceptible to its toxic effects.

The only attempt to commercialise a GM grass has been by Monsanto and Scotts in their application to the USDA for deregulation of a line of Roundup Ready bent grass in February 2002. In July 2002, Scotts also planted the first trial golf courses with the new variety[4]. However, concerns were raised about the potential for gene-flow and contamination from the GM grass by, among others, HybriGene' s president Bill Rose and Monsanto's main competitor in GM grasses. HybriGene has produced a GM male sterile bent grass which they claim will solve the problems of gene flow[5]. The application to commercialise Monsanto's transgenic Roundup Ready bent grass has since been withdrawn.

3.1.2 Salinity tolerance, drought tolerance and disease resistance

Salinity and drought tolerance have proved more difficult than herbicide tolerance to achieve. Those involved in the field trials (see details on GeneWatch web site) have used a variety of genes from other plants or bacteria which code for compounds which are thought to protect seed against desiccation threat[6] , increase the level of sugars that protect against freezing stress[7], or a variety of other compounds that protect against osmotic shock in freezing, drying or high salinity conditions[8, 9]. However, GM saline and drought tolerant grasses remain some way from being a reality.

Disease resistance, usually to fungal diseases, has also used a variety of genes from plants or fungi which give some degree of protection[10, 11,]. Creeping bent grass showed delayed symptoms of dollar spot (by up to 45 days) when the PR5K gene from *Arabidopsis thaliana* was introduced[12]. Dollar spot, caused by the fungus *Sclerotina homeocarpa,* is an important disease on golf courses with the highest management costs of any turf grass disease. However, symptoms were just as severe as for non-transgenic plants when the disease did develop. Therefore, disease resistant grasses are a long way from commercialisation because the degree of resistance achieved is not sufficient.

3.2 Environmental impacts

There are serious environmental concerns raised by the growing of GM grasses for both for turf and fodder that are much greater than for many food-crop species. This is because of two important characteristics of grasses. Firstly, they are perennial and, secondly, they are freely wind pollinated. In addition, many spread vegetatively via tillering (where underground shoots grow and emerge as new plants). As with the genetic modification of other grasses such as maize and rice, the process frequently results in many copies being incorporated together with gene silencing and instability[13, 14, 15]. Therefore, there may be unintended effects of the process that may affect the behaviour of the plant.

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These factors increase the likelihood of the main environmental risks that:

- the GM grass itself becomes invasive and disrupts natural ecosystems or becomes a troublesome weed;
- the introduced genes are transferred to other grasses, increasing their weediness or invasiveness.

3.2.1 Increased weediness and invasiveness

The trait which has been introduced into the GM grass, such as herbicide tolerance, disease or stress resistance, will influence how well the grass will survive in the environment.

All the traits that are being researched, could give a competitive advantage to the GM grass, allowing it to spread or persist. There may also be unintended impacts as a result of the GM technique which also affect the grass's environmental performance.

Creeping bent grass and Bermuda grass are used extensively as amenity grasses, but they are also very troublesome weed species in many crops. If these were to become herbicide tolerant, they would be more difficult for farmers to control. Drought, salinity or disease resistance could also allow these grasses to extend their ranges and become unmanageable weeds or disrupt ecosystems. There has been little research which has considered the potentially disruptive environmental effects of GM grasses per se.

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Bent grass is used on golf courses in the UK, but as Andy Newell, head of turf biology at the Sports Turf Research Institute in Bingley, West Yorkshire, which advises the Royal and Ancient Golf Club on grasses said, there could be unwanted consequences. “A herbicide-tolerant grass would certainly be useful to the greenkeeper, but only until it gets into weedy grasses. Then it becomes a nightmare[16].”

3.2.2 Gene flow to other grasses

Many of the grasses grown for amenity purposes have had little domestication and often have wild relatives growing close by. In the UK, it is only the potential for gene flow from the forage rye grass, *Lolium perenne,* that has been considered in any depth. Studies have concluded that these readily outcross with wild and feral populations of *Lolium* spp and also some fescue species with the production of fertile hybrids[17, 18]. Modelling has suggested that if grown on a large scale, pollen from GM rye grass could contaminate small native populations growing close by[19].

In the USA, there are very few studies of gene flow from creeping bent grass even though it is close to commercialisation. A study by scientists at Pure Seed Testing[20] has shown that cross-pollination from a GM herbicide tolerant bent grass to the same non-GM species gave levels of contamination varying according to environmental conditions. A level of 0.1% at between 246-1,043 metres was predicted. The same study showed that six of twelve naturalised *Agrostis* sp tested were able to hybridise with the GM bent grass.

In the US, all of the bent grass seed is produced in the Willamette Valley, Oregon. It is also exported to Europe. Because of the potential for gene flow from GM to non-GM grass, the Oregon Department of Agriculture has established a special 11,000 acre area outside the Willamette Valley where growing GM grass will not be allowed[21]. Other measures, such as dedicated combines, buffer zones and burning of stubble, are also required.

However, because grasses are grown very widely, often in semi-natural environments and, for example, golf courses may be next to woods and pasture, control of gene flow to native species or other amenity grasses will not be simple. Grass seeds may move in a wide variety of ways, including as a contaminant on wool, in bird seed and in seed mixtures. Control systems applied in seed production areas are unlikely to be effective once GM grasses are released to the environment.

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3.3 Health impacts

Since grass is not eaten by people it does not pose the same health risks as other GM foods may. The only apparent issue is to do with the allergenicity of pollen. It was suggested that GM techniques could be used to remove allergens from grasses to reduce problems experienced by people with seasonal hay fever[22] and one of the major allergens, Lol p 5, has been switched off using GM technology[23]. In laboratory tests, the allergic potential of the GM rye grass was reduced. However, not all the relevant antigens are not well identified are there are likely to be more than one or two, so this is unlikely to be a practical option on a large scale, particularly because pollen travels so freely and it will be impossible to replace all grass with GM varieties.

It is also conceivable that new allergens could be introduced into the grass pollen as a result of genetic modification.

3.4 Conclusions

Herbicide tolerant GM amenity grasses are close to commercialisation in the US. Grasses are freely wind pollinating species, often perennial and able to spread by tillering. Where non-GM grasses of the same or compatible species exist in proximity, it will be impossible to contain gene flow. The first GM grass proposed for commercialisation had no gene containment measures and if, not withdrawn, would over time have led to the inevitable contamination of non-GM and native US species of grass if it was grown on any scale.

Two of the species being modified commercially for herbicide tolerance, bent grass and
Bermuda grass are important weed species. The introduction of herbicide tolerance genes or stress and disease resistance genes could increase the their weediness and make them much more difficult to control. Both GM grasses or wild native grasses that become contaminated could also disrupt ecosystems if they prove better able to survive and dominate other species.

The UK seems unprepared for the possible intentional or accidental importation of GM amenity grasses

The UK seems unprepared for the possible intentional or accidental importation of GM amenity grasses. Whilst there has been research and evaluation of forage grasses, no analysis of other grasses has been undertaken, even though they are much closer to commercialisation. Some amenity grass seeds are imported into the UK, including from the US, and Europe is seen as an important export market for bent seed produced in Oregon. Consideration of the extent of the risks and measures will be needed to monitor grass seed imports and the effectiveness of controls should be undertaken before commercial growing begins.

4. Biofuels, plastics and industrial feedstocks

People are looking for new or improved sources of industrial chemicals which rely less on petrochemicals and have lower requirements for external energy inputs

Increasingly, people are looking for new or improved sources of industrial chemicals which rely less on petrochemicals and have lower requirements for external energy inputs for extraction and processing. Increasing or improving the potential of plants to provide such raw materials is one important area of research. GM techniques have been used in such approaches in an effort to produce biofuels, industrial oils, to provide biodegradable plastics and more useful starches. The status and potential for each of these are reviewed here.

4.1.1 Biofuels

There are two major biofuels - bioethanol, produced from starch or sugar, and biodiesel produced from vegetable oils[24]. Bioethanol is produced through the fermentation of crops such as maize and sugar beet. Biodiesel is made by reacting any natural oils or fats with alcohol (usually methanol) to produce a fatty acid alkyl esters - biodiesel. Biodiesel can be used on its own or as an additive to reduce vehicle emissions.

There are two main drivers of the production of biodiesel – cost and concerns over supplies of oil and the need to reduce fossil fuel use because of the potential for climate change. However, whilst there is considerable research being conducted to improve the economics of biofuel production generally, there appears to be little if any research using GM which is specifically directed at, say, improving the sugar or oil producing characteristics to improve their usefulness as biofuels. Where GM may come into biofuels production in the short term, is if GM crops which are modified for agronomic reasons (such as herbicide tolerance) are used for biofuel production

To use plant oils as a significant replacement for fuel from petroleum is not a practicable option because of the amounts of land that would be needed

To use plant oils as a <u>significant</u> replacement for fuel from petroleum is not a practicable option because of the amounts of land that would be needed. Only 2% of current petroleum uses could be substituted by the entire global plant oil production, mainly used for food today[25]. Genetic modification is not going to impact significantly on this situation although GM oilseed crops modified for agronomic improvements, such as herbicide tolerance, could be grown for this purpose.

In European terms, the prospects for GMHT crops in biofuels are also poor because of the results of the Farm-Scale Evaulations which have shown that the there is likely to be adverse effects on farmland wildlife if GMHT oilseed rape or sugar beet are grown commercially. These are the first two GM crops that might be used in this way. GM oilseed rape and sugar beet would also raise the prospect of gene flow to non-GM crops being produced for food use and gene-flow to wild relatives.

4.1.2 Fatty acids and oils for non-food use

It is possible that modified oilseed crops could produce speciality oils suitable for industrial purposes to substitute for petrochemicals. The main oilseed crops grown today are soybean, oilseed rape, oil palm and sunflower, which produce a relatively restricted range of fatty acids (palmitate, stearate, oleate, linoleate and alpha-linolenate) that are of limited use for industrial purposes. However, there are a range of other novel fatty acids which are produced naturally by some plants (see Table 2) that have a much wider variety of potential uses in, for example, detergents, nylons and lubricants. Very often, these plants produce high levels of the novel fatty acid (as much as 70-80% of their total fatty acid components), but often have limited immediate agronomic potential because of characteristics such as non-uniform flowering and low yield[26]. Some, such as the castor oil plant, also have problems associated with the toxicity of other compounds produced naturally by the plant and allergenicity. Therefore, efforts have been made to genetically modify conventionally grown oil-producing species so they produce fatty acids which are industrially useful.

Table 2: Plants naturally producing novel fatty acids
From Jaworski & Cahoon (2003)[26] and Murphy (2002)[25]

Fatty acid	Plant species	Common name	Uses
Lauric acid	*Cuphea avigera*		Fuel, food
	Litsea stocksii		Detergents, food
	Myrica cerifera	Wax myrtle	Soaps, food
	Brassica tournefortii	African mustard	Lubricants
Petroselenic acid	*Coriandrum sativum*	Coriander	Nylons, detergents
	Helianthus annus	Sunflower	Coatings, food
Alpha linolenic acid	*Linum usitatissimum*	Flax	Paints, varnishes
Gamma-linolenic acid	*Borago officinalis*	Borage	Therapeutic compounds
Ricinoleic acid	*Ricunus communis*	Castor	Plasticisers, cosmetics
Vernolic acid	*Crepis palestina*		Resins, coatings
Crepenynic acid	*Crepis alpina*	Hawksbeard	Coatings, lubricants
	Aleurites	Tung oil tree	Enamels, varnishes
Waxes	*Simondsia chinensis*	Jojoba	Cosmetics, lubricants

Following identification of the enzymes involved in the production of these novel fatty acids, the genes which code for them have been transferred to induce their production in a different plant. However, this has not proved as straightforward as once anticipated. It has been difficult to achieve the high levels of the fatty acid (90%) that would be required to make them economically useful and maximum levels achieved have been about 40-70% - for example, when genes for jojoba enzymes have been cloned and expressed in *Arabidopsis*, the transgenic plants have 49-70% of their oil content as wax[27].

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The problems seem to have arisen because fatty acid synthesis is much more complex than was once thought. Fatty acids have at least three roles in plants as a constituent of membranes, in cell signalling, and for storage. However, these are not controlled by separate pathways and when novel fatty acid synthesis has been induced by GM, it has not been possible to restrict the presence of the acid to the seed storage sites. There has, for example, been leakage with the new fatty acid being found in cell membranes where it can be destabilising and adversely affect their function. Protective breakdown of the novel fatty acids (where plants try to remove the new compound) has been reported[28] and the timing and specificity of promoter genes has also been identified as a problem.

One high lauric acid oilseed rape has been commercialised in the USA. It contains a thioesterase gene from the Californian bay but it has not proved a commercial success because the levels of laurate obtained (40%) have not been economically viable. It does not appear that this oilseed rape is being grown anywhere at the present time.

4.1.3 Biodegradable plastic

Currently, the majority of the plastics used in the world are developed from non-renewable petrochemicals. They require considerable industrial processing and do not bio-degrade when discarded. Because of the numerous types of plastic and the problems with extraction and sorting, recycling has been difficult. There has also been both a political and social reluctance to instigate re-use schemes. Developing biodegradable plastics has therefore become the focus of research and this has included the production of GM crops to provide the raw materials.

Biodegradable plastics can already be produced from a range of naturally occurring protein-based polymers. These include[29]:

- *using starch from plants such as maize to produce polylactide (PLA).* Starch is extracted from the plant, which is then broken down to lactic acid and chemically treated to produce long chains of lactic acid or polymers. These can be used in similar ways to current plastics. PLA is commercially produced by CargilDow (a 50/50 joint venture between Cargil and Dow), which markets the products under the name of NatureWorks[30]. DuPont make a similar product;
- *treating a high amylose starch under high pressure at high temperature to produce packaging materials*. This is made by an ICI subsidiary, National Starch and Chemical, and has recently been marketed in the US as Eco-Foam.
- *using polyhydroxyalkanoates (PHAs), a class of polymers naturally produced by bacteria, to synthesise plastics.* The first biodegradable plastic from PHAs extracted from bacteria grown in fermenters was Biopol, which was initially commercialised by ICI in the late 1980s. The Biopol division, along with the ICI's agriculture sector, became Zeneca in 1990. In 1996, Biopol was sold to Monsanto who in turn sold it to Metabolix in 2001. The main problem has always been cost - Monsanto sold Biopol at $16 per kilogram, which is 18 times the price of polypropylene[32]. Some research suggests that because production of PHAs from micro-organisms requires glucose - which in turn is produced from energy intensive maize - and energy for cooling and extraction, PHA production is more energy intensive than fossil fuel based plastics[31]. However, Zeneca's original Biopol was produced from PHAs made by the micro-organism *Ralstonia eutropha* (formally *Alcaligenes eutrophus)*, but researchers have now transferred multiple copies of the genes to make PHAs in *E. Coli* [33] . Other micro-organisms have also been engineered to alter their production of PHAs and Metabolix now claim to have a commercial scale bacterial production system utilising *E. coli* K12 that can produce PHAs at under $1 per pound ($2.2 per kilogram).

Bacterial genes coding for the production pathways have been introduced into a variety of plants so that they produce PHAs

Finding new sources of PHAs to use in the production of plastics has been the main application of GM in this area. Whilst PHAs can be made by micro-organisms, the potential to use plants has also been explored because this would remove the need for external sources of energy as the plants' own energy systems are used[34]. Although some micro-organisms naturally produce PHAs, the metabolic pathways do not exist in plants. Therefore, bacterial genes coding for the production pathways have been introduced into a variety of plants so that they produce PHAs[35, 36].

However, it has not proved entirely straightforward to produce PHAs in plants. Initially, genes from *Ralstonia eutropha* were transferred into the experimental plant, thale cress (*Arabidopsis thaliana*), which led to low levels of a PHA, called PHB, being produced in the cytoplasm but growth was retarded[35, 38]. Later, the expression of the *R. eutropha* PHB genes was targeted to chloroplasts of *A. thaliana* and the plants exhibited normal growth and had a PHB content of 14% of dry weight although the leaves showed slight chlorosis (iron deficiency) after prolonged growth[39]. Levels of production of PHB in *Arabidopsis* leaves have been increased to approximately 40% dry weight (4% wet weight), but stunted growth and loss of fertility were seen in high yielding lines[40]. Substantial changes to the overall chemical composition of the plants was also seen. PHB has also been produced in cotton (*Gossypium hirsutum)*[41, 42], the fibres of which had improved thermal insulating properties, and maize (*Zea mays*) cell suspensions[43].

However, PHB produces plastic which is quite brittle and inflexible. Therefore, Monsanto has attempted to produce PHBV in plants because this compound results in plastics which are more flexible and have greater utility. They have succeeded in producing PHBV in the leaves of *Arabidopsis* and oilseed rape (*Brassica rapa)* seed[44] but levels achieved were low - less than 3% in leaves and seed - and would have to reach 15% to be economically viable. Evidence of low fertility, sterility, and poor growth were also recorded.

Evidence of low fertility, sterility, and poor growth were also recorded

There have only been three known outdoor field trials of a GM plant producing PHAs. Two of these were carried out by Monsanto during 1996, one involving soybean in Illinois and the other with oilseed rape in North Dakota. Monsanto have claimed commercial confidentiality over the genes used in these crops. The third trial was carried out by the University of Hawaii between 2001 and 2002 with GM maize which had been transformed with genes from *Ralstonia eutropha*.

The prospects for producing plastics from GM plants are not good at present and much more research is required before they become a commercially viable option.

4.1.4 Industrial starch production

About 20-30 million tons of starch are produced annually. Its major use is in coatings in the paper and textiles industries, but it is also used in many food products as a thickening or gelling agent and in glues. Most starch is obtained from maize, but potato, cassava and wheat are also important sources. In the application of GM to starch production, it is the potato - the tubers of which consist almost entirely starch - that has been most widely used. GM potatoes for starch production could be one of the first GM crops to be given approval for commercial growing in Europe.

The prospects for producing plastics from GM plants are not good at present

Producing designer starch

Starch is a polymer of glucose molecules which are linked together in chains with various branches. Starch is composed of two chains, amylose (20-30%), a mainly linear polymer, and amylopectin (70-80%), which is larger and more branched. The characteristics of starches depend on the relative amounts of amylose and amylopectin[45].

High amylose starches are used as thickeners and gelling agents as they set quickly, and as coatings for fried snacks because they brown evenly and crisp well. High amylopectin starches give good freeze-thaw characteristics to foods; enhance paper strength and printing properties; improve adhesives; and are useful in livestock feed. Often, extracted starch is treated chemically or physically to make it more suitable for its intended purpose. It is an aspiration of biotechnologists to modify crops to produce the type of starch needed for a particular purpose and remove the need for costly treatments[46].

Research has therefore been aimed at understanding and modifying the starch production enzyme systems in plants. These enzymes control the production of amylose and the branching needed to produce amylopectin. To lower the amount of amylose produced, the activity of an enzyme, granule-bound starch synthase (GBSS), has been reduced using antisense technology[47]. Another copy of the GBSS gene is introduced which interferes with the operation of the natural gene, lowers the production of GBSS and thus leads to less amylose and more amylopectin being produced. This approach has been very successful and GM potatoes altered in this way may be commercialised in Europe soon (see below).

Attempts to increase the amylose content of potatoes by reducing the activity of a starch branching enzyme, SBE B, had no effect on the levels of amylose produced, but there was a 50-100% increase in levels of phosphorus in the starch produced[48]. It appears that, although present in lower amounts than SBE B, the enzyme SBE A has a larger effect on the final starch structure[49]. The depression of the activity of another enzyme, AGPase, in GM potatoes led to reduced levels of amylose[50].

Therefore, whilst the production of a GM potato with high levels of amylopectin has been straightforward, producing other GM designer starches is not yet a reality and is likely to depend on more understanding of the starch synthetic pathways.

GM potatoes with altered starch production may be commercialised in Europe soon

Modified starch producing GM potatoes in Europe

One of the main companies involved in the genetic modification of potatoes is Amylogene, initially founded by Svalof Weibull and the Swedish paper manufacturer Lyckeby Starkelsen, but now wholly owned by BASF Plant Science. In 1991, Amylogene began field trials with GM potatoes in Sweden and, in 1998, applied for a marketing consent under the EU Deliberate Release Directive 90/220/EEC, which has been resubmitted under the new Directive (2001/18/EC). The potatoes have been genetically modified using antisense technology to reduce the activity of the enzyme, granule-bound starch synthase (GBSS). The GM potatoes produce 98% amylopectin and only 2% amylose starch. The amylopectin starch is more useful to the paper industry than amylose starch. The application is for cultivation, industrial use and the use of post starch extraction pulp as animal feed. The potatoes have not yet been given consent for any commercial use or cultivation because of the EU moratorium on the commercialisation of GM crops but may be approved in 2004. They could be grown in Eastern Europe, the Nordic countries, Germany, the Netherlands, Belgium and France which grow potatoes for starch production. The UK does not grow potatoes for this purpose.

Despite lacking EU marketing consent, the Swedish authorities allowed Amylogene to plant over 350 hectares of the potatoes in 1999. Amylogene had persuaded the Swedish government that because the potatoes were being grown under contract and were all then processed by the company, this did not constitute commercial growing.

4.2 Environmental impacts

The environmental impacts of crops modified to produce industrial feedstocks will depend on the characteristics of the compound being produced, any direct effects it may have and impacts on wild related species if gene transfer takes place. Little attention appears to have been paid to the potential dangers and more investment is being targeted at finding out whether the transformations can be made to succeed. However, the kinds of potential impacts that will need to be considered include whether:

- animals feeding on the crop will be affected by the altered composition. Birds and rabbits are the most likely to be affected;
- the altered chemical composition affects persistence in the environment. Lipids and starches are important in the survival of seeds and tubers and this will need to be investigated;
- other characteristics such as disease resistance are affected as this may influence the impact if gene flow takes place;
- secondary impacts on biodiversity if herbicide tolerant or insect resistant GM crops are used.

4.3 Health impacts

The main health issues which may arise through the use of GM crops for industrial feedstock production are:

- inadvertent consumption of the crop as food identity preservation systems would be needed;
- cross-pollination of neighbouring non-GM crops, leading to the introduction of potentially harmful compounds and/or economic losses for the non-GM farmer. The likelihood of this arising will depend on the crops involved and, therefore, would be high for oilseed rape and low for potato in the UK;
- a new allergen being produced which triggers allergenicity on inhalation.

Cross-pollination of neighbouring non-GM crops could occur

4.4 Conclusions

The use of GM potatoes with a modified starch profile is the most advanced application of GM in the field of industrial feedstock production. Other applications are proving more difficult because of the complex biochemical pathways involved, the multiple role of lipids, and economics often the levels of the compound produced are not high enough to make it economically viable. There are also likely to be limitations on the amount of a plant's resources that can be diverted without affecting its growth and performance in other ways.

Some of these problems may be overcome with time, but there are also important environmental and health issues that will need to be considered, particularly if crops are used which can hybridise with neighbouring crops or wild species. The changed nature of lipids or the presence of new precursor compounds for plastics not naturally made in the plant kingdom may have ecological impacts, but little attention appears to have been paid to this issue.

Depending on the crop involved and the scale of production, contamination of non-GM crops and resulting economic damage are factors which will also have to be considered.

5. Plantation trees

A focus on fast growing short-rotation plantation tree species to allow costs to be more quickly recovered is considered important for the application of biotechnology, although there are no GM tree products which are commercially available yet. As well as poplars (including cottonwood and aspens), eucalyptus, willows and birches have been highlighted as potentially important targets for genetic modification on economic grounds in Europe[57]. Table 3 shows the types of trials with GM trees that have taken place worldwide, most of which are intended to be grown in *"intensive, short-rotation (e.g. 3-25 years) plantations"* [52].

Poplars are the tree of choice for plantations and genetic modification because;

- they can be propagated vegetatively;
- they have a wide geographical distribution and there are opportunities to use the technology on a global scale;
- members of the *Populus* genus can be crossed fairly easily;
- poplars are amenable to genetic modification via the use of Agrobacterium mediated transfer;
- they grow rapidly.

GM spruce and pine are much less advanced than poplar and eucalyptus as they are technically more difficult to genetically engineer.

Because forestry is an industry which is increasingly global in nature, corporations are heavily involved in research into GM trees both directly and by sponsoring research in the public sector. For example, corporate members of Oregon State University's Tree Genetic Engineering Research Cooperative (TGERC) include many multi-national timber companies such as International Paper, Westvaco and Wyerhauser[53]. MacMillan Blodel, Monsanto, Shell and Union Camp are also reported to be funding research at TGERC along with public input from the US Department of Energy and Environmental Protection Agency[54]. A similar consortium at Washington State University - the Plant Molecular Genetics Cooperative – receives financial support from Westvaco, Westerhaeuser and Champion International.

Corporations are heavily involved in research into GM trees

Another joint venture, ArborGen, has been formed by Fletcher Challenge Forests (a New Zealand company), International Paper (the world's largest producer of paper and packaging), Westvaco (a US company which merged with Mead in January 2002 to form MeadWestvaco, owning over 3 million acres of forest and licensing another 3 million acres), and Genesis (a New Zealand tree genomics company)[55]. ArborGen has been established to facilitate research into GM trees and to try and overcome some of the obstacles restricting access to intellectual property - many genes and techniques have been patented by others, making it more efficient to join forces and license the technology from them.

5.1 What's under development

Research is generally aimed at facilitating pulp and paper production and increasing productivity

Trees are being modified for a number of different traits, which are generally aimed at facilitating pulp and paper production and increasing productivity, and research is being conducted across the globe. Laboratory based work and field trials have taken place in Europe (including the UK), New Zealand, North and

South America (see GeneWatch web site). In Canada, for example, four trials are taking place over five years - one began in 1997 (poplar) and the others in 2000 (white and black spruce) - using a marker gene and , in the case of white spruce, insect resistance genes.

In the USA, most work has been conducted by universities and the companies ArborGen and Westvaco. The first open air trials started in 1997 and were all for poplar species. The trees had been modified for marker genes, insect resistance and herbicide tolerance and the trials were undertaken by the University of Oregon, Monsanto and Weyerhaeuser. The largest trials to date are two glyphosate tolerant trials for 6 acres each and both were started in 1999.

Table 3: Genetically modified trees grown in field trials[56]
Other tree species have been genetically modified and grown in laboratories and greenhouses (see text for examples) but comprehensive information is not available.

Common name	Species	GM trait
Silver birch	*Betula pendula*	Marker genes.
American chestnut	*Castanea dentata*	Blight resistance.
European sweet chestnut	*Castanea sativas*	Herbicide tolerance (glyphosate).
Eucalyptus/Red River Gum	*Eucalyptus camuldensis*	Marker genes. Herbicide tolerance (glyphosate). Insect resistance (*Bt* toxin).
Rose gum/Flooded gum	*Eucalyputus grandis*	Marker genes.
		Herbicide tolerance (glyphosate).
Tasmanian blue gum	*Eucalyputus globulus*	Marker genes.
Sweetgum	*Liquidambar spp*	Herbicide tolerance (2,4-D).
Spruce/Norway spruce/ Scots pine	*Picea spp* including: *Picea abies* *Picea sylvestris*	Insect resistance (*Bt* toxin). Marker genes.
Poplars/Aspen/Cottonwood	*Populus spp* Including: *Populus nigra* *Populus Tremuloides* *Populus deltoides* *Populus tremulata*	Herbicide tolerance (glufosinate, sulphonyl urea, glyphosate). Insect resistance (*Bt* toxin). Disease resistance. Altered lignin content. Male sterility. Female sterility. Increased growth rate. Bioremediation. Marker genes.
Apple	*Malus domestica*	Marker genes. Improved rooting. Disease resistance (scab and blight). Altered flowering time. Insect resistance. Altered fruit ripening. Altered sugar content.

Crab apple	*Malus sylvestris*	Insect resistance. Fungal disease resistance.
Plum/Cherry	*Prunus spp* *Prunus domestica*	Disease resistance. Altered morphology. Altered ripening. Marker gene.
Orange	*Citrus spp*	Marker gene.
Kiwi	*Actinidia deliciosa*	Fungal disease resistance.
Olive	*Olea europea*	Fungal disease resistance.
Papaya	*Carica papaya*	Virus resistance. Delayed ripening.
Walnut	*Juglans spp*	Insect resistance (*Bt* toxin). Improved cutting rootability. Disease resistance. Altered flowering time.

5.1.1 Alteration of lignin biosynthesis

The structure of wood is created by three main chemicals: lignin, cellulose and hemicellulose. Lignin gives wood its hardness and maintains the wood's structure as it rots thus helping to provide a habitat for many species. The indigestibility of lignin helps provide defence against attack and there is even some evidence that lignin is produced in the non-woody part of the tree when it is under attack from pathogens[57].

Lignin presents a major obstacle for the paper industry as it must be removed in order to pulp the wood

However, lignin also presents a major obstacle for the paper industry as it must be removed in order to pulp the wood and this process uses large amounts of water and energy. Much research has therefore been carried out to try to use GM techniques to reduce lignin and/or to modify its composition so it is easier to remove. The main focus has been on genes coding for enzymes involved in the lignin biosynthetic pathway such as cinnamoyl CoA reductase (CCR), cinnamyl alcohol dehydrogenase (CAD)[58, 59], O-methyltransferase (COMT)[60, 61] and 4-coumerate co-enzyme A ligase (4-CL)[62]. Multiple gene modifications of CAD and 4-CL have also been achieved[63]. The usual approach is to lower the activity of the gene by sense or anti-sense suppression - a gene of identical or similar sequences to the natural gene is introduced in the normal (sense) or reverse (anti-sense) direction. This interferes with the functioning of the gene and so reduces the amount or activity of the enzyme it codes for.

These approaches have been relatively successful in reducing the amount of lignin or modifying its composition to make it easier to extract. Poplars with reduced CAD activity had improved paper making qualities, but those with down-regulated COMT produced a lignin structure that was more difficult to extract[64]. Some of the CAD down-regulated trees also showed poor growth performance in greenhouse studies but grew normally in the field. Reduction in lignin via interference with 4-CL tends to result in a compensatory increase in growth rate and cellulose content [62,63], which may aid maintenance of structural stability. However, manipulation of the CCR gene in tobacco led to growth impairment[65], suggesting that it may not be a good target for tree manipulation, although growth impairment was not evident when CAD was also down-regulated[66]. When COMT activity is reduced in poplars, a red colouration of the wood is seen which varies in distribution and intensity over time[61,64,67].

There is consequently some way to go before GM trees with easily extractable lignin are available. Currently, scientists are starting to understand the complexities of lignin production and compositional control. Because lignin plays a number of important roles in trees - including structural integrity, disease resistance and the facilitation of transport of compounds around the plant - the full impacts for the tree and ecosystem of manipulating lignin remain to be understood.

The full impacts for the tree and ecosystem of manipulating lignin remain to be understood

5.1.2 Herbicide tolerance

Many trees, including the main plantation trees, poplars and eucalyptus, have been genetically modified to be tolerant to both glyphosate and glufosinate herbicides. It appears that the genes used are the same as those used in GM food crops the EPSPS for resistance to glyphosate (Roundup) and the *bart* gene for resistance to glufosinate (Liberty).

5.1.3 Insect resistance

As with herbicide tolerance, the genes used to achieve insect resistance in trees are the same as those used in GM food crops - the Cry toxin genes derived from the bacterium *Bacillus thuringiensis* (*Bt*). GM eucalyptus which is insect resistant and herbicide tolerant (to glufosinate) has been produced in Australia[68]. Poplar trees have been modified with the Cry3A gene to protect the trees from attack by the beetle, *Crysomela tremulae*[69].

5.1.4 Disease resistance

Research has been carried out to genetically modify trees to be resistant to a variety of diseases. Field trials have been conducted on poplar trees resistant to soft rot, septoria, venturia, malamtsora and marssonina; rhododendron resistant to phytophora; and silver birch with general fungal resistance (see GeneWatch web site for details). These have used a variety of plant based proteins and peptides which are thought to be associated with disease resistance in plants[70,71].

As well as producing GM disease resistant plantation trees, the use of GM to produce disease resistant native species is also being promoted because of the increasing threat of introduced pathogens[72]. At the College of Environmental Science and Forestry, State University of New York, work is being undertaken to look at blight (*Cryphonectrica parasitica*) resistance in the American Chestnut (*Castanea dentata*) and resistance to Dutch elm disease fungus *(Ophiostoma-novo-ulmi*) in American elms. A GM elm tree which it is hoped will be resistant to Dutch elm disease has been created at Abertay University (Dundee) with funding from the UK Forestry Commission[73], but this has not yet been planted outside or its resistance to the fungus evaluated.

A GM elm tree which it is hoped will be resistant to Dutch elm disease has been created

5.1.5 Bioremediation

The use of trees for bioremediation - where living organisms are used to clean up toxic chemical waste - is also being investigated. In research at the University of Georgia, using a gene from a bacterium which gives resistance to high levels of toxic organic mercury through its conversion to less toxic elemental mercury, yellow poplars have been genetically modified so they can grow in high concentrations of mercury and convert it to the less toxic form[74]. However, the mercury is then released from the tree in vapour form and will eventually be recycled into the more toxic organic form.

Perhaps the most contentious trial (because it involved a human gene) that has been conducted - by the University of Washington - was for poplar trees genetically modified to increase their ability to break down trichloroethylene (TCE) by the addition of a human cytochrome gene, P450 2E1[75]. Trichloroethylene is a contaminant found on many industrial sites. It was commonly used as a metal degreasing agent as well as a dry cleaning agent. It has been suggested that the GM trees could be coppiced on a 5-7 year cycle to prevent flowering and gene flow. However, such a coppice cycle may not guarantee against flowering and questions have been raised about trichloroethylene that has not been fully metabolised being translocated to the leaves and stems of the trees and then being ingested and dispersed by insects and animals.

5.1.6 Increased production

There are two ways of increasing tree production that are being investigated. Firstly, silver birch and poplars have been modified to increase the expression of glutamine synthase. It is thought that this will increase the amount of nitrogen assimilated by the trees and therefore increase growth rates[76]. The other method being used is to try and alter the hormone biosynthesis of trees, which it is thought will alter their architecture (e.g. trunk and branch growth and shape). Work so far has involved introducing the rol gene from *Agrobacterium tumefaciens*[77] and modifying the synthesis of the growth hormone, giberellin[78]. These have resulted in increased growth rates in laboratory studies.

5.2 Environmental impacts

Despite the claimed advantages of developing GM trees, there is considerable concern about their environmental, social, economic and political implications. Most attention has been paid to the risks directly associated with the genetic modification, the change it causes in the tree (insect resistance or herbicide tolerance, for example), and how stable the modifications will be over time. The likelihood of harmful environmental effects will vary according to the species involved. For instance, a spruce tree will be grown for many years whilst papaya trees produce fruit in the first year and are then only grown for another eighteen months. However, as with GM crops, there are also wider questions about the intensive production systems GM trees will facilitate.

There is considerable concern about the environmental, social, economic and political implications of GM trees

5.2.1 Gene flow

Trees have developed excellent mechanisms to transfer genetic material over wide areas. Pollen and seed may travel many miles and some trees can also reproduce asexually via suckers. Because even those trees grown in plantations - such as eucalyptus and aspen - are relatively undomesticated, related native trees with which they can cross fertilise are often nearby. Again, like GM crops, the foreign genes transferred in the GM process will not be containable. Transfer to native species is therefore inevitable unless all GM trees are made infertile (although this could have its own environmental consequences see below). Much of the debate about gene flow has centred on whether it would be a problem at all – would native trees become more invasive if they acquired beneficial genes from GM trees and were better able to survive insect or disease attack, for example, or would the GM trees themselves become invasive[79]? Whilst there is limited knowledge about crossing (hybridisation) between plantation trees and native species, the introduction of

Pollen and seed may travel many miles and some trees can also reproduce asexually via suckers

non-native species shows that the potential is real. The Japanese larch (*Larix kaempferi*) was introduced into Scotland, hybridised with the native European larch (*L. decidua*) and produced a fast growing hybrid now used in forestry. Similarly, in France, a hybridisation between introduced Eastern cottonwood (*Populus deltoides*) and native black poplar (*P. nigra*) has also become widely used in plantations[80]. Some trees have become invasive in new environments. For example, the sycamore (*Acer pseudoplatanus*) was introduced into Britain in the 18th Century and has been considered a major pest[81].

5.2.2 Sterility

Because trees are so long-lived, it is uncertain whether they would remain sterile throughout their lifetime

In an attempt to avoid the dangers of gene flow, several GM trees have been modified to be sterile and, since trees can often be propagated vegetatively, continued reproduction would still be possible. However, whilst rarely used for human food, the flowers and seeds produced by forest trees are important in maintaining the biodiversity of forests by providing food for insects, birds and mammals. But even in poplars, where insect use of flowers is thought to be limited[85], little data exists upon which to base predictions. Also, because trees are so long-lived, it is uncertain whether they would remain sterile throughout their lifetime. In orchard situations, flowering and fruiting are crucial parts of the system and sterility is therefore not an option. Despite the apparent emphasis on controlling gene flow, economic factors are also behind the research into sterility since preventing reproduction *"could increase yield by redirecting resource allocation into wood production"* [82]' and would also avoid the irregularities in wood caused by flowering and seed production.

5.2.3 Herbicide tolerance

GM trees have been made tolerant to a range of different herbicides (see Table 3) with the claimed advantage that herbicide application would be easier during the establishment phase when minimising competition from weeds is important. However, not only may such trees eventually spread the herbicide tolerant gene and possibly cause problems in tree control elsewhere, but the early stages of plantation development are important for woodland biodiversity, which would be threatened by the increased use of herbicides[83].

5.2.4 Insect tolerance

Currently, insecticide use in forestry is much more restricted than for crops because of the problems of scale and application. The use of GM insect resistant trees would lead to the insecticide (usually the *Bt* toxin from the bacterium *Bacillus thuringiensis)* being present in the forest ecosystem for many years. Not only would there be effects on target species, but the beneficial insects feeding upon them could be harmed as could organisms involved in the decomposition of leaves and dead trees[83]. Resistance among target insects is also likely to develop, threatening the effectiveness of *Bt* sprays which are used on forests[84]. The use of refuges - areas of non-GM trees intended to reduce the likelihood of *Bt* resistance emerging - has been proposed[85]. However, such strategies have not been followed by farmers growing GM *Bt* maize commercially in the USA, where about one third did not include refuges in 2000[86], so such safeguards may not be successful.

5.2.5 Altered lignin content

Lignin is an important structural component of trees as well as playing a role in defence against disease and pests. It is too early to say what the effects of alterations to lignin content would be if these were transferred to native species or the impacts on biodiversity arising directly from growing trees with altered lignin content. It could alter palatability to species feeding on them, disease resistance and, by potentially increasing susceptibility to wind damage, where trees can grow[83]. Because lignin affects the rate at which decomposition takes place, impacts on soil are also possible. Syngenta's four-year trials with low lignin GM trees in England and France detected no change in growth rate or disease resistance while pulping qualities were improved[87], but ecological impacts were not investigated.

5.2.6 Plantations

Plantations raise questions about environmental sustainability, equity and aesthetics

Plantations raise questions about environmental sustainability, equity and aesthetics[88]. Exotic species are often used (such as eucalyptus in South Africa) and monocultures are common. As such, they can have negative effects on biodiversity and are highly susceptible to disease and insect attack. Plantations also have social consequences. Heavily mechanised and centralised, they offer little in terms of local employment and profit but frequently rely on local subsidies[88]. They also contribute to local environmental degradation through removal of water and nutrients. Increasingly, plantations are being established in more tropical regions to improve growth rates as a result of better climates and to improve economic gains through cheap labour and land. Southern countries will, therefore, bear a disproportionate risk - socially, economically and environmentally.

5.3 Health impacts

Fruit and nuts from GM trees will raise similar questions to those associated with other GM food crops. The genetic modification could bring about unintended changes, resulting in the production of toxins. Following the genetic modification of an aspen tree in Germany, it began to flower in its third, rather than its seventh year as expected[89], highlighting how unexpected changes may arise through the genetic modification process. The introduced protein could also prove to be allergenic. Tree pollen allergies to birch, alder, hazel, hornbeam and oak are well recorded[90], so this could form one route of exposure even if the tree product is not ingested.

5.4 Conclusions

The reasons that GM trees are claimed to be needed in forestry have been given in the position statement of the International Union of Forestry Research Organisations (IUFRO) Working Party on Molecular Biology of Forest Trees[91]:

> *"Tree plantations are expected to continue to expand as a result of increasing demand for their many renewable products, their importance to mitigation of greenhouse gases, and the environmental protection afforded to large areas of native forest. It is therefore important that rates of plantation productivity be made as high as possible within the context of good environmental stewardship. Transgenic technology, wisely used, promises significant economic and environmental benefits."*

How real are these benefits and do they justify the development of GM trees despite the ecological and social harm that may arise?

- *Increased demand?* Like the justification for GM food crops, increasing populations and the demand for more wood products for paper and construction are given as the main reasons for developing GM trees because of their predicted productivity increases. However, little attention has been paid to the option of reducing demand through decreasing usage and recycling. Enormous amounts of unnecessary packaging are now used and much of the predicted increase in demand is predicated on consumption patterns following those in the USA.

- *Mitigation of greenhouse gases?* In addition to GM low lignin trees reducing the amount of energy required for the intensive, polluting processes used in paper production, it is also claimed that growing more trees more quickly will help to absorb the carbon dioxide (CO_2) produced by burning fossil fuels. Under the Kyoto Protocol on Climate Change, countries are allowed to plant GM trees as part of their strategy as long as proper risk assessments are undertaken. Trees, like other plants, absorb CO_2 and use it to grow. With trees, the CO_2 is 'fixed' in their wood and oxygen is released. However, the science is extremely uncertain and no-none knows exactly how much CO_2 will be fixed by a tree under different conditions and, as climate changes even more, a net increase in the production of CO_2 from trees is considered possible as their metabolism may alter. If the strategy of growing GM trees to mitigate greenhouse gases were pursued, there could also be enormous social consequences for developing countries if they were 'persuaded' to set land aside to grow trees to compensate for the polluting activities of the developed world[92]. As importantly, it diverts attention from strategies to reduce the production of CO_2 in the first place, which is a much more straightforward way of tackling climate change but not in the economic interests of the developed world and its industries.

Little attention has been paid to the option of reducing demand through decreasing usage and recycling

- *Protecting native forests?* If trees can be grown more productively in plantations, the argument is that there will be less demand placed on native forests. However, this avoids looking at alternative options for how native forests can be best preserved and how the reduction in use and recycling of tree products could be improved. Instead, commercial interests are keen to promote an increased use of paper and packaging.

Establishing agreement about the environmental safety of releasing GM trees to the environment will pose more challenges than for GM food crops. The data considered necessary to determine genetic stability, the extent and rate of gene flow, and the persistence and invasiveness of a GM food crop typically involves experiments lasting over several generations of the plant, conducted under different environmental conditions. The characteristics which make trees so attractive to genetic engineers - namely their long generation times and slow growth mean that collecting similar data about their environmental performance will require much longer periods if it is to match that considered acceptable for GM crops. However, having to conduct ecological research over many years would compromise the economic viability of GM trees and conflict with the claimed benefits of speeding up tree domestication and improvement.

Having to conduct ecological research over many years would compromise the economic viability of GM trees and conflict with the claimed benefits of speeding up tree domestication and improvement

Reconciling these issues in a manner which commands public confidence will be a particular challenge for the regulation of GM trees. Judgements will have to be made much more explicitly given the lack of data, revealing the inevitably subjective nature of risk assessment. Even more demandingly, the approach which is taken will either have to satisfy, or be sensitive to, different social, economic and regulatory regimes in different countries to avoid acrimonious trade disputes. A rigorous assessment of the claimed justifications for GM trees and a detailed evaluation of the alternatives are essential.

6. Fibre Crops

GM cotton is already in commercial production and it is likely that it is already being widely used

GM cotton is already in commercial production and it is likely that it is already being widely used (it is not treated differently from non-GM cotton, so it is impossible to know how and where it is being used). In addition, research is taking place to investigate alternatives to the current major fibre sources - cotton and wood - and synthetic fibres. This is being driven by a number of factors, including:

- the limits on where cotton production can take place - which is restricted to sub-tropical climates;
- the high use of chemicals and water;
- EU regulations on waste packaging and recycling mean that biodegradable materials have advantages;
- growing of food crops is becoming less economic and so many farmers are seeking alternatives.

An EU based research project, the IENICA, has examined the potential uses of fibre crops in Europe[93] and has identified areas such as textiles, pulp and paper, wood based panels, fibre reinforced composites (e.g. replacements for fibre glass), fibre cement composites, packaging materials, filters and absorbents, insulation products, polymers and plastics. Whilst flax, hemp *Miscanthus* and reed canary grass have been identified as likely species, it is noted that little or no breeding has taken place specifically for the fibre market. If the economic and political will to increase the range of fibre crops remains, it is likely that both conventional breeding and genetic modification will be offered as solutions to improving these crops.

6.1 Cotton

In 2002, Australia and the USA approved the first of the second generation of Bt cottons containing two Bt toxin genes

6.1.1 Overview

GM cotton is the most advanced of the non-food GM crops, with millions of hectares being grown commercially. GM cotton was first introduced in the USA in 1996 and, in 2002, 6.8 million hectares (about 12% of the global cotton area) of GM cotton were grown commercially in eight countries - the USA, Mexico, Argentina, China, India, Indonesia, Australia and South Africa[94]. This was the same area as was grown in 2001.

Three types of GM cotton are being produced - herbicide tolerant (45%), insect resistant (25%), and both herbicide tolerant and insect resistant (30%). Herbicide tolerance is almost exclusively to glyphosate (Roundup) and about 2% is tolerant to bromoxynil. Insect resistance is based on *Bacillus thuringiensis* toxin genes (*Bt*) with most *Bt* cotton containing one *Bt* gene. In 2002, Australia and the USA approved the first of the second generation of *Bt* cottons containing two *Bt* toxin genes (Bollgard II). After the current growing season (2003-04), Ingard (with only one *Bt* toxin gene) is to be removed from the market in Australia and only Bollgard II will be available to reduce the risk of resistance emerging (see below). Monsanto are also conducting large scale trials with Bollgard II with a Roundup Ready gene to give herbicide tolerance[95]. In China, GM cotton containing one *Bt* gene and another non-*Bt* insecticidal gene, cowpea trypsin inhibitor, is being grown commercially[96].

Herbicide tolerant cotton can be grown in Argentina, Australia, South Africa and the USA[97]. Only *Bt* cotton is licensed in the other countries. In 2002, GM cotton made up 77% of the USA's cotton growing area, 74% of South Africa's, 45% of China's, 30% of Australia's, 25% of Mexico's and 5% of Argentina's.

Monsanto and its subsidiary, Calgene, are the main developers of GM cotton globally. Monsanto owns the majority of the patents relating to GM cotton production together with patents for key *Bt* toxin and herbicide tolerance genes. Other companies usually have to license the technology from Monsanto. Monsanto specialises in *Bt* insect resistance (marketed as Bollgard I and II, Ingard or NuCotton) and glyphosate tolerance (marketed as Roundup Ready cotton). Calgene produces bromoxynil tolerant cotton (marketed as BXN cotton).

Monsanto owns the majority of the patents relating to GM cotton production together with patents for key Bt toxin and herbicide tolerance genes

Other companies are involved in a more minor way. For example, DuPont has partial regulatory approval for sulphonyl urea tolerant GM cotton (which will be sold as STS cotton) in the US but needs to gain approval for the changed use of sulphonyl urea before marketing. Aventis (recently sold to Bayer), in partnership with Stoneville Pedigree Seed Co, is commercialising bromoxynil tolerant GM cotton in Australia. China is the only country where GM cotton production is largely and increasingly in the public sector.

Companies are now anxious to extend GM cotton production, especially in Asia and Africa. Having welcomed India's decision to grow GM cotton commercially for the first time in 2002, at the end of the Earth Summit in South Africa, Monsanto announced its plans to extend its GM cotton sales into Uganda and then Kenya[98]. Columbia is also said to be undertaking 'pre-commercial' production of *Bt* cotton[99] and field trials with the second generation *Bt* cotton, Bollgard II, have been conducted in Burkina Faso[100].

Companies are now anxious to extend GM cotton production, especially in Asia and Africa

There is little GM cotton research being conducted outside herbicide tolerance and insect resistance. The work that is being undertaken includes searching for sources of genes to use for insect resistance to replace or complement *Bt*. These include a gene from the camphor tree[101] and insecticidal proteins (known as cysteine and serine proteinase inhibitors), which are found in some plants. Disease resistance (for Fusarium and Verticillium wilt control) and resistance to waterlogging are also being investigated.

Increased cotton fibre strength has been another goal of transgenic cotton research but this has proved technically difficult to achieve[102]. Stability of transformed plants has been low and expression of the enhanced fibre strength trait has been disappointing. Much of the early work was undertaken by Agracetus, but this was reduced following its takeover by Monsanto. Public sector efforts since that time have been no more successful. Monsanto have also been reported to have been attempting to produce a coloured cotton fibre which would reduce demands for dyeing.

As well as being used in cloth production, GM cotton may also find its way into Euro or other bank notes which are produced using a cotton based paper[103]. However, cotton is not only used for fibre production as oil extracted from the seed is used in food production. In December 2002, the EU gave approval for the importation of two cottonseed oils from GM insect resistant and herbicide tolerant cotton[104]. Both of these cottonseed oils come from GM cotton varieties containing antibiotic resistance genes, although these will not be found in the oil.

Cottonseed is also used in animal feed. Bollgard II has recently been given approval for animal feed use in Australia even in those areas where growing is restricted because of concerns about potential weediness[105].

6.1.2 Performance of *Bt* cotton

In the US, *Bt*-cotton was grown on 37% of the cotton acreage in 2001[106] and the Department of Agriculture has concluded that, overall, *Bt* cotton has led to increased yields[107]. However, estimating yield effects of adopting *Bt* cotton is difficult because local environmental conditions and presence of pests can vary. Increased yields are more evident in the south-eastern states where budworm and bollworm infestation rates are highest[106]. There have also been failures and disappointing results. In 1996 in Texas, several thousands of acres of *Bt* cotton were attacked by bollworm and the crop failed[108].

In South Africa the data reveals that significant increases in yields were only recorded on irrigated farms

In South Africa, Monsanto report that in four trials with *Bt* cotton on smallholder farms, yields increased by 17-38%[125]. Another report puts the increase in South Africa at 25%. However, closer examination of the data reveals that significant increases in yields were only recorded on irrigated farms[128]. In rain-fed systems, there was no significant difference in yield between *Bt* and non-*Bt* cotton in the first three years of adoption. In India, where *Bt* cotton has only been grown commercially for one year, there has been intense controversy about the perfomance of the crop, with competing claims about yield. Monsanto's data suggested potential yield increases in the order of 80%[109]. Other studies suggest that, although bollworms were lower in the *Bt* crops earlier in the season, this was not maintained and cotton yields for *Bt* were less than for non-*Bt*[110]. Indian *Bt* cotton also appears to have been more susceptible to disease, leading to failures for some farmers[142]. Gene Campaign in India, whose own research showed 60% of farmers using *Bt* cotton failed to recoup their investments, believes that the failure is due to poor varieties being transformed in Monsanto's rush to commercialise *Bt* cotton there[111].

In Indonesia, although increased yields have been reported, *Bt* cotton suffered insect attack by cotton bollworm and *Spodoptera* in its first year of commercial growing in 2001[112]. Although yield increases of 5-10% have been reported in China, a farmer survey[122] did not show any yield benefit for the *Bt* varieties being grown there. This was attributed to a new improved non-*Bt* variety being available which outperformed the *Bt* one, and to farmers using saved seed rather than buying new *Bt* seed each season.

6.1.3 Performance of herbicide tolerant cotton

In 1997, 54 farmers on the Mississippi sought compensation when Monsanto's HT cotton failed to grow properly

In the US, the only country where data are available, herbicide tolerant (HT) cotton made up 56% of the total cotton acreage grown in 2001[106], the vast majority of which was Roundup Ready. Overall, yields of HT cotton are reported to be higher than conventional varieties and with significant increases in net returns[106, 113]. However, in Mississippi in 1997 and other south-eastern US states in 1998 and to a lesser extent in 1999 and 2000, yield has been variable[114]. In 1997, 54 farmers on the Mississippi sought compensation when Monsanto's HT cotton failed to grow properly. The bolls, which provide the cotton, were deformed and many fell off prematurely. The Arbitration Council (which moderates between farmers and seed companies) eventually ruled that Monsanto's Roundup Ready cotton failed to perform as advertised and recommended payments of nearly $2 million to the three farmers who had not settled out of court.

It is now thought that this fruit abortion where cotton bolls do not form properly and drop off was caused by the movement of glyphosate to the reproductive tissues of cotton where it accumulates and causes damage[115]. Late season growth can compensate for yield losses but this delays harvest and, in some places, the season was not long enough for compensatory growth to occur, so yields were reduced[116]. Monsanto are now reported to be recommending that only Roundup Ultra or Roundup UltraMax preparations of glyphosate should be used on Roundup Ready cotton or yields may be reduced[117], presumably because these formulations are less damaging.

Similar problems have not been reported for bromoxynil tolerant cotton (BXN), although a far smaller area is grown than Roundup Ready cotton. However, bromoxynil does not control sicklepod, an important weed of cotton in the US, and therefore the use of mixtures with other herbicides such as MSMA (monosodium methylarsonate) is being investigated for BXN cotton[118].

6.1.4 Chemical use

Herbicide

Herbicide tolerance is intended to make weed control easier for farmers as they will be able to spray the GM cotton with the herbicide to kill weeds, leaving the crop unaffected. This allows the use of broad spectrum herbicides, such as glyphosate, which can kill the majority of green plants. One argument used in favour of herbicide tolerant crops is that they will lead to a reduction in chemical usage because crops will need fewer applications and, in the case of glyphosate, that the herbicide is less environmentally damaging than others commonly used.

Whilst there has been a change in the pattern of herbicide use on cotton in the USA, with the use of glyphosate increasing markedly from 1996 to 1998 there has been no overall reduction in the amount of herbicide used (measured in pounds of active ingredient applied per acre) on HT cotton when compared to conventionally produced cotton[113]. The results of the Farm-Scale Evaluations with herbicide tolerant crops, show that simply substituting one herbicide for another less acutely toxic one does not necessarily result in environmental improvements[119]. GMHT oilseed rape and sugar beet performed poorly in biodiversity terms, whilst GM maize was better. No such experiments have been undertaken for GMHT cotton.

In the USA, the use of glyphosate increased markedly from 1996 to 1998 but there has been no overall reduction in the amount of herbicide used

Insecticide

The major claim for *Bt* cotton is that it will decrease the use of insecticide which conventionally produced cotton requires. In Arizona and Mississippi, there were dramatic reductions in the use of insecticides on the budworm/bollworm complex (BBW) between 1995 and 2000 which are likely to be attributable to the adoption of *Bt* cotton. But, in Alabama, insecticide use against BBW doubled between 1997 and 2000[120]. Overall, there appears to have been a reduction of about 1.5 treatments per acre, but use of insecticides on insects which are not affected by *Bt* may have started to increase[121].

In China, insecticide use on non-*Bt* cotton was reported to be five times higher than for *Bt* cotton[122]. In Australia, there has been a reported reduction in insecticide use, but this has declined over the four year period of commercial growing from a 52% reduction in 1997; 44% in 1998; 37% in 1999 and 28% in 2000[123]. CSIRO, an Australian research institute, reports that Bollgard II required 75% less insecticide in three years of field trials[124]. In their trials in South Africa, Monsanto report an average reduction in the number of sprays of 5.8 per year[125]. Trials in India reported that there were three sprays less per season against bollworms[109]. However, problems with pink bollworm in *Bt* cotton later in the season are reported to be leading to large increases in insecticide use[126].

In China, insecticide use on non-Bt cotton was reported to be five times higher than for Bt cotton

Whilst bollworms may be controlled to varying degrees by growing *Bt* cotton, pests which are not affected by *Bt* may increase in numbers and require control. Damage due to the green and brown stink bugs (which are not affected by *Bt*) is now increasing in the USA, with stink bug damage sometimes being three times higher in *Bt* than non-*Bt* cotton fields[127]. These pests are benefiting from the decline in bollworms and the spectrum of pests is starting to change. In South Africa, the pest spectrum has also been noticed to change since *Bt* cotton cultivation began. For example, although not confined to *Bt* cotton fields, the vegetable stink bug (an insect resistant to *Bt*) has reappeared after 50 years and local scientists are concerned that another *Bt* resistant group of insects, jassids, could pose a serious threat in the future[128].

Scientists are concerned that another Bt resistant group of insects, jassids, could pose a serious threat in the future

In Australia, scientists warn that the addition of a second *Bt* gene to address the problem of declining levels of *Bt* during the season and variable susceptibility in the bollworm/budworm pests, will further alter the balance of insect pests with increases in insects such as aphids[129], green mirids and two-spotted mites, which will demand more complex control measures. The increases in insecticide use on such pests is not usually included in estimates of changes in insecticide use on *Bt* cotton.

6.1.5 Gene flow

Gene flow may take place following fertilisation of one plant by the pollen of another GM plant. The likelihood of this happening depends on the compatibility of the two species involved and, for wild species, whether the gene(s) then become established in the population in later crosses. Different chromosome numbers prevent transfer to some wild cottons and relatives. The potential for GM cotton to survive outside agricultural fields is another way in which altered genetic material could persist in the environment and alter genetic diversity.

Cultivated cotton

Cultivated GM cotton could pollinate neighbouring fields of non-GM cotton (whether grown organically or conventionally). Cotton pollen is large and sticky - so wind dispersal rates are therefore low - and most cotton is self-pollinated, but outcrossing does occur as a result of insects, particularly bees, feeding on cotton[130]. The extent of gene flow will depend on the type of insect pollinators, proximity of GM to non-GM fields of cotton, wind direction and strength (as this affects insect flight patterns), as well as other environmental factors such as landscape.

US studies of gene flow from GM cotton suggest that cross pollination is less than 1% at a distance of 25 metres[131]. In Australia, a lower frequency of outcrossing was detected with less than 1% at 7 metres[130]. Variations in findings arise from differences in the pollinating species and their behaviour in diverse parts of the world.

Gene flow to cultivated cotton could lead to loss of markets for organic or non-GM farmers if their crops become contaminated, and adequate separation will be required. In the US, distances required to maintain seed purity in conventional cotton vary depending on the state and may also include the use of buffer zones of cotton to reduce the likelihood of cross-pollination. In Arizona, to maintain contamination below 0.08% for certified seed, 0.05% for registered seed, and 0.01% for foundation seed, isolation distances are 660 feet (20 m), 1320 ft (40 m) and 2,640 feet (80 m) respectively. A US scientific advisory panel has suggested that these separation distances may be inadequate for GM seed isolation[132]. The isolation distance for conventional cottons of different lint colours is three miles with no border or buffer fields.

Wild cottons

Cotton (*Gossypium* spp) grows as an annual or perennial shrub and is cultivated world-wide. Four species are grown commercially, of which *G. hirsutum* (upland cotton) is cultivated most commonly. *G. barbadense* (sea island cotton, pulpulu haole or Pima) is also grown in the United States and *G. arboreum* and *G. herbaceum* are also grown for fibre in Africa and Asia. They are also found as feral populations. There are up to 46 other species included in the genus *Gossypium* with species indigenous to Africa, Central and South America, Asia, Australia, the Galapagos Islands and Hawaii.

The isolation distance for conventional cottons of different lint colours is three miles with no border or buffer fields

Wherever compatible wild species of *Gossypium* coexist with cultivated cotton, gene flow may occur at some time. Any effect is likely to depend on whether it confers an advantage or disadvantage. Insect resistance, for example, may allow a plant species to extend its range if insect attack becomes more limited. Equally, as has happened with gene movement from conventional crops to related wild species, a disadvantageous trait could, at worst, lead to a local species extinction[133]. Even if the rate of gene flow is low, gene flow could have serious ecological impacts or could lead to the development of troublesome weeds for farmers.

Concerns about gene flow from upland cotton to native *G. tormentosum* have led to the sale of GM *Bt* cotton being banned in Hawaii. Similarly, *Bt* cotton cannot be grown in Southern Florida south of Interstate 60 to protect feral populations of *G. hirsutum*[134]. In Australia, commercial growing of Bollgard II cotton (containing 2 *Bt* genes) and Bollgard II/Roundup Ready cotton has been restricted to south of latitude 22^{0} South because of concerns over gene flow to native cotton in northern Australia[105]. Separation distances of at least those used for isolating coloured cottons (3 miles in the US) have been suggested as a minimum separation distance for GM from wild cottons by US scientists[132].

Concerns about gene flow from upland cotton to native G. tormentosum have led to the sale of GM Bt cotton being banned in Hawaii

Weedy cotton

GM cotton could become established in the environment if it is able to survive outside agricultural fields. Genes that give the cotton an environmental advantage would increase the likelihood of this arising and 'escaped' GM cotton could then become a pest or weed. Lack of knowledge about the factors that control the growth of cottons limits prediction. Uncertainty about the potential for insect resistant cotton to become weedy has led Australia to restrict commercial growing of Bollgard II to southern areas where environmental conditions are less conducive to the proliferation of cotton[105].

6.1.6 Resistance to *Bt*

One of the major concerns about the introduction of *Bt* crops has been that insect pests will develop resistance to the toxin in the same way that resistance emerges to chemical insecticides. Not only would this render the protection ineffective but, because *Bt* is used as a pesticide by direct application in both organic and conventional systems, it could compromise its usefulness here as well. When used directly as an insecticide, the spores that produce *Bt* are applied in spray form when the need arises. Natural *Bt* is only applied occasionally and degrades in three days[135]. In contrast, in *Bt* crops, not only is the *Bt* present in a more active form, it is produced at varying levels throughout the growing season. Exposure is constant and more likely to encourage the development of insect resistance in pests. Because some insect pests of cotton, such as the cotton bollworm, also affect a variety of other crops, it is not only cotton farmers who may suffer through the lack of effectiveness of *Bt* if insect resistance emerges.

One of the major concerns about the introduction of Bt crops has been that insect pests will develop resistance to the toxin

Resistance would lead GM cotton farmers on to a treadmill of requiring a new GM insecticidal crop in the same way that farmers have been forced to use new chemical insecticides as resistance emerges. For organic and small-scale farmers, the complete loss of an insect control mechanism could lead to crop failures and economic vulnerability.

Development of resistance to *Bt crops* seems inevitable and management plans are being developed to delay this. Naturally occurring *Bt* resistant diamond back moths have been reported in the field (not associated with the presence of Bt) and resistance in at least 11 other species (including the tobacco budworm, pink bollworm and the cotton bollworm) has been identified in the laboratory[136, 137]. However, although resistance to the Cry1Ac *Bt* toxin can be induced readily in pests such as the pink bollworm after only three rounds of selection (in terms of exposure to Bt) in the laboratory[138], there have been no reports of resistance emerging in the field following the use of *Bt* crops.

Resistance management strategies in the USA and Australia are based partly on 'refuges' of non-*Bt* crops areas where insects will not be exposed to *Bt* - to reduce the likelihood that resistance will emerge. The gene(s) that code for *Bt* resistance would not give an advantage and would be unlikely to become widespread in a population. In addition, to ensure that insects are killed when they do feed on the *Bt* cotton, the level of *Bt* in the GM crops has to be sufficiently high. This is known as the 'high dose/refuge' strategy. In Australia, resistance control measures also require 'pupae busting' - tillage to kill overwintering budworm pupae which may have developed resistance to *Bt*[139]. There has been a cap of 30% of the cotton acreage grown with Ingard cotton in Australia. In 2004/05, when only Bollgard II will be able to be grown, this will be increased to 80% as the presence of two *Bt* toxins is expected to delay the emergence of resistance[140].

There are considerable uncertainties over whether these management plans will work and for how long. Often, *Bt* cotton does not provide a sufficiently high dose of *Bt* in the plants to kill all susceptible pests. The decline in Cry1Ac levels in *Bt* cotton as the season progresses further compromises the high-dose strategy (although Bollgard II should be better in this respect). Naturally occurring levels of resistance may be higher than expected, making refuges ineffective because lower selection pressure will be required for an insect population to express the gene at high levels. In the field in 1997, levels of resistant pink bollworm were about 100 times higher than predicted[141].

Ensuring farmers comply with the *Bt* refuge system and other resistance management plans is also difficult and there is evidence that this has failed in the USA, Australia, India and South Africa[143].

Therefore, whilst resistance associated with the use of *Bt* cotton has not yet been encountered in the field in any country, questions remain about whether resistance control measures will be successful in the longer term.

6.2 Hemp and flax

There are considerable uncertainties over whether these resistance management plans will work and for how long

The use of hemp and flax - and their genetic modification - as alternative sources to cotton for natural fibres has been proposed because they are more suited to temperate conditions and have less reliance on chemical inputs[144]. To isolate fibres from hemp and flax they have to be subjected to 'retting' where they are harvested but left on the field to allow natural fungal enzymes to work in the breakdown process. This process is highly dependent on environmental conditions and current industrial enzyme processes to simulate the natural process are prohibitively expensive. Genetic modification of flax or hemp to alter the characteristics of the pectin layer and facilitate fibre extraction and improvement of fibre quality via modification of cell wall structure are therefore particular targets of current research. Identifying relevant genes is one subject of an EU research project on hemp the HARMONICA project[145].

The only field trial to have actually taken place with GM fibre crops other than cotton is for herbicide tolerant flax in Canada.

6.3 GM plants to produce spider silk proteins

A different approach to fibre production in plants has been the use of genetic modification of plants to produce spider silk

A different approach to fibre production in plants has been the use of genetic modification of plants to produce spider silk. This 'dragline' silk is a high protein fibre which has a high elasticity and is one of the strongest materials in the world. These properties make it very attractive for a range of applications, including protective clothing. Nexia Biotechnologies Inc has produced spider silk proteins (Biosteel) in transgenic plants, which would be suitable for large scale production. The company is collaborating with the Institute of Plant Genetics and Crop Plant Research in Germany, who have announced successful production in both tobacco leaves and potato tubers with up to 2% of the total soluble proteins of the endoplasmic reticulum as spider silk proteins[146]. The first and second generation transgenic plants showed normal growth and morphology. However, it is possible that the high energy cost of spider silk production will affect plants in stressful conditions.

Nexia has also reported successful production of Biosteel in cell culture[147] and is genetically modifying goats to produce spider's silk in their milk[148].

Nexia is working with the Canadian military to produce lightweight body armour from Biosteelâ and is also working on medical applications, including wound closure systems and ligament prosthetic devices[149].

6.4 Conclusions

Of the fibre crops, it is GM cotton which is already in commercial production and grown globally. Increasingly, GM cotton is being targeted to growers in the developing world and how it will affect them is an important question. It certainly seems that *Bt*-cotton can lead to reductions in use of the massively high levels of insecticides that are commonly applied to conventional cotton. This, in turn, could lead to reduced exposure and health benefits for poor farmers who do not have the education or equipment to use chemicals safely. However, to be able to use *Bt*-cotton, poor farmers will have to be able to invest in the increased costs of GM seeds. Whilst they may not have to buy as much chemical, seed costs will rise in the form of 'technology fees'. For most small farmers this will continue dependency on loans and the financial risk that entails. In South Africa,

the technology fee was $60/ha in 2002 and may rise to $70 in 2003[150]. In 2002 in the USA, technology fees were $80/ha for *Bt* cotton; $17-22/ha for Roundup Ready cotton; $101/ha for *Bt* and Roundup Ready; $15-25 for BXN. In Australia the technology fee for *Bt* cotton is $98/ha.
In South Africa, one company, Vunisa Cotton, sells all the products needed by conventional cotton farmers in Makhathini, where GM cotton is grown[151]. Vunisa is the only provider of credit and advice to farmers. They sell Delta Pines' GM cotton seed using Monsanto's patented *Bt* gene and Monsanto has supplied technical support to Vunisa in the form of a person who trains farmers about GM cotton, the need for refuges and so on. If yields are maintained or increased, farmers may be able to pay the increased costs of seed and sustain their loan repayments. However, if insect resistance emerges or the cotton crop fails for other reasons, farmers may face losses they are unable to cover. These are very real risks that are widely acknowledged. Companies are already developing second generation insect resistant crops because of the prospect of resistance emerging.

The over ridding interest in GM cotton is in large-scale globally applicable uses but the sustainability of this approach remains to be seen

As in the majority of the current uses of GM crop technology, the over ridding interest in GM cotton is in large-scale globally applicable uses. The sustainability of this approach remains to be seen.

7. Flowers

Another area of GM research has been in floriculture. There is a long history of breeding flowers of ever more exotic colours, size or shape. Genetic modification is seen as a way of introducing new forms and increasing the market for flowers. There have been three main ways in which flowers have been genetically modified:

- altering flower colour to introduce new colours into a species;
- lengthening vase life so that flowers will last longer once purchased;
- herbicide tolerance.

Genetic modification is seen as a way of introducing new forms and increasing the market for flowers

The first species to be targeted have been carnations and chrysanthemums. Florigene, a company established in 1986 with the main purpose of bringing genetic modification techniques to the cut flower industry, is the main company involved in GM flowers. A subsidiary of Nufarm, an Australian chemical company, Florigene's main research facilities are in Melbourne in Australia but its product development and commercial activities are centred in Holland.

Florigene has three carnation varieties approved for marketing in the European Union in 1997 and 1998 - two varieties have altered colour (and resistance to the herbicide, sulfonyl urea) and one has an extended vase life. However, none are currently being grown or sold in Europe. Florigene has two commercial varieties of carnation available in Australia - Moondust (a light mauve colour) and Moonshadow (a violet colour). In Japan, Suntory also market a mauve GM carnation, Moondust.

All of Florigene's patents are based on flowers and altered characteristics for the cut flower industry (see Table 4).

Table 4: Florigene's patent portfolio

Rose Plants	
US5792927 US5480789	Genetically transformed rose plants and methods for their production.
WO9200371 EP0536327	Rose plants and methods for their production and genetic transformation.
US5530182	Methods for production of hybrid rose plantlets from rose somatic Embryos.
Carnations	
AU703841 WO9635792 EP0824591 AU5493096	Transgenic carnations exhibiting prolonged post-harvest life.
WO9217056 US5589613 EP0582603.	Carnation plants and methods for their transformation and propagation.
Chrysanthemums	
US5567599 WO9203041 AU8433091	Method for producing transformed chrysanthemum plants.
General Change in Pigmentation	
CN1216583 CA2247922 AU1862197 WO9732023	Genetic sequences encoding flavenoid pathway enzymes and uses thereof. (NB: Such enzymes help in the genetic manipulation of pigments in flowers.)

The first species to be targeted have been carnations and chrysanthemums

7.1.1 Lengthening vase life

Transgenic carnations have been produced where senescence is delayed and vase life is lengthened as a result

Approaches to lengthening vase life, an important characteristic in marketability, have been similar to those used to delay ripening and increase shelf-life of fruits such as tomatoes. Senescence (ageing) of flowers is partly controlled by the production of a plant hormone, ethylene, which is also involved in the ripening of some fruits. Florigene's work largely uses antisense technology where the normal process of translation of the genetic code is interfered with. When a gene is activated, it is transcribed and its message sent to the rest of the cell through the production of a substance called messenger RNA (mRNA). The presence of extra copies of a naturally occurring gene or a gene in the reverse orientation leads to the production of additional mRNA that interferes with normal gene translation and effectively reduces the levels of the gene product. In this way, genetic modification using copies of genes naturally found in a plant can be used to block or modulate the operation of those genes. Using such antisense technology, transgenic carnations have been produced where the level of production of ethylene is reduced because the enzymes involved in its production are interfered with[154]. Senescence is delayed and vase life is lengthened as a result.

Another approach to extending vase life has been to introduce a gene, *etrl-1l*, from *Arabadopsis* to make the plant insensitive to ethylene[152]. However, the resulting delayed senescence was variable according to the variety transformed and plants showed reduced rooting of cuttings and fruit ripening, so propagation may be problematic. Similarly, when petunias were made ethylene insensitive by introducing a mutated version of the ethylene receptor gene, higher mortality was seen, possibly associated with increased disease susceptibility[153].

7.1.2 Altering flower colour

Alternation of flower colour has been achieved through the modification of the production of the major pigments, known as anthocyanins, responsible for flower colour[154]. The under- and over-expression of genes in the anthocyanin synthetic pathways leads to flowers with different intensities of colour. Real novelties, such as blue roses, which have not been achieved by conventional breeding, are seen as important targets for the genetic modification of flowers.

Although creating a blue rose has been an aspiration of Florigene, it has not proved easy

Although creating a blue rose has been an aspiration of Florigene, it has not proved easy[155]. Roses do not have the correct biochemical pathway and even when the key enzyme genes from petunia (flavenoid 3'5' hydroxylase and dihydroflavenol reductase) were introduced, the flowers were not blue but pink. This was because of the acidic environment in the cell vacuole where the pigment was produced – like litmus paper, it is only blue in alkaline conditions. Although they have not produced a blue rose, Florigene's mauve and purple carnations are produced through the introduction of these two genes. Other researchers now hope that, by introducing another enzyme gene, they will be able to produce the elusive blue rose, but this has yet to be achieved[156].

Another approach to altering flower colour has been to change the intensity of pigment production by introducing genes which result in the activation of specific pathways[154]. Sense and antisense inhibition of genes involved in colour synthesis has been undertaken to produce new colour variants in the gentian, lisianthus[157], and torenia[158].

7.1.3 Others

Hokko Chemical Industry has manipulated the pigment gene of cyclamen and has developed white, red, pink and a mixture of red and white flowers. Other Japanese researchers are using genetic manipulation to produce disease resistant and heat resistant cyclamen[159]. Fluorescent large white bluebells, tobacco and lavender have been produced by transferring a fluorescent protein gene from the jellyfish[160]. The scientists exhibited these flowers at a show in Italy in the hope that they would reassure people about the usefulness of genetic modification[161].

Fluorescent large white bluebells, tobacco and lavender have been produced by transferring a fluorescent protein gene from the jellyfish

7.2 Conclusions

Genetically modified flowers are already on the market in Australia and Japan. Sales are restricted to cut flowers, but it is likely that sales of seed to gardeners will follow. Whilst the cut flower market means environmental impacts may be restricted – flowers are often cut and sold before pollen is produced or distributed – this will not be the case if the seeds are sold directly to gardeners. Depending on the species and country involved, the potential for gene transfer to other cultivated plants or to wild relatives is possible. If the interest in GM flowers takes off and extends to the horticultural market, the growing of GM plants and their escape from gardens would be a worrying prospect. In the UK, exotics which have escaped from gardens and caused ecological damage, include rhododendron and Japanese knotweed.

If the interest in GM flowers takes off and extends to the horticultural market, the growing of GM plants and their escape from gardens would be a worrying prospect

8. Conclusions and recommendations

When considering the application of GM to non-food crops, it is evident that, for grasses, trees and fibre crops, the modifications that are proving most successful are those which are being used in GM food crops as well – herbicide tolerance and insect resistance. In the case of one GM non-food crop currently available, cotton, it is only these two traits which are used. Flowers are one exception to this, where it has proved possible to modify flower colour and vase life using the techniques originally applied to delay ripening in GM tomatoes. The other success is potatoes with modified starch.

Complex characteristics which are often associated with more than one gene, and environmental interactions make their reliable modification even more difficult

In the case of traits such as disease resistance and drought or salinity tolerance, progress has been much slower. These are complex characteristics which are often associated with more than one gene, and environmental interactions make their reliable modification even more difficult.

Where the aim is to produce new compounds, or modified amounts of existing ones, the picture is mixed. A GM potato with high levels of amylopectin is on the verge of commercialisation, but this is the only example where clear success has been achieved. In other cases, such as the production of novel oils or feedstock for plastic production, the situation is less positive. There is much more spin than substance to the claims that are made for GM crops in industrial uses.

Modifying existing biochemical pathways to redirect production to form new oils has been difficult because of the lack of understanding of the systems guiding the production and use of fatty acids in cells. The key roles played by these molecules can be easily disturbed, leading to abnormal growth and performance. Similarly, but with apparently less acute effects on plant development, altering starch production is not straightforward because of the complexity of the enzyme systems involved.

Another major obstacle in using GM plants to produce the raw materials for manufacturing is whether they can produce enough of the required compound to be economically viable

When it comes to the production of new compounds, such as PHAs for use in plastics manufacture, an additional problem is faced. The compounds, and/or the diversion of resources to them, can be very damaging to the plant. Another major obstacle in using GM plants to produce the raw materials for manufacturing is whether they can produce enough of the required compound to be economically viable. When producing high value drugs, relatively low levels of production may be acceptable because of the high price the product will command. But the same is not true for many industrial feedstocks, where alternatives may be available at lower costs.

Furthermore, if, for example, a plant has to be modified to produce 70-80% of its fatty acids in a novel form to make it economically viable, this may not even prove to be physiologically possible. It may, therefore, be more productive to improve the agronomic performance of plants already producing high concentrations of specialist fatty acids - such as borage, evening primrose and flax - through conventional breeding and agricultural techniques.

When considering the environmental and health implications of non-food GM crops, the questions will centre on a combination of the crop being modified and the manner in which it has been changed. (For herbicide tolerance and insect resistance, there is a much better knowledge base than for the production of PHAs in a plant, for example.) However, there has been very little attention paid to these issues and, if these GM plants prove to be viable, there will need to be some urgent research to address questions of environmental and health effects of exposure to new compounds.

There will also be questions relating to the crop which has been modified. Grasses pose particular problems because they are freely outcrossing and because seed is so easily spread. If GM amenity grasses are commercialised in one country, it is difficult to see how they could be prevented from spreading to other countries over time. Given the investment in this area, and the prospect for early commercialisation in the US, the UK and Europe need to consider this matter urgently.

Like grasses, trees are relatively undomesticated and often outcross easily, making containment very difficult

Trees also pose considerable problems in assessing the risks involved. Their long life span means that designing experiments to assess risks is more problematic than for annual crops. Like grasses, trees are relatively undomesticated and often outcross easily, making containment very difficult. This is another area which demands consideration as an international risk issue.

If GM food crops are used for non-food purposes and these are grown in proximity to the same non-GM crops to be used for human or animal consumption, there will be important questions about safety and marketability. Such applications therefore need to be considered in discussions on the coexistence of GM and non-GM crops as they could compromise this considerably, depending on the crop involved.

If GM food crops used for non-food purposes are grown in proximity to the same non-GM crops to be used for human or animal consumption, there will be important questions about safety and marketability

Arising from the research carried out for this report, GeneWatch UK makes the following recommendations:

- A review of the problems of national containment of GM trees and grasses must be conducted under the auspices of the Cartagena Protocol, which regulates the trade in GMOs and encompasses the issue of unintended transboundary movement. The UK government should press the EU to take this issue forward at Protocol discussions and consider its own position. There are good grounds for an international moratorium on the production of GM grasses and trees if these issues cannot be resolved.

- A review of the various methods of producing designer oils and starches in plants should be conducted. In particular, it should consider the relative merits of GM compared to improving agronomic performance of plants making the products naturally. This should be used to inform research and investment priorities in this area.

- In considering future UK policy in relation to GM crops, the interaction between GM crops intended for non-food applications and non-GM food crops should be evaluated. Contamination of non-GM foods by any GM crop, whether intended for food or non-food use, could have equally damaging economic consequences.

- Basic research should be commissioned which investigates the impacts of introducing the production of new compounds into plants and altering levels of naturally occurring compounds. This should focus on the environmental performance and human health implications of the plant itself and other plants acquiring the gene(s). This would include considering toxicity for fauna and allergenicity for humans; seed survival and dormancy; disease resistance and susceptibility; and soil composition.

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