Biotechnology (GMO) issues and research priorities in natural resource management

Report to Land & Water Australia

John Stanley, Keith Hutchinson, Ian Godwin, Peter Gregg, Robin Jessop, Margaret Katz, Kathy King, Julian Prior and Brian Sindel
University of New England

David Thompson
Care Pty Ltd

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GPO Box 2182
Canberra ACT 2601
Telephone: 02 6257 3379
Facsimile: 02 6257 3420
Email: public@lwa.gov.au
WebSite: www.lwa.gov.au

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Authors: John Stanley, Keith Hutchinson, Ian Godwin, Peter Gregg, Robin Jessop, Margaret Katz, Kathy King, Julian Prior and Brian Sindel
University of New England
Armidale NSW 2351
john.stanley@pobox.une.edu.au

David Thompson
Care Pty Ltd
174 Rusden Street
Armidale NSW 2350
care@northnet.com.au

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Abbreviations

ACCC	Australian Competition and Consumer Commission
AFAA	Agrifood Awareness Australia
ANZFA	Australian and New Zealand Food Authority (now FSANZ)
APVMA	Australian Pesticides and Veterinary Medicines Authority (formerly the National Registration Authority, NRA)
AQIS	Australian Quarantine and Inspection Service
BA	Biotechnology Australia
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNA	deoxyribonucleic acid
EA	Environment Australia
EPBC	Environment Protection and Biodiversity Conservation
ESRC	Economic and Social Research Council
ESA	Ecological Society of America
EU	European Union
FSANZ	Food Standards Australia New Zealand
GEFZ	genetically engineered free zones
GMAC	Genetic Manipulation Advisory Committee
GNA	*Galanthus nivalis* agglutinin
GM	genetically modified
GTC	Gene Technology Committee
IOGTR	Interim Office of the Gene Technology Regulator
IRM	integrated resistance management
NLRD	notifiable low risk dealing
NRA	see APVMA
NRC	National Research Council
NSWFA	New South Wales Farmers' Association
OGTR	Office of the GENE Technology Regulator
RNA	ribonucleic acid
TGA	Therapeutic Goods Administration
TT	triazine tolerant
THT	transgenic herbicide tolerant
WTO	World Trade Organization

Research specialisms of authors

John Stanley	Entomology and biological control
Keith Hutchinson	Grazing systems
Ian Godwin	Animal physiology
Peter Gregg	Agricultural pest ecology and management
Robin Jessop	Crop and pasture agronomy
Margaret Katz	Microbiology
Kathy King	Soil biodiversity
Julian Prior	Natural resource policy and rural extension
Brian Sindel	Weed ecology and management
David Thompson	Agro-ecological economics

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Executive summary

Over the last two decades biotechnology has advanced to a level where it is generally feasible to make particular changes to the genetic code, and therefore to the expressed characteristics, of living organisms. The product of such a change is called a transgenic or genetically modified organism (GMO).

Such alterations to the structure and/or function of biological entities have the potential to alter the basis of many biologically based activities, including agriculture and aquaculture, medicine, hygiene and health, food production and processing, biochemical production, pest control, eco-tourism, and bioremediation.

A component of Land & Water Australia's mission is to inform national debate on new and emerging issues confronting natural resource management. Hence, the prospect that GMOs might affect primary industries and natural resources is of interest.

This report aims to summarise current and proposed GMO activities and make suggestions on targeted research investment that might better prepare Land & Water Australia (LWA) to help manage these new resources. This is despite the obvious limitations of trying to foresee the implications of such a new and broadly applicable form of technology.

GMO technologies have broad similarities as a biochemical class of activity. However, the influence that any GMO might have will depend on the particular genetic modification in question. Hence, rather than recommendations, we have provided a set of options for LWA managers to consider in the light of the examples of GMO activities and possible impacts on resources that we discuss.

A large section of the report is devoted to opportunities for LWA to contribute to public policy and risk assessment. This is in response to the polarisation of the community on the issue of whether or not GMOs should be released into the general environment. Some see marvellous opportunities to design organisms to overcome problems in agriculture (yield limitations, pestilence and climatic limitations) or in medicine (cheaper 'smarter' medicines). Others foresee ecological problems involved with the release of arbitrarily altered organisms, or consider GMOs as unethical meddling with nature.

LWA could play an important role in developing the GMO debate by improving the credibility of information about GMOs and taking an 'honest broker' position.

Executive summary by section

Genetically modified micro-organisms and viruses

Genetically modified micro-organisms have been used for 20 years in the production of pharmaceuticals (eg. human insulin, bovine somatotrophin), vaccines (eg. the hepatitis B vaccine) and enzymes (eg. rennet for the production of cheese). However, none of these applications involve the release of genetically modified micro-organisms or viruses.

The issues for LWA in regard to GM micro-organisms are likely to revolve around their release into the general environment. Prospects include using GM micro-organisms for bioremediation to clean up industry or general wastes and by-products (eg. sewage, pesticides, metals, oils, nuclear waste), in farm animals (eg. to improve the food conversion efficiency of ruminants or reduce methane production) and to control pests or diseases.

Although the relative simplicity of micro-organisms means they are more amenable to genetic modification than higher order organisms, their size and diversity has rendered them difficult candidates for ecological research. A low level of ecological knowledge will cause difficulties when considering them for general release. This presents an urgent requirement for research on the ecology of micro-organisms in order to improve regulation.

Plant GMOs

Some 90% of varieties of genetically modified crops currently in commercial use throughout the world confer either insecticidal or herbicide tolerance properties on plants. While the former aim to reduce reliance on pesticides, herbicide tolerance is designed to enable the more widespread use of certain chemicals for weed control.

Genetically modified cotton (Bt cotton) has been grown for seven seasons in Australia. It is the only broadacre GMO in production in Australia and has been comprehensively compared with the conventional varieties. A detailed case study is attached to this report to show the complexity of issues and questions on the benefits of GMO crops. At least initially, proposals for the release of GMO crop types are likely to include simple gene changes, from one to a few, that confer insecticidal traits in conjunction with herbicide resistance traits. Bt cotton has been a successful introduction on economic and environmental grounds in comparison to conventional cotton.

For three seasons, cotton varieties have been grown containing transgenes for herbicide resistance to glyphosate. The only varieties available in Australia are products by Monsanto with the trade name Roundup Ready® (RR) cotton. They allow glyphosate applications to control a broad spectrum of weeds up until the fourth leaf stage of the cotton crop. There are therefore a few transgene combinations now available in cotton varieties: Bt alone, RR alone, and varieties with both Bt and RR. In 2002–03 an estimated 40–45% of the cotton planted was RR. This included 15% that had both Bt and RR transgenes. Overall in that year about 55–60% of the cotton area planted would be considered GM (Bruce Pyke, Reseach and Extension Manager, Cotton Research and Development Corporation, Narrabri NSW, pers. comm. 2003).

We are now rapidly approaching the situation where it will be technically possible to insert herbicide-resistance genes into all major Australian crop species. GM herbicide tolerant (HT) crops are perceived to offer flexibility in weed management because they may allow herbicides such as the non-selectives, glyphosate and glufosinate ammonium, to be used ‘in crop’ that would otherwise not have been possible. This offers the potential for better mammalian safety, less residual activity, a broader spectrum of weeds controlled and incorporation of different modes of action to help delay herbicide resistance in weeds.

However, the use of GM HT crops is not without problems. They could lead to increased use of chemicals for weed control, with consequent health and environmental effects. This will partly depend on how a herbicide associated with a HT crop substitutes for currently used herbicides. A second concern is a shift in the weed flora, and particularly the more rapid evolution of weed populations that are resistant to the particular herbicide to which the crop or pasture variety is resistant. A third problem is that GM HT crops may themselves become major weeds, particularly as volunteers in succeeding crop rotations. Another risk is for the transfer of herbicide resistance from transgenic crop varieties to their weedy relatives, the main consequence of which would be the loss of previously effective broad-spectrum herbicide strategies within a variety of Australian farming and environmental systems. While studies indicate that the likelihood of successful hybridisation is low, some level of introgression appears inevitable. Risks may also be associated with introgression of traits such as tolerance to drought, frost, acid soils, temperature extremes or salt.

Animal GMOs

The production of GM animals lags somewhat behind that of plants and microbes, but is rapidly gaining as technologies develop. Most cases of genetic modification of animals currently relate to research settings where models of human diseases have been developed using genetically modified laboratory animals. However, the use of genetically modified farm animals that have enhanced production traits is developing rapidly, as is the use of farm animals to make novel products. Normally the only environmental issues arising from their development are those associated with adjustment to existing farm management systems (ie. changes to stocking rates, shifts in seasonal breeding etc.).

There is some concern that if genetically modified animals escape into the natural ecosystem they will develop feral populations. In most cases, the modifications developed for farm animals are likely to render these animals less suitable to the natural environment. No genetic modification of native terrestrial vertebrates is envisaged and it is again likely that modified animals would be less environmentally fit in most cases. Possible exceptions to this are in the area of aquaculture of native species, where GMOs may pose a threat to natural populations of the same species and those at lower trophic levels.

Genetic modification of arthropods for bio-control and human disease prevention could be fraught with unknown ecological consequences. There are no current international guidelines in this area.

GMO segregation

To address initial concerns about market access, food labelling and product identification, GMO products will need to be segregated. This will be physically difficult for products like grains, because they are usually reproductive, numerous, tiny and highly dispersive. They are also likely to be very similar in size and density to their conventional counterpart, making effective mechanical separation impossible. Segregation will also be expensive if it means major duplications within the transportation and production processes.

The crucial questions are about the level of mixing that is acceptable and achievable. Currently, commercial interests concentrate on standards that address food safety or 'true to label' product standards in force. This does not necessarily mean that they are also acceptable on environmental grounds.

As industry approaches regulators with proposals to self regulate for segregation, it will be important that the regulators are well informed of the accuracy of those proposals. LWA might choose to play a role in reviewing, verifying, or encouraging research on the efficacy of such protocols.

Considerable attention to and research into risk-assessment approaches will be required, given that comprehensive scientific data will not be available for each new product. Research into the quality and efficacy of GMO products tends to take precedence over ecological studies when driven by commercial interests, as is generally the case. LWA might be able to influence policy to address this imbalance to ensure more ecological information is available to judge the environmental safety of GMO release proposals in future.

GMO regulation, product choice and economic issues

Regulation

Regulation of gene technology in Australia recently culminated in the *Gene Technology Act 2000* (C'wlth): This Act came into force on 21 June 2001. In summary, the Act does the following:

1. Establishes the Office of the Gene Technology Regulator (OGTR) and a ministerial Gene Technology Committee (GTC) to administer the legislation and make decisions under it.
2. Establishes three advisory committees (scientific, ethics and community), from which the GTR and the GTC can acquire advice. The ethics committee can advise on ethics of animal experimentation related to gene technology, for example. GM plants and crops are to be tested for any risks that they may pose to native plants, their potential to spread pollen to conventional plants or related weed species, and their potential to become a weed. The efficacy of recent protocols for testing will be examined further in this report.
3. Prohibits persons from researching, manufacturing, producing, releasing or importing GMOs unless such dealing is:
   (i) exempt;
   (ii) a notifiable low risk dealing (NLRD) defined as contained research, which demonstrably is low risk to workers, general public and to the environment;
   (iii) on the Register of GMOs; or
   (iv) licensed by the Regulator.
4. Establishes a basis for assessing risks to human health and to the environment, arising from dealings with GMOs and including the opportunity for public input.
5. Provides for monitoring and enforcement of the legislation. Unauthorised dealings in GMOs are subject to penalties of $1.1 million or 5 years imprisonment.
6. Establishes a central and publicly available database for all GMOs and GM products approved in Australia.

Several government agencies are directly or indirectly involved in the control of GMO product safety.

The *Australian Competition and Consumer Commission* (ACCC): one of its aims is to prevent consumers from unfair trading, false, misleading and deceptive conduct.

The *Australian Quarantine and Inspection Service* (AQIS): has the responsibility for quarantine matters. including the import of GM products, which may pose risks from the introduction of pests and disease.

The *Australian Pesticides and Veterinary Medicines Authority* (APVMA) (formerly the National Registration Authority): this authority evaluates, registers and regulates all agricultural and veterinary chemicals.

The *Therapeutic Goods Administration* (TGA): responsible for the regulation of therapeutic goods, including GM pharmaceuticals, to ensure their quality, safety and efficacy.

With seven national regulatory bodies potentially involved, there is a distinct risk that the GMO importation, production and distribution processes will become overly bureaucratic There is certainly the need for achieving agreement on the GMO regulatory process between the State and Territory and Commonwealth governments. A Council, comprising Ministers from each State and Territory will be established to provide guidance on the regulatory framework and the policies which underpin OGTR legislation.

Product choice

There are only six GM food and fibre commodities, mainly grown overseas, which may be currently available for sale in Australia. The crops and their new genetic attributes are: soybeans (herbicide tolerance and high oleic acid varieties); canola (herbicide tolerance); maize (herbicide tolerance, insect and virus protection); potatoes (insect and virus protection); sugar beet (herbicide tolerance); and cotton (herbicide tolerance and insect protection). Currently no GM fruits or vegetables are marketed in Australia.

With the exception of recently released GM enzymes and pharmaceuticals, GM animal products are unavailable. A GM micro-organism is commercially available called No-Gall® as a treatment for crown gall on fruit trees and roses.

Global acceptance of GMO food is currently low. Some envisage that as empirical evidence for GM safety increases, ie. GMO use increases without recognised harm, that acceptance will naturally increase and many currently hotly debated issues will subside.

Economics

The adoption of new technologies such as GMOs in agriculture will be significantly influenced by their impact on farm business performance. The availability of GMOs alone will not be sufficient to ensure their widespread adoption, as their ability to contribute positively to farm profitability must be demonstrated.

Resource-management policy may also become a key driver of GMO product supply in agriculture. If the current trend toward 'clean and green' agriculture persists, and particularly if market premiums are paid for this type of production, many farmers will be looking for alternative production systems (assuming they are affordable). GMOs may provide some solutions in this area and act as an alternative to what has happened elsewhere in the world where agriculture is heavily publicly subsidised through 'environmental grant schemes' as opposed to direct price support.

LWA may have a role in assessing the extent to which GMO technology can contribute to improved resource management in agriculture. It will be important to recognise that a 'one-size-fits-all' solution to resource management issues will be ineffective and that there is a need for continual learning within individual farming systems regarding how alternative technologies impact upon the environment. Accordingly, the capacity of GMOs to replace existing technologies will vary.

Ultimately, the level of GMO inclusion in mainstream agricultural production will be driven by:

1. the demand for products containing GMOs by consumers
2. the demand for GMO input technology by farmers
3. the supply of GMO technology.

The first point is largely determined by price, quality (and consistency), safety, supply and trade access. For GMO food products demand will ultimately be based on perceptions of safety.

Producers will demand a clear benefit in business performance from GMO technologies, or they will not be adopted. This will in turn depend on market trends and economic benefits at the producer level. The decisions might not be based simply on the most profitable option. GMO options might reduce or increase risk or social status.

Supply of GMOs will not only be determined by the consumer and producer demand, but by legislative requirements via their impacts on production costs. Manufacturers will not invest funds in GMO development without clear signals that the market will accept these products. Government resource management policy will also be a key driver of GMO product supply.

The development of a GM variety that removes some limitation on production at the farm level might cause considerable overall shifts in land-use patterns. This might have flow-on effects for industries that support the currently established production systems.

Public policy

The highly contentious issue of GMOs is likely to be one upon which the public policy debate will wage for many years. The debate will have social, ethical, religious, scientific, political, economic, legal and cultural dimensions. In part, the discourse is about what is known and what is not known, and perceptions about the levels of risk and uncertainty. However, like many complex debates it is also about the frames that individuals and groups bring to the discussions. These frames are often determined by the value and ethical positions taken by participants. Those stakeholders holding ecocentric ethical viewpoints will seek different information, and assess perceived risks and costs and benefits differently to those with a more anthropocentric ethical position. What is clearly lacking within the GMO policy arena is the provision of appropriate fora within which various stakeholders can exchange concerns and views with each other and with policy-makers in a constructive and informed manner.

There are both extrinsic and intrinsic objections to GMOs, the conflation of which tends to confuse the ethical debate. Extrinsic objections relate to the perceived harm that may come from the use of GM technology.

Intrinsic ethical objections, on the other hand, relate to the belief that the process of producing GMOs is itself objectionable. Intrinsic ethical objections are likely to come from those who argue from deeply ecocentric or religious ethical positions.

Dealing with extrinsic objections may be a complex undertaking, but they are easier to address (if not resolve) than intrinsic objections due to the fact that the substance of the objections can be identified and critically appraised.

The primary ethical issues within the GMO debate are as follows:

- food safety and consumer concerns
- environmental impacts (eg. gene escape, loss of biodiversity within 'wild' populations)
- apparent uneven distribution of perceived risks and benefits
- transparency of decision-making and policy formulation processes
- accountability
- equity
- power of decision-making and policy formulation processes
- ownership of GMOs — 'patenting life forms'.

Within the policy discourse it is important to distinguish ethical claims ('GM technology is wrong') from empirical claims ('gene escape into wild populations is very likely'). Empirical claims can be examined and analysed through research and modelling. The line between empirical and ethical claims becomes blurred when assessing 'acceptable' levels of risk. Within the GMO discourse there is currently a very vigorous debate waging about whether policy should adopt the precautionary principle or the principle of reasonable risk (and how these terms might be defined).

The above discussion raises a number of issues, the resolution of which may involve possible roles for LWA. In exploring potential roles that it may play in helping inform public policy, LWA should be cognisant of the critical analysis of GMO-related public policy that has occurred within the United Kingdom, the European Union and the United States. It should be recognised the domestic GMO policy debate in Australia will also have international policy influences and impacts.

LWA has the potential to adopt a clear role of helping inform the policy development process through targeted research and through acting as an independent facilitator of the process of public discourse on GMOs. This latter role in particular would require maintaining a clear degree of independence from all GMO-vested groups, including large government-based entities.

Other biotechnology techniques

GMO technology is not a technology in isolation. Many biotechnological techniques are developing rapidly and could reasonably be expected to increase the rate, success, and range of possibilities with GMOs. They might be used to improve the ability to identify useful genes for transfers, make successful genetic alterations, and monitor for the presence of GM products for product purity measurements, gene flow studies and risk assessment. For example, it is possible to generate microarrays to monitor changes in gene expression in GMOs. This technique, and techniques in proteomics, can help with assessments of the safety of genetic modifications by comparing them with their conventionally derived counterparts.

There are so many biotechnological approaches that we could not properly deal with them in so short a consultancy, but we considered that it was important to make some comment to indicate that knowledge in these fields is growing exponentially, and that the snapshot of GM technology delivered in this report will date rapidly.

Options for LWA research investment

Caution: The options presented here are ideas drawn from the examples we present and our understanding of agriculture, ecology and bio-molecular science. How a new, far reaching and generally untried technology such as GMOs will be used is obviously unpredictable. Conviction abounds, but empirical evidence remains thin. We provide these options for consideration only.

The central themes to the options we present are to assist with public policy, and to improve risk assessments and research into land-use distribution changes. These address, respectively, the difficulties of the heavily polarised and empirically ill-informed public GMO debate, the limited scope of conventional risk-assessment approaches, and the potential of GMOs to substantially change the ecological, agricultural and economic boundaries of bio-productivity. The public and regulators may need an 'honest broker'.

It is possible that GMO technology will have a major effect on resources at the landscape scale via indirect effects. Research is currently under way looking at direct effects of particular GMO products in immediate biological interactions; for example, on whether GM cotton impacts on other arthropods besides the pests it was designed to control. Such detailed research is probably outside the LWA charter. We consider that the removal of production limitations, for example with GM crops, might cause a relatively rapid change in the allocation of land devoted to certain crops on a large scale. Note that this is not peculiar to GMOs, but the rate or extent of varietal improvements is likely to increase considerably with GMOs and that would be due to the new technology. No one appears to be considering this prospect in preparation for GM releases in general.

The prospect of changes to land use has become important in recent proposals to grow cotton in northern regions of Australia. In simplistic terms, the solution to lepidopteran (moth) pests offered by Bt cotton could allow cotton to be economically and environmentally viable in northern regions. Consideration of changes to land-use patterns appears to have occurred in a somewhat reactionary way, rather than pre-emptive. LWA might look to support research that would broadly model expected cropping distribution patterns, or indeed changes to livestock type, numbers and distribution, should certain obstacles to production be overcome by GM technology.

Options by section

Genetically modified micro-organisms and viruses

Options for LWA to research here would include efforts to improve our knowledge of the ecological interactions of micro-organisms:

- Become involved in the risk-assessment process. Support research aimed at developing tools that could be used to monitor perturbations in microbial ecology following the introduction of genetically modified micro-organisms and to monitor the spread and persistence of genetically modified organisms in the environment.
- Support research on GMOs that may potentially benefit the Australian environment (eg. for bioremediation). Development in this area would improve our basis for whether or not Australia permits release of genetically modified organisms.

Plant GMOs

Many of the crop protection strategies used in Australian cropping systems are for weed control and impact directly on the soil and water resources on which agriculture is based. The current and potential introduction of transgenic herbicide tolerant (THT) and other GM crop varieties is likely to affect how weeds are controlled, either improving the situation or leading to greater weed and environmental problems. However, most of these potentially beneficial and detrimental effects have not been studied in any detail and so provide many options for LWA investment.

For example, what would be the effect of THT crops on herbicide use and environmental pesticide load? Would their widespread use in Australia lead to increasing herbicide resistance in weeds, as reported recently in the USA (*New York Times*, 14 January 2003)? Would THT crop introduction cause problems for weed management such that cultivation may again need to play a significant role? What is the likelihood and what are the potential consequences of outcrossing of transgenes to native plants and weedy relatives in Australia? What would be the effects on the resource base if glyphosate was no longer effective in controlling weeds, as could conceivably occur with the overuse of THT technology? The issue would be particularly pertinent in reduced tillage systems dependent on glyphosate for weed control (Derksen *et al.* 1999). Would the sustainability of conservation farming systems and annual cropping systems in semi-arid regions be jeopardised?

Alternatively, several steps have been proposed to reduce the risks to the resource base from GM crops. Another option for LWA is to commission research to test the effectiveness of such protocols.

Changes to land-use patterns on a large scale might result from the introduction of GMO crops. Although not a GM crop, triazine tolerant canola (TT canola), possesses herbicide tolerance similar to that being developed in GM varieties. This has made the crop particularly easy to manage. Canola area in Australia has increased considerably over the last decade from 107,000 ha (1991–92) to 1,190,000 ha (2002–03) (ABARE 2003) and, although price and other varietal improvements have contributed, it would be reasonable to expect that a considerable amount of this expansion was due to the herbicide tolerance trait. Associated land development and chemical practices will have followed this expansion, as would the chemicals directly associated with any herbicide-tolerant crop. Whether this improves or reduces the long-term net environmental or economic benefit depends of the types of practices replaced by the crop.

Improvements to yield via GM improvements might reduce the area needed world wide for agricultural production. Whether or not this eventuates will depend on worldwide demand, individual growers' choices and Australia's export position. LWA might choose to conduct or instigate broad inquiries/surveys of primary producers with the aim of determining how they might change their cropping patterns if certain types of crops became available via GMO technology.

Animal GMOs

Genetically modified production animals pose little environmental risk, especially if containment can guarantee that feral populations cannot establish.

Research activities on existing feral populations to determine more appropriate control measures would be beneficial both for now and if GMOs are introduced.

As no guidelines exist (Australian or international) for the release of GM arthropods, LWA should continue to monitor progress in this area and be ready to provide comment on possible ecological impact if or when guidelines are drawn.

Genetic modification of aquaculture species in Australia imposes considerable risk because of the propensity for their escape and breeding with native populations. LWA should become involved in policy-making in this area. Some areas of possible research include the use of physiologically modified (as against genetically modified) animals to simulate the effects of the GM animals in ecological trials.

GMO segregation

- An educational program to present a balanced assessment of pros and cons of GMOs to primary producers. This is an urgent need and could be run between a number of relevant funding bodies.
- Research to examine the on-farm advantages and problems associated with GMO effects on farming systems (eg. rotation constraints, seed production changes, storage options).
- Market research to establish acceptability or otherwise of new GMO products (again this could be joint research with other funding bodies).

GMO regulation, product choice and economic issues

LWA could undertake research into:

- determining the risks and benefits of GMOs
- providing a forum or hub for accurate dissemination of information on GMOs and similar technology to the public
- determining consultation requirements for new technology like GMOs.

These processes would include more detailed areas, such as:

- monitoring implementation of legislation
- tracking levels of farmer and general public acceptance of GMOs
- hazard and benefit identification and analysis
- research to quantify processes underlying significant hazards
- incorporation of economic parameters in evaluating future risk
- GMO competitive advantage versus clean-green export image
- support for GM control of animal pests to enhance natural capital
- minimising environmental risk of GMOs.

Public policy

Adopt a clear role of helping inform the policy development process through targeted research and through acting as an independent facilitator of the process of public discourse on GMOs. The latter role in particular would require maintaining a clear degree of independence from all GMO-vested groups, including large government-based entities.

A number of potential strategic functions can be identified within the role of helping inform and develop public policy

- As an independent convenor of forums for public participation and informed stakeholder discourse
- As an independent convenor for stakeholder negotiations
- As a funder of appropriate policy research that falls within the defined R&D mandate of LWA. Such research may have social, economic and scientific dimensions.
- As a funder of R&D that fills knowledge gaps relating to the sustainable natural resource management impacts of GMOs (eg. bioremediation, gene escape risk assessments, biodiversity impacts)
- As a co-funder or broker of research in partnership with other R&D organisations in order to fill knowledge gaps relevant to the LWA mandate

Comment on credibility

All the options presented on research into GMOs must be (and must be seen to be) absolutely objective and independent. Many of Australia's influential organisations in the GMO arena are strongly perceived to have already aligned themselves with sides of the GMO debate via large investment in the future of GMOs or even if simply by public misconception of their charter. In our previous experience into GMO trials, before the release of a GMO, participants can become strongly oriented towards the development of an acceptable product, leaving the research into the potential harm or even overall benefits to non-commercial interests. To balance the approach, it is imperative that all interests are represented in a research portfolio, including health, environment, society and production to balance the approach. In our view there exists the potential role for organisations such as LWA to be the 'honest brokers' in such matters, commissioning research from organisations like universities with similar scope and independence.

Introduction

Scope of this report

Over the last decade or so, biotechnology has advanced to a level where it is generally feasible to make particular changes to the genetic code, and therefore the expressed characteristics of living organisms. The product of such a change is called a transgenic or genetically modified organism (GMO).

GMOs are being developed in many countries as possible improvements to conventional biologically based products. The scope of changes possible, or rapidly becoming so, is extremely broad. There have been single-gene changes in crop species to protect them from insect pests or to allow the general spread of a herbicide which does not harm the crop, to multiple-gene changes (but still with relatively few genes) to produce a pharmaceutical in a plant or udder of a animal, or even to introduce a genetically based strategy to eradicate an invasive pest species.

It could reasonably be proposed that such broadly applicable genetic techniques are capable of rapid or significant changes to the resource base of key biologically founded activities, including agriculture and aquaculture, medicine, hygiene and health, food production and processing, biochemical production, pest control, biological military uses, eco-tourism, and bioremediation. Such changes could broadly impact on biological resource management.

This consultancy had a clear directive to explore the grounds for such an expectation, and highlight areas that could be studied to better understand or implement these developments in biotechnology on Australia's resource base. In consultation with Land & Water Australia (LWA), the terms of reference were confined to GMOs rather than biotechnology in general.

Reflecting the central aim of LWA to provide leadership and policy guidance on Australia's natural resource use at a landscape scale, we sought to address the following question. "How might genetically modified organisms influence the resource management interests of LWA and how might LWA delegate its research efforts to best address such changes?" Therefore, each section of the report, written by experts in the particular biological field, covers several examples of genetic engineering and options within those disciplines for strategic research.

Although GMO technologies have broad similarities as a biochemical class of activity, the influence that any GMO might have on LWA interests will depend on the particular organism and modification in question. Therefore, this report does not provide a list of recommendations but rather a set of options for LWA managers to consider in the light of the examples of GMO activities and possible impacts on resources that we discuss.

The mission of Land & Water Australia is "to provide leadership in generating knowledge, informing debate and inspiring innovation and action in sustainable national resource management" (LWA 2001). One corporate value is to promote the principles of national strategies relating to both the environment and to economic development. The *Primary Industries and Energy Research and Development Act 1989* (the PIERD Act), under which LWA operates, has as its core aim to increase both environmental and social benefits. Enacting clauses allow a wide range of "R&D for the productive and sustainable management of the land, water and vegetative resources that underpin Australia's primary industries and regional communities", LWA defines rural landscape to include "arenas of production sustaining significant primary industry as well as the bulk of Australia's natural capital".

The scope of this report is within the wide charter of LWA. The use of beneficial GMOs for agriculture, human food, and the enhancement of our natural capital, by better control of pests and diseases, is a major objective for this new technology. However, there are potential disadvantages. We have been asked to take a broad view, by incorporating those major elements and issues, which determine net benefits. Key issues are the effectiveness of widely ranging regulatory legislation for risk minimisation, public acceptance and choice of food products, ownership of seed, markets, margins and other economic parameters. There can be substantial interplay of these issues as they reflect tensions between agriculture, social benefit and sustaining our natural capital. From this structure, we aim to distil current and emerging trends that warrant monitoring and possibly R&D investment by LWA.

Background on GMOs

Over the centuries, many characteristics of livestock, plants, and micro-organisms have been altered by ‘conventional’ methods of selective breeding. This has been limited to the concentration of desirable characters into individuals within groups which can be ‘naturally’ mated. This limited the pool of traits available to any breeding program to those within a species or those that could form hybrids between species. Biotechnology has reached a stage where, although currently using relatively crude, rudimentary genetic methods (agrobacterium and ballistic gene insertion) it can modify the genetic make-up of an organism from a much wider range, importantly beyond those that normally mate or hybridise. This represents an enormous increase in the pool of characteristics that might be chosen to improve a biological product.

A wide spectrum of beliefs about the likelihood of net benefit from GMO technology exists. Many consider this has huge net benefits to production, while others see it as cause for serious concern, because perhaps we do not understand the potential ramifications well enough, or consider it to be ‘meddling with nature’.

Genetically modified micro-organisms were first put into commercial use in 1985. Since then, several medical and agricultural products have been produced by colonies of GM micro-organisms in stainless steel vats under factory-like conditions. These applications have received little criticism compared with more recent concerns over intentions to genetically modify animals and plants, because the latter will generally involve releases into the environment at a much larger scale, bringing implications of disturbance to naturally created or evolving ecosystems.

This report does not attempt to deliver a common message regarding the likelihood of net benefits or otherwise of GMOs. Each contributor has discussed their own discipline area and, in this way, the report probably best reflects the inconclusive state of play on current attitudes to GMO releases. It appears that each GMO needs to be addressed on a case-by-case basis to determine the merits of taking any associated risks, if introductions are to be pursued.

A more detailed description of the introduction and adoption of GM cotton is presented as a case study at the end of this report. It is the only broadacre example of a GMO crop in general production in Australia. After several years of use it demonstrates net benefits compared with recent conventional cotton production systems. The example also indicates the level of research and experience in a particular case that is needed to determine whether or not a GMO will have a net benefit, whether social, economic and/or environmental. As an early and single example, this case study is not intended to imply that all GMOs will necessarily offer such benefits. For example, GM canola, another GM crop, presents considerably different risks and so might be considered a less likely candidate for net overall benefit. Regulation based on excellent scientific interpretation of the agronomic, environmental and social risks and benefits is required.

Some people are highly optimistic that net benefits will be realised from the development and release of GMOs. Delivering the 8th Annual Lecture to the British Ecological Society (1999), J.E. Beringer asked

> … why are we so lacking in imagination that we can only see perceived problems and few benefits? Advantages [of GMOs] will outweigh disadvantages because we have a technology that allows the precise modification of species and, as our understanding of genes and gene expression expands, will enable almost any imaginable change to be made to our crops and livestock. However, the realization [of these benefits], without continued concerns about environmental harm, will depend upon a much better understanding of factors that affect the ability of released plants and animals to survive and to spread in the environment [in a damaging way].

On the other hand, some scientists remain concerned that our current knowledge of genetic interactions does not reflect the optimism or precision implied by the foregoing quote. For example, Schubert’s (2002) commentary in the Nature Biotechnology journal considers that the introduction of GMOs requires thorough toxicological testing akin to that carried out before drug releases. He considers that insufficient attention is being given to the possibility that the same gene introduced to different cells could produce different protein molecules, change overall gene expression, and that biochemical pathways could interact to produce novel molecules. He considers that there is no *a priori* way of knowing that this would not lead to the biosynthesis of molecules which are toxic, allogenic or carcinogenic. The highest priority is to closely control the introduction of GMOs so that enthusiasm, either generated by economic or academic interests does not unbalance the evaluations of risks and benefits in this innovative field.

In general, the case for optimism is supported by factors such as the 8–10 year time-span between initiation and release of a GMO. This provides time for additional knowledge to be gained, for regulatory protocols to be refined, for public confidence and acceptance to grow, and for markets and competitive outcomes to develop. Even the inevitable high failure rate in individual GMO projects will sometimes provide valuable knowledge to refine GM technology and reduce future social and environmental risks. Some of the GM projects reported here directly address solutions for environmental problems. Others demand the development and application of more rigorous testing of GMOs before being cleared for release.

The charter of LWA (below) uniquely covers the need to reduce the tension that already exists between agricultural innovation, exemplified by GM products, and those opposed to GMO technology.

The GMO debate – 'saviour or saboteur?'

Few technologies have generated debate so intense as that on the benefits and risks of GMOs. Supporters of the technology insist that GMOs must be the 'way forward' for improving food supply and its nutritional quality and reducing the environmental impact of conventional agriculture, so that global agriculture can produce the food and fibre that is needed to meet expanding human needs. Critics passionately reply that this new technology threatens the safety of human food, enhances risks to the environment and will impose dependence of small farmers on the technology developed and owned by large multinational corporations.

The scope of the debate is wider than the development and use of GMOs. For many people, this new technology presents a quantum leap in human intervention in the natural world. For some, the leap is a positive move to meeting human needs and sustaining the global environment. Ridley (1999) puts forward a strong case for optimism, based on human record for successful innovation. Equally, we are compelled to minimise risk in the application of powerful and intrusive technology, by insisting on mandatory and rigorous testing protocols. Science and technology are fallible, so that the case for optimism must be balanced by the need for caution.

GMO release and the precautionary principle

Under Australia's *Gene Technology Act 2000* there is no exemption for any release of a GMO into the environment and this is supported by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The Office of the Gene Technology Regulator (OGTR) has noted that this non-exemption policy reflects a continuation of the approach under the voluntary Genetic Manipulation Advisory Committee (GMAC) system that formerly applied. Currently, it would appear that OGTR has not yet comprehensively reviewed the GMAC rules for pre-release testing. In the plant GMO section that follows, we will provide examples of field-testing protocols that are in current use and we will outline the need to tighten these to reduce the risk and consequence of gene escape. We suggest that this is an area of concern to LWA.

The *precautionary principle* is often cited as a somewhat definitive basis upon which to judge whether or not an innovative step should be taken. Unfortunately, it remains essentially subjective, doing little more than reflecting the attitude to risk expressed by those using it. Few would argue against a need for caution and prudent regulation to reduce human and environmental risk when implementing new technologies, but the range of interpretations possible allows an extreme application of the precautionary principle that would never allow any risk to be taken. This ignores the risk of doing nothing.

The debate on how best to introduce new technology might be better served by revolving around the levels of constraint that should be placed on the application of any innovative technology. History shows that innovation in agriculture has provided a solution without which we might have been faced with a stark choice between famine, population control or the cultivation of all wild land (Ridley 1999).

Genetically modified micro-organisms and viruses

Perspective

Genetically modified micro-organisms have been used for 20 years in the production of pharmaceuticals (eg. human insulin, bovine somatotrophin), vaccines (eg. the hepatitis B vaccine) and enzymes (eg. rennet for the production of cheese). However, none of these applications involve the *release* of genetically modified micro-organisms or viruses. In this section, applications that involve the release of genetically modified micro-organisms or viruses into the environment will be considered.

Release of micro-organisms and viruses poses special risk-assessment problems:

- Monitoring the spread of the micro-organisms or viruses is difficult.
- The effect of the micro-organisms or viruses on non-target species can be difficult to evaluate.
- Large numbers of micro-organisms have to be released for many applications.
- Some micro-organisms can multiply rapidly.
- Horizontal gene transfer is (naturally!) widespread in bacteria. If the genes that are introduced into the micro-organism are on mobile genetic elements such as plasmids, transposable elements or bacteriophage, there is a risk of transfer to other bacterial species. The risk of horizontal gene transfer can be addressed through the design of safer systems for the construction of genetically modified microorganisms (Davison 2002).

Some of these risks are not peculiar to the release of a genetically modified micro-organism or virus.

Some of the potential applications of gene technology that involve the release of genetically modified micro-organisms or viruses are listed below. In a small number of cases, release of genetically modified micro-organisms has already received approval, in Australia or overseas.

Examples of genetically modified micro-organisms

Control of frost injury to plants

The US Environmental Protection Agency granted the first approval for the release of a genetically modified bacterium in 1985. The bacterium was *Pseudomonas syringae* which had been altered to prevent the production of a protein that promotes the formation of ice crystals on plants. The genetically modified bacteria did not contain any foreign DNA and after 18 days could not be detected in the soil (Committee on Scientific Evaluation of the Introduction of Genetically Modified Microorganisms and Plants into the Environment 1989). The bacterium is normally found in the environment. A potential risk might be the loss of normally occurring frost injury in non-target plants, especially if the altered bacterium could spread. If frost is an important limiting factor in the propagation of non-target plants, the spread of ice-minus bacteria could have an environmental impact.

Control of plant diseases

The first genetically modified micro-organism approved for commercial release in Australia (and overseas) is *Agrobacterium radiobacter* var K1026 (NOGALL), a strain developed at the Waite Agricultural Research Institute, University of Adelaide. *Agrobacterium radiobacter* is used in the biological control of crown gall, a bacterial disease of stone fruits, nut trees and roses. Unmodified *A. radiobacter* produces a natural antibiotic that is crucial to its biocontrol activity. The genetic modification prevents the transfer of genes involved in the production of the antibiotic to other soil bacteria and thus prevents immunity to the biocontrol agent. The modified bacterium does not contain any foreign DNA.

Other potential biocontrol agents are under development (eg. modification of *Pseudomonas* species for the control of fungal diseases (Deleij *et al.* 1995)). The use of these genetically modified micro-organisms has the potential to reduce use of chemicals for the control of bacterial and fungal diseases. If the engineered bacteria do not persist in the environment, the effect on non-target species would be no greater than when chemical methods are used. However, if the genetically modified micro-organisms do persist, the environmental consequences would be more difficult to predict.

Control of insect pests

A number of different strategies involving use of genetically modified bacteria and viruses to control insect pests are under investigation. Some of these, such as *Bacillus thuringiensis* (Bt), involve expression of microbial genes by GMO plants, and are discussed further in that section of this report.

Another area of research interest is the genetic modification of baculoviruses — viruses that infect insects (Hails 2001). Though baculovirus infection is usually lethal, their use as biocontrol agents has been limited due to the length of time it takes to kill the insect. Genes that encode various insect toxins (eg. Bt toxins) could be inserted into baculoviruses to make them more effective as biocontrol agents.

As for the control of plant diseases, the use of these genetically modified micro-organisms and viruses has the potential to reduce use of insecticides, with substantial environmental benefits. If the engineered micro-organisms and viruses do not persist in the environment or are specific to an introduced pest species, the effect on non-target species would be no greater than when chemical methods are used. However, if the genetically modified micro-organisms do persist and/or are non-specific the environmental consequences would be more difficult to predict.

Modification of plant-associated microbes

Bacteria that have a beneficial effect on plant growth (eg. nitrogen-fixing bacteria and bacteria that produce plant hormones) are potential targets for genetic modification. In 1997, the US Environmental Protection Agency approved the commercial release of a genetically modified *Rhizobium melitoli* (Dormal PLUS™), which contains extra copies of two genes that enhance nitrogen fixation (Urbana Laboratories, <www.urbana-labs.com/dormalplus.htm>). The producers of Dormal PLUS™ claim that lucerne seed inoculated with Dormal PLUS™ has a yield increase of 6% over that inoculated with unmodified *Rhizobium*. Many researchers have investigated the genes involved in colonisation of plant roots, with the aim of engineering nitrogen-fixing bacteria which can colonise non-leguminous plants. Increased productivity of crop plants could potentially reduce land-clearing. However, if modified bacteria were able to colonise non-target plants there would be serious concerns about the possible environmental impact.

Control of feral animals

CSIRO is investigating the use of genetically engineered ‘immunocontraceptive’ viral vaccines for the control or mice, rabbits and foxes (Seamark 2001). The control of introduced pest species has obvious benefits for the environment. For such a strategy to be accepted, the virus must be absolutely specific to the host target (Williams 2002).

Modification of rumen micro-organisms

In ruminants, a high proportion of energy intake is lost due to inefficient digestion of cellulose. Modification of rumen bacteria to improve digestion of cellulose is one focus of research. The strategies include introducing genes for cellulolytic enzymes which function at low pH (Wallace 1994) and genes which allow rumen bacteria to degrade xylose and pectins (Varga and Kolver 1997). The use of genetically modified rumen micro-organisms could have an environmental impact if the increased feed efficiency of ruminants led to increased stocking rates and greater use of marginal lands. If the modified bacteria could colonise native animals, it might impact on their feed efficiency and could, as a consequence, lead to enhanced reproductive capabilities. However, the trials to date suggest that genetically modified micro-organisms compete so poorly in the rumen that their potential usefulness is questionable.

Vaccines

Genetically modified viruses and bacteria are being developed for the prevention of human and animal disease. Some examples include the development of a recombinant vaccinia virus–rabies vaccine (Aguilar-Setien *et al.* 2002) and a recombinant porcine adenovirus swine fever virus vaccine (Hammond *et al.* 2000). The safety of such vaccines would have to be thoroughly evaluated before release, especially if vaccinated individuals will shed infectious virus or bacteria.

Bioremediation

The use of micro-organisms for chemical decontamination has been called bioremediation. Many micro-organisms are naturally able to transform toxic chemicals into harmless products. The aim of genetic engineering research is to increase the efficiency of the chemical transformation process or increase the range of toxic chemicals which are degraded. For example, the US Natural and Accelerated Bioremediation Research (NABIR) program is aimed at the development of bioremediation techniques for the removal of radionuclides and metals from the 7000 US Department of Energy sites where subsurface contamination, generated during 50 years of research, development, and testing of nuclear materials, has been detected (<www.lbl.gov/NABIR/index.html>).

Soil microbes

In this section, the specific roles of soil GMOs for mediating processes that enhance crop yields and for degrading hazardous environmental pollutants are reviewed, along with the valuable role that this technology can play in increasing our understanding of the structure, processes and ecology of soil microbial communities (Metting 1992). Many of the methods developed for detecting GMOs are now being used to monitor the survival of soil microbes, and to identify their niches and roles in the complex community of the soil food-web.

The fate of microbial inocula introduced into the soil environment is less predictable than the introduction of plants. For microbial introductions to prevail, they must be able to compete successfully with highly diverse indigenous populations that are well adapted to soil type, and to survive under stress and subject to a wide range of natural predatory soil fauna. Microorganisms that function within a symbiotic relationship with plants would appear to be better subjects for engineering and introduction than free-living, self supporting GMOs. One early example of symbiont success (also mentioned above) was an engineered strain of *Rhizobium meliloti* that improved nitrogen fixation and growth of lucerne in field tests (Ezzel 1987).

The eukaryotic fungi differ both anatomically and physiologically from the prokaryotic bacteria. Nevertheless, as heterotrophs they can effectively combine in functionally important soil processes such as the decomposition of organic detritus. Interspecific competition within each phylum is strong. Non-engineered fungal species have been used as effective control agents of soil-borne plant diseases since the 1970s. A cross-phylum example has been the antagonistic colonisation of the take-all fungus in wheat by rod-shaped bacteria in rhizosphere soil. The engineering of existing species of both soil fungi and bacteria might be able to promote disease control, but there is a general view that the prokaryotes present better opportunities for genetic manipulation.

GMOs can enter the soil in a variety of ways, including wash-down of microbes applied as foliar treatments for crops. Another external source could be engineered chemo-autotrophs (eg. *Thiobacillus*), which are used in the mining industry to accelerate the leaching of metal from ores. However, specialised microbes survive in the competitive soil environment and it is also unlikely that the planned introduction of GMOs will have a significant effect on non-target wild strains and their essential servicing functions. Only one or a few inserted genes among thousands would be involved and, in any case, gene interchange is a common phenomenon in the soil microbial community. However, because of their novelty, there is need to evaluate risks associated with their release into the environment and to assess their survival and effectiveness in expressing their designed function.

GMOs for soil bioremediation and study of community function

Within the well-adapted soil community there is substantial transfer of genes, by conjugation (transfer of bacterial plasmids — chromosomal free DNA), transduction (bacteriophage mediated) and transformation (uptake and expression of extra-cellular DNA). This lability presents a problem for the introduction of soil GMOs, as the dispersal of their genes will also be fostered by interactions with other soil biota as well, and by the physico-chemical environment eg. water movement. Detection and monitoring of GMOs require a wide range of techniques for detecting single cells *in situ*, assaying their activity and monitoring their dispersion. A marker system based on insertion of the *lux* gene (from marine organisms) into selected soil inocula, has been effective, because soil provides little background luminescence. The *lux* gene and other insertions are replacing the earlier and publicly sensitive use of antibiotic resistance markers. Hot spots of antibiotic resistance genes have been identified in all soil environments. It has been recommended that the use of genes encoding resistance to all clinically relevant antibiotics should be avoided.

The fact that only a small proportion of bacteria is readily accessible by standard culturing techniques, and bacterial cells lose their ability to grow on solid media after exposure to environmental stress, severely complicates assessment of their environmental fate. However, there has been rapid progress in developing new tools and techniques to fill the void. Phylogenetic identification and classification of bacterial and fungal hosts is critical for safety evaluation. The use of 16S rDNA fragments, amplified from directly extracted nucleic acid genes as a molecular marker, is now an established and successful method for determining phylogenetic relationships, and sensitive and highly effective software for assigning sequences to a ‘genetic tree’ is a major achievement. Also, combining advanced microscopic technique with either reporter genes or fluorescing probes, has facilitated *in situ* analysis of microbes.

The continuing development and application of these new techniques has improved our ability to define and to analyse the structure and functional diversity of terrestrial and aquatic microbial communities.

Options for LWA suggested by GMO examples of micro-organisms

- Become involved in the risk-assessment process. Support research aimed at developing tools that could be used to monitor perturbations in microbial ecology following the introduction of genetically modified micro-organisms and to monitor the spread and persistence of genetically modified organisms in the environment.
- Support research on GMOs that may potentially benefit the Australian environment (eg. for bioremediation). Development in this area would improve our basis for assessment of whether or not Australia should permit release of genetically modified organisms.

Plant GMOs

Perspective

Random genetic changes occur spontaneously in wild plant species. People have been engaged for centuries in plant breeding using selective crossing to improve a beneficial trait, followed by back-crossing to a parent to eliminate unwanted genes. Genetic engineering can target desirable traits more precisely, by transferring specified genetic material into plant cells. By exercising this greater control over the process, improved plant performance can be achieved more rapidly. The success rate for engineered plants is continually being improved by growing access to genomic libraries and by newer techniques for transferring genes into unrelated species to express novel traits not enabled by traditional breeding techniques. Laboratory-based transfer may involve cellular uptake of the new DNA using a carrier or by the fusion of whole cells. Tissue culture is then used to encourage the growth of modified cells to produce a fully functional plant. A simple example of the stages and methods used in the production of GM plants is given in Appendix 2. GMO success depends on the choice of genes for transfer, their expression and on the interaction between inserted genes and the cellular environment in which they reside.

Wheat has been the staple grain crop in Australia since the 1860s, with management and genetics being the drivers of yield changes. Between 1860 to 1900, yield declined from 1 to 0.5 tonnes per ha and this can be attributed to nutrient exhaustion and to mismatch between imported varieties and the Australian climate. Over the next 50 years, with combined use of superphosphate, fallowing, new varieties, and movement of cropping to the slopes and plains, yield recovered to a level of 1 tonne per ha. Between 1950 and 1980, legume nitrogen and rotations, mechanisation, and the introduction of semi-dwarf strains increased production to 1.4 tonnes per ha. By 2000, yield had increased to 1.8 tonnes per ha and this was substantially due to the increasing use of leguminous grain crops in the rotation (Angus *et al.* 2001). Such enhanced cropping diversity in the farming enterprise can provide improved soil fertility and financial stability. It also provides a greater market for new GM cultivars, and it is likely that further diversification will be provided by subsidiary GM varieties, wherein the chemical nature of the food provided will produce a range of health-enhancing products. Examples are improved nutritional balance, polyunsaturated fats, reduced allergens and vitamin supplementation.

GM plant products and research

The Plant Biotechnology Centre (Agriculture Victoria) has a novel project to enable 'on–off' switching of the lignin gene in pasture grasses. Success could either increase the 'toughness' of grasses under recreational use or increase the 'softness' of grasses by reducing lignin content, which contributes to a low nutritive value for ruminants.

The Plant Molecular Biology and Technology Unit (University of Melbourne) has developed a hypo-allergenic rye-grass, and has a project to develop a vaccine for control of grass pollen induced hay fever. It also has reported a successful tissue culture system for propagating macadamia — the sole Australian native species to be commercialised as a crop.

GM plant research protocols — an example

The CRC for Molecular Plant Biology has detailed its breeding strategies, protocols and time lines (CRCMPB 2001). These exemplify current Australian planning and practice. The following steps are involved:

Pre-product planning:

- Assess status of intellectual property (IP) and 'freedom-to-operate' (Patents).
- Preliminary tests for potential allergens, toxicities and other anti-nutritional effects including undesirable protein modifications.
- Devise a strategy for a full evaluation of food safety.

First-stage product development

- Optimise gene constructs.

- Modify regulatory systems and coding sequences to produce desired expression level and its temporal and spatial expression pattern.
- Identify best transgenic lines based on sufficient events to base evaluation.
- Insertion events, followed by stability evaluation over a minimum of three generations.

Field testing

- Test the agronomic performance of chosen lines in multiple field trials.
- Segregation-based removal of the first-stage selectable markers.
- Development of an effective marker for following the transgene in breeding material.
- Multiple field trials to determine the quality of seed from the GM plant.

Plant (and other) GMO release to the environment

The Ecological Society of America (ESA) is a prestigious body representing 8000 ecological scientists. In a recent policy statement (26 March 2002), it supports the judicious use of biotechnology. The following are extracts from this statement.

> GMOs have the potential to play a role in sustainable agriculture, forestry, aquaculture and bioremediation. However, both deliberate and inadvertent releases of GMOs into the environment could have negative ecological impacts under certain circumstances. Engineered organisms that may pose some risk and hence require scrutiny include cases where there is uncertainty about environmental effects. These could be cases where:
>
> - There is little prior experience with the organismal trait and host combination
> - An organism may persist without human intervention
> - A genetic exchange is possible between a transformed organism and other organisms
> - The trait confers an advantage to the GMO over native species in a given environment
> - An assessment of environmental risk is needed to minimize the likelihood of negative ecological effects such as:
> - Creating new and more vigorous pests and pathogens
> - Exacerbating the effects of existing pests through hybridization with related transgenic plants or animals
> - Harm to non-target species, such as soil organisms, non-pest insects, birds and other animals; and
> - Irreparable loss or change in species diversity and genetic diversity within species.

Given that losses in diversity needed to be clearly associated with introduction of GMOs and not other aspects of management, then these categories present a reasoned assessment of risks to the environment, which need scrutiny in any determination of net benefit.

The following protocol, used by CSIRO in January 2002, provides an example of the controls applied in Australia for minimising the risk of gene escape from GM plants. A range of controls can include the following:

The inclusion of buffer crops to act as pollen traps. Some species have a low tendency to disperse and only small buffer zones may be required. Crops with lighter weight pollen, easily wind dispersed, may need either larger buffer zones, or pollen containment by placing polythene bags over the flowers before maturity. Crop management practices, such as pruning can minimise flower formation. Where flowering and seed production are not required, plants can be harvested before flowering so that seed and pollen are not produced.

Animal and bird proofing and/or insect minimisation. Seeds can be harvested by hand to avoid seed dispersion. Postharvest clean-up procedures include the incorporation of plant residues into the soil, followed by at least a two-year monitoring period to check whether the environment may have been contaminated. Buffer plants are usually destroyed after the trial. At times, they are examined first to determine the extent of ‘gene flow’ from the trial plants to the buffer plants.

Deleterious gene escape from GM plants has already occurred. A recent international case, occurred this year in Canada and involved escape through pollen movement. Cross-pollination from GM canola varieties led to triple herbicide resistance among canola varieties, which should serve as a warning to producers to use their new herbicide-resistant varieties wisely according to the guidelines.

In Australia, GM canola (produced by Monsanto and Aventis) trials were conducted in Tasmania from 1996–99 and for a further three years to evaluate environmental persistence. The trials from 1996–99 reached seed-production scale, with a voluntary protocol provided by GMAC. This included advice to minimise the risk of trans-genes and gene flow from the trials to other crops and to weeds of the Brassica genus. In the post-trial three-year period, the then interim office of the gene technology regulator (IOGTR) identified non-compliance, and ordered remedial action and an extension to the trial period. Failure to adhere to the advised protocols was first detected in February 2001. Non-compliance was found at 21 of the 57 sites. Each of these sites was deemed non-compliant based on the discovery of one or more canola volunteer plants that had flowered or set seed or on which the seed pods had shattered on or close to a site within three years of the crop.

Insect-resistant GM plants

Perspective

Breeding plants which resist insects is not new. Before World War II, commonly used crop varieties had varying levels of resistance to the pests they had co-evolved with. Exploitation of this resistance, either deliberately or unconsciously, was a major component of insect pest management strategies of the time. Some successes had been achieved in breeding for pest resistance by conventional means.

After World War II, with the widespread adoption of cheap and effective synthetic organic insecticides such as DDT and the organophosphates, breeding resistant varieties received less attention. Indeed, existing sources of resistance were lost in some cases. The case of gossypol (and related terpenoids) in cotton is instructive. These secondary compounds provide resistance to most chewing insects. Wild *Gossypium* species, which contain them in abundance, are little affected by the pests of cultivated cotton. However, gossypol is toxic to monogastric animals, and if cottonseed meal is used for pigs and poultry it must be heated, leading to a loss of protein quality. Gossypol was therefore deliberately bred out of American cotton varieties in the 1950s, and these varieties went on to form the basis of elite cotton lines in many countries around the world. High gossypol lines now have poor yield, poor quality and undesirable agronomic characteristics compared with current elite varieties.

Even if insect-resistance traits are not deliberately selected against, as in the case of gossypol, they can be accidentally lost during the course of breeding if yield and quality are the primary selection criteria. Variety trials have commonly been conducted under intensive insecticide coverage, and in these circumstances the most favoured genotypes are likely to be those which devote more of their resources to yield, perhaps at the expense of secondary chemicals which provide resistance to pests. This may explain why in soybeans, for example, insect-resistant varieties have 10–40% lower yields than susceptible ones, in the absence of pests. There has been no deliberate selection against insect resistance in soybeans, in contrast to the gossypol case in cotton.

The legacy of this historical trend of accidental or deliberate loss of resistance is that, within plant species, sources of resistance tend to be in older and poorer varieties. This makes breeding for insect resistance (by conventional means) a tedious and costly process. The process has nevertheless resulted in some significant successes for Australian agriculture in the last three or four decades. Major pests such as the sorghum midge, *Contarinia sorghicola*, and the spotted alfalfa aphid, *Therioaphis trifolii maculata*, have been brought under control by breeding or importing resistant varieties. Integrated pest management programs which have a resistant variety as a major component are usually stable and strong.

The role of biotechnology in breeding varieties resistant to insects

Breeding for insect resistance using conventional methods of repeated backcrossing and selection will continue to have a role in insect pest management for Australian agriculture. In cotton, for example, there are many morphological and biochemical traits which confer resistance to many significant pests, and considerable variation among current varieties in resistance to these pests. Resistance incorporated by conventional breeding is frequently polygenic, and therefore less susceptible to resistance-breaking pest biotypes.

Nevertheless, biotechnology, in the form of genetic manipulation, has special advantages for developing pest-resistant varieties. It offers a quick way of incorporating resistance into current elite varieties, avoiding tedious backcrossing and selection. Given the situation outlined previously, leading to the concentration of resistance traits in poor varieties, this is a considerable advantage. The downside of this is that the traits most suitable for incorporation using current biotechnology are simple monogenic ones. This leaves them vulnerable to resistance-breaking biotypes, unless they are carefully managed.

The other major advantage of biotechnology over conventional breeding is that the store of resistance traits is not limited to the gene pool of the plant species. Genes from other higher plants, or from other organisms entirely, can be exploited. This greatly expands the potential for breeding resistant varieties.

Bacillus thuringiensis (Bt)

Bacillus thuringiensis (Bt) is a common spore-forming soil bacterium that produces a crystalline protein toxin (known as a δ endotoxin) when it sporulates. There are many strains of Bt and many variants of the Bt toxin. A genetically modified strain that produces several different toxins has been created. The toxins in this strain are also more resistant to ultra-violet light. Because the strain does not produce viable spores it cannot compete with naturally occurring Bt (Sanchis *et al.* 1999). Other researchers have investigated increasing the production of toxins in Bt to reduce production costs and transferring Bt toxin genes to other bacteria (eg. to soil bacteria to provide control of insects that attack plant roots).

Bt toxins are grouped into families designated Cry1, Cry2 etc. There are currently over 130 Bt toxins known, and this total is probably conservative because many recent discoveries are commercial-in-confidence. Figure 1 shows a genetic distance map for many of the known toxins. Each family tends to be specific to a given order of insects. For example, Cry1 toxins have most activity on Lepidoptera. This is because they bind to specific sites on the gut epithelium, leading to rupture of the cells and invasion of the insect haemocoel by secondary pathogens. This specificity is valuable in insect pest management, because it leaves beneficial insects (predators and pathogens) relatively unaffected.

Bt has long been used in organic and conventional agriculture, in the form of foliar biopesticides containing Cry1 toxins and spores of *Bacillus thuringiensis* var. *kurstaki*. There were 182 Bt products registered by the United States EPA in 1955 (Shelton *et al.* 2002), though they never constituted more than a few percent of the total sales of insecticides. In Australia, some of these formulations have been widely used against *Helicoverpa* spp. on cotton. In this role they have been limited by their slower killing speed compared with many conventional pesticides, but their advantage has been ‘softness’ for natural enemies. Current cotton use is limited by restrictions imposed to avoid the development of resistance to Bt cotton. Other uses of foliar Bt have included application to brassicaceous vegetables against cabbage moth, *Plutella xylostella*, and cabbage white butterfly, *Pieris rapae*. It is also widely used in home gardens against many lepidopteran pests.

Commercial biotechnology became involved with Bt in 1990 when Monsanto patented a gene encoding for a protein almost identical to Cry1Ac, and subsequently introduced it into US cotton varieties under the trade name Bollgard®. It was subsequently introduced to Australian varieties by CSIRO and Deltapine as Ingard®, and is now in elite varieties produced by the two major cotton-seed companies, Cotton Seed Distributors and Deltapine. Other Bt genes encoding proteins similar to Cry 2Aa, Cry2Ab (for *Helicoverpa* spp. in cotton), Cry 1Ab and Cry9C (for European corn borer and other lepidopteran pests in corn) and Cry 3A (for Colorado beetles in potato) have since been exploited. In 2000, Bt varieties of maize constituted 19% of the total acreage in the USA. Bt cotton comprised 39% of the total acreage, ranging from 67% in Mississippi to 3% in California, primarily reflecting the relative importance of lepidopteran pests in these regions. Adoption of Bt potatoes has been low, at only about 3% of the crop. In Australia, Bt cotton is the only pest-protected GM crop that has been released commercially. It comprises 30% of the total acreage, at which level it is currently capped for the purposes of resistance management. We consider Australian experience with Bt cotton in some detail later in this report.

Beyond Bt – other insecticidal genes

Most insect-protected crops released around the world have used genes from Bt, and there are still many genes from this source which remain to be exploited (Fig. 1). The specificity of Bt toxins, however, means that there is a limited repertoire for each pest. For *Helicoverpa armigera*, for example, only four toxins (Cry1Ac, Cry1Ab, Cry2Aa and Cry2Ab) are effective (Akhurst 2002). However, there is another class of insecticidal proteins in *Bacillus thuringiensis*, the Vips (vegetative insecticidal proteins), which are found in vegetative cells of *B. thuringiensis* (and other *Bacillus* species), as opposed to spores. It is likely that these will prove to be a diverse and potentially useful category of toxins for genetic manipulation, but their effects on non-target organisms remain to be clarified.

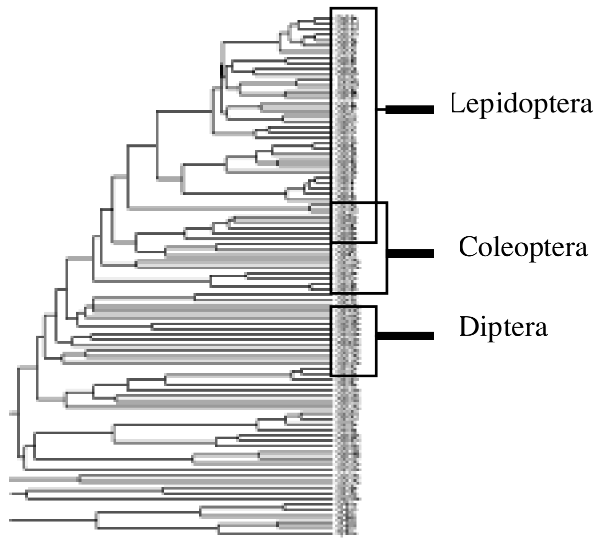

Fig. 1. Taxonomy of Bt toxins (Crickmore *et al.* 1998)

There are several alternative sources of resistance, mostly derived from plant genes (Gatehouse 1998). Lectins, especially those expressed by the GNA (*Galanthus nivalis* agglutinin) gene from snowdrops, have long been considered as potential candidates for genetically engineered plants. There are, however, no commercial plant varieties with this GM. Lectins have undesirable effects on mammals and other non-target organisms, and are unlikely to obtain approval from OGTR in Australia.

Proteinase inhibitors, especially the trypsin inhibitor from cowpeas, are also long-standing candidates for genetic manipulation. Many plants have been transformed with the cowpea trypsin inhibitor gene, but there are few commercial releases (and none in Australia). A small percentage of the large area of Bt cotton in China is made up of varieties which also express cowpea trypsin inhibitor (Shelton *et al.* 2002). The problem with proteinases has been that the target insects readily adapt to them through increased production of the protein digesting enzymes. This is a form of induced tolerance rather than genetically selected resistance. However, potential remains for exploitation of these genes. In Australia, Hexima Ltd, a joint venture between the University of Melbourne and Pivot Ltd, an Australian agricultural company, has patented a gene for a proteinase inhibitor derived from wild tobacco, and is working on modifications to its structure for potential use against insect pests in cotton and other crops.

Other genes that target selective features of insect metabolism include chitinases, which affect chitin, the primary component of the insect exoskeleton material, as well as cholesterol oxidases and alpha-amylase inhibitors. Further plant defence chemicals for which the genes have been identified and which could be incorporated in transgenic varieties include the drimanes, terpenoids which have antifeedant actions, especially on aphids, and the cyclic hydroxamic acid, DIMBOA, which confers resistance to the European corn borer in maize (Gatehouse 1998).

The *H. armigera* stunt virus is a very small RNA virus particle specific to *H. armigera*, which can be incorporated in the genome of cotton (Hanzlik *et al.* 1999), and may be useful in future GM varieties. However, current varieties with this transformation have not given sufficiently high expression to be useful.

Possible issues for Land & Water Australia

The only insect-resistant transgenic crop released commercially in Australia, Bt cotton, would appear to be an almost unqualified success. It has had significant environmental benefits affecting LWA's portfolio. For example, in the central and northern regions of NSW, endosulfan contamination in waterways has declined markedly in the same time frame as Bt cotton has been taken up (Muschal 2000). Not all of this has been due to Bt cotton — restrictions on certain methods of application of the chemical, the development of substitute chemicals, and adoption of IPM by the cotton industry have all helped. Nevertheless, Bt cotton has had significant direct and indirect influences on this trend. In addition, contamination of beef by endosulfan residues has been greatly reduced, with no detections in the 2001–02 season. These environmental gains have come at the same time as economic benefits for growers, with no apparent adverse effects on non-target organisms or human health.

The public, however, does not seem to be widely aware of these benefits, and still sees GM cotton as an environmental threat rather than a benefit. LWA could provide forums in which this imbalance could be redressed. When organisations such as CSIRO and Cotton Australia attempt to do this, they are seen as partisan. Obviously LWA would need to avoid this risk, by adopting the 'honest broker' role. This role might extend to the commissioning of research in the area. While there is a plethora of organisations conducting research on water quality, it often seems not to be quantitatively related to changes in agricultural practices, including GM crop adoption.

On the other hand, other Bt or pest-protection GMs might not be as benign as Bt cotton appears to have been. An example is the proposal for Bt eucalypts. LWA needs to remain aware of what is happening and contribute to discussions on risk assessment for new proposals to trial or release GM crops, via OGTR.

A major implication of insect-resistant transgenic crops is that they may stimulate changes in land use, which may affect a wide range of issues in LWA's area of interest. An example is the current trials of Bt cotton in northern Australia (Strickland *et al.* 1998). Previous attempts to grow cotton in northern Australia were abandoned after the disastrous pest crisis in the Ord River area in the early 1970s. However, new systems are likely to enable cotton growing in these regions. Bt cotton is likely to be a key factor in these systems. This may include Bollgard II® which, while currently not licensed for commercial release north of latitude 22°S, has still to be trialled in these regions. Transgenic cotton, along with other modifications — especially growing the crop during the dry (winter) season — are likely to enable cotton production with much less pesticide use than old systems such as the Ord, and maybe less than current southern systems. Cotton might be produced with fewer environmental problems relating to pesticides than current horticultural crops (such as melons) in these regions. However, this will mean that cotton will be grown where it was not grown before and this will have many potential environmental impacts relating to land and water quality. LWA needs to contribute to this discussion and perhaps commission and facilitate research in these fields.

Weeds and GM crops

Transgenic modifications have the potential to radically alter crop-protection strategies used in Australian agriculture where pesticide sales alone cost farmers $1550m annually (Radcliffe 2002). Emphasis has been given to 'pest protected' crop varieties, such as Bt cotton (discussed elsewhere in this report), and to 'herbicide tolerant' crop varieties. While the former aim to reduce reliance on pesticides, herbicide tolerance is designed to enable the more widespread use of certain chemicals for weed control (Duke 1995). However, transformation studies have also focused on the herbicide-resistance trait because the physiological basis is well characterised, resistance is often a dominant single-gene trait and it can be used as a selectable marker for transformed plants (Mazur and Falco 1989).

Transgenic herbicide tolerant (THT) crops are perceived to offer flexibility in weed management. Herbicides that lower mammalian toxicity, less residual activity, or have different modes of action to commonly used chemicals (which may help delay herbicide resistance in weeds), may be able to be used 'in crop' that would otherwise not have been possible. Similarly, THT crops may provide the opportunity to control recalcitrant weeds, such as nutgrass (*Cyperus* spp.) in cotton (Sindel 1995), as well as a broader spectrum of species. For these reasons, most attention so far has been given to developing transgenic crop varieties which are resistant to the two 'non-selective' chemicals — glyphosate (38%) and glufosinate ammonium (37%) (OECD 1993, cited by McLean and Evans 1995). However, for pasture legumes, emphasis has been placed on increasing varietal tolerance to currently used selective herbicides rather than to non-selective chemicals which, if used, could lead to a reduction in species diversity within a pasture system (Dear *et al.* 1995).

Current and emerging trends

Some 90% of varieties of genetically modified crops currently in commercial use throughout the world confer either insecticidal properties on plants (eg. Bt corn and Bt cotton) and/or herbicide tolerance properties (eg. Roundup Ready® canola, soybeans and cotton) (NRC 2000, cited by Radcliffe 2002) and we are now rapidly approaching the situation where it will technically be possible to insert herbicide-resistance genes into all major Australian crop species (Hamblin and Atkins 1995).

In Australia to date, cotton resistant to the herbicide glyphosate, and carnations that contain a marker gene conferring resistance to the sulfonylurea herbicides, are the only GM herbicide tolerant crops to have been released commercially, though several other crops such as sweet lupins modified for resistance to glufosinate ammonium have been approved for experimental releases (McDowall and Holland 1995). Large-scale field trials have been under way on herbicide tolerant canola for several years and these experimental crops have attracted considerable attention from lobby groups on either side of the GM debate. While the technology for gene transfer for pasture plants is behind that for some of the more important crop plants, rapid progress is being made, such that lucerne (*Medicago sativa*), subterranean clover (*Trifolium subterraneum*), white clover (*T. repens*) and several other species can all now be genetically modified (Dear *et al.* 1995). Approval has also been given for experimental release of glufosinate-resistant subterranean clover (McDowall and Holland 1995), but Radcliffe (2002) believes that herbicide-tolerant clover and lupins are unlikely to be used commercially, presumably because of either market or environmental factors.

Based on proposals currently before gene technology regulators in Australia, and experience with herbicide tolerant crops in Canada and the USA, it is likely that there will be many more applications for trials and commercial release of such varieties in Australia over the next 5 to 10 years.

Potential effects on the resource base

Given the current research emphasis and community expectation for lower pesticide use in agriculture, concerns have been raised over the commercial use of THT crops and their effects on farming systems and the land and water resource base.

One concern is that the use of THT crops will lead to increased use of chemicals for weed control with consequent health and environmental effects. This will partly depend on how a herbicide associated with a THT crop substitutes for currently used herbicides. There are indications from Australia and overseas that the introduction of GM herbicide-tolerant crops may lead to either a decrease or increase in herbicide use depending on the system concerned. The type of herbicide is also important. For example, it could be argued that there would be less environmental contamination with GM glyphosate tolerant canola than with the non-GM triazine tolerant (TT) and imidazolinone ('imi') tolerant canola varieties currently grown commercially in Australia, because the latter varieties rely on herbicides with greater soil residual activity. Whether or not the THT crops would lead to greater herbicide use if introduced may depend on whether or not they remove a limitation on the area of that crop sown. For example, the introduction of TT canola in 1994 with the ability to control certain weeds was an important contributing factor to the tenfold increase in area sown to canola in subsequent years and the accompanying increase in triazine herbicide use across Australia (Radcliffe 2002).

A second concern with THT crops is a shift in the weed flora, for example, to weeds with protracted and late emergence periods (Forcella 1999), and particularly the more rapid evolution of weed populations that are resistant to the particular herbicide to which the crop or pasture variety is resistant. If THT crop varieties are to be released in Australia and be an effective tool in weed management then they need to be incorporated into an integrated weed management framework where all appropriate weed control options are utilised so that resistance to any single technique does not develop. If used alone as a single strategy, THT crops and their associated herbicides will fail to be effective in the long term, just as single chemical treatments are currently failing due to the development of herbicide-resistant weeds. Other selective herbicides would remain effective within those crops, albeit against a different spectrum of weeds, though conceivably, if one or two GM-related products swamp the market, competitive products and companies may not survive and then alternative herbicides may not be available when they are ultimately needed (Baldwin 1999).

Another concern is that THT crops may themselves become major weeds, particularly as volunteers in succeeding crop rotations (Sindel 1995). This is more likely to be a problem where ‘volunteer’ crop weeds from the preceding crop are normally controlled by the herbicide to which the THT crop plant is resistant. A recent study by Perry (2002), for example, has shown that Roundup Ready® cotton volunteers were present in significant numbers in fields previously sown to a Roundup Ready® cotton variety as well as in off-field sites where cotton had been stored or transported and where glyphosate might normally be used to control rogue cotton plants. Moreover, recent experience with GM canola trials in Australia has shown that canola may continue to emerge as a volunteer plant for 3 to 5 years after it was first sown. So the persistence and movement of volunteer crop weeds appears to be a valid problem.

One of the greatest risks from the introduction of THT crops into Australian cropping systems is the potential for transfer of herbicide resistance from transgenic crop varieties to their weedy relatives, whether they be related weedy species or weedy races of the crops themselves (Duke 1995; Medd *et al.* 1995). For herbicide-tolerance transgenes, the main consequence of such introgression would be the loss of a previously effective chemical weed control strategy (Sindel 1997). In most cases, this will be to the non-selective ‘safety net’ herbicides glyphosate and glufosinate.

Introgression will depend on both the presence of plants that could receive the transformed gene and the frequency of outcrossing and sexual compatibility of the species, and yet we have very little data on these aspects to carry out adequate risk assessments for most crops and weeds in Australia (Sindel 1997). Particular concern has been raised over cross-pollination between herbicide-tolerant canola plants and their weedy relatives. While studies in Australia, Europe and Canada (summarised by Salisbury *et al.* (1995) and Glover (2002)) indicate that there are substantial barriers to gene flow to weedy crucifer species, and that the likelihood of successful hybridisation is low, introgression to weedy relatives from this species and as well as from many other GM species to their weedy relatives is likely to be inevitable (Glover 2002).

It must be remembered that herbicide resistance in a weed population in non-GM systems usually begins from a very small base level and can increase over a relatively short time to involve a majority of the population when the population is subjected to intensive herbicidal selection pressure. Therefore, it can be argued that THT crops that provide even a slight risk of flow of herbicide resistant genes into weedy species should not be considered. Medd *et al.* (1995) believe that intra and interspecific diversity in weed floras is a major constraint to weed management, and the utility of existing herbicides must not be compromised in any way in order that their viability and current spectral efficacy is ensured.

On the other hand, the transfer of herbicide resistance to most non-weedy wild or native plants is likely to pose less of a threat for weed management, although there is some concern over genetic contamination in the natural environment. Herbicide-resistant plants are unlikely to have any competitive advantage in natural habitats where herbicides are not used.

It is not only the THT crops that may influence weed management issues. It is conceivable that a scenario may arise where a minor weed which is currently being suppressed by native insects and diseases is no longer subject to such biological constraints because of the introduction of a pest protected GM crop variety and is able then to develop into a major weed pest. Equally, drought, frost, acid soil, temperature or salt tolerance could be risky traits if they were passed from transgenic crops to their weedy relatives. Weeds may then be more tolerant of a wider range of environmental conditions and may spread to and pose problems in previously uninfested areas. For example, increasing the salt tolerance of rice (*Oryza sativa*) through genetic engineering could allow weedy wild rice relatives, eg. *O. rufipogon*, to invade marshlands and displace native species (Shaner 1996).

Options for LWA investment

Many of the crop protection strategies used in Australian cropping systems are for weed control, and impact directly on the soil and water resources on which agriculture is based. The current and potential introduction of THT and other GM crop varieties is likely to affect how weeds are controlled, either improving the situation or leading to greater weed and environmental problems. However, most of these potentially beneficial and detrimental effects have not been studied in any detail and so provide many options for LWA investment.

For example, what would be the effect of THT crops on herbicide use and environmental pesticide load? Would their widespread use in Australia lead to increasing herbicide resistance in weeds as reported recently in the

USA (*New York Times*, 14 January 2003)? Would THT crop introduction cause problems for weed management such that cultivation may again need to play a significant role? What is the likelihood and what are the potential consequences of outcrossing of transgenes to native plants and weedy relatives in Australia? What would be the effects on the resource base if glyphosate was no longer effective in controlling weeds, as could conceivably occur with the overuse of THT technology? The issue would be particularly pertinent in reduced tillage systems dependent on glyphosate for weed control (Derksen *et al.* 1999). Would the sustainability of conservation farming systems and annual cropping systems in semi-arid regions be jeopardised?

Alternatively, several steps have been proposed to reduce the risks to the resource base from GM crops. Another option for LWA is to commission research to test the effectiveness of such protocols.

Animal GMOs

The human–animal bond, ethics, domestication and breeding

The attitude of humans to domesticated vertebrate animals is culturally variable and often illogical. The anthropological debate has polarised people into opposing factions, one materialistic and the other maintaining that particular species are bonded to man and their consumption is socially and psychologically unacceptable (Plous 1993). Research on human–animal bonding is increasing and is matched by increasing public awareness of animal welfare. This awareness has been expressed through a strengthening of the animal welfare movement and for researchers a requirement for ethical animal experimentation.

Human–animal bonding, contrasts with the human–plant bond, which is limited to the conservation of wild plant species, and is not linked to the choice of food. However, the issue of conserving wild vertebrate species is comparable to the conservation of wild plant species. Currently, gene technology has been proposed for the re-constitution of the extinct Tasmanian tiger, using preserved DNA. However, such an attempt is opposed by the conservation movement, which argues success would diminish the case for protecting existing wild species. At the other end of a wide spectrum of animal products, the human use of xeno-transplants of organs from the un-bonded pig, although showing success, is declining in acceptability because of the risk of transferring viral disease.

The domestication of wild animals for soil tillage, human food and fibre accompanied the expansion of post-Neolithic agriculture. Domestication enabled control of breeding, using traditional selection and crossing to develop special purpose strains and breeds. From the 1940s, the rate of genetic improvement for both production and quality was enhanced by study of parent-offspring and sibling relationships for enumerating the heritability of attributes and their genetic correlations. This enabled development of quantitative breeding plans to complement traditional visual selection. By the 1970s, genetic progress was slowing and the technology of genetic engineering is being evaluated. As is the case for plants, the traditional and the new genetics are likely to fuse to restore the declining rate of breeding progress.

Environmental concerns

The National Research Council's Committee on Agricultural Biotechnology, Health and the Environment's major scientific concern is the potential environmental impact of the escape or release of GMOs. Much of this concern is based on the huge uncertainty involved in identifying the environmental problems at an early stage and the great difficulty in establishing remediation after a problem is identified.

We need to distinguish between those GMOs designed for deliberate release compared to those designated for confinement, with the potential for escape.

The NRC provides (NRC 2002) principles of risk analysis as applied to GMO release. Based on current knowledge of population genetics, domestic species and ecosystems it is possible to classify GMOs into categories of high to low probabilities of spread into the environment. The risks of possible harms can then be estimated from the probability of spread. The risk is thus the product of two probabilities, the probability of exposure and the probability of harm (assuming exposure has occurred).

Hence, the sequence for risk analysis is to:

- identify the potential harms
- identify the hazards which may produce these harms
- determine the likelihood of exposure
- quantify the likelihood of harm from that exposure
- multiply the probabilities of the above four parameters to prioritise risk

There is a need to continually update this procedure as new knowledge appears.

Harm can generally be regarded as species or community perturbations that result in ecological community instability.

Generally, the risk assessment principles lead to the consideration of the following variables:

- the effect of the new gene(s) on the fitness of the GMO in the ecosystem
- the ability of the GMO to escape
- the stability of the existing community.

Once a new gene is introduced into a community via a GMO, natural selection for fitness will determine the ultimate fate of that gene, assuming that the initial population is large enough to cope with the initial perturbations associated with introduction (Muir and Howard 2001).

Fitness is determined by six components: juvenile and adult viability, age at sexual maturity, female fecundity, male fertility and mating success. If an organism is fitter than its relatives in the receiving population then the GMO will eventually replace or at least establish within that community. If it is less fit, then it will be removed from the population. If fitness is similar then the GMO will persist along with the non-GMO population (Muir and Howard 2001).

GMOs are often adapted to a wider range of environmental conditions, such as having the ability to obtain phosphorus from phytic acid (Golovan *et al.* 2001). This would allow these organisms to access phosphorus from sources from which it would normally be unavailable. A new gene which increases fitness (adaptation) increases the likelihood of establishment.

Many domesticated farm animals have been modified to enhance production traits. Generally, most of these traits have been selected for by conventional means, and this selection in most cases reduces fitness of the animals to the natural environment, largely because of physiologic imbalances with available nutrients in the natural environment. GMOs selected for these traits may well be even less fit to these environments.

Risks posed by GMO escape

The dangers of animals novel to the Australian environment escaping and establishing feral populations is well known (eg. rabbits, pigs etc.). Any modification to species that readily produces feral populations that makes them even more fit to the natural environment could be very detrimental. However, as discussed earlier, most modifications to these species for production purposes decreases their fitness, and hence are not a problem. A few exceptions may be the pig and mouse modified for phytase-based digestion (Golovan *et al.* 2001).

The modification of insects to reduce the risk of disease transmission, such as the mosquito modified to prevent carriage of the malaria parasite, has potential ecological risks. This mosquito then is advantaged (due to no parasites) and an increase in mosquito numbers may result, leading in turn to increases in other mosquito-borne diseases. Modification of insects for biocontrol of other insects is also an area being investigated at present. However, no current guidelines exist for environmental risk assessment for release of GM arthropods (Hoy 2000). Genetically modified aquatic organisms for aquaculture generally have a high escape potential and, if fitter for the Australian environment, would be an area of major concern. Crustaceans such as crayfish have the ability to travel overland and many molluscs have planktonic larvae that are very difficult to confine. There is a need for research into determining the ecological hazards of transgenic aquatic organism escape into the Australian ecosystem.

International GM animal technology

Across the international spectrum there has been a range of GM research directed at enhancing animal production. Myostatin acts as an inhibitor to muscle growth in animals. In beef cattle, this inhibition increases both the number and the diameter of muscle filaments. There are traditional breeds of cattle that naturally carry genes for double-muscling, producing carcasses with a high ratio of muscle to fat. Identification and function of their genes are being widely studied (Kobolak and Bolcskey 2002), although GM modification does not seem to have been reported at this stage. A double-muscled sire is an unusual looking animal and would probably appear as freakish to the public. There is strong likelihood of public resistance to such a product as there has been for battery hens and is likely to be for Israel's production of featherless chickens (*Sydney Morning Herald*, May 2002).

Australian GM animal research, including native species protection

CSIRO is leading our national GM animal research. The application of substantial resources has been limited to aquatic fauna, where there is a likelihood of public acceptance of the food product. CSIRO GM research on domestic livestock is aimed at wool production and quality, and disease control, improvements will indirectly promote production. A third research level seeks to genetically modify insect carriers of human disease. Finally, CSIRO research is evaluating the environmental potential of eliminating aquatic and terrestrial pest species to encourage re-establishment of native fauna. This portfolio is not directed at human food products and is likely to receive strong public acceptance.

Gene technology for domestic ruminants: CSIRO's research using gene technology is focused on wool production, specifically the rate of growth and quality of wool.

- Wool growth depends substantially on supply of the amino-acid cysteine. Sheep rely on bacteria in their alimentary tract to supply cysteine. Bacterial genes for cysteine production have been successfully inserted into mice. The mice have been able to produce their own cysteine, enabling increase in growth of their fur. The next step is to transfer this model to sheep.
- Sheep carrying a modified growth hormone have been developed and are undergoing trials, under secure conditions, at Armidale and Perth. The sheep are healthy and more productive than their 'unmodified cousins'.

GM aquatic species: As catches from marine fisheries decline, the development of aquaculture is assuming a greater importance. The Pacific oyster is suited to aquaculture and is regarded as a gourmet food. However, it is an invasive species and is becoming established in colonies of native rock oysters along the east coast. CSIRO is developing a GM Pacific oyster with gene insertion to curtail adult breeding, if they should escape from aqua-farms. Success would assist the balance between the demands of production, food quality and conservation of our native species. Gene technology is also being used to improve the resistance of prawns and oysters to viral diseases.

GM research for eliminating European carp: The introduced European carp are choking Australia's Murray–Darling river system and severely reducing the native fish species. CSIRO researchers plan to genetically modify the carp by introducing a gene to produce males rather than females. If successful the European carp could be approaching extinction within 20 to 30 years. This new research provides an example of the potential of GM technology to conserve native species that face extinction and restore the capital of our natural environment.

Options for LWA with animal GMOs

- Genetically modified production animals pose little environmental risk, especially if containment can guarantee that feral populations cannot establish.
- Research activities on existing feral populations to determine more appropriate control measures would be beneficial both for now and if GMOs are introduced.

As no guidelines exist (Australian or international) for the release of GM arthropods, LWA should continue to monitor progress in this area and be ready to provide comment on possible ecological impact if or when guidelines are drawn.

Genetic modification of aquaculture species in Australia imposes considerable risk because of the propensity for their escape and breeding with native populations. LWA should become involved in policy-making in this area. Some areas of possible research include the use of physiologically modified (as against genetically modified) animals to simulate the effects of the GM animals in ecological trials.

GMO segregation

Perspective

Under commercial production systems, current producer sentiment suggests that the segregation of GMO products from conventional material would be necessary (NSW Farmers' Association reports). This will involve separation of product at production and receival points, and will involve additional costs in the marketing chain. It will also require the establishment of quick and simple tests for differentiating GMO and conventional product (possibly an important R&D project).

The ability to identify GMOs will be important for the companies producing GMOs, to protect their economic interests. With biological products like microbes, crops or animals, retention by a primary producer of the reproductive entities, capable of starting the next batch, crop or herd is avoided, to maintain the need for supply from the legally eligible company. Likewise, regulatory authorities will require the means for identification to enforce segregation for environmental and marketing reasons.

The justification for any segregation will be price differentials, or the ability to sell into particular markets. Comments on the Queensland Department of Primary Industries (QDPI) web page, suggest that for States not growing GMO varieties of particular crops (such as maize), opportunities may exist for sales advantages where conventional maize is required. If GMO maize becomes available it will be important to be able to differentiate the two maize types and to physically separate the two products.

The impression that GMO canola is likely to soon become available for broadscale release in Australia has caused some local councils to suggest banning such products from the whole of individual shires. Public perceptions concerning the environmental and health threats resulting from GMO crops of many types indicate a poor knowledge of both the biology of GMOs and the current legal impossibility of banning such products or providing absolute biological quarantine at this scale, should they become widespread: this suggests an immediate need for a balanced educational program to combat many misconceptions in relation to this new technology.

Equally important, some examples of the occurrence of mixing of GM and non-GM crops there have recently been reported. A report in *New Scientist* (23 November 2002, article by P. Cohen, p.7) of the discovery of GM maize (containing a pharmaceutical protein, the actual chemical was not reported for commercial secrecy reasons) growing in soybeans in Iowa and Nebraska has led to concerns about the overall safety of growing crops with modified chemical properties in combination with conventional crop-production systems. Within any crop-rotation system, self-sown plants from earlier crops (also called volunteer or carryover plants) are common, and it is difficult to completely prevent this. Under Australian conditions, similar problems have occurred with GM canola trials in Tasmania; the idea that trials could be conducted with a crop that sheds huge numbers of seeds at or before harvest, and yet will have so little plant carryover as to require a relatively short period of follow up monitoring, is difficult to understand. This plant carryover is a serious problem which has yet to be resolved; indeed, canola is probably one of the most difficult crop plants to prevent the growth of self-seeded material in future crops. Regulatory requirements to address problems with carryover plants will likely impose considerable restriction to the flexibility of cropping sequences and other land use.

The solution to GM plant carryover into non-GM crops requires a research effort aimed at understanding the potential for shed seeds to germinate over time, and how to design rotational systems (including a pasture phase) which minimise any such effects. The 'working solution' often put forward by those proposing GMO releases is that some low level of contamination needs to be deemed acceptable, so that industry has a figure to work/continue with. In effect this might avoid the more fundamental question of whether or not it should continue, ie. the difficult questions about just what level of contamination matters for ecological or other segregation reasons. The boundary areas and subsequent monitoring times required to contain outcrossing or volunteer presence appear to have been underestimated in the recent past, and more appropriate information should be used or collected to make such decisions in the future. In many cases, the ecological studies are too limited or simply not conducted in conjunction with the agronomic studies to provide authorities with the answers they need, to decide whether such market-driven impressions of contamination are also ecologically acceptable or even agriculturally achievable.

The viability of transport and marketing systems that can separate GM and non-GM crops of the same species is questionable. In Canada, another major canola-producer, there have been no attempts to segregate. Canada is able to maintain sufficient markets, apparently because its markets are countries that do not have GM concerns. With another crop such as cotton, separation has not generally been needed with any of its products, even edible oils. About 1–2% of the seed produced per year in Australia is sold to markets in Japan as GM free. This seed is tested and deemed to have less than 5% GM content (Ken Loughnan, Cargill Oil Seeds Ltd, Melbourne, pers. comm. 2003; Graeme Hollis, Auscott Ltd, Moree NSW Office, pers. comm. 2003).

The OGTR has requested comment from industries on the protocols that the industry would impose to achieve segregation if self-regulated to some degree. The aim of the recently released Canola Industry Stewardship Protocols is to design systems for the production concurrently of both conventional and GM canola. The idea of parallel development of the two crop forms has some implicit problems.

While with some crops, the two forms (conventional and GM) have seen few problems of coexistence (eg. cotton), the impending broadscale release of an edible GM crop like canola has serious implications. The above-mentioned document assumes co-existence but complete separation of the two types of canola. If this is maintained throughout the whole production/marketing system, it will prove almost impossible. Imagine the canola transport operation; it will necessitate complete duplication of the whole handling operation including trucks and silo storage capacity. If this is to be done, financial returns will need to justify this expenditure. This is not likely.

Assuming end-users will be buying the product on the basis of extremely low levels of contamination (interestingly called ‘adventitious presence of off-types’) a level of 1% or the market standard has been suggested. These off-types in the past have commonly been weed or other crop seeds; the level of market acceptance of GM seeds in non-GM products has not been clarified.

Relatively little science appears to have been used to attempt to solve the problems mentioned above. The 400 metres separation of canola seed-production blocks and 5 metre separation of GM and non-GM canola are interesting arbitrary choices, especially when the normal density and rotations of canola in regions such as the southern slopes of New South Wales is considered.

Options for Land & Water Australia on GMO segregation

- An immediate need for a balanced educational program to combat many adverse perceptions in relation to this new technology.
- The solution to GM plant carryover into non-GM crops requires a research effort aimed at understanding the potential for shed seeds to germinate over time and how to design rotational systems (including a pasture phase) that minimise any such effects.

GMO regulation, product choice and economic issues

Perspective

The safety of GM human food products is of primary importance and sets the scene for regulatory legislation. It should be noted that many of the safety issues raised about GM products and human health apply equally to conventionally produced foods. The presence of allergens and nutritional imbalance are examples. There is no current evidence to show that GM food is inherently harmful. The precautionary nature and the rigor of current procedures to assess product safety should reassure the public. However, nothing in science is absolutely resolved and openness of regulatory procedures and public scrutiny should continue to be developed. One recent recommendation to the UK Government was the development of a survey protocol to monitor changes in public health levels, which could be associated with the consumption of GMO food (Donaldson and May 1999). Sound statistical associations in this area would clearly be useful. However, survey design would be difficult and its operation could be a disincentive (risk) for industry to produce these products.

Global acceptance of human GM food is currently low. However, the wide industry usage and public acceptance of microbial GM products, such as rennet for making cheese, is high, and this also applies to GM production of pharmaceuticals such as the recombinant hepatitis B vaccine or insulin. Clearly, the human culture of 'worry-about-change' can be assuaged by time. Labelling of GM foods to provide public choice should help. Development and use of xeno-transplants is at the other end of the human health spectrum, and although the transplant might not be a direct genetic modification, animals that are genetically modified are likely to be used in the process to greatly increase success rates. The high level of choice may be exercised by the recipients of organ transplants needs to be very carefully weighed against trans-species risk of introducing new viral diseases to humans.

An important secondary area of concern to human health could be the consequences of significant gene escape from GMOs. This could lead to a reduction of important services provided by a clean environment. Examples could be approval of a 'leaky' field protocol for GM plants, leading to problems of weed control, or a significant and damaging gene escape from soil microbes, which have been engineered for bioremediation. Such issues could be of direct concern to LWA and they will be dealt with in detail.

National legislation on GMOs

GMO legislation aims to reduce the risks to human and environmental health of this technology to acceptable levels in order to harvest its benefits. The history and the current status of our national legislation are summarised in this section. This legislation provides the instrument for minimising risk and maximising the net benefits to be gained. Hence, it will be important to monitor its future development, along with agreements to be reached with State legislation and local government.

Between 1975 and 1987, control over the new genetic technology was the joint responsibility of the Recombinant DNA Monitoring Committee and representatives from the Academy of Science. From 1987 to 21 June 2001, the Australian technology was overseen by the Genetic Manipulation Advisory Committee (GMAC). GMAC was an independent group of scientific experts whose charter was to assess risks to human health and the environment that might attend the application of gene technology and to provide advice on risk management. GMAC's recommendations were sought and complied with voluntarily. Compliance was generally high. The committee also provided expert advice on biosafety to statutory committees that were responsible for GMOs and their products. However, without regulatory powers the committee had limited capacity for legally enforceable auditing and monitoring of compliance, and for imposing penalties for non-compliance. Further, there was no clear market path for producers of GM products and no certainty on standards that may be applied for risk management. Community consultation and transparency of decision-making were regarded as inadequate.

Gene Technology Act 2000: This Commonwealth Act came into force on 21 June 2001. In summary, the Act does the following:-

1. Establishes the Office of the Gene Technology Regulator (OGTR) and a ministerial Gene Technology Committee (GTC) to administer the legislation and make decisions under it.
2. Establishes three advisory committees (scientific, ethics and community), from which the OGTR and the GTC can acquire advice. The ethics committee can advise on ethics of animal experimentation related to gene technology for example. GM plants and crops are to be tested for any risks that they may pose to native plants, their potential to spread pollen to conventional plants or related weed species, and their ability to become a weed. The efficacy of recent protocols for testing will be examined further in this report.
3. Prohibits persons from researching, manufacturing, producing, releasing or importing GMOs unless such dealing is:
   (i) exempt
   (ii) a notifiable low risk dealing (NLRD) defined as contained research, which demonstrably is low risk to workers, general public and to the environment
   (iii) on the Register of GMOs
   (iv) licensed by the regulator
4. Establishes a basis for assessing risks to human health and the environment, arising from dealings with GMOs and including the opportunity for public input
5. Provides for monitoring and enforcement of the legislation. Unauthorised dealings in GMOs are subject to penalties of $1.1 million or 5 years imprisonment.
6. Establishes a central and publicly available database for all GMOs and GM products approved in Australia.

Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act): This Commonwealth Act came into force in July 2000. Under the legislation, the minister may accredit a management plan only if satisfied that there has been adequate assessment of the certain and the likely impacts of the action(s) to be taken under the plan on each matter of the environment to which the declaration relates. GM plants are included because of the risk of gene escape. The grounds are similar to those of the OGTR (Item 2 – above).

GMO provisions of national regulatory bodies (notably the EPBC), as they relate to local government, are as yet undefined. Regional local governments are starting to discuss restriction or outright banning of GMOs, although their power to do so under State or Commonwealth legislation is questionable. The Government of Victoria is canvassing the possibility of establishing genetically engineered free zones (GEFZs), the form that they may take, their potential costs and benefits, and how they might be implemented and managed.

Regulatory bodies

Food Standards Australia New Zealand (FSANZ). The aim of FSANZ (formerly the Australia New Zealand Food Authority, ANZFA) is to provide adequate food information so that the public can make informed choices and to prevent misleading and deceptive conduct. FSANZ is responsible for ensuring all foods are safe to eat. It examines both GM foods developed and grown in Australia and overseas food products. GM foods undergo more rigorous testing than other foods. Safety tests investigate the function of inserted genes, the digestion of GM additions during passage through the human gut and whether or not the product is allergenic.

The ANZFA standard provides for both mandatory pre-market safety assessment and criteria for mandatory labelling. The appropriate minister is enabled to reconcile conflict with our international obligations relating to world trade (WTO). The Australian Consumers Association reported during 2002 (David Metherall, *Sydney Morning Herald,* 10 May 2002) that there had been international pressure on an Australian delegation to vote against labelling regulations on the basis that they may be challenged by appeal to the WTO. Metherall reported a belief that many food manufacturers, concerned about consumer backlash, have changed their products and supply of raw material to avoid the GM label.

There are only six GM food and fibre commodities, mainly grown overseas, that may be currently available for sale in Australia. The crops and their new genetic attributes are:

- soybeans – herbicide tolerance and high oleic acid varieties.
- canola – herbicide tolerance
- maize – herbicide tolerance, insect and virus protection
- potatoes – insect and virus protection
- sugar beet – herbicide tolerance
- cotton – herbicide tolerance and insect protection

Currently no GM fruits and vegetables are marketed in Australia. Cloned horticultural plants, a technique dating back to Roman times, are not classed as genetically modified. With the exception of recently released GM enzymes and pharmaceuticals, GM animal products are unavailable. A GM micro-organism called No–Gall® is commercially available as a treatment for crown gall on fruit trees and roses.

Australian Competition and Consumer Commission (ACCC): One of ACCC's aims is to prevent consumers from unfair trading, and false, misleading and deceptive conduct.

Australian Quarantine and Inspection Service (AQIS): Has the responsibility for quarantine matters including the import of GM products, which may pose risks from the introduction of pests and disease.

Australian Pesticides and Veterinary Medicines Authority (APVMA) (formerly the National Registration Authority, NRA): This authority evaluates, registers and regulates all agricultural and veterinary chemicals.

Therapeutic Goods Administration (TGA): Responsible for the regulation of therapeutic goods, including GM pharmaceuticals, to ensure their quality, safety and efficacy.

With seven national regulatory bodies potentially involved, there is a distinct risk that GMO importation, production and distribution processes will become overly bureaucratic. There is certainly the need for achieving agreement on GMO-process between State and Commonwealth governments. A council, comprising ministers from each State and Territory will be established to provide guidance on the regulatory framework and the policies which underpin OGTR legislation.

Labelling and choice

The FSANZ standard provides for mandatory pre-market safety assessment, and for criteria for mandatory labelling. Labelling is required where novel DNA and/or protein is present, and where food has altered characteristics, such as flavours, which exceed 1% in the final food. Food prepared at point-of-sale is exempt from labelling, along with products with 1% or less of genetically modified material. These standards have been applied to compulsory labelling, which took effect from 7 December 2001.

Recently, FSANZ has clarified the labelling of products as 'GM free'. This label is to be viewed as an *absolute* claim that no GM food, ingredient, processing aid or additive has been employed in the production process. The ACCC has also advised that "GM-free claims must not be deceptive or misleading, and that such claims must be supported with evidence. The absolute nature of the claim has been successfully tested in the courts and should be given thorough consideration before it is used".

The argument for labelling GM food to enable public choice is persuasive. However, multinational and manufacturing companies may be ambivalent on this issue. While there is no scientific evidence that GM food presents a human health risk, the emergence of any major health problem that could be associated with GM food would be disastrous. On the other hand, if manufacturers object to labelling and choice then a growing public perception of 'cover-up' would be inevitable.

Markets and margins as drivers for GMOs

The GMO issue in Australian agriculture is entering the arena at a time of considerable upheaval over the impact of farming on the environment. This may be unfortunate as it suggests the public may view the use of GMOs with some trepidation, and many of the potential benefits will be overshadowed by negative and unsubstantiated opinion. Equally, it means there is scope for publicising those aspects of GMOs which are positive for the environment, eg. Bt cotton.

Ultimately, the level of GMO inclusion in mainstream agricultural production will be driven by:

- the demand for products containing GMOs by consumers
- the demand for GMO input technology by farmers
- the supply of GMO technology.

Consumer demand

As pointed out earlier this report, public concern over the human health implications of GMOs has emerged as a key factor governing market acceptability of GM products.

Whether this concern is rational or not is a moot point since market research clearly indicates that the primary determinants of consumer preferences are price, quality, safety (microbial and chemical contamination), consistency of quality and supply and trade access factors (Douglas *et al.* 2002). Concerns over the safety of GMOs, particularly in human food products, have been raised, and ultimately the demand by consumers for GMO products will be influenced by their perceptions of product safety. These perceptions are largely shaped by the activities of the media and various lobby groups, as opposed to personal exposure to products or first-hand factual information.

In the current climate of intense public scrutiny of agriculture's environmental track record, there is some irony in this turn of events. Consumers and environmentalists are demanding that food and fibre production in rural Australia be modified so as to ameliorate perceived or real negative environmental impacts. Increasingly, society questions the use in agriculture of production systems utilising pesticides, fertilisers and frequent cultivation. And yet, many GMO developments offer a rapid solution to reducing the negative impacts of these systems. For example, the use of pesticides in the cotton industry has received increasing attention in recent years. However, the Australian cotton industry has been an early adopter of GMO technology precisely to address the issue of increased reliance on insecticides and herbicides (eg. Bt and Roundup-Ready® cotton). Anthony (2000) reports that, during the 1998–99 season, genetically modified cotton reduced the use of insecticides by an average 38% (relative to conventional cotton) and in some regions the reduction was as high as 54%.

Anthony also points out that, while GMOs in agriculture are viewed with trepidation by the public, there has been little controversy over the use of gene technology in human medicine, despite the fact that there are on the market some 80 biotechnology drugs that are directly ingested or injected by humans. It is clear that the 'spin' put on new technologies by various interest groups can make or break them in terms of public acceptance.

Critics of GMOs maintain that they present an additional risk to the environment, but this appears to ignore the fact that being able to produce more food and fibre from the same area of land reduces the need for further clearing of native vegetation to expand production. The extent to which this prevents clearing will depend upon the signals individual farmers receive in their enterprises. Expansion to capitalise on higher yielding, or easier to grow but lower yielding, crops is also a possibility; for example, triazine tolerant (TT) canola in Australia (not a GM variety but very similar in attributes to those of the new GM versions), and herbicide tolerant soybeans in the USA.

The sometimes irrational and emotive nature of the GMO debate makes it difficult to predict how consumer demand will emerge as a driver of GMO technology. In terms of LWA research priorities, perhaps it is sufficient to say that LWA should maintain a watching brief on public acceptance and, where possible, ensure that factual information is placed in the public arena where such information falls within their resource-management charter (pesticides, water and soil quality issues are examples). LWA may have a role by acting as a filter to the information that enters the GMO debate.

Without adequate filters, it is possible that policy surrounding GMOs will be shaped by uninformed public opinion. The outcome will be similar to that currently emerging in NSW where the (mostly urban) public have been led to believe that rural Australia is rapidly becoming a wasteland. This concern has been addressed through somewhat unstrategic political expediency in natural resource policy, leading to a heavy emphasis on regulatory control and a high level of antagonism.

If this approach is used, there is a risk that the production and administrative costs associated with GMO adoption will outweigh the production and environmental benefits (as seems likely with other resource-management issues).

A final point on consumer demand. It is unlikely that population growth, increased demand for food and declining crop yields will drive GMO adoption on a global basis. As documented by Lomborg (2001), fears of global population explosion and massive food shortage appear to be unfounded. Despite the fact that starvation is still a major problem in some parts of the world (largely a result of social and political factors), calorific intake in both the developed and developing world has increased by 24% globally and 38% in developing countries since 1961. Calorific intake is forecast to rise further to 2030. Moreover, the food price index has fallen 150% since 1955 and wheat, maize and rice yields in developing countries have risen 150% since 1960 without the widespread adoption of GMOs.

Producer demand

The issue of GMOs in agriculture will be a moot point if users of the technology (ie. farmers) cannot see a clear benefit from GMOs on farm business performance. Ultimately, the decision to adopt will primarily be driven by financial considerations, including risk at the farm level. There are a number of factors that will be important here:

Market trends — as outlined above, if consumers reject GMO technology in agriculture, adoption by farmers will be negligible.

Production economics and margins — widespread adoption of new technologies in agriculture relies almost exclusively on proven profitability. GMO technology must emerge as demonstrably more profitable than existing technologies to be considered as a mainstream alternative.

Additional profitability has already been demonstrated in a number of instances. For example, Ingard® cotton (genetically modified for pest resistance) has been shown to generate an economic benefit of $200–300 per ha (mode) over conventional cotton, due largely to reduced pesticide applications and costs (see Fig. 3 later in report). Adoption rates amongst cotton growers have been high and are probably not higher due to the fact that only 30% of a farm can be planted to Ingard® as it is a genetically modified crop and restrictions have been placed on its use. These restrictions are associated with the need to manage potential resistance to single-gene Bt cotton, and will probably be relaxed when two-gene cotton is released.

Improved margins from GMOs may occur via a number of mechanisms including:

- reduced production costs, as is the case for Ingard® and a number of other GM crops where pest resistance has been engineered. Genetic modification can also be used to allow for modification of cropping practices leading to cost reductions. For example, Round-up Ready cotton enables glyphosate to be applied directly to young cotton plants, reducing the use of pre-emergence herbicides, reducing the number of cultivations and the need for manual cotton chipping.
- higher yielding varieties
- higher quality varieties
- positive interactions with other farm enterprises (eg. impacts of legumes on following crops in rotations).

It should also be noted there can be negative effects on profit margins. GM products often have higher costs due to monopoly conditions (eg. Ingard®) and/or involve the payment of license fees. Over time as new products enter the market, these costs are likely to fall; for example, the licence fee for Ingard® cotton has already fallen.

Economic risk — variability in financial performance is also an important driver of technology adoption amongst farmers. Where GMOs lead to greater stability of income (eg. improved yield stability), their adoption will be viewed more favourably.

Sovereign risk — risks posed by government intervention in the use of GMOs are likely to impact significantly on adoption rates. In the present climate of heavy government involvement in agriculture, this will feature strongly in the decision-making process of farmers.

Social drivers — increasingly, farmers are being made aware of the off-farm impact of their decisions. Overwhelmingly, this trend has highlighted negative effects, and farmers have been given little credit for the significant changes in production techniques they have embraced over the past 15 years to protect 'public goods'. In the case of GMOs (as discussed above), there is potential for this driver to operate in the opposite direction through the production of positive off-farm effects (eg. reduced pesticide contamination).

Yet, while some GMOs have the capacity to modify current farming practices and improve resource-management outcomes, this will be offset by concerns over the general safety of GMOs including fears of modified gene escape. LWA can play a role in ensuring the risks, costs and benefits of GMOs are fully and correctly assessed and do not suffer from the same partial analysis which has been applied to many resource management decisions in Australian agriculture.

Regional economic drivers — significant changes in regional production mixes or technologies can have impacts on the economic performance of regional economies. For example, cotton-growing economies and employment in northern NSW and south-eastern Queensland are supported by seasonal cotton chipping activity. This activity may be virtually eliminated with the widespread adoption of Roundup-Ready cotton.

GMO supply drivers

The factors outlined above that impact on the demand for GMOs will dictate their supply. Manufacturers will not invest funds in GMO development without clear signals that the market will accept these products.

However, in the case of GMOs, legislative requirements are also likely to determine the level of product supply as they can have a significant impact on production costs.

At present, due to the monopoly supply situation for most products, manufacturers are likely able to absorb these costs due to their dominant market share. This situation may change as new players enter the market.

Government resource-management policy may also become a key driver of GMO product supply in agriculture. If the current trend toward 'clean and green' agriculture persists, and particularly if market premiums are paid for this type of production, many farmers will be looking for alternative production systems (assuming they are affordable). GMOs may provide some solutions in this area and act as an alternative to what has happened elsewhere in the world where agriculture receives heavy public subsidies through 'environmental grant schemes' as opposed to direct price support schemes.

LWA may have a role in assessing the extent to which GMO technology can contribute to improved resource management in agriculture. It will be important to recognise that a 'one-size-fits-all' solution to resource-management issues will be ineffective and that there is a need for continual learning within individual farming systems as to how alternative technologies impact upon the environment. Accordingly, the capacity of GMOs to replace existing technologies will vary.

An indirect impact of GMO agricultural enterprises on a landscape scale is the potential changes to land-use patterns. From an economic perspective, the following comments reflect possible impacts or reactions of Australian growers given the availability of a potentially more-efficient GM variety.

1. The export market is usually the residual market for Australian growers, so any increased production

would probably be exported (so long as the world market was not swamped to the point where world prices fell to unprofitable levels).

2. Australian growers would probably not reduce areas grown, just get more yield from their existing area (just like if you employ more efficient irrigation methods but have the same amount of water, you do not use less water, you just use the same amount to grow more, assuming you have enough land).
3. GM products which change the crop input mix could have flow-on effects to the regional economy (eg. reduced pesticide sales).
4. Similarly, significant land-use changes could have significant regional economic impacts due to changes in input/output mixes and the impact of that on other regional businesses linked to cropping.

Public acceptance of GMOs

International surveys, multinationals and Australian response

Combined results from international surveys (*ca.* 2000–01) of international attitudes to GM food show the following and incomplete matrix of responses:

Per cent	USA	UK	Japan	10 countries
Acceptance	23	48	–	–
Non-acceptance	30	–	–	–
Undecided	47	–	–	–
Lack knowledge	–	69	–	–
Benefit > risk	–	–	33	60

These fragmentary results suggest that people have little understanding of how GM food differs from conventional food and, in some countries (eg. the USA and Japan), a higher level of concern about dietary change. Confidence in GM food products will no doubt grow with time, provided that human health problems do not emerge.

Acceptance of plant GMOs varies between countries, with high levels in the USA, Argentina and Canada. At the other end of the scale, Portugal has prohibited their use. Currently, there is limited use of GM crops in the European Union, where research tends to be focused on gene processes and extension of the technology. This would enable a second wave of product development.

Farmer choice has been for GMs with a lower requirement for pesticides and herbicides rather than those with claims of yield increase. Benefits ranging from 30–50% in reduced use of these chemicals are achievable without affecting yield. However, GMO effectiveness within this range would seem to depend on seasonal events. Herbicide tolerant soybean is the world's major GM crop and is currently grown on 33 million ha across seven countries. This represents over 60% of world GM crop plantings.

Sales of GM crops in the USA and fees associated with their technology surged 12.9% in 2001, while sales of conventional crop products fell by 7.4% to a total of US$25.8b. If this rate of decline was sustained, then, other things being equal, the use of conventional cultivars would halve within 10 years. The dominance of US agrochemical multinationals is illustrated by the following values in US dollars of their sales for 2001.

- Syngenta $6323m
- Bayer# $6278m – expected to rise with Aventis acquisition
- Monsanto $5212m
- Dupont $3842m
- BASF $3114m
- Dow Chemical $2842m
- Makhteshim-Agan $784m

With the current delay in labelling regulations and the limited availability of GM foods, it is too early to test Australian response to these products. Australian plant GM research on the staple grains and cotton fibre, aims to locate and modify the genes that can control pests, disease resistance, tolerance to nutritional deficiencies and climatic stress. These factors underpin production but do not relate directly to modifying the composition of human food. Our current GM animal research also 'steers clear' of animal food products, with the exception of oysters and prawns. Given the relatively low level of attention currently given to GM animal food products worldwide, then it is highly likely that our existing national research, which is directed at wool production, the reduction of animal disease and the protection and regeneration of native aquatic and terrestrial species, will have a high level of public acceptance. This applies to plant GM research as well. The current scope of our national research in GM agriculture is building a portfolio of knowledge and skills that will prepare us for the second wave of GM products. The hope is that these will be directed at increasing the efficiencies and competitiveness of our agricultural industries and the protection and enhancement of our national resource base.

Public policy and GMOs

The highly contentious issue of GMOs is likely to be one upon which the public policy debate will wage for many years. Scientists (both for and against), environmentalists, bioethicists, users of the technology (eg. farmers) and the public will all be participants in this debate. At times the issue of GMOs will be highly contested and dynamic. It is impossible to predict whether the debate will eventually dissipate or whether it will continue over many decades, such has been the case with that over nuclear energy.

The debate will have social, ethical, religious, scientific, political, economic, legal and cultural dimensions. In part, the discourse is about what is known and what is not known, and perceptions about the levels of risk and uncertainty. However, like many complex debates it is also about the frames that individuals and groups bring to the discussions. These frames are often determined by the values of and ethical positions taken by participants. Those stakeholders holding ecocentric ethical viewpoints will seek different information, and assess perceived risks and costs and benefits differently to those with a more anthropocentric ethical position.

In attempting to understand and critically analyse the nature of the policy discourse over GMOs it is useful to employ a conflict analysis and negotiation framework. Like many so-called environmental disputes, the conflict over GMOs has a number of distinguishing characteristics.

- it is a highly complex debate
- it is largely a public policy dispute
- government is often called upon to play multiple roles: as stakeholder, protagonist and dispute resolver
- it is highly value-laden with high-value diversity
- it is very science-laden and involves complex, highly contested and incomplete science with high uncertainty over outcomes and assessments of risk
- litigation may be the primary recourse for dissatisfied stakeholders.

Table 1 illustrates in simple terms the characteristics of the conflict over GMOs that either contribute to its resolution or constrain it. Utilising a conflict analysis framework allows the use of a range of analytical tools as well as a selection of potentially useful dispute resolution and policy development strategies. Three such strategies include consensus-building strategies with key stakeholders, mediated decision-making processes, and joint fact-finding approaches to resolving areas of contested science.

Table 1. Characteristics of public policy conflicts that contribute to their ease or difficulty of resolution. Characteristics that relate to GMOs are in italicised bold type (adapted from Lewicki *et al.* (1999)).

Characteristics	Difficult to resolve	Easy to resolve
Value diversity of stakeholders	***Wide***	Narrow
Exclusivity of outcomes	***(Perceived) Zero sum***	Positive sum
Size of stakes	***High***	Low
Relationship	Single interaction	***Long-term interactions***
Stakeholder representation	***Some stakeholders absent, unrepresented or ineffectively represented***	Representative and effective
Certainty of outcomes	***High uncertainty***	High certainty
Issue complexity	***Highly science-laden, technically complex, or limited data***	Low level of scientific or technical complexity, data rich
Levels of negotiation	***Multilevel***	Single level
Number of parties	***Many***	Two
Ideological component	***High***	Absent or low
Balance of power between stakeholders	***Unbalanced***	Balanced
History	***Longer history of highly adversarial negotiation***	Recent initiation with low adversarial component, or collaborative interactions
Parties' need to resolve	***Low in the case of some opponents***	***High in the case of proponents***
Perceived distribution of costs or harm	***Uneven distribution***	Even distribution
Neutral third-party involvement	***Absent***	Independent mediator/facilitator utilised when appropriate

Ethical dimensions within the GMO debate

For the purposes of this discussion, 'ethics' will be defined as that parcel of values by which people live. An individual's ethical viewpoint will guide their decision-making, how they interpret information or events, and their notions of 'good' and 'bad'. The ethical positions of individuals and groups have had a strong influence over the GMO debate. To ignore ethical positions within the debate is to misunderstand the context of the debate. Analysis of the ethical positions of stakeholders with an interest in GMOs will give insights into the policy alternatives that are more or less likely to be attractive to them. If a consensus-building process is utilised with stakeholders in order to develop appropriate policy, then the ethical positions of each of the stakeholders must be explicitly explored.

There are three main theoretical traditions within ethical theory, all of which have relevance to the current discourse surrounding GMOs.

- *Utilitarian theory* — holds that we should act in a manner and make choices that maximise the benefits and minimise the costs for society. Normally, public policy pursues utilitarian objectives. Those promoting and opposing GMOs have both utilised utilitarian arguments in supporting their cases.
- *Rights theory* — holds that human beings have certain rights within society that should not be imposed upon by others. Rights-based arguments are often posed against utilitarian arguments. Those promoting and opposing GMOs have both utilised rights-based arguments in supporting their cases.
- *Virtue theory* — holds that we should act in a manner that is just and fair and that does the least harm.

Extrinsic and intrinsic objections to GMOs

Comstock (2000) argues that there are extrinsic and intrinsic objections to GMOs, the conflation of which tends to confuse the ethical debate. *Extrinsic* objections relate to the perceived harm that may come from the use of GM technology.

Intrinsic ethical objections, on the other hand, relate to the belief that the process of producing GMOs is itself objectionable. Intrinsic ethical objections are likely to come from those who argue from deeply ecocentric or religious ethical positions.

Dealing with extrinsic objections may be a complex undertaking but they are easier to address (if not resolve) than intrinsic objections, due to the fact that the substance of the objections can be identified and critically appraised.

Ethical issues within the GMO debate

Several issues have been raised within the GMO debate that have become the focus of ethical discourse. The primary ethical issues within the GMO debate are as follows (FAO 2001):

- food safety and consumer concerns (see, for example, ESRC (1999))
- environmental impacts (eg. gene escape, loss of biodiversity within 'wild' populations; see, for example, Raybould and Gray (1994) and Hails (2000))
- distribution of perceived risks and benefits
- transparency of decision-making and policy formulation processes (see, for example, ESRC (1999))
- accountability
- equity
- power of decision-making and policy formulation processes
- ownership of GMOs: 'patenting life forms'.

Concerns over GMOs are in part related to perceived risks and threats of the technology to the environment, agricultural production, food safety, human health, and market access for agricultural products. Another concern is that, while the perceived threats may impact upon many, the claimed benefits appear to accrue to only a few, primarily to corporations and agribusiness (and particular research fields). A final area of concern of GMO opponents relates to perceptions of a lack of transparency in the decision-making and policy-formulation process. Some stakeholder groups feel that they are unrepresented in the policy discourse, and thus do not have voice within policy negotiations.

Ethical positions and their influence upon judgments about GMOs

The ethical spectrum is often portrayed as spanning a range from 'deep green' (strongly ecocentric) at one end, through to 'deep brown' (strongly anthropocentric) at the other. Though simplistic and two dimensional, even a model such as this can be useful in analysing and understanding the ethical positions of groups and individuals in relation to GMO technologies.

The proponents of GMOs often argue from viewpoints situated somewhere along an anthropocentric ethical range from human welfare ecology[1] (light green–light

1. The *human welfare ecology* ethical view proposes that we must protect and maintain the environment for the sake of humankind. Increasingly, human welfare ecology is the normative ethical view taken by Australian governments, and is more or less the ethical basis for ecologically sustainable development (ESD) principles.

brown) through to a strongly developmentalist[2] (deep brown) ethical position.

Opponents of GMOs may also come from an ethical position of human welfare ecology through to that of a deep ecology[3] (deep green) ethical position. Those who raise *intrinsic* objections to GMOs are likely to hold ethical views positioned towards the ecocentric end of the spectrum. Alternatively, intrinsic objectors may also do so on religious or cultural grounds.

Within the policy discourse it is important to distinguish ethical claims ("GM technology is wrong") from empirical claims ("gene escape into wild populations is very likely"). Empirical claims can be examined and analysed through research and modelling. The line between empirical and ethical claims becomes blurred when assessing 'acceptable' levels of risk. Within the GMO discourse there is currently a very vigorous debate waging about whether policy should adopt the precautionary principle[4] or the principle of reasonable risk[5] (and how these terms might be defined).

There is another dimension to assessment of risk that is highly dependent upon the ethical position of those making the assessment. Risk is normally defined in terms of the following equation.

Risk = probability of a hazard occurring × impact of the hazard

While the probability ranges of a hazard occurring may be calculated and quantified, the impact of the hazard is essentially a subjective assessment. For a deep ecologist, the loss of one species may be unacceptable. To the strong developmentalist, the loss of a species with no clear instrumental value to humankind may be judged insignificant. Thus, assessments of risks will often vary depending upon the ethical filter of the individual or group.

Where such ethical diversity occurs in relation to a public policy issue, policy-makers should consider taking a new negotiated approach to policy-making. Such an approach involves convening a transparent consensus-building process that allows all stakeholders a voice, that recognises diversity of values and ethical positions, and that utilises, where possible, factual evidence within the policy formulation process. Where science is utilised in a *joint fact-finding* decision-making environment supported by all stakeholders, it is less likely to be contested, and the roundabout of adversarial science may be avoided.

A potential role for LWA in informing and developing public policy

The above discussion raises a number of issues, the resolution of which may involve possible roles for LWA. In exploring potential roles that it may play in helping inform public policy, LWA should be cognisant of the critical analysis of GMO-related public policy that has occurred within the United Kingdom, European Union and the United States. It should be recognised the domestic GMO policy debate in Australia will also have international policy influences and impacts.

Potential roles for LWA are briefly canvassed below.

1. *As an independent convenor of forums for public participation and informed stakeholder discourse*

   > Building the legitimacy and accountability of political decisions on GM food requires a much more participatory style of decision-making, in which a far wider range of options are considered. The outcomes of this process cannot necessarily be foreseen. This would require politicians and scientific advisors to make significant changes to their ways of making decisions. Not least it would require a sharing of power over the process and possible outcomes, although this short term sharing of power should ultimately result in enhanced powers to act. The consequences of this logic have not been fully accepted in political and scientific advisory circles, with the result that entrenched but manifestly unsuccessful approaches prevail (ESRC 1999, 4).

Many observers have called for a GMO public policy discourse that is participatory, inclusive, equitable, transparent and accountable. Some of the concerns expressed about GMOs by a range of groups and individuals (including scientific, conservation, farmer

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2. A strongly developmentalist ethical position regards natural things as only having instrumental value in terms of improving the lot of humankind. If a living thing does not have instrumental value then it has little or no value. Moderate developmentalism was the normative ethical position of Australian governments during the post-WWII development boom of the 1950s and 1960s.
3. Deep ecology proposes that all natural things, ecosystems, life and landscapes have an intrinsic right to exist. This right is not transcended or negated by the needs of humankind.
4. Proponents of the precautionary principle argue that when an activity might present threats to human health or the environment, precautionary measures must be taken, even if a cause and effect relationship cannot be established to scientifically acceptable levels. The precautionary principle normally argues that the burden of proof of the safety of an activity or technology remains with the proponent of that activity or technology. Those taking a utilitarian ethical position (e.g. public policy-makers) often argue for the application of the precautionary principle.
5. Reasonable risk is premised upon the belief that public decision-making (legislative, regulatory and adjudicatory) requires judgments based upon tested risk-assessment procedures. Advocates of this approach believe that most important environmental decisions can be studied, quantified and weighed through the use of scientific and analytic tools. Development proponents often utilise reasonable risk arguments.

and consumer groups) appear to be amplified by the lack of a clear opportunity to contribute to the public policy discourse in a structured and strategic fashion. Providing the forum for such a participatory process may help mitigate the more inflammatory claims and position-taking that occurs when the public debate is conducted by way of the media.

For any government planning to initiate such a process, one of the substantial challenges is the selection of the agency that should be charged with the responsibility for designing and convening the process. The responsible organisation may have an interest in GMOs, but ideally must also be seen by a wide range of stakeholders (including the public) as not having so strong an interest as to be perceived as trying to influence the outcome of any discourse. Thus, they must be seen as interested but also as relatively independent. For this reason it would be difficult (though not impossible) for the OGTR to play this role as it has specific statutory responsibilities to fulfill.

Secondly, the organisation must be seen to have (or have access to) the experience or expertise in the processes and skills required to convene and manage such a participatory process.

Thirdly, the organisation must have public recognition by a range of stakeholder groups, and have the vested government authority to undertake such a process.

Apart from lacking the vested authority, LWA appears to substantially meet all the above criteria that would qualify an agency as being potentially capable of undertaking such a participatory process. For these reasons, LWA may be well placed to play the role of convenor and manager of a participatory process that contributes to GMO policy development if the Federal Government should decide to initiate such a process.

2. *As an independent convenor for stakeholder negotiations*

Stakeholder negotiations may occur within a broader participatory process as described above or they may occur as a separate process. For a negotiation to occur and be successfully resolved, a number of design and process conditions must be met. Among these conditions are the following:

- a negotiation forum must be created
- stakeholders must have effective representation within the negotiation process
- the package of issues and outcomes that are the subject of the negotiation must clearly defined and agreed to by stakeholders
- issues of risk, uncertainty, knowledge gaps and contested science must be identified and explored within the negotiation
- the negotiation is more likely to proceed smoothly if it is facilitated by an independent third-party mediator.

There is a clear role for a Federal agency to convene and manage such a negotiation process. For example, over the past decade, the experience in the United States with mediated environmental negotiations convened and managed by the Federal Environmental Protection Agency has reportedly been very positive (USEPA 1999).

3. *As a funder of appropriate policy research that falls within the defined R&D mandate of LWA. Such research may have social, economic and scientific dimensions.*

> Environmental disputes pose powerful challenges to civil societies. More often than not, they are complex and hard fought affairs that present urgent and practical problems to be solved. Frequently, they are laden with contested scientific and technical information and important collisions of social and economic values. Inevitably, they are also political fault lines in larger ideological wars … In the abstract, infusing high quality information into a controversy and having it serve as a foundation for decision-making should be a straightforward matter. One asks the right questions, obtains data through rigorous and accepted methods, analyzes and interprets the data in ways that are logical, and then submits the findings to peer review. Unfortunately, information rarely threads into solutions in such a direct way. More often, information gathering is done by warring experts as part of an adversarial and contentious process tinged with suggestions of actual or implied litigation. Productive lines of communication are often severed. In other cases, vital information is an afterthought to the economics and politics of deal making. Alternatively, vast amounts of money may be spent on irrelevant or unusable research in information collection. Surprisingly often, disagreements on key points remain unresolved and uncertainties that can undermine the future stability of an agreement are left unaddressed (Adler *et al.* 2000).

The need for policy research — that is, research that is specifically targeted to inform the process of policy development — is often overlooked. It is often overlooked because its pluralism may transcend narrow sectoral or disciplinary boundaries (and therefore funding guidelines), or because policy-makers are not always active initiators of research. Policy research may involve social, economic or scientific dimensions.

The broad nature of the LWA research focus renders it well placed to broker GMO-related policy research. However, the challenge within policy research is often the initial identification of specific research needs, the outcomes of which will inform or improve the policy focus.

4. *As a funder of R&D that fills knowledge gaps relating to the sustainable natural resource management impacts of GMOs (eg. bioremediation, gene escape risk assessments, biodiversity impacts).*

Where knowledge gaps can be identified that fall within the mandate of LWA's strategic plan, and where this research is not being funded by another agency, then LWA may choose to directly fund such research. Examples of such research foci may include bioremediation, gene-escape risk assessments, biodiversity impacts, identification of threatening processes, and improved contributions to ecosystem services.

5. *As a co-funder or broker of research in partnership with other R&D organisations in order to fill knowledge gaps relevant to the LWA mandate.*

Where knowledge gaps can be identified that fall within the mandate of LWA's strategic plan, and where this research can been funded through partnerships with other R&D agencies, a number of advantages may accrue. Cost sharing and cost savings may be achieved, and strategic research linkages may be forged. Where industry partners are involved as co-funders, an additional advantage may be the imbuing within these organisations of additional perspectives and objectives that coincide with those of LWA.

Other biotechnology

The LWA brief was restricted to GMOs in an effort to provide reasonable coverage and depth within other consultancy limits. However, there were several areas of biotechnology somewhat associated with GMOs that warrant mention because they improve the picture in general of the influence of biotechnology on LWA's charter, and may bear further investigation. Clearly, a full discussion is not possible because of the limitations to this consultancy, but it may also help to clear up several common misconceptions that these other biotechnologies are somehow GMOs. They are certainly not GMOs but might be used in conjunction with, or even to improve the prospects of GM technology. These have been brought out of the discussion to avoid any possibility that they might be confused with GMOs *per se*.

Markers

Genetic marker techniques are not GMO techniques, rather they assist scientists to identify the presence of a gene in an organism. The gene of interest might be a possible candidate for gene transfer, or the gene might be a transgenically introduced gene and therefore be applied to a GMO, but marker technology is not a GMO technique and has been used for many years in non-GM applications to assist selective breeding. The relevance of marker techniques to GMOs is that such techniques greatly improve the identification of genes in individuals and so can assist in prospecting for characteristics.

Xenotransplants

Xenotransplants (ie. the development of an organ or tissue of one species in another species) are not GMOs. The DNA content of the cells of the recipient host organism and the cells of the transplant tissue are different. The DNA of each has not been altered, necessarily. However, the development of xenotransplants will almost certainly involve the use of GMOs as host or tissue implants so may well be common in the future of xenotransplants. Again we must stress that xenotransplants are not necessarily GMOs.

Cloning

Cloning is not a GMO technique. Cloning is the development of a new individual from the DNA of an individual. This produces another organism with identical DNA to the donor, and therefore is very similar in appearance and many other characteristics, at the same development stage, to the donor (like identical twins), but the DNA is not necessarily modified by genetic techniques. Again, the use of cloning along with GMO technology, for example to clone a GMO, would appear possible and perhaps even desirable if rapid generation of a superior organism were warranted.

Cloning technology involves insertion of the whole DNA complement from a donor cell into an emptied ovum. Because the whole genome is inserted, the resulting individual is a clone of the donor, but not a genetic modification. Mice were the first animals to be cloned using embryonic cells. Sheep were first cloned from embryonic cells in 1995. One year later 'Dolly' was cloned from adult non-embryonic cells at the Roslin Institute, Edinburgh. The method using non-embryonic cells has been now extended to cows, cats, pigs and rabbits. However, success has always been accomplished at great costs and loss of viable embryos so that it is questionable whether the technology will be of practical use to industry. Cloning is not a reliable procedure. 'Dolly' prevailed as a moderately arthritic albeit generally healthy sheep after 276 attempts. The success rate with other species has not greatly improved (the 2002 Guardian interview of Ian Wilmut who led the cloning team). Post 'Dolly', it is notable that Wilmut and other leading international researchers have left cloning research and turned their attention to basic research at the stem cell level, to better understand developmental plasticity at the human genome level, which is not within the scope of this report.

Australian experience with Bt cotton — a case study

Introduction

Bt cotton is so far the only GMO which has been widely used in Australian agriculture. In this report we have therefore considered it in some detail. While many of the conclusions we draw from this case study may not apply to other GMOs, the Bt story will illustrate some of the potential benefits and risks of GMO technology, and the kind of ecological complexity and range of issues that need to be considered.

The first field trials with Bt cotton in Australia were in the 1992–93 season, when 150 transgenic plants were grown in carefully contained areas. The scale of these trials gradually increased over the next four seasons. During this time, data on pollen movement, gene introgression into conventional varieties, and impacts on non-target organisms (especially beneficial insects) were collected to satisfy APVMA registration requirements and so that the (then) Genetic Manipulation Advisory Committee could advise on commercial release. Major concerns raised by GMAC included the potential spread of the Bt gene to closely related native *Gossypium* species (of which there are about 15 in Australia), and the potential for resistance in *Helicoverpa* spp. The latter might have threatened the viability of continued use of foliar Bt in organic and conventional agriculture, as well as wasting the potentially valuable resource of transgenic material for the cotton industry. Strategies adopted by the industry to deal with this problem are discussed later.

It is now generally accepted that the risk of transgene escape to wild relatives of cotton is very low (Brubaker 2002). In contrast to the situation with transgenic canola, the wild relatives of cotton are not significant weeds. Also in contrast with canola, there are major genetic barriers to hybridisation between native *Gossypium* species and cotton. No natural hybrids have ever been recorded. Further, cotton does not persist as a perennial in the major cotton-growing regions of Australia because it is killed by frost.

Commercial release of Bt cotton occurred in the 1996–97 season. In that year, 8% of the cotton acreage was transgenic. In the following two seasons it rose to about 15%. In these years the limiting factor was the availability of seed. The acreage increased to 28% in 1999–2000, and in the 2000–01 and 2001–02 seasons it has been capped at 30% (Table 1). In each of these seasons, the performance of Bt cotton in terms of yield and insecticide use has been monitored in a series of reviews commissioned by the Cotton Research and Development Corporation (Pyke and Slack-Smith 1997; Pyke 1998, 1999; Kwint 2000; Doyle *et al.* 2001, 2002). These reviews used data collected by cotton consultants responsible for monitoring pests in paired Bt and conventional fields. Growers responses have been assessed by qualitative questions.

In all these reviews, the industry response to Bt cotton has been positive. Initially, there were complaints about the cost of the license. Monsanto charged Australian growers $245 per ha, much more than it was charging US growers. There were complaints about the standard of support and advice provided by Monsanto to growers. There was also some disappointment with the level of protection provided by the Bt gene, especially late in the season and when stresses associated with temperature and moisture occurred. The expression of the gene weakens as cotton plants age (Fig. 2). Also, Australian *Helicoverpa* spp., especially *H. armigera*, are less susceptible to Bt toxin than their American counterparts, *Helicoverpa zea* and *Heliothis virescens*. These factors often result in Bt cotton performing like conventional cotton (ie. failing to kill *Helicoverpa* larvae) towards the end of the season. Despite these difficulties, growers and consultants appreciated the potential of the technology. It represented the first high-level resistance to the key pests of cotton, and a solid foundation for the development of effective integrated pest management programs.

The last two CRDC reviews indicate that many of these early problems have been resolved. The license fee has been reduced to $170 per ha, and levels of support from Monsanto have clearly improved. Experience has been gained in managing Bt cotton to maximise the efficacy of the gene, and the unrealistic expectations of the early years have been moderated. The major complaint of growers at present is that they cannot get enough Bt cotton, due to the 30% cap.

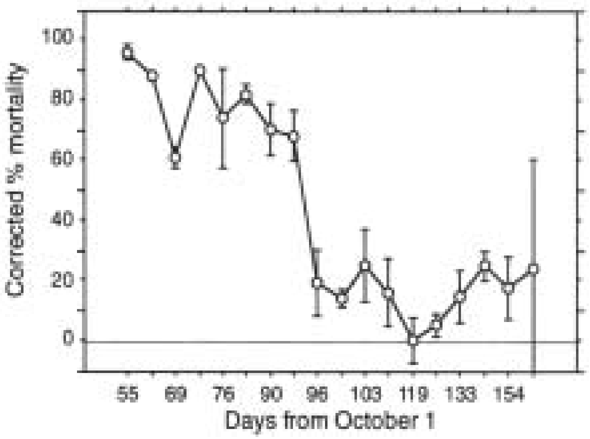

Figure 2. Mortality of *Helicoverpa armigera* fed on Bt cotton leaves from plants at various times during the cotton season. From Fitt *et al.* (1998)

Economically, the early years of Bt cotton did not return significant benefits to growers. The saving in insecticides was approximately balanced by the cost of the license and additional seed costs (currently $9 per ha). There were no consistent differences in yield between Bt and conventional cotton. Some paired comparisons showed a yield advantage to the transgenic varieties, but in others the reverse occurred. However, in the last two seasons this has changed. The 2001–02 Ingard® review (Doyle *et al.* 2002) indicates a consistent yield advantage of about 5% (0.44 bales/ha) associated with Bt cotton. This trend was statistically significant in all but two of the 11 regions surveyed. There has also been a clear trend to cost savings in insecticides in recent years. In 2001–02, the average grower of conventional cotton spent $504.40 per ha on insecticides. For Bt cotton the average cost was $327.11, including the license fee. The trend for higher yields and lower costs in Bt cotton is resulting in some clear economic benefits. While some paired comparisons indicated a loss from growing Bt cotton, the great majority showed an advantage. The modal value was a benefit of $200–300 per ha (Fig. 3).

Despite the increasing evidence for economic benefits, the main reasons cited by growers for planting Bt cotton are associated with the environmental benefits of using less pesticide. Bt cotton is considered especially valuable in 'sensitive' areas. These include fields which are close to houses and roads, where insecticide application operations (especially aerial ones) are highly visible. They also include fields close to watercourses, wetlands and cattle-grazing areas, where insecticide pollution might have serious consequences for the grower as well as the environment.

Current and potential effects of Bt cotton on pesticide use

In every season since the introduction of Bt cotton, there has been a reduction of insecticide use (Table 2). The reduction has been greater for insecticides targeted at the key pests, *Helicoverpa* spp., as might be expected in view of the fact that these are also the main targets of Bt cotton. The reduction has been greatest in the last two seasons. This might be because these seasons had relatively light insect pressure, but it is more likely to be because growers and consultants are developing increased confidence in Bt cotton, and more experience in its management.

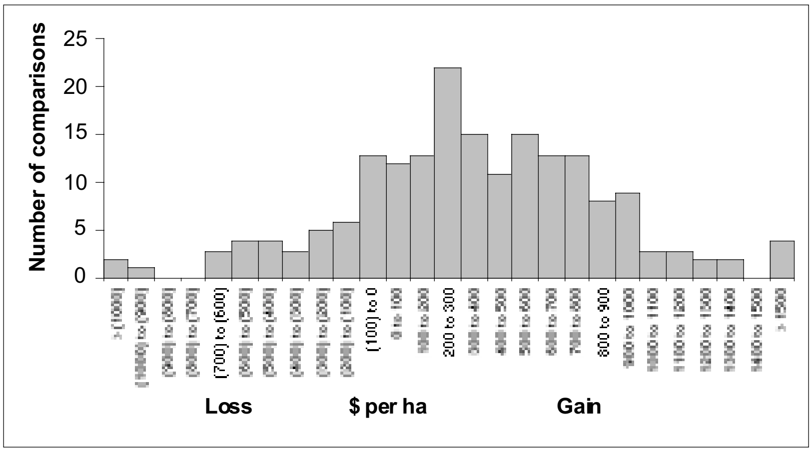

Figure 3. Economic benefits of Bt cotton in paired comparisons with conventional cotton, 2001–02. Comparisons take into account yield differential, costs of pest control, the cost of the Ingard® licence and extra seed cost. Data from Doyle *et al.* 2002

The average reduction in insecticide use had been 48%. When multiplied by the proportion of the acreage which was Bt cotton for each season, the reduction across the whole industry has been from 4 to 19% (Table 2).

Current Bt cotton has a single gene for Bt toxin which is expressed well over the first two thirds of the growing season but diminishes in expression over the last third. It might therefore be expected that there would be a greater reduction in insecticides used mostly early in the season, compared with late-season sprays. Table 2 shows, in percentage terms, the reductions achieved in the use of various chemical groups. There has been an 80% reduction in endosulfan applications. Endosulfan is an insecticide which has been widely used early in the season against *Helicoverpa* spp. It has had a problematic history with regard to contamination of waterways, and has produced residues in beef cattle which have affected Australia's export beef markets. Reductions in the use of this environmentally risky chemical are a major benefit of Bt cotton. There have also been major reductions in the use of carbamates and to a lesser extent synthetic pyrethroids. While these groups are not associated with major off-site environmental problems, they are 'hard' chemicals within the crop; that is, they are destructive to natural enemies. Reducing their use will enable predatory and parasitic insects to exert greater effects, not only on *Helicoverpa* but also on secondary pests such as mites and aphids.

On the other hand, reductions in the use of organophosphates have been relatively limited. These chemicals are largely used late in the season, and often against non-lepidopteran pests such as aphids and mites which are not affected by Bt toxin. In the case of systemic granular insecticides, and miticides, which are directed at pests not affected by the Cry 1Ac toxin in Bt cotton, there have been no consistent changes. This suggests that cotton farmers are not, as might perhaps be expected, increasing their use of insecticides against pests unaffected by Bt to protect their investment in the license fee required to grow the GM crop. It also suggests that these pests are not becoming more of a problem with the removal of the protection from insecticides targeted mainly at *Helicoverpa*. This was originally thought to be a likely risk. Qualitative surveys of consultants provide little evidence of this risk being realised. In the 2001–02 surveys, however, there is one insecticide which is used more widely in Bt cotton (average of 0.64 sprays) than in conventional cotton (average 0.15 sprays). It is fipronil, a product recently registered for control of green mirids, *Creontiades dilutus* — a sucking pest which is not affected by Cry IAc toxin. This suggests that this species may become more problematic in Bt cotton compared to conventional, as might whiteflies (*Bemisia tabaci* Type B) in some regions.

The category of 'other' insecticides includes products such as fipronil and imidacloprid, another insecticide targeted at sucking pests. It also includes newer insecticides aimed at *Helicoverpa* spp., such as spinosad, emamectin benzoate and chlorfenapyr, and biopesticides such as nuclear polyhedrosis virus and foliar Bt. In general, within this category there have been larger reductions in insecticides targeted against *Helicoverpa* spp. than those targeted against other pests.

Over the next two seasons, two-gene Bt cotton (expressing Cry2Ab as well as Cry1Ac toxin, and to be sold in Australia as Bollgard II®) is expected to become commercially available. This may see a relaxation of the area limit in the resistance strategy, perhaps expanding Bt acreage to as high as 80%, which would greatly increase the impact of Bt varieties on pesticide reduction across the whole cotton industry. Initial trials of two-gene cotton indicate that it also has improved efficacy, which implies even fewer insecticide treatments, particularly later in the year (Fitt 2000). It is therefore anticipated that the introduction of Bollgard II® will reduce insecticide use in Australian cotton by as much as 70%.

Table 2. Reductions in insecticide use (number of sprays) for *Helicoverpa* spp. and in total, and the level of adoption of Bt cotton, 1996–97 to 1999–2000. Sources: Pyke and Slack-Smith (1997), Pyke (1998, 1999), Kwint (2000), Doyle *et al.* (2001, 2002), and ABARE (2001)

Season	Reduction to applications for *Helicoverpa* spp. (%)	Reduction to all applications (%)	Total area of cotton ('000 ha)	Area of Bt cotton ('000 ha)	Proportion of crop Bt cotton (%)	Reduction of insecticide overall (%)
1996–97	57	52	396	30	8	4
1997–98	44	41	448	64	15	6
1998–99	43	38	551	85	15	6
1999–2000	47	40	455	125	28	11
2000–2001	66	54	505	175	30	16
2001–2002	77	64	417	125	30	19
Average	**56**	**48**	**462**	**101**	**21**	**10**

Bt cotton and integrated pest management (IPM).

Integrated pest management is an approach to pest control in agriculture that recognises that optimal control of pests requires several methods used in concert. The cotton industry in Australia has gained an important tool in Bt cotton which facilitates improved IPM (Fitt 2000). Cotton growers are aware that insect pest populations can be extremely damaging. In a few days, *Helicoverpa* spp. can arrive in numbers capable of major economic damage. Means of reducing the pest population include 1) Plant varieties resistant to pests, whether of GM or conventional origin; for example, varieties with the okra leaf characteristic provide considerable resistance to mites. 2) Allowing natural mortality factors to impose losses. Like many noctuid moths, *Helicoverpa* spp. produce large numbers of eggs, of which only a very few survive. Most succumb to the weather, wind or rain or desiccation, or are eaten by other insects such as predatory beetles or parasitic wasps. 3) Cultural control, such as ‘pupae busting’, and measures designed to increase the abundance of natural enemies such as strip planting with lucerne.

Before the introduction of Bt cotton, prospects for IPM were not promising. There were fewer effective pesticides, because the resistance of pests was increasing. Pyrethroid resistant insects could often be killed, but only if insecticides were applied when eggs had only just hatched. This forced a situation where growers perceived that they could not afford to wait and see if a certain level of eggs produced a damaging level of larvae. They had to estimate if an egg lay had the potential to cause damage and if so apply insecticide, targeting hatch. In Bt cotton it is paramount to wait until the crop has had time to reduce the pests in the crop before pesticides are considered. There is no point in introducing a crop which kills larvae when they feed on it, only to spray it with insecticide on hatch. This has produced a waiting period. While the grower waits for Bt cotton to kill larvae they are also aware that wind, rain, heat, predators and parasites are also having an impact. The waiting will often lead to a decision not to use an insecticide and predators and parasitoids will be maintained and perhaps increased for the next influx of *Helicoverpa* spp. They will also impact on secondary pests, such as aphids and mites. The key point is that Bt cotton allowed weather, and predators and parasites, to contribute. Relying so much on natural mortality (environmentally clean, free pest control) was more difficult to justify in economic terms 10 years ago. Very few growers were prepared to leave crops unsprayed to find out the contribution of natural mortality factors. Even if they did, the large areas being treated with insecticide by neighbouring farmers diminished beneficial populations in the area. Within this new farming system, conventional (non-Bt) cotton is often receiving fewer sprays than 10 years ago, and yielding at levels comparable to Bt crops. This is a clear indication of the potential of natural mortality factors in the absence of higher levels of applied pesticides. Recent studies which quantify improvements in gross margins associated with the use of ‘soft’ insecticide regimes (ranging from 5–6% for conventional cotton and 5–25% for Bt cotton) will further increase the adoption of IPM based on the combination of Bt cotton and natural enemies (Hoque *et al.* 2000; Johnson *et al.* 2001).

Obviously, Bt cotton alone has not been responsible for these changes. Failure of existing pesticides, new ‘softer’ insecticides which retain natural enemies of the pest, and grower willingness to test the boundaries of IPM have all made important contributions. However, the general reduction in insecticide use on a wide-scale throughout the early and mid season, on both conventional and Bt cotton, has been strongly influenced by the introduction of Bt cotton and this has provided a major step toward recognising the contribution of other factors to pest management. The relative absence of insecticides offers an opportunity for other pest control strategies; that is, true IPM. Cotton thus provides us with an example of a

Table 3. Percentage reductions in the average number of insecticide applications for key chemical groups directed at heliothine and other pests from conventional to Bt cotton from 1996 to 2002. Sources: Pyke and Slack-Smith (1997), Clark and Long (1998), Clark (1999), Kwint (2000), Doyle *et al.* (2001, 2002)

Season	Endosulfan	Carbamates	Ovicides	Organo-phosphates	Synthetic pyrethroids	Miticides	Granular systemics	Others
1996–97	86	64	75	16	50	na	na	na
1997–98	81	43	34	25	29	4	–7	69
1998–99	70	62	63	24	35	–23	0	44
1999–2000	71	50	58	29	45	14	na	47
2000–01	90	50	70	41	49	–19	76	68
2001–2002	84	82	82	27	47	–10	0	72
Average	80	59	64	27	43	–6	17	50

farming system in which the potential contribution of a GM plant towards reducing pesticide use has been much greater than might be expected by simple comparisons of the number of sprays it requires compared with its conventional equivalent.

Effects of Bt on non-target organisms

Given the specificity of Bt toxins compared with most conventional insecticides, it would be expected that there would be few effects on non-target species. No significant effects have been recorded in vertebrates from either foliar Bt or Bt in GM plants. Shelton *et al.* (2002) review several studies which indicate no toxicity or allergenicity of current Bt plants for humans or domestic livestock. Of interest is the case of StarLink maize, expressing the Cry9C toxin, an Aventis product which was approved for animal but not human consumption in the USA. This split registration was on suspicion that Cry9C could be allergenic to humans, being less susceptible to breakdown in the digestive tract than other Bt toxins, though such effects were never clearly demonstrated. StarLink maize was later found to have contaminated products for human consumption and was voluntarily withdrawn from registration, at considerable cost to Aventis, farmers and regulatory agencies. Split registrations of this nature are no longer issued in the USA.

For insects, laboratory studies suggest that green lacewing larvae feeding on European corn borer from Bt corn plants have reduced growth rates and survival, (Hilbeck *et al.* 1998). Though this work has been criticised on technical grounds (Shelton *et al.* 2002), it is not unlikely that the few lepidopteran larvae which survive Bt toxins are nutritionally different from normal larvae. Results from these laboratory studies have not been reflected in changes in field populations of beneficial insects (Fitt and Wilson 2002). Research conducted towards the registration of Bt cotton in Australia showed no significant differences in populations of generalist predators such as ladybirds, lacewings and damsel bugs in Bt cotton compared with unsprayed conventional cotton. Aphids and leafhoppers, which are unaffected by Cry1Ac toxin, are probably the major prey items for these insects in cotton, rather than *Helicoverpa* spp. (Stanley 1997). Reductions were found in the numbers of some specialist parasitoids of *Helicoverpa* spp., as might be expected in view of the decreased availability of hosts in Bt compared with conventional cotton. Similar results have been shown for the parasitoids of cabbage moths in transgenic canola (Schuler *et al.* 2001). However, cotton is not the major supplier of *Helicoverpa* spp. as hosts of parasitoids in most Australian farming systems — crops such as sorghum and sunflower fill this role. It is therefore unlikely that populations of these specialist parasitoids will be seriously threatened by Bt cotton, even when a high proportion of the acreage is transgenic. In any case, the most reasonable comparison is between Bt cotton and conventional cotton under normal management practices, not unsprayed. In this comparison there are usually more natural enemies of all types in Bt cotton because of the reduced insecticide use.

The most likely non-target organisms to be affected by Bt are other Lepidoptera. In Australian cotton, most of these Lepidoptera are pests, and few if any are of conservation interest. In the USA, concern has been voiced over the possible effects of Bt corn on the monarch butterfly, *Danaus plexippus*, a large and colourful species with a fascinating migration pattern. This insect is of conservation interest and has a high public recognition factor. Laboratory studies showed that the survival and growth rates of the larvae of this species were adversely affected by pollen from Bt corn dusted onto the leaves of their host plant, milkweed (Losey *et al.* 1999). Milkweed commonly occurs in and around cornfields in the USA. Moreover, corn fields (both conventional and Bt) are not usually sprayed (the benefit of Bt corn is mostly higher yields, not reduced insecticide use). Consequently, it was thought that Bt pollen might present a net risk to monarch butterfly populations. However, it has recently been shown that maize pollen does not spread more than a few metres from the field, and that monarch butterflies prefer to oviposit on plants that are not in corn fields, and are not covered in corn pollen (Tschen *et al.* 2001). Finally, there are very few Bt corn varieties that express the toxin in pollen. They never constituted a large proportion of the acreage, and are no longer used. It is therefore considered now that Bt presents a small risk to the monarch butterfly, especially in relation to other risks including conventional insecticides (Shelton *et al.* 2002).

The risks to non-target Lepidoptera might be greater if Bt genes were introduced into native plants, which support many species of conservation interest. Some years ago there was a proposal within CSIRO to introduce Bt into certain *Eucalyptus* species for protection against lepidopteran pests of plantation timber. This proposal appears to have been quietly dropped, probably because of the recognition of potential effects on non-target organisms as well as the widespread hybridisation between many *Eucalyptus* spp. While this may indicate that the Australian regulatory system is functioning effectively, this proposal is evidence that unwise use of GM technology remains a potential risk.

Resistance management for Bt cotton

The presence of only a single gene leaves current Bt varieties vulnerable to insect resistance problems. There is no doubt that resistance to Bt can occur. High level resistance has been produced in heliothine moths in the laboratory in the USA (Gould 1998), China and Australia (Bird *et al.* 2002; Akhurst 2002). So far there are no confirmed cases of resistance to a transgenic Bt crop in the field. Recent data suggesting low-level changes in baseline susceptibility to Cry1Ac (Dang and Gunning 2002) require further investigation. However, resistance to foliar Bt has developed in the cabbage moth, *Plutella xylostella*, under field conditions in a number of countries (Shelton *et al.* 2002).

A resistance management strategy (IRM) is in place to avoid resistance to Bt cotton (Fitt 2000; Schulze and Tomkins 2002). This strategy was required for registration of Bt cotton and is reinforced by the conditions of the licence required of growers to buy Bt cotton. The Australian cotton industry has a long tradition of adopting such strategies for managing resistance to conventional insecticides. These strategies are developed by the Transgenic and Insecticide Management Strategy (TIMS) Committee of the Australian Cotton Growers Research Association, which includes scientists, growers and insecticide industry personnel. Changes to the Bt resistance management system are developed by this committee.

The IRM for Bt cotton is based on the premise that, like most (but not all) resistance to conventional insecticides, Bt resistance will be functionally recessive and initially present at low frequency. Provided non-random mating can be avoided, homozygous recessive individuals will be rare, and heterozygotes will remain susceptible to the toxin (Shelton *et al.* 2002). Thus, a good supply of homozygous susceptible moths is required to mate with potentially resistant moths emerging from Bt cotton. In part, this supply is ensured by maintaining a cap of 30% on the acreage of Bt cotton in all -growing regions. In addition, growers are required to plant specific refuge crops, which can include unsprayed conventional cotton (10% of the Bt area), sprayed conventional cotton (100% of the Bt area) and various areas of other crops including pigeon pea, corn and sorghum. Quite specific conditions are required for the management of these refuge crops. The destruction of overwintering pupae by cultivation ('pupae-busting') after harvest is also required for Bt crops (Schulze and Tomkins 2002).

It is anticipated that two-gene (Bollgard II®) cotton will not require as stringent resistance management, because there is unlikely to be cross-resistance for the two types of Bt toxin it contains, since the receptors on the gut epithelium are different. Single-gene Bt cotton will be withdrawn when it becomes available and it is likely that the cap on acreage will increase to around 70–80%, and refuge requirements may be relaxed. However, in the event that widespread resistance to Cry1Ac appears before this, Bollgard II® will effectively present only a single gene. The cotton industry is aware of this danger and the Bt resistance management scheme has widespread support, despite the obvious short-term economic disadvantages.

While the IRM adopted by the Australian cotton industry is conservative by comparison with those used in other countries, and appears to be scientifically well designed and effectively implemented, it would be unwise to assume that such schemes can be easily developed for all industries adopting transgenic crops. The cotton industry has relatively few growers who tend to be scientifically and technologically aware. It also has channels of communication and a tradition of adopting industry-wide schemes for resistance management to conventional pesticides. The same advantages may not exist for other industries, and the dangers of resistance to transgenic crops should not be underestimated.

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Appendix 1 — Agencies and groups

Regulators

Australian and New Zealand Food Authority – ANZFA: see Food Standards Australia and New Zealand
Australian Quarantine and Inspection Service – AQIS: <http://aqis.gov.au/>
Australian Pesticides and Veterinary Medicines Authority – APVMA: <http://www.apvma.gov.au/>
Environment Australia – Legislation: <http://www.ea.gov.au./about/legislation.html>
Food Standards Australia and New Zealand – FSANZ: <www.anzfa.gov.au>
Genetic Manipulation Advisory Committee – GMAC: <http://health.gov.au/gene/gmac/>
Interim Office of the Gene Technology Regulator – IOGTR: <http://www.health.gov.au/gene/genetech/iogtr>
National Registration Authority – NRA: see Australian Pesticides and Veterinary Medicines Authority

Scientific associations and public awareness groups

CSIRO: <http://www.genetech.csiro.au>
European Union – EU: <http://europa.eu.int/comm/research/quality-of-life/gmo>
Agrifood Awareness Australia – AFAA: <http://www.afaa.com.au>
Biotechnology Australia – BA: <http://www.biotechnology.gov.au>
New South Wales Farmers' Association: <http://www.nswfarmers.org.au>
Ecological Society of America –ESA: <http://esa.sdsc.edu/statement0601.htm>

Appendix 2 – Glossary

Prefatory note:

Italicised text denotes definitions quoted from the numbered references below, indicated by the superscripted number immediately following the word. Text in regular format adds context to the definition for this report, provided by the report authors.

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Arthropod[1] Member of the Arthropoda: *The largest phylum in the animal kingdom in number of species, including crabs, insects, spiders, centipedes, etc., amounting to eighty per cent of known animals. Metamerically segmented, cuticle of chitin, usually hardened between joints; paired appendages, segmentally arranged, used for locomotion, feeding and sensation etc.*

bacteriophage[1] *(phage). A virus (q.v.) that parasitises bacteria either virulent, or temperate. Initiates infection of a cell in another organism by attaching to the cell, breaching the cell wall by enzymatic action, and passing genetic material into the cell. The machinery that the cell usually uses for synthesis of its own material (proteins) 'reads' the phage DNA to produce more of the bacteriophage. The relevance to this report is the genetic transfer method this presents, ie. the transfer of genetic material from one species to another via means other than within species sexual transfers.*

baculovirus Baculoviruses are rod-shaped viruses that contain a circular, double-stranded DNA genome. They infect only invertebrates, particularly insects in the larval state. There are two subgroups of baculoviruses, the nuclear polyhedrosis viruses and the granulosis viruses.

biotechnology Technology based on biological processes. Technology of biological reactions involving organic molecules (biochemistry: the chemistry of living organisms). There is an enormous range of biotechnologies. Some common examples include; organic chemistry in medicinal drug development, genetic manipulation (q.v.) (ie. genetic engineering), proteomics (q.v.), genomics (q.v.), use of antibodies (eg. ELISA tests, ie. enzyme-linked immunosorbent assays for 'identikits' or diagnostics).

biotype[1] Existence within a particular species of a number of genetically different races or forms, which, though indistinguishable in structure, show differences in physiological, biochemical, or pathogenic characters.

brassicaceous vegetables Flowering plants belonging to the Brassicaceae family of cultivated vegetables, including cauliflower, brussels sprouts, cabbage, kohlrabi, broccoli, turnip, and Chinese cabbage.

broad spectrum herbicide A herbicide that kills a wide range of plant species. For example; glyphosate, glufosinate of ammonia and triazine.

Bt cotton Cotton varieties which have been genetically modified by the introduction of at least one type of transgene (q.v.) from the soil bacterium, *Bacillus thuringiensis* conferring the ability to express a toxin which kills lepidopteran insects (butterflies and moths). The Bt cotton varieties used in Australia are Ingard® varieties (single-gene Bt cotton) and Bollgard II® varieties (two-gene Bt cotton, ie. two different types of Bt toxin gene expressed).

chemoautotrophs[1] *Obtaining energy from a simple inorganic reaction, the nature of which varies according to species, eg. oxidation of hydrogen sulphide to sulphur by Thyobacillus. Several kinds of autotrophic bacteria are chemoautotrophic.*

conjugation[2] *Bacterial conjugation is another example of genetic recombination. Bacteria normally reproduce asexually, by simple growth and division. Some species of bacteria occasionally undergo sexual conjugation. It is the process by which DNA is transferred from an F+ bacterium to an F- bacterium. In this process part or all of one strand of the chromosome of the donor cell, designated F+ or (+) cell because it carries the sex factor F, is transferred into a recipient cell of the same species, the (-) cell, which lacks F. As a consequence the recipient cell now acquires some new genes which are combined into its chromosome.*

enzyme[2] *A protein specialized to catalyse* [increase the rate of] *a specific metabolic reaction.*

epithelium[1] *Sheet or tube of firmly coherent cells, with minimal material between the cells. Lines cavities and tubes and* *covers exposed surfaces of body. The cells are frequently secretory, and the secretory part of most glands is made of epithelium.*

eukaryotic cells[1] E*ucaryotic (eukaryotic) cells are the units of structure of all organisms except bacteria, and blue green algae (and viruses). By contrast with prokaryotic (q.v.), the eucaryotic cell has a nucleus (in some cases more than one) separated from the cytoplasm by a nuclear membrane, and the genetic material borne on a number of chromosomes consisting of DNA and protein. Nuclear division is by mitosis. Fungi (mushrooms, moulds, rusts, yeasts, etc.) are simple eucaryotic organisms.*

feral I*ntroduced organisms escaped from control and causing problems, generally used in reference to animals but sometimes plants.*

gene[1,4] *Unit of the material of inheritance. A gene is a length of DNA which contains the information needed to result in the production of a specific amino acid chain. This in turn may lead to production of a biologically active molecule such as a hormone.*

genetic code[2] *The set of triplet code words in DNA coding for the amino acids of proteins.* Often used more generally to describe the sequence of genes of all the DNA of an individual (genome, q.v.) coding for the characteristics of a complete individual.

gene flow The movement of genetic material from one individual to another with the potential to be incorporated into another genome eg. pollen movement from the anther of one plant to the stigma of a receptive recipient plant is gene flow.

genome[2,4] *All the genes of an organism or individual. Strictly speaking, DNA in the mitochondria is included.*

genomics[5] *The cloning and molecular characterization of entire genomes.*

GMO Genetically modified organism. The artificial modification (ie. not by natural methods like sexual reproduction used in conventional breeding) of the genetic code (q.v.) of an organism ie. of the DNA segments comprising the genes (q.v.) of an organism. This may be the duplication, deletion, altered control mechanisms of, or introduction of genetic material in order to alter the traits (characteristics) expressed by the organism. eg. the use of recombinant DNA techniques for the introduction of a gene that codes for the crystalline toxin in Bt cotton (q.v.) to impact on cotton pests.

GMO segregation The separation of genetically modified organisms or products containing GMO material from that deemed to be non-GMO during research, production and distribution eg. the separation of seeds from GMO crops from non-GMO seeds in supply chains by dedicated or cleaned harvesters, transporters, cleaning facilities, sales/distribution and waste disposal methods.

haemocoel[1] B*ody cavity which is really expanded part of the blood-system, containing blood. Well developed in Arthropoda (q.v.) and Mollusca* (eg. slugs and snails) *where the coelom is small. Unlike the coelom it never communicates with the exterior and never contains germ cells.*

herbicide A chemical formulation that is used to kill plants of one sort or another. Typically applied as a solid (granule or dust) or liquid (droplets as a spray) to the soil (to kill weeds on germination) or foliage of seedlings or larger more developed plants. Herbicides are generally categorised by the types or range of plant species that they impact upon. eg. a broad spectrum herbicide kills a wide range of plant species whereas a specific herbicide is active on a single or very reduced range of species.

herbicide-resistance gene A gene which if present or introduced into a plant's genome, confers the characteristic (trait) of resistance to a type or group of herbicides.

herbicide-tolerant (HT) crop A crop that is tolerant to a herbicide (q.v.). Tolerance, as opposed to resistance, indicates a less than 'complete' level of resistance.

heterotrophs[1] *Organism requiring a supply of organic material (food) from its environment. All animals and fungi, most bacteria and a few flowering plants are strongly heterotrophic, requiring organic substances from which to make most of their own organic constituents.*

hybridisation[1] *A hybrid is a plant or animal resulting from a cross between parents that are genetically unlike; often restricted to the offspring of two different species or of well marked varieties within a species. Hybrid may be fertile (capable of producing offspring), or sterile.*

ice-minus bacteria The US Environmental Protection Agency granted the first approval for the release of a genetically modified bacterium in 1985. The bacterium was *Pseudomonas syringae* which had been genetically altered to prevent the production of a protein that promotes the formation of ice crystals on plants, hence it has been called ice-minus bacteria.

introgression The persistence and spread of a gene within a population of organisms once introduced into the genome of some individuals eg. a herbicide-resistance gene might introgress (be introduced and persist) in a weed population if the gene confers some ecological survival benefit to the individuals within that population with that gene. In such a case individuals expressing the gene will be selected for and lead to a greater proportion of progeny, increasing the frequency of that gene, ie. towards introgression. If the gene reduces fitness or indeed if it has no benefit, it will decrease in gene frequency, away from introgression.

Lepidoptera[1] *Butterflies, moths. Order of endopterygote insects. Two pairs of wings covered with scales; larva a caterpillar with prolegs on abdomen. Adults feed on nectar of flowers using highly specialized, often coilable, proboscis; larvae usually feed on plants.*

luminescence The property of some substances to give off light under certain conditions, eg. if under an ultraviolet light source. The introduction of a luminescence gene (suggested from marine organisms since many produce light), along with the transgene/s of interest, could improve the efficiency with which individuals or lines of organisms which have received the transgene can be identified for further selection or identification, assisting breeding programs or monitoring. Suggested in the context of this report to replace antibiotic resistance genes as a marker for the presence of the transgene of interest.

micro-organism[1] *Microscopically small organism; unicellular plant, animal or bacterium.*

monogenic A trait is described as monogenic if only one gene is involved in the expression of the characteristic that it codes for, for example, the expression of the Bt toxin in cotton is monogenic whereas yield of cotton lint will be determined by several genes and therefore be polygenic (q.v.).

outcrossing *Inbreeding* (incrossing) *is reproduction by mating*/crossing *closely related individuals as opposed to outbreeding* (outcrossing) *by the mating*/crossing *of less related individuals*. In the context of this report, for example, outcrossing is the reproduction between a crop variety and a less related plant species, not necessarily deliberate breeding. For example, the transfer of pollen from a crop variety (cultivar) (eg. *Brassica napus*, canola) to a less related plant variety or species by natural or deliberate breeding, be that other plant, a crop variety, weed species (eg. *Brassica rapa*, turnipweed) or any plant that is at least to some extent a 'natural' recipient. Progeny from such a crossing or mating would represent outcrossing.

plasmid[2] *An extrachromosomal, independently replicating small circular DNA molecule.*

phylogenetic analysis The categorisation of the relatedness of species via determination of their relative similarity of representative sections of their DNA.

polygenic A trait is described as polygenic if more than one gene is involved in the expression of the characteristic that they code for eg. yield of most crops will be determined by several genes where as the expression of the Bt toxin in cotton is monogenic (q.v.).

proteinase inhibitor Proteinases are enzymes which breakdown proteins. A proteinase inhibitor interferes with the action of such enzymes, reducing or stopping the breakdown of protein.

prokaryotes[1] Prokaryotic means having *chromosomal material in the form of haploid DNA (ie. unpaired chromosomes) without the important protein component as in eucaryotic (q.v.) chromosomes and not separated from the cytoplasm by a nuclear membrane.* All bacteria are prokaryotic.

proteomics The identification and characterisation of the complete set of proteins encoded by the genome of a species.

rennet[3] *Curdled milk from calf's stomach, or artificial preparation, used in curdling milk for cheese.* The relevance of rennet to this report is that fear of transmission of bovine spongiform encephalopathy (mad cow disease) in European countries has led to the outlawing of this traditional use of calf stomachs. A genetically modified micro-organism is now used to produce the enzyme (rennin) used in the curdling process.

reporter genes[5] Reporter genes are nucleic acid sequences encoding easily assayed proteins. They are used to replace other coding regions whose protein products are difficult to assay. They can be attached to other sequences so that only the reporter protein is made or so that the reporter protein is fused to another protein (fusion protein). Reporter genes can 'report' many different properties and events eg.: the strength of promoters, whether native or modified for reverse genetics studies; the efficiency of gene delivery systems; the intracellular fate of a gene product (<http://opbs.okstate.edu/~melcher/MG/MGW4/MG429.html>)

rhizosphere[1] *Zone of soil immediately surrounding roots which is modified by their activity. It is characterized by enhanced microbiological activity and often by changes in the relative proportions of types of organisms present compared with surrounding soil. This is due to changes in nutrient status of soil arising from removal of nutrients by root absorption and release of other root exudation and by sloughing off of dead cells.*

ruminant[1] *Mammal belonging to the sub-order Pecora of the order Artiodactyla. Deer, giraffes, sheep, goats, antelopes, oxen. No upper incisor teeth. Often with bone-cored horns. Stomach usually complicated.*

selective breeding The selection by humans of individual organisms for mating to produce offspring with desirable characteristics eg. collecting pollen from a cotton plant that exhibits high fibre yield and deliberately placing it on the stigma of a cotton plant exhibiting a high level of pest resistance. This mating or crossing will produce a large number of progeny (seeds grown through to mature plants), some which may well display both desirable characters (high yield and high pest resistance). Note that selective breeding has been practiced for many years in agriculture but is distinguished from the collection of desirable genetic traits (characteristics) by transgenic methods by the breeding occurring via natural sexual means once the selection of individuals are made. Note also that the transfer of pollen or semen from the male to the female might be artificially assisted in modern selective breeding techniques eg. artificial insemination with prized stud animals.

spectral efficacy Describes the spectrum (range of different) weeds that a herbicide effectively controls. In the context of this report spectral efficacy is suggested to be reduced if certain weed species become resistant, perhaps to the extent that a herbicide becomes so ineffective that a chemical is lost as an option for management.

transduction[2] *The transfer of genetic material from one cell to another by means of a viral vector* (see bacteriophage).

transgenes Genes that have been artificially (ie. not by normal biological means such as sexual breeding) transferred from one genome to another.

transgenic An organism is described as transgenic if it has one or more genes in its makeup which were derived from an artificial transfer using genetic engineering techniques from another individual of perhaps another species.

transgenic herbicide tolerant (THT) crops Crop varieties that have had genes for a level of tolerance to one or more types of herbicide artificially transferred into them from another individual whether that be of the same or different species.

virus[1] *A member of a group of sub-microscopic agents that infect plants and animals, usually manifesting their presence by causing disease, and are unable to multiply outside the host tissues. The fully formed mature virus (or viron) consists of nucleic acid within a protein or protein and lipid coat. Nucleic acid is either DNA or RNA in animal viruses, RNA in plant viruses and DNA (and occasionally RNA) in bacteriophages.*

volunteer A plant that has **not** come about from a deliberate intention to grow it at a certain time and position eg. seeds split onto the ground during harvesting operations may subsequently germinate and develop into plants. Those plants would be described as volunteers. They may grow outside typical, deliberate cropping periods or cycles.

xeno-transplants Tissue or organs from one species transplanted into another species eg. heart valves from pigs transplanted into humans to replace defective human heart valves.