The Social and Economic Benefits of Molecular Plant Breeding

An Economic Impact Analysis of Projects from

The Molecular Plant Breeding CRC

Prepared For

MPB CRC

MOLECULAR PLANT BREEDING CRC

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The details of this assessment are based on the assumptions provided by the Molecular Plant Breeding CRC.

ABBREVIATIONS, ACRONYMS & DEFINITIONS

ABARE	Australian Bureau of Agricultural and Resource Economics
A$	Dollar (Australian)
Average farm yield (FY)	Average yield (typically in tons/hectare) is the yield achieved by farmers in a defined region over several seasons.
BCR	Benefit Cost Ratio
DM	Dry matter
Economically attainable yield (AYa)	Optimum (profit maximising) yield given prices paid/received by farmers, taking account of risk and existing institutions.
Event	In the context of genetic modification an event is a plant transformed with a specific combination of genetic elements. That is, a plant whose genetic code has been altered, typically with the insertion of a specifically designed genetic sequence.
FAO	Food and Agriculture Organization
GM	Genetic modification
GNP	Gross national product
ha	Hectare
kg	Kilogram
MJ	Megajoules
Molecular markers	Molecular markers are the genetic signposts that flag the presence of genes that control particular traits. Markers can be used to identify the presence of a gene directly from a sample of plant or grain without the more lengthy process of screening for physical or chemical characteristics.
MPBCRC	Molecular Plant Breeding Cooperative Research Centre
NPV	Net present value
Outputs	The end products of a CRC's activities. This includes publications, patents, prototypes, graduate students, etc.
Potential yield (PY)	Maximum yield with latest varieties, removing all constraints, including moisture, at generally prevailing solar radiation, temperature, and day length.
SME	Small and Medium Enterprises
Theoretical yield (TY)	Maximum theoretical yield for prevailing solar radiation based on prevailing knowledge of crop physiology and photosynthetic efficiency.
Total factor productivity (TFP)	The ratio of a quantity index of all marketable outputs to the corresponding quantity index of all marketable inputs.
USDA	United States Department of Agriculture
Water-limited potential yield (PYw)	Maximum yield under normal rain fed conditions, removing all constraints as for PY except for moisture.

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SUMMARY OF THE MOLECULAR PLANT BREEDING CRC

DELIVERING A SUSTAINABLE FARMING FUTURE – THE LONG-TERM POTENTIAL OF MPBCRC PROGRAMS

The Molecular Plant Breeding CRC (MPBCRC) has made a major contribution to current efforts to lift agricultural productivity in Australia. The MPBCRC outputs are particularly timely as the world now faces considerable challenges to feed its growing population. Not only is the number of mouths increasing but urban expansion, climate variability, and rising costs of fuel and fertiliser are placing pressure on food production levels. The world is currently experiencing historically low levels of food reserves that have significantly reduced global food security. This exacerbates the urgent need to increase the productivity of Australian agriculture in general, and crop and forage production in particular.

MPBCRC has delivered significant insights and progress to advance the rate of crop breeding and the production of new varieties.

This Economic Impact Analysis Report articulates the key activities and outcomes of the MPBCRC and describes their contribution to the Australian economy. Descriptions, commercial overviews and assumptions behind the analysis provide context to the figures. While the primary purpose of the analysis was to determine the economic impact of the CRC's program, it also summarises the broader social, commercial and environmental benefits arising from the work. The MPBCRC's significant contributions to the training of agricultural researchers and educating the community about agricultural biotechnology are also highlighted. As many of the CRC's programs are still in progress, the analysis is based on pragmatic implementation scenarios that include an assessment of the probability of successful implementation.

The MPBCRC was established in 2003, following on from the success of the CRC for Molecular Plant Breeding (1996-2003). It is a cooperative venture combining government, universities, institutes and industry, focused on developing genetic marker and genetic engineering technologies relevant to the grain and pasture industries. The Centre focused on:

- long-term research and innovation to deliver sustainable development in Australian agriculture;
- the transfer of research outcomes into commercial products to benefit Australia;
- education of graduate researchers in order to ensure Australia's future in agriculture, and
- collaborations between researchers and industry to focus and capture intellectual property outcomes.

MPBCRC has been instrumental in advancing Australia's crop and pasture industries by developing and commercialising innovative molecular plant breeding technologies.

THE CHALLENGES

Demographers now project that the world's population will double during the next half century, from 5.3 billion people in 1990 to more than 9 billion by 2050 (Bongaarts 1994). Virtually all of this increase will occur in developing countries, with more than 50% of this population living in urban city environments (Lupien 2010). At the same time, growth in agricultural production has slowed down or become stagnant. With food production barely keeping up with consumption, there needs to be a strong commitment to developing the technologies required to increase food productivity across agricultural industries. It is estimated that agricultural production must grow by 70% to meet this demand (FAO 2010).

At present, major issues affecting the ability of farmers to produce an increasing global food supply include:

- dwindling water resources;
- loss of arable land;
- weather volatility;
- climate change;
- changes in methods of food production to produce processed foods and ingredients for animal feed;
- a reluctance of the market to accept new technologies such as the genetic modification of plants; and
- delays in technology investment and the resultant slowing of technology adoption and implementation.

These factors affect the predictability of supply and contribute to reduced productivity of food sources. The health and well-being of Australia's future population is strongly linked to the success of our agricultural industries which are in turn underpinned by the implementation of innovative solutions to address these challenges.

MPBCRC - SOLUTIONS

The MPBCRC programs will provide benefits to Australian growers and producers in three ways:

- decreases in the costs of production;
- increases in output (yield); and
- decreases in operational variability, leading to increased and more consistent profit.

The main beneficiaries will be cereal growers and dairy and beef producers. Consumers too, will benefit from more stable and resource-efficient production of food. Students and teachers benefit from the development and delivery of curriculum materials describing the application of these new molecular technologies, as well as job creation in agricultural and allied industries.

While this report is limited to examining the impact of CRC outputs on the cereal and pasture industries in Australia, many of the technologies will be relevant in other countries and could earn additional royalty income for Australia. However, the main focus of the CRC was on generating benefits for Australia no off-shore benefits have been included in this analysis.

The Molecular Plant Breeding CRC –

- *Laying the foundations for a sustainable farming future.*
- *Leading the conversion of genetic and molecular discoveries into innovative solutions, to deliver benefit to Australia's grain and pasture industries.*

PROGRESS MADE AND VALUE CREATED

This report focuses on eight projects which are broadly representative of the activities and contributions of the CRC to Australian agricultural and allied communities, under the research themes of transgenic and non-transgenic technologies and the outreach training and communication programs.

The main outcomes from the programs selected were:

Drought tolerant wheat – delivery of 28 experimental transgenic wheat lines containing genes for drought tolerance. Three field evaluations have been completed with yield improvements of 10-20% observed. This program has the potential to deliver a substantial return on investment.

High energy (high fructan) perennial ryegrass – consistently demonstrated higher plant sugar levels than the best non-transgenic commercial cultivars in the glasshouse and the field. The first product is primarily for use by the dairy industry and is due to be ready for commercialisation in 2018. This is expected to deliver improved pasture quality, cow productivity and ultimately farm gate returns.

High digestibility (low lignin) forages – will be easier for animals to digest. In this way the plants will deliver higher unit food values which is expected to produce faster weight gain and lower animal methane emissions. Although still at experimental stage, the technology is being applied to a range of forage species and holds a solid cost-benefit advantage that will be of interest to beef and sheep producers across a number of climatic regions.

Salt-tolerant germplasm – With 83% of cropping land in Australia at risk of salinity stress, salt-tolerant varieties will be important to sustaining higher yields. The parts of the genomes of both wheat and barley that are associated with salt tolerance have been identified and markers associated with good performance have been found and trialled. Experimental salt tolerant germplasm appears to increase biomass by 10%.

Genetic markers and breeding strategies– are expected to make a substantial contribution to the rate of productivity growth in the cereal industry. The databases and algorithms developed by this program are used extensively by researchers and commercial breeders Rather than assess individual markers this analysis assess the collection of markers as a package.

Molecular markers for pasture improvement – Pasture improvement has historically attracted less investment than cereals and yet is of major importance to livestock industries. Major opportunities exist for cultivar improvement and marker assisted breeding has the potential to substantially accelerate yield improvement and trait optimisation.

Training researchers - the MPBCRC has produced 43 graduates. Based on recent demographic analyses, the MPBCRC training program is expected to supply two-thirds of the industry demand for plant scientists and one-third of the demand for breeders between 2010 and 2015.

Community education programs - A broad range of education programs have been delivered to farmers, the metropolitan-community, students and teachers. The risk of community rejection of biotechnologies has reduced substantially from 80 to 20% during the period of the CRCs community outreach activities. Many factors contribute to community perceptions of the technologies and it is difficult to assess the impact of individual activities, however anecdotal evidence suggests that the MPBCRC programs provided a significant contribution to this change in perceptions.

The conclusion of the MPBCRC at the end of June 2010 marks the end of a 13 year journey in the development and application of genetic technologies focused on improving crops and addressing the key issues affecting crop production in Australian agriculture. In all, the Commonwealth Government, the participant institutions and numerous commercial partners contributed a total investment (cash and in-kind) of $240 million ($80 million in the first CRC and $160 million in MPBCRC). With a collaborative research effort of this scale, it would be impractical to conduct a comprehensive EIA comprising every single project from the MPBCRC program. The eight projects included in this analysis are broadly representative of the CRC's efforts and account for approximately 50% of its cash and in-kind expenditure over its seven year tenure. This analysis is intended to indicate the likely return on investment from its leading research programs. It is important to note that some projects were excluded from this EIA for the simple reason that not every project can be included with the finite resources available. Exclusion from this analysis does not imply a lack of merit.

Due to the time required to implement and deploy CRC outputs into new plant varieties, many assumptions have been made, particularly relating to the prospects for successful commercialisation, the magnitude of the benefit delivered and rate of adoption by farmers. These assumptions are conservative and take into consideration normal agricultural practices. They are described in detail in the analysis section of each project.

As many of these programs are still in development they will be continued with existing partners, as per below:

- Development of MPB germplasm – AGT Pty. Ltd., InterGrain Pty. Ltd., LongReach Plant Breeders Pty. Ltd., University of Adelaide, CIMMYT;
- Get into Genes education program – Diary Futures CRC, Australian Centre for Plant Functional Genomics;
- Ryegrass improvement – Gramina Pty. Ltd., PGG Wrightson Ltd., DPI Vic and Dairy Futures CRC;
- Salt tolerance program – SARDI, University of Adelaide; and
- Wheat program – DPI Vic and BASF Plant Science.

Based on this analysis and assuming its new technologies are adopted in the manner described below, the MPBCRC research will potentially deliver over $439 million in economic improvement to Australian agriculture.

1 ORIGINS OF THE MPBCRC

The primary focus of the MPBCRC has been to:

- *Enhance collaboration among researchers and industry;*
- *Capture and deploy intellectual property resources more effectively;*
- *Establish, develop and undertake world-class, high quality, industry focused research programs in molecular breeding for cereals and pastures;*
- *Commercialise products of CRC research for the benefit of Australia and broader global communities, providing return on investment;*
- *Attract and train excellent plant breeders and agricultural researchers;*
- *Foster relationships between participants and grow and leverage each participant's contributions; and*
- *Promote MPBCRC's profile as a global leader in the agricultural sector.*

The MPBCRC has led the conversion of genetic and molecular discoveries into innovative solutions, to deliver benefit to Australia's grain and pasture industries.

The CRC commenced in 2003 with funding for seven years under the Cooperative Research Centre Program by the Commonwealth Government. The MPBCRC built on the success of the first CRC for Molecular Plant Breeding (CRCMPB) that operated from 1996 to 2003.

The focus of the MPBCRC has been in the development of molecular marker and genetic engineering technologies, relevant to cereals such as wheat and barley, and pastures such as perennial ryegrass and clover. The centre also focused on commercialisation and the process of bringing technologies to the market for maximum benefit.

The Centre's core objectives were to enhance:

- the contribution of long-term scientific and technological research and innovation to Australia's sustainable economic and social development;
- the transfer of research into commercial or other outcomes of economic, environmental or social benefit to Australia;
- the value to Australia of graduate researchers, and

- collaboration among researchers, between researchers and industry, and to improve efficiency in the use of intellectual property and other research outcomes.

These broad objectives have been condensed into two major research themes: transgenic and non-transgenic approaches, as well as two outreach programs in education and communications.

The MPBCRC is a cooperative venture between:

- Department of Primary Industries, Victoria (DPI Vic);
- The University of Adelaide;
- South Australian Research and Development Institute (SARDI);
- The Western Australian Agriculture Authority [formerly the Department of Agriculture and Food, Western Australia (DAFWA)];
- Murdoch University, WA; and
- International Maize and Wheat Improvement Centre, Mexico (CIMMYT).

Technologies developed by the centre are delivered to market through partnerships between the CRC's commercialisation company, Molecular Plant Breeding Pty Ltd, and a range of commercial partners. Delivery of the products will be via breeding organisations, seed companies and marketing companies. The Centre also holds strategic relationships with functional genomics groups worldwide to provide access to genes and allied technologies.

> *A vision to see Australia's crop and pasture industries underpinned by innovation in molecular plant breeding.*

The Beginnings - CRC Molecular Plant Breeding

The original CRCMPB operated from 1996 – 2003. It sought to apply the developing molecular biology tools to the cereal and pasture grass industries. Initially, the CRCMPB set out with four main objectives:

- To improve resistance to plant diseases;
- Improve the flour performance of Australian wheat, the malting characteristics of Australian barley and the nutritional value of Australian pastures;
- Develop genetic markers for controlling resistance to seven major plant stresses, efficiency of breeding, plant root health and product quality, and

- Develop new tools for efficient breeding of wheat, barley and pasture grasses, and implement these into each major area of production.

This was a large task and the CRCMPB finally focused on two areas – the discovery of genes and genetic makers in cereals and in pastures.

The establishment of the new MPBCRC in 2003 took these molecular genetics tools and insights from the initial CRCMPB and implemented them in commercial partnerships with seed companies, international agribusinesses, and cereal and pasture breeding programs.

The role of Cooperative Research Centres (CRC)

Cooperative Research Centres are an initiative of the Commonwealth Government intended to foster collaborative links between industry, research organisations, educational institutions and government organisations.

The focus of the CRC program is to address major challenges that require medium to long-term collaborative efforts. A primary goal was to link researchers with industry and focus research and development efforts towards industry and community needs. The program also strongly emphasised education and the need to produce industry-ready graduates.

The program commenced in 1990 and to date 168 Cooperative Research Centres have been formed. In 2010, there are 48 CRCs operating in six sectors covering: environment, agriculture and rural-based manufacturing, information and communication technology, mining and energy, medical science and technology, and manufacturing technology.

Further information on the CRC program is available at www.crc.gov.au

PART 1 – THE CHALLENGES TO BE ADDRESSED

2 CURRENT GLOBAL CHALLENGES - THE ECONOMIC AND INDUSTRY CONTEXT

- *World population will rise to at least 9.1 billion people by 2050.*
- *Global agricultural production must grow 70% by 2050.*
- *Consumption of meat is expected to increase, leading to an increase in pasture and cereal demand.*
- *Even in good years food production does not exceed consumption by a significant margin.*
- *Additional pressure on food production is anticipated from demand for biofuels.*
- *As well as yield/hectare, other traits such as drought tolerance and pest resistance are important for food production reliability.*
- *Biotechnology has the potential to deliver outcomes that are not accessible through conventional plant breeding.*

2.1 GLOBAL FOOD CRISIS

A growing demand

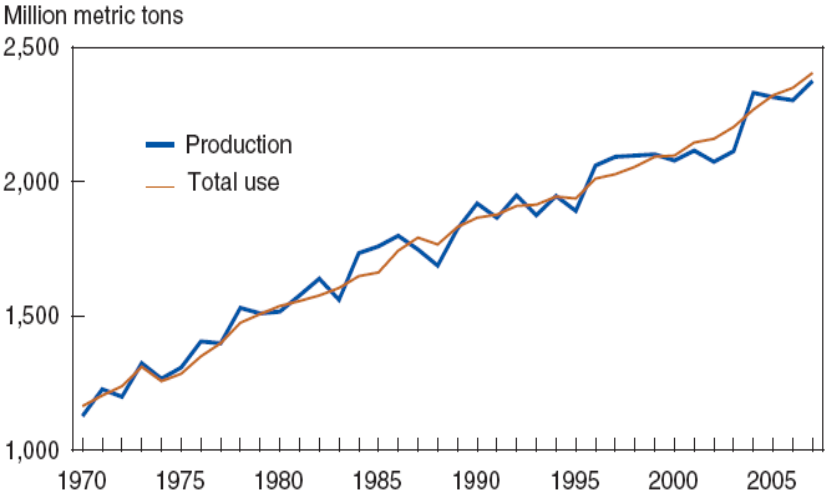
World population is expected to rise to 9.1 billion by 2050, an increase of 34% over the population in 2009 (UN 2009a) and so demand for agricultural commodities is expected to rise steadily over time. Options for increasing land under cultivation are very limited and consequently agriculture is under pressure to increase its productivity at least at the same rate.

Increasing incomes in developing countries are expected to increase consumption overall, and particularly consumption of meat. As the demand for meat increases there will be a substantial increase in cereal demand (due to the need in the northern hemisphere for 7 kg of grain to produce 1kg of beef) (Leibtag 2008). Additional pressure on grain production is anticipated from biofuel producers. The US production of biofuels was forecast to quadruple by 2022 (US Congress Renewable Fuels, Consumer Protection, and Energy Efficiency Act of 2007).

Seven out of the last eight years has seen production lag consumption (USDA 2007).

Between 1998 and 2007, seven of the last nine years saw global food production lag consumption (Figure 1). This has lead to a sharp decline in food stocks worldwide. At the end of 2008/09 the cereal stocks-to-use ratio remained its second lowest in three decades (FAO 2010a). According to the Food & Agriculture Organisation (FAO) the number of undernourished people in the world reached 963 million in 2008 (FAO 2008a).

Figure 1 Total world grain and oilseeds



Source: USDA PS&D Database.

Currently supply responses are restricted by:

- Arable land being converted to other uses such as urbanisation, industrialisation, forestry and biofuel production;
- Desertification and land degradation (nearly one third of the world's crop land has become unproductive and abandoned in the past 40 years) (UN 2009b);
- Productivity growth slowing: reduced from 2.0% in 1970-90 to 1.1% in 1990-2007 (US Department of Agriculture);
- Water shortages and more volatile weather effecting supply predictability, and
- Resistance to deployment of GM technologies for certain crops in certain regions.

Global agricultural production must grow 70 percent by 2050 (FAO, 2010).

2.2 AN AUSTRALIAN PERSPECTIVE -AGRICULTURAL PRODUCTION & PRODUCTIVITY

Whilst agriculture has been overtaken by mining in recent years in terms of economic scale, we cannot eat iron ore, and national and global demands on food require ongoing development of Australia’s agricultural sector.

The MPBCRC focused primarily on cereal and pasture production servicing the following sectors:

- Wheat,
- Barley,
- Dairy,
- Beef and Sheep.

WHEAT INDUSTRY

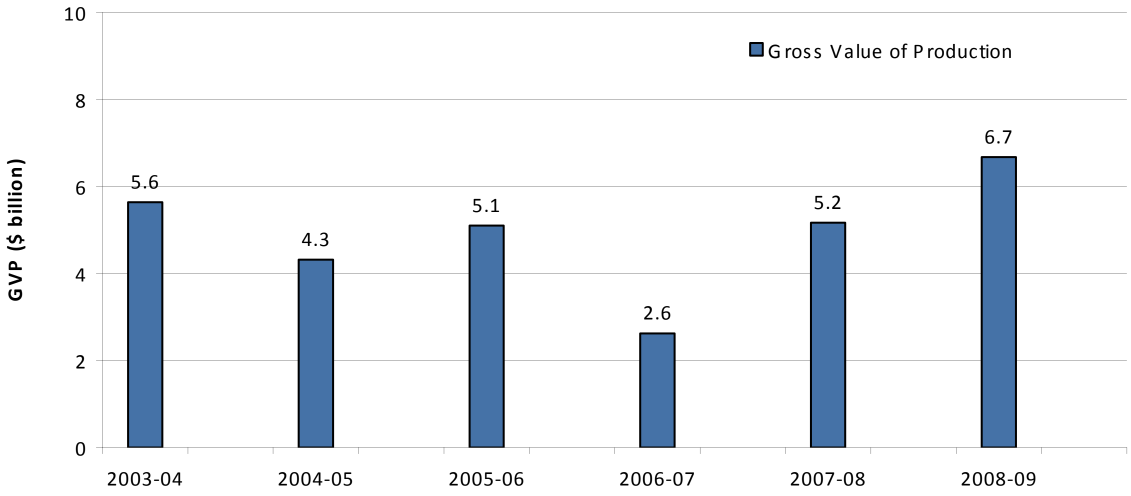
Wheat is the largest grain crop in Australia. Most wheat varieties grown in Australia are sown in autumn, grow rapidly during the spring months and mature from early to mid-summer. The wide geographical spread of wheat growing areas means that growers are subject to differing climatic conditions and soil types and so require a considerable range of adapted varieties.

Global wheat consumption in 2008-09 reached a record 651 million tonnes. This is 27 million tonnes above the previous record in 2005-06 and 37 million tonnes more than last season (ABARE 2008). Australia produces approximately 20 million tonnes per year.

> *ABARE estimates if Australia as a whole forgoes new genetically modified wheat and canola varieties it could lop $918 million a year off its Gross National Product in a fiercely competitive world market by 2018 (Finkel 2008).*

The value of annual wheat production in Australia is shown in Figure 2. Since 1990/91, seventy-five percent of Australia’s total wheat production has been exported. Between 2003/04 and 2007/08 Australia has been the third largest exporter of wheat behind the US and Canada.

Figure 2 **Gross value of wheat production (2003-04 to 2008-09)**



Source: ABARE (2009).

BARLEY INDUSTRY

Barley is an important grain industry in Australia, second in production only to wheat. It is an integral part of farm cropping systems due to its high yields, timeliness of on-farm activities, and rotational benefits to break leaf and root disease cycles.

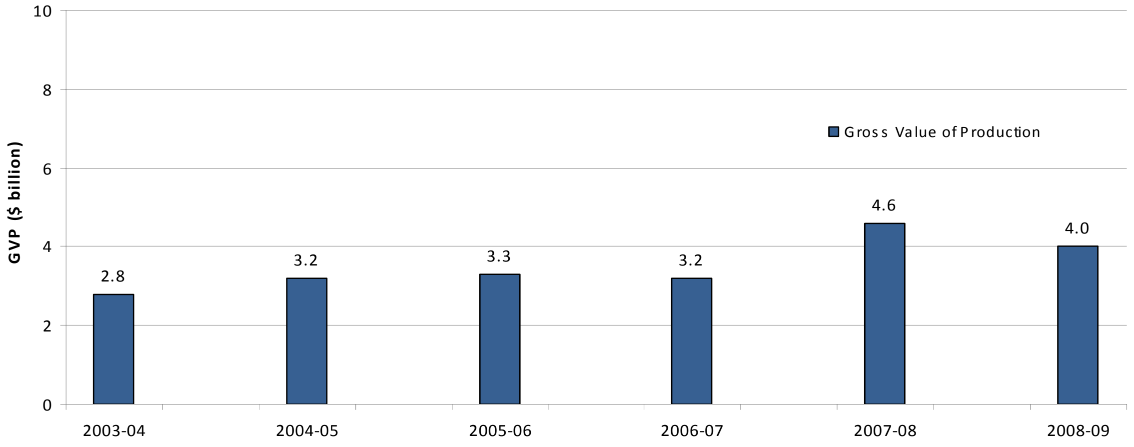
Annual production averages approximately 6.6 million tonnes per year (ABARE 2010). It is a widely grown crop occupying a large geographic area – almost 4 million hectares, dispersed from Western Australia to southern Queensland (Barley Australia 2009).

Australia produces around 2.5 million metric tonnes of malting barley and 4.1 million metric tonnes of feed barley. Malting barley can attract a price premium of $30-40 per tonne over feed barley. Australia’s average malting selection rate is the highest of the world’s exporting nations, with around 35-40% selected as malt. Domestically, malting barley demand is around 850,000 tonnes per year and Australian domestic feed use is around 2 million tonnes each year.

THE DAIRY INDUSTRY

The dairy industry is Australia’s third largest rural industry behind beef and wheat. It generates over 9,388 million litres and $4.0 billion in value each year (2008/09 figures, Dairy Australia 2009)(Figure 3). Improvements in farm productivity assist in the growth of milk production.

Figure 3 Gross value of dairy production (2004/05 to 2008-09)



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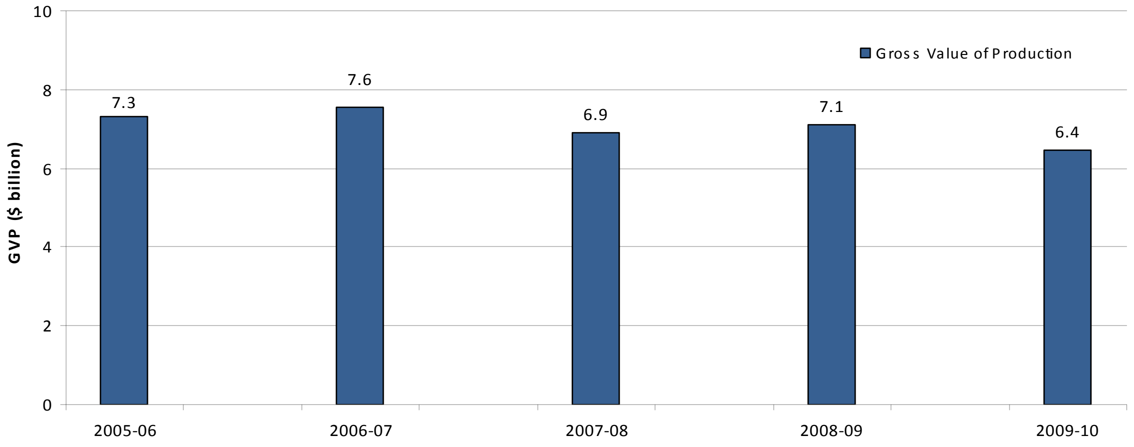
ource: ABARE (2009).

THE BEEF INDUSTRY

Australia is the world's second largest exporter of beef. The beef industry plays a vital role in Australia's agricultural economy as a major contributor to exports and in the use of cereals for feedlots. The Beef Industry's gross value of production is approximately $8 billion (Figure 4). The direct contribution of the export of beef and live cattle to Gross Domestic Product is approximately 1% (MLA 2009).

Australia produces almost 2.1 million tonnes of beef and veal, exporting 67% of production to over 100 countries (2008/09). Beef contributes 17% of total Australian farm exports, making it the most valuable farm export in 2008-09.

Figure 4 Gross value of beef production (2005/06 to 2009-10)



Source: ABARE (2009).

The red meat industry also includes a large sheep and lamb slaughter industry that would benefit from improved pasture varieties. Over the past five years the gross value of this sector has averaged $1.7 billion annually (ABARE 2009).

An insight into increasing yield and profitability in Australian crop agriculture are provided in Appendix 1.

PART 2 - MPBCRC'S RESPONSES TO THESE CHALLENGES

3 ASSESSING THE MPBCRC IMPACT

MPBCRC projects are anticipated to impact crop productivity and the farming community in two ways:

- by delivering once off increases in cropping productivity, and
- by increasing the rate at which cropping productivity improvements will be delivered in the future.

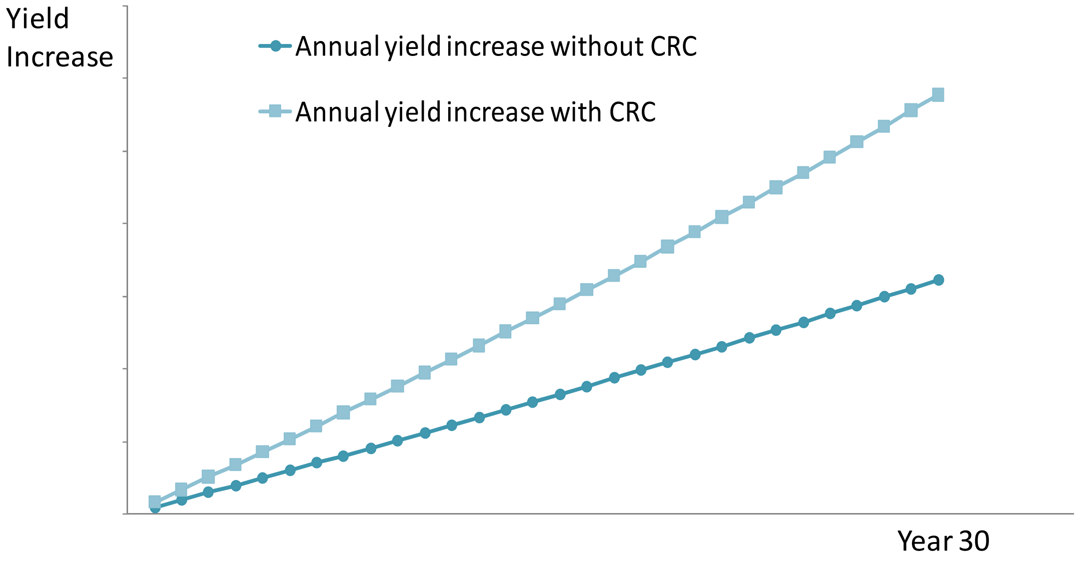
Outputs from the MPBCRC are diverse and include: industry & academic publications, international patents, field trials, products, training packages, PhD student completions, engagement with SME's, and engagement with international partners. The majority of MPBCRC outputs are used by pre-breeding research and commercial breeders leading to new varieties that can be adopted by growers.

For many of the MPBCRC's projects, the intended benefit is an increase in yield for Australian growers. This has been delivered either as:

- a once off yield improvement (for example by deploying a genetic event that boosts crop yield by 10%); or
- improved farm productivity, (for example by an additional 1% per year over and above the existing 1% per year) by improving the efficiency of breeding programs. This enables breeders to increase the rate of yield improvement through the varieties they release.

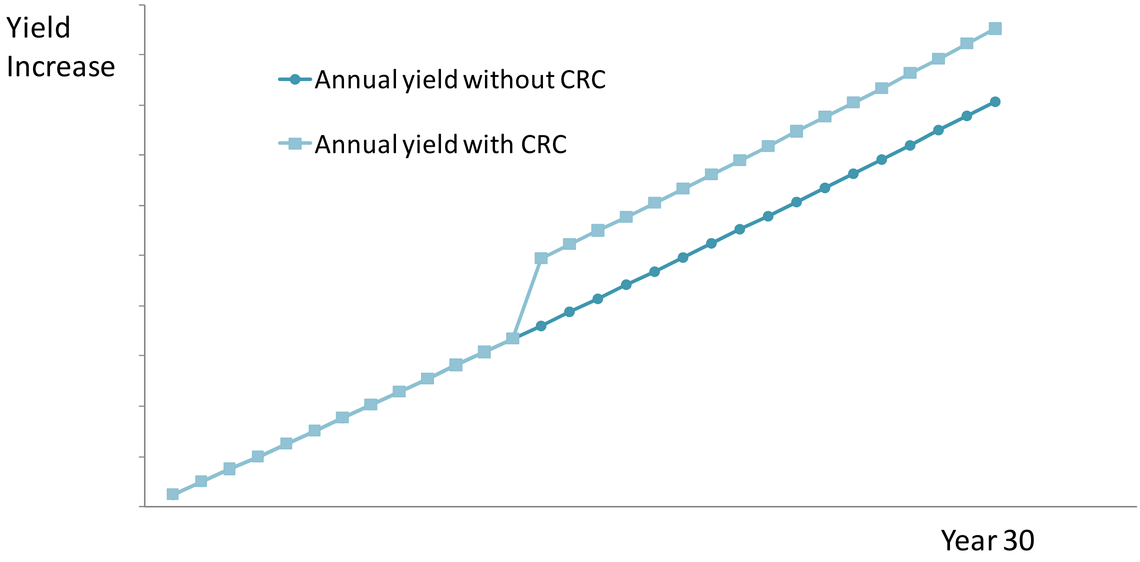
Figure 5 and Figure 6 illustrate these two effects on the rate of yield improvement. Conventional breeding improvements are likely to gradually improve the rate of yield improvement in an incremental way.

Figure 5 Yield outcome from improved breeding conventional breeding efficiency



A GM event is assumed to enable a significant step in the yield as new varieties based on these technologies are released.

Figure 6 Yield outcome from introduction of a GM event



Assessment of the impact and value of new molecular breeding technologies requires an appraisal of technical merit or process improvement, and also the measurement or estimation of the extent of adoption of each new technology. This provides an indication of the permanent gain it provides to growers and its life span.

3.1 THE SCOPE OF THE PROGRAMS

PROGRAM 1: TRANSGENIC TECHNOLOGIES

The analysis considered three outputs for the Transgenic Technologies program.

- *Drought Tolerant Wheat*
- *High Energy (High Fructan) perennial ryegrass*
- *High Digestibility (Low Lignin) forages for temperate and tropical regions*

Table 1 Key Transgenic Technology Outputs

Product	Usage	Comment
Transgenic Cereal Outputs		
Drought Tolerant Wheat	Wheat farmers	33% of growing seasons have below average rainfall. MPBCRC's drought-tolerant technology could increase yields in these years by 10 to 20%.
Transgenic Forage Outputs		
High Fructan (High Energy) perennial ryegrass	Pastoral industries – mainly dairy, but also beef, sheep	Higher nutritive quality leading to increased productivity in the range of 10 to 20% higher farm gate gross value.
Low Lignin (High Digestibility) forages for temperate and tropical regions	Pastoral industries – mainly, beef, sheep, but also dairy	Improved herbage quality leading to increased productivity in the range of 10 to 20% higher farm gate gross value.

PROGRAM 2: NON-TRANSGENIC TECHNOLOGIES

Three outputs from the Non-transgenic technologies program were assessed.

- *Salt-tolerant germplasm*
- *Genetic markers and breeding strategies*
- *Molecular markers in pasture plant improvement*

Table 2 Non-transgenic Technology Outputs

Product	Usage	Comment
Non-transgenic Outputs		
Salt-tolerant wheat and barley germplasm	Cereal farmers on salt affected land	83% of Australian cropping land is affected by elevated surface salt levels. Salt tolerant varieties could increase the available yield on some of this area.
Genetic markers and breeding strategies	Breeders	Trait and genomic markers have been developed for use in the wheat and barley breeding programs. Technologies (MRT, TSP, ddSNP etc) have been developed to facilitate marker usage by researchers and breeders.
Molecular markers in pasture plant improvement	Breeders	Genetic improvement in pasture plants is designed to increase the profitability of the livestock enterprise through increasing the productivity and quality of the sward.

PROGRAM 3: EDUCATION AND TRAINING

The education and training program played a key role in attracting and training new recruits to plant science. Two outputs from the Education and Training Program were assessed.

- Trained Researchers (PhDs)
- Community education programs

Table 3 Education and Training Outputs

Product	Usage	Comment
Trained researchers (PhDs)	Pre-breeders and breeders	According to industry demographics 50% of the Australian plant researcher and breeder community is over 50 years of age (Agri-business Consultants 2006). The ability of Australia to remain competitive in this industry is dependent on this community being replenished.
Community education programs	Schools and the wider community	Plays an important role in the overall effort to gain community acceptance and understanding of biotechnology and genetic modification.

4 THE BENEFITS OF MPBCRC PROGRAMS - ANALYSIS OF PROJECTS

4.1 OUTPUT 1: DROUGHT TOLERANT WHEAT

Project **Drought Tolerant Genetically Modified Wheat**

Assessment of candidate genes for drought tolerance (improved water use efficiency) in transgenic wheat.

- *Drought is a prevalent problem in Australian agriculture and has a major impact on crop yields.*
- *Conventional breeding has made little progress in offsetting this impact and the international agribiotech firms have in the past been generally focused on other crops and priority areas. Therefore, this research by MPBCRC was unique and highly valued by Australian farmers.*
- *The program delivered 28 experimental transgenic wheat lines containing candidate genes for drought tolerance.*
- *Three 'proof of concept' field evaluations have been completed. Some transformed plants demonstrated yield improvements under drought conditions of 10 to 20% compared to untransformed control plants.*
- *Due to the prevalence of drought, even a modest average yield improvement of 3.8% delivers a substantial return on investment (ROI) – 8.6 : 1 and an NPV per dollar invested of $12.85.*
- *Even if adoption is slower than expected, ROI is still substantial at 5.1 : 1.*

Background Every time a farmer plants a crop of wheat in Australia, there is a 50% chance that the crop will be subjected to water stress. This results in average annual losses of over $200 million. This program focused on increasing wheat productivity under water stress.

The program produced a variety of transgenic wheat plants expressing different candidate genes for drought tolerance. The candidate genes for drought tolerance are derived from maize, thale cress, a moss and yeast. 'Proof of concept' trials evaluated the agronomic performance, including yield, of the transgenic wheat lines under rain-fed, drought-prone conditions.

The program partner was BASF Plant Science. It is noteworthy that during the earlier life of the MPBCRC (from 2003 to 2008), the major international agribusinesses had moved away from investing in biotech wheat and the collaborative program conducted by BASF Plant Science and the CRC stood out as one of very few examples of a major strategic investment in the development of GM wheat. Alternative developments by other players is likely to be many (>>10) years away. Recent developments in 2009 and 2010 have seen a number of major international agribusinesses, including Monsanto and Dupont Pioneer, starting to invest in GM wheat again but this does not detract from the leading position established by the MPBCRC and BASF Plant Science.

Apart from several very recent releases, conventional wheat breeding programs have been attempting to develop drought-tolerant wheat for over 40 years with relatively little progress.

The transgenic approach taken by MPBCRC presents a potential solution to the difficult and complex problem of efficient water use. Monsanto has a drought tolerant genetically modified (GM) corn in the regulatory approval phase, showing that GM technologies can provide a viable alternative to conventional breeding for drought tolerance.

This project is still at the experimental stage and so all benefit calculations are estimates.

Project cost $6,760,401

Outcomes **Productivity and economic returns will be obtained through the delivery of:**

- **Increased wheat plant productivity due to improvements in conversion of available moisture to grain during periods of below average rainfall,**
- **Improvement in average wheat yield per hectare resulting in better “farm gate” returns to the farmer and supply chain participants,**
- **Greater continuity of grain supply to exporters, millers and processors, and**
- **Potential to capture additional returns from export markets via technology royalties.**

Commercial plan	New transformants suitable for commercial use will be prepared, deregulated and licensed to breeders who will cross them with adapted germplasm. Progeny of these crosses will be screened and the best candidate(s) developed and released as a new cultivar for sale to growers.

Potential impact

Farmers growing grain crops in an arid or semi arid Mediterranean climate (30 – 35 % of the world's wheat area) routinely encounter drought during the grain filling period. Wheat varieties that demonstrate less of a yield deficit under water stress conditions will generate higher grain production and "farm gate" productivity in low rainfall seasons.

An estimate was made by the agricultural consultant SGA Solutions Pty Ltd, of the potential benefit of a drought tolerance trait based on an analysis of historical growing season rainfall, yield and price data and examining the correlation between below average yield of wheat and below average growing season rainfall.

> *The forecast yield improvement averaged across the national crop, over a 20 year period will be a one-off 3.8%.*

The adoption of this technology is anticipated to be rapid as all wheat growing areas would receive yield benefits in over 50% of years (assuming a one-off lift in yield potential) (Table 4).

An adoption profile of drought tolerant wheat is outlined in Figure 7.

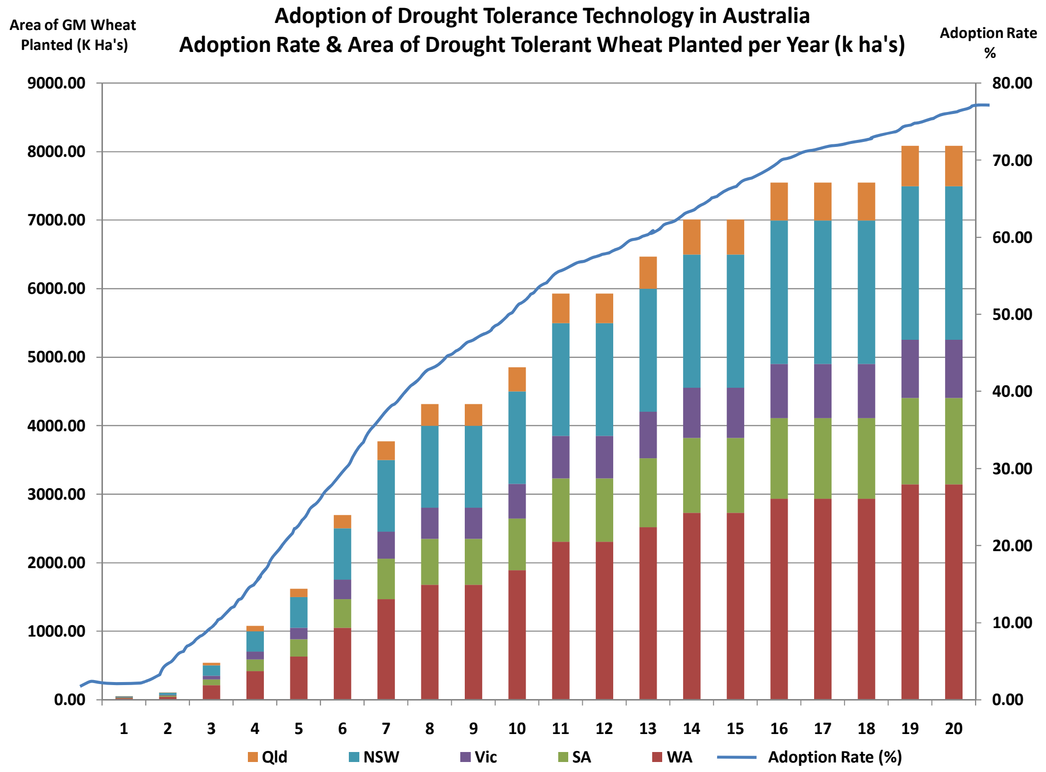
Table 4 Benefits of avoiding yield loss due to below average rainfall

State	Frequency of drought % years	Value of incremental wheat production due to the technology	
		K Mt	$m
WA	65.4	2,130	675.01
SA	57.7	839	268.73
Vic	50.0	703	221.76
NSW	65.4	1,782	567.91
Qld	61.5	372	118.37
Total		5,830	1,851.00

Source: SGA Solutions.

Note: A drought is defined as a year with below average rainfall in the growing season.

Figure 7 Expected adoption profile of drought tolerant wheat varieties



Source: SGA Solutions.

Key variables driving the program's net benefit are adoption rate and yield benefits. The discount rate also has a significant impact on outcomes, as benefits do not begin to appear until 2018.

COST BENEFIT ANALYSIS FOR DROUGHT TOLERANT WHEAT

Analysis Assumptions

Risk

- Three years of field trials demonstrated a yield increase in certain lines that is reproducible. We consider this as demonstrated proof of principle.
- Given residual regulatory and commercial risks, the likelihood of deployment of a variety from research has been set at 30%.

Successful commercialisation

- It is assumed that commercialisation (first sales of seed) occurs in 2018.

Impact

- The lift in average yield is assumed to be 3.8% as calculated by SGA Solutions.
- Commercialisation costs (including regulatory approval in Australia): $7.5 million.

Adoption

- There is no evidence of shortcomings in plant performance associated with the transformation. The novel trait can be crossed into all existing varieties and applied to all growing regions.
- Given that all areas of wheat production in Australia are vulnerable to drought, it is assumed that adoption will be extensive and relatively rapid. The genetic transformation will have to be crossed into a range of germplasm suited to different areas. The report assumes that the drought tolerant trait would be deployed in 80% of the Australian wheat crop over 20 years (ie. 4% per year). This is modeled on the introduction of the first semi-dwarf varieties in Australia derived from CIMMYT material. These introductions were released in 1973. Breeders released new and improved varieties regularly and by 2003, 193 varieties had been released in Australia incorporating CIMMYT genetic material (Brennan et. al. 2004).

Market Size

- Average Australian production of wheat: 19,409,600 tonnes per year.
- Value of wheat: $250 per tonne.

Figure 8 Output 1: Annual flow of net benefits over 30 years (undiscounted)

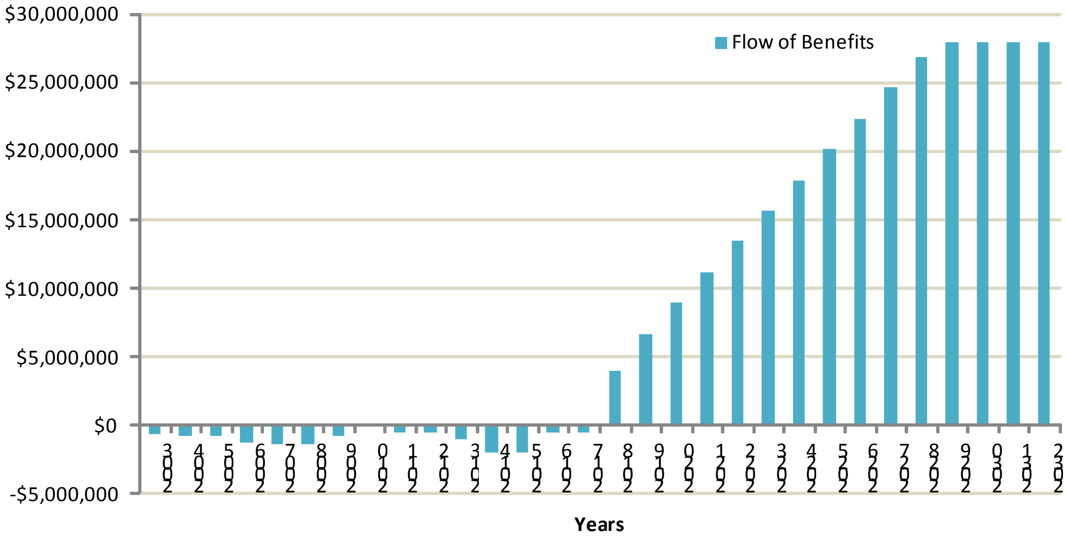


Table 5 Cost benefit outcomes for Drought Tolerant Wheat (30 year period)

Based on activities to date and associated benefits into future

Discount rate	5%	8%
Base case		
Present Value Benefits	$86,073,000	$43,914,000
Present Value Costs	$10,028,000	$8,193,000
PV CRC Costs	$5,918,000	$5,279,000
Net Present Value	$76,045,000	$35,721,000
Benefit / Cost ratio	**8.6**	5.4
NPV per $ invested by CRC	$12.85	$6.77
Sensitivity Testing NPV $ and BCR		
5% yield increase (instead of 3.8%)	$102,046,000 11.2	$48,987,000 7.0
2% yield increase (base case 3.8%)	$34,802,000 4.5	$14,679,000 2.8
2% annual adoption (base case 4%)	$40,752,000 5.1	$17,734,000 3.2
Delayed 5 years till 2023	$44,167,000 5.8	$19,061,000 3.6

After the wind up of the MPBCRC, DPI Victoria will continue to invest in research relating to drought-tolerant GM wheat and BASF Plant Science has recently announced an expansion of their collaboration with Monsanto into GM wheat.

4.2 OUTPUT 2: HIGH ENERGY (HIGH FRUCTAN) PERENNIAL RYEGRASS

Project **Genetically Modified (GM) Perennial Ryegrass** with increased fructan biosynthesis for use by the dairy, beef and sheep industries.

- *MPBCRC conducted Australia's first, and the world's largest, field trials for GM perennial ryegrass and tall fescue.*
- *Field evaluation trials achieved consistently higher fructan levels than the best commercial cultivars.*
- *Commercialisation is likely to deliver improved pasture and dairy cow productivity, in terms of quality, quantity and farm gate returns.*
- *Conventional plant breeding would require an additional 3-5 years of work into improvement of fructan levels to achieve approximately 30-50% of the levels achieved in this program.*
- *A MPBCRC product from the genetically modified technologies is expected to be ready for commercialisation in 2016.*
- *A substantial return of 7.3 : 1 to be achieved from the primary application to the dairy industry (benefits for pasture intensive livestock sectors were not included in the calculation).*
- *Adoption from planned animal grazing trials is expected to be faster than the assumption used in this analysis.*

Background Pastures that are fast to digest will aid energy and nutritive value uptake for livestock. This improves volume, quality and continuity of milk and meat supply. Fructan is a natural sugar produced by forage grasses and an important component in the nutrition and productivity of grazing animals, especially dairy cattle.

MPBCRC produced transgenic perennial ryegrass plants with increased fructan levels and evaluated their agronomic performance under field conditions. Strategic Bovine Services modelled the potential impact of increased fructan levels and found that milk production could increase both within and across lactations by approximately 20% assuming a constant stocking density (cows/hectare) (SGA Solutions).

By comparison with the GM approach deployed in this project, it is estimated that conventional plant breeding could at best aspire to produce 30-50% of the fructan levels achieved in this project and require a further 3 – 5 years of development work to do so.

Project cost $13,878,291

Outcomes

- **Consistently higher fructan levels than the best available commercial cultivars were achieved from perennial ryegrass in the proof-of-concept field evaluation trials.**
- **Development of technical data for inclusion in the biosafety regulatory package required for regulatory approval.**
- **Crosses performed between the best performing transgenic lines and elite breeder germplasm for the development of final cultivars.**
- **Generation of transgenic plants which can be submitted to regulators (OGTR in Australia) for approval to release.**

Productivity and economic returns will be obtained through the delivery of:

- **Improved pasture productivity in terms of quantity and quality, leading to improvements in dairy cow conversion of grass to milk;**
- **Improved dairy cow productivity throughout the growing season resulting in better "farm gate" returns to the farmer;**
- **Improved volume and continuity of milk supply to dairy processors, and**
- **An unquantified potential for foreign earnings from export markets via technology royalties that has not been included in this analysis.**

Commercial plan Transgenic cultivars will be further developed by forage seed breeding companies and marketed to farmers (principally dairy) in relevant climatic regions. This will firstly be in Australia, and subsequently in South America and possibly other countries, where perennial ryegrass cultivars provide the feed base for milk production.

Potential Impact The expected increase in available metabolisable energy (+2.0 Mj/ Kg Dry Matter) will generate the following benefits:

- Milk production – increased milk production within and across lactations (estimated by Strategic Bovine Services to be +6 lt/cow/day = + 19.6% at constant stocking density (cows/hectare)).
- Fodder production – increased quantity and quality of stored hay and silage.

- Reduced use of grain, concentrates and irrigation water.
- Pasture production – increased biomass available and longer pasture life-cycle.
- Increased volume of product available and continuity of supply for the milk processing industry.

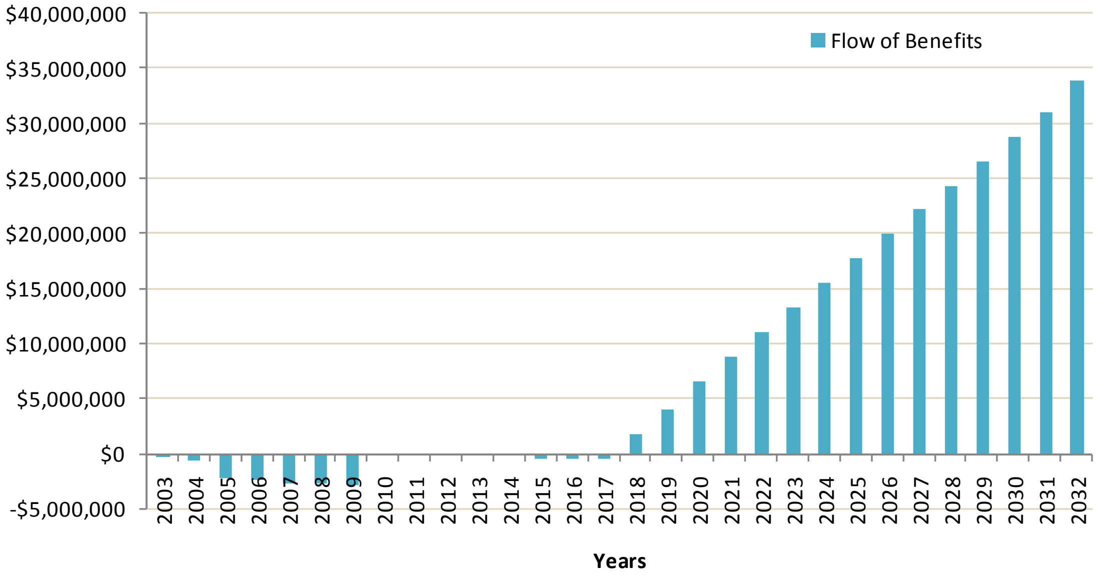
> *Benefits to the Australian sheep and beef industries from productivity improvements in meat and wool production are estimated to be an additional $208 million.*

The first product from this project is expected to be ready for commercialisation in 2018.

COST BENEFIT ANALYSIS FOR HIGH ENERGY PERENNIAL RYEGRASS

The key variables that drive value of the program net benefit are adoption rate and the increase in milk production per hectare.

Figure 9 Output 2: Annual flow of net benefits over 30 years (undiscounted)



> *Small changes to improve nutrition can greatly increase animal performance. A 6% unit increase in digestibility can result in a 27% increase in summer milk production. This could translate to millions of dollars in benefits to the dairy industry.*

Analysis Assumptions

Risk

- Given the residual regulatory and animal performance risk, the likelihood of deployment of a variety from research has been set at 70%.

Successful commercialisation

- Three years of field trials demonstrate high levels of fructan production by transgenic plants. It is assumed that successful commercialisation (first seed sales) will be achieved in 2018.

Impact

- The increase in Australian dairy industry "farm gate" productivity is estimated to be approximately $3.3 billion in Australia (including 2.5 billion in Victoria) for the 2014 to 2030 period (calculated by SGA solutions).
- Commercialisation costs (including regulatory approval in Australia): $7.9 million.
- Increase in milk production and revenue assumed to be 20%.

Adoption

- The analysis assumes the maximum adoption level of high energy perennial ryegrass varieties will reach 80% of dairy pastures within 20 years.

Market Size

- Average Australian dairy gross value of production: $3.3 billion
- Percentage of milk production based in perennial ryegrass pastures: 40%
- Benefits to beef and sheep industries not included in analysis.
- The potential royalty income from overseas markets is not included.

Table 6 Cost benefit outcomes for High Energy Perennial Ryegrass (30 year period)

Discount rate	5%	8%
Base case		
Base case 20% production increase		
Present Value Benefits ($)	$105,929,000	$53,184,000
Present Value Costs	$14,504,000	$11,927,000
PV CRC Costs ($)	$10,997,000	$9,643,000
Net Present Value ($)	$91,425,000	$41,257,000
Benefit / Cost ratio	**7.3**	4.5
NPV per $ invested by CRC ($)	8.31	4.28
Sensitivity Testing NPV $ and BCR		
10% production increase	$38,518,0003.7	$14,690,000 2.2

This program will continue after the wind up of the MPBCRC through Gramina Pty. Ltd., the PGG Wrightson Group Companies (PGG Wrightson Genomics and PGG Wrightson Seeds), DPI Vic and its commercialisation arm Agriculture Victoria Services Pty. Ltd., and the Dairy Futures CRC.

4.3 OUTPUT 3: HIGH DIGESTIBILITY (LOW LIGNIN) FORAGES - TEMPERATE & TROPICAL

Project	**Designer grasses -** Low lignin technology in Fescue, Paspalum and Brachiaria species for use in beef and sheep production.

- *High digestibility forages are expected to increase meat production and potentially reduce livestock methane emissions.*
- *The forages are applicable to a wide range of species from tropical, subtropical and temperate regions.*
- *Given the potential applications in sub-tropical pastoral agriculture, the products are likely to have significant offshore interest.*
- *Return on investment is significant and beneficial (1.2 : 1) even based on modest assumptions of meat yield and product adoption.*

Background

Indigestibility is a key impediment to grazing animals extracting nutrition from herbage and is predominantly due to the plant material, lignin. This program addresses the lignin production in key forage species to improve their digestibility and available energy for livestock production. Improving the digestability of forages therefore has potential to raise beef and sheep meat productivity. The technology developed in this project can be applied to a wide range of grass types and so could benefit numerous regions.

This project is still at the experimental stage and so all benefit calculations are estimates.

Project cost $13,966,507

Outcomes

The production of transgenic cultivars with reduced levels of certain stem lignins will increase digestibility and metabolisable energy (est +1.0MJ ME / Kg DM per hectare) and will generate the following benefits:

- **An increase in the nutritional value of the available dry matter Increased meat and wool production per hectare;**
- **Reduced production inputs through reduced use of grain and stored fodder.**

Commercial plan

The resulting cultivars will benefit beef and sheep producers in tropical, sub-tropical and semi-dry Mediterranean climatic regions of Australia, New Zealand, and North and South America. Managed pastures of tall fescue, paspalum and brachiaria cultivars provide the feed base for livestock production in these regions.

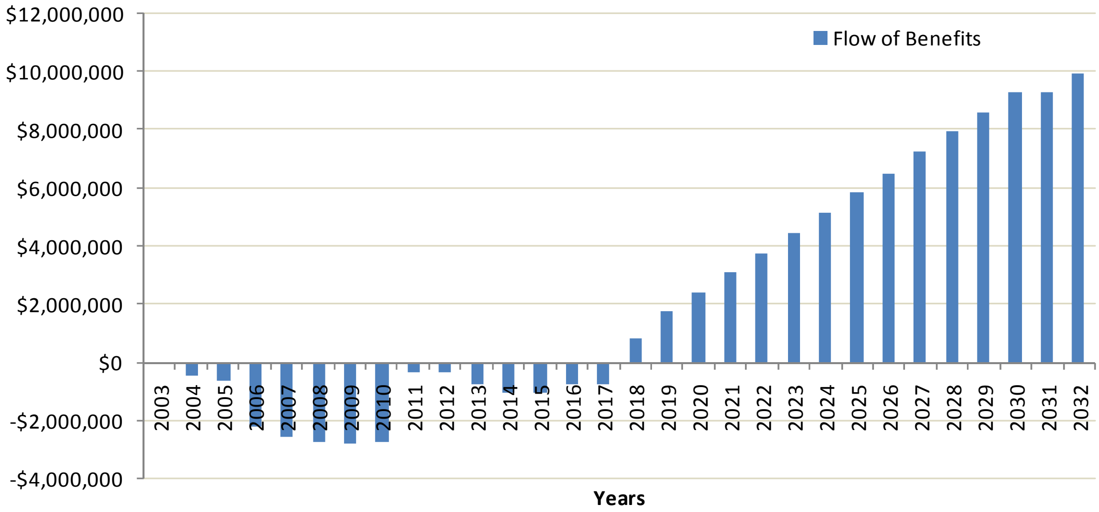
Potential impact

The proposed improvements to the nutritional value of forage pastures from the MPBCRC tall fescue program are forecast to substantially increase beef and sheep industry “farm gate” productivity.

Productivity and economic returns will be obtained through the delivery of:

- Improved pasture productivity in terms of quality (+1.0 Mj ME/Kg DM) leading to gains in sheep and beef cattle conversion of grass to wool and meat;
- Improved sheep and beef productivity (ie. live weight gain) on a per head (Prime Lamb +20.83% & Steer +23.87%) and per hectare basis throughout the growing season. This will result in improved “farm gate” returns to the farmer and supply chain participants.

Figure 10 Output 3: Annual flow of net benefits over 30 years (undiscounted)



The key variables that drive the value of the program net benefit are adoption rate and animal productivity. The adoption rate in particular is critical.

COST BENEFIT ANALYSIS FOR HIGH DIGESTIBILITY FORAGES

Analysis Assumptions

Risk

- New events in tall fescue and other species are now in development after initial trials on tall fescue were unsuccessful. It is possible that these new species will also be unsuccessful.
- The likelihood of deployment of at least one variety from research that displays a +1.0 Mj ME/Kg DM improvement has been set at 70%.

Successful commercialisation

- It is anticipated that commercialisation will commence with the first low lignin cultivar in 2017 and proceed with new cultivars in additional forage species in 2019 and 2020.

Impact

- Increase in meat production and associated farm gate revenue if implemented across 40% of the potential pasture area is $19 million per annum.
- Commercialisation costs for forages are assumed to be $7.9 million, including Australian regulatory approval.

Adoption

- Tall fescue is principally found from southern Queensland, through the tablelands and upper slopes of New South Wales, as well as in Victoria, parts of Tasmania, South Australia and Western Australia (NSW Agriculture 2003).

- It is estimated that 15% of the cattle industry and 20% of the sheep meat industry are grazed on tall fescue based pastures. Adoption of the variety is assumed to be 40% of these pastures over 30 years.
- Percentage of production based in pastures in which the technology could be deployed is approximately 5%.

Market size

- Cattle numbers are currently around 24.5 million, with Queensland accounting for 42% of total meat cattle numbers (ABS, 2010).
- Total sheep and lamb numbers have declined from 115 million in 1999 to less than 72 million in 2008-2009. Victoria now accounts for 38% of total sheep and lamb numbers.
- Average Australian red meat gross value of production: $8.7 billion.

Table 7 Cost benefit outcomes for High Digestibility Forages (30 year period)

Discount rate	5%	8%
***Base case** 5% profit increase*		
Present Value Benefits ($)	$26,856,000	$13,635,000
Present Value Costs ($)	$14,324,000	$11,514,000
PV CRC Costs ($)	$10,541,000	$8,986,000
Net Present Value ($)	$12,532,000	$2,121,000
Benefit / Cost ratio	**1.9**	1.2
NPV per $ invested by MPB CRC ($)	$1.19	$0.24
Sensitivity Testing NPV $ and BCR		
10% profit increase (base case 5%)	$39,388,000 3.7	$15,756,000 2.4
Adoption of 20% of fescue pastures	$2,460,000 1.2	($2,883,000) 0.32

This program will continue after the wind up of the MPBCRC through Gramina Pty. Ltd., the PGG Wrightson Group Companies (PGG Wrightson Genomics and PGG Wrightson Seeds), DPI Vic and its commercialisation arm Agriculture Victoria Services Pty. Ltd., and the Dairy Futures CRC.

4.4 OUTPUT 4: SALT-TOLERANT GERMPLASM

Project **Developing Wheat and Barley Germplasm for Salt Stressed Environments**

- *Eighty-three per cent of cropping land in Australia is at risk of salinity. Some of this is low level and can be tolerated by existing varieties.*
- *Developing varieties with salt tolerance will increase yields from salinity affected areas. However, the long lead time to commercialisation reduces their economic valuation despite the additional benefits.*
- *The MPBCRC has identified the regions in both wheat and barley genomes that harbour the salt tolerance trait and their associated markers.*
- *Experimental salt tolerant germplasm appears to increase biomass under typical saline conditions by 10%.*
- *The newly identified salt tolerant varieties could be worth $130m per year to Australian grain growers.*
- *If the same yield benefit is able to be achieved in lightly saline areas, in addition to heavily saline areas used in the calculation, then economic value could increase substantially.*

Background

Salinity is a major problem for agriculture in many parts of the world, especially in arid and semi-arid regions with low precipitation. In Australia, estimates show 83% of cropping land is at risk of salinity (67% for 'transient' salinity plus 16% for seepage salinity (Rengasamy 2002)). Australia's lost production opportunity cost is estimated to be $1.3 billion per annum (Rengasamy 2002).

To illustrate the scale of the issue, Western Australia has the largest area of dry-land salinity in Australia and the highest risk of increased salinity in the next 50 years. An estimated 4.3 million hectares (16%) of the south-west region of Western Australia have a shallow groundwater table and a high potential to develop salinity problems. This is predicted to rise to 8.8 million hectares (33%) by 2050 (Australian Natural Resources Atlas 2000). Of this 4.3 million hectares (16%), 81% is agricultural land. (Risk calculation is based on an assessment of depth to the water table.)

For the purposes of this analysis it was conservatively estimated that the area that would benefit from a salt tolerant variety was 10% of the current production area.

Through the development of novel screening methods and their application to diverse germplasm, variants with heritable salt tolerance were found in barley. The MPBCRC has identified the regions of both wheat and barley genomes that harbour the salt tolerance trait and their associated markers.

This project is still at the experimental stage and so all benefit calculations are estimates.

> *Experimental salt tolerant germplasm appears to increase biomass under typical saline conditions by 10%.*

Project cost $6,398,664

Outcomes

- **Development and implementation of screening protocols for salinity tolerance.**
- **Salt tolerance identified in barley and wheat germplasm.**
- **Novel alleles incorporated into MPBCRC germplasm by crossing and selection.**
- **Identification of barley and wheat genome regions responsible for salt tolerance.**
- **Alleles and markers for demonstrable salt tolerance identified and awaiting validation in adapted germplasm.**

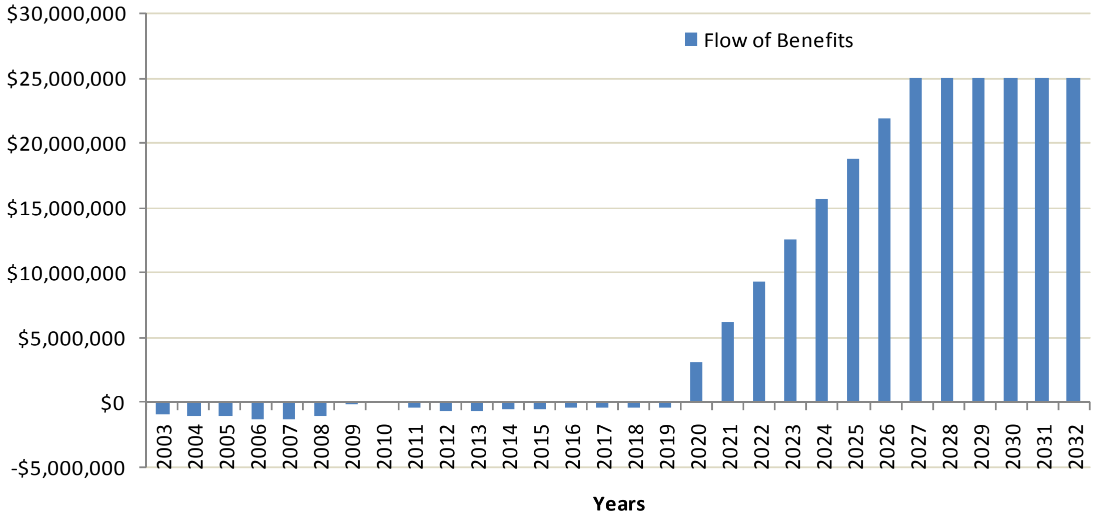
Commercial plan The germplasm is available and suitable for use by breeders as parents. Breeders will need to conduct further evaluations. The markers and all research details have been published.

Potential impact The CRC for Soil and Land Management estimates transient salinity costs the farming economy in Australia $1.3 billion per year.

> *If 10% of growth reduction could be alleviated by the newly identified salt tolerant alleles, this would be worth at least $130 million per year to Australian grain growers.*

The project shows that breeding for tolerance is feasible and so there is a reasonable prospect that a significant reduction could be achieved in the existing salt induced yield deficit.

Figure 11 Output 4: Annual flow of net benefits over 30 years (undiscounted)



The key variables that drive value of the program net benefit are adoption rate and yield benefits. The likelihood of successful commercialisation is also a key driver of any benefits.

COST BENEFIT ANALYSIS FOR SALT TOLERANT GERMPLASM

Analysis Assumptions

Risk

- Barley and wheat display degrees of heritable salt tolerance. Markers associated with this desirable trait have been identified. Transferring the trait to adapted germplasm is time consuming but poses few risks.
- Validation of the trait's performance in adapted germplasm is not yet available. The likelihood of deployment of a variety from the MPBCRC research is set at 50%.

Successful commercialisation

- The assumption is that successful commercialisation will be 10 years away for both barley and wheat.
- Commercialisation and distribution/launch costs (including regulatory approval) are assumed to be $3.6 million.

Impact

- In this analysis, it is assumed that 10% of crop production is affected by salinity.
- Furthermore, as salt affected areas may also be subject to additional stresses (boron or aluminum deficiency, acidity/alkalinity etc) for which the salt tolerance generated

through this project is not a solution, the amount of salinity affected production that would be amenable to this solution was reduced by a further 30%.

- The yield improvement generated from the deployment of salt tolerant alleles identified by MPBCRC is estimated to be 10% of the current yield in salt affected areas.

Adoption

- It is assumed that the maximum level of adoption of a new variety will reach 10% of the Australian wheat crop and 10% of the Australian barley crop, and that it will take five years from release to reach this adoption level.
- Uptake over the area affected is assumed to be rapid, reaching 80% of the affected area in eight years. This is due to the release of targeted varieties that include the trait.

Market size

- Average Australian gross revenue from barley: $1.3 billion per year.
- Average Australian gross revenue from wheat: $4.9 billion per year.
- This technology also provides potential for abandoned salt affected land to be brought back into production, however for the purpose of this analysis no benefit from the cultivation of additional (salt affected) land has been included.

Table 8 Cost benefit outcomes for Salt-Tolerant Germplasm (30 year period)

Discount rate	5%	8%
***Base case** 5% production increase and 10% of crops affected*		
Present Value Benefits	$31,228,000	$15,517,000
Present Value Costs	$7,833,000	$6,728,000
PV CRC Costs	$5,873,000	$5,340,000
Net Present Value	$23,395,000	$8,789,000
Benefit / Cost ratio	4.0	2.3
NPV per $ invested by CRC	$3.98	$1.65
Sensitivity Testing NPV and BCR		
20% area affected by salt	$54,622,000	$24,306,000
	8.0	4.6

The salt tolerance program will continue with the MPBCRC partners SARDI and the University of Adelaide. Development of MPB germplasm will continue with AGT, InterGrain, LongReach Plant Breeders, the University of Adelaide and CIMMYT.

4.5 OUTPUT 5: GENETIC MARKERS AND BREEDING STRATEGIES

Project

The generation of trait and genomic markers for wheat and barley.

Development of technologies for expediting marker genotyping.

This project includes a number of sub-projects are covered including:

- High-throughput genotyping and testing methods (eg. Multiplex Ready Technology, Temperature Switch PCR, dideoxy SNP detection);
- Phenological adaptation;
- Wheat and barley, mapping and markers;
- Disease genetics; and
- Barley characteristics.

- *Genetic markers offer a viable means to boost the rate of productivity gain in the cereal industry, accelerating breeding as well as aiding in addressing disease resistance.*
- *This was the central 'conventional breeding' project for MPBCRC.*
- *Over 30 markers discovered by MPBCRC are now being used by breeders.*
- *MPBCRC was the first to publish markers for resistance to crown rot and root lesion nematode.*

Background

Molecular marker technology allows plant breeders to make some selection decisions based on the genetic make-up of the plant (i.e., its DNA) instead of observing plant or grain performance through a full year-long lifecycle. This can increase efficiency in plant breeding, as it enables laboratory assays to be applied early in the plant growth cycle, and/or at early generations in plant breeding cycles, and potentially at low cost.

From any cross between selected parents only the most promising progeny is advanced for costly evaluation of economically important traits across environments and seasons. With selection based on molecular (DNA) markers, this selection process can be earlier cheaper and more selective.

MPBCRC research has identified associations between molecular markers and economically important traits in cereal crops. The program covered new markers for specific traits, as well as the development of simple, low-cost, robust and high-throughput systems for assaying markers. Strategies for the integration of molecular marker technology into plant breeding programs, both for ‘simple’ (single-gene) and ‘complex’ (multiple-gene) traits are also included in this program.

There are already new varieties being launched that have benefited from the application of molecular genetics. The challenge for this analysis is to estimate the likely increase in genetic performance over time and the proportion of the gain that is due to the activity of the MPBCRC.

Project cost $12,728,366

Outcomes

- **Generated DNA markers associated with cereal crop genes controlling traits of agronomic importance including: salt and drought tolerance, disease resistance, grain quality, plant architecture, and phenology (including markers for traits in wheat that are relatively difficult to characterise, as well as markers for frost tolerance in barley).**
- **Developed low cost markers in a format compatible with high-throughput genotyping for use by breeders.**
- **Developed methods of genotyping to facilitate testing of multiple markers in a single test.**
- **Established supporting systems such as databases, primer design protocols, and laboratory capability for deployment of high-throughput genotyping in breeding programs.**
- **Developed and tested novel breeding strategies (eg. ‘multi-locus’ and ‘whole genome’) in barley to combine multiple unrelated traits such as high yield, high malt quality and good disease resistance in a single crossing program.**
- **new varieties of clovers will be produced in the next few years using MPBCRC gene marker tools.**

Commercial plan

These tools and technologies have been made freely available to researchers and breeders and are used extensively so the economic benefits of this project accrue to cereal breeding organisations rather than the CRC and the industry benefit must be calculated indirectly.

Potential impact

This research will accelerate breeding progress in a range of crops, making breeding more efficient and therefore improve the rate of yield (genetic) gain. This acceleration however, is occurring in a context where breeding progress is generally slowing as it faces a “diminishing returns” scenario.

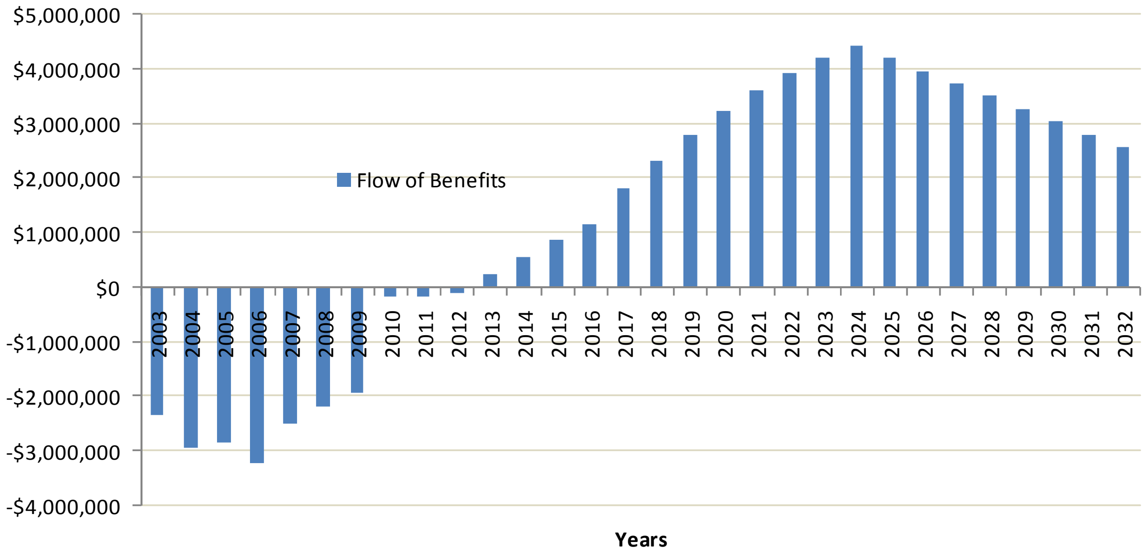
> *Early benefits will arise from breeder access to research germplasm that has yielded clarification of simple trait-marker associations.*

The greatest impact of this technology will be realised as breeders improve their precision and reduce their costs of optimising important but complex traits (such as yield and water use efficiency), or expensive-to-measure traits (such as bread making quality).

Eathington *et al.* (2007) estimated that marker assisted breeding approximately doubled the rate of genetic gain relative to conventional breeding of corn over a three year period. Edgerton (2009) expects that by 2030 approximately 20% of the genetic gain in corn over the preceding 25 years will be attributable to marker assisted selection (30% to genetic modification and 50% to conventional breeding including hybrids).

At an estimated 0.35% improvement in genetic gain per year from new varieties, the economic benefit to the Australian wheat industry of a two-year reduction (from 9 to 7) in the breeding time for a new cultivar would be USD$6.93/hectare (~AUD$8.50) (Brennan and Martin, 2006).

Figure 12 Output 5: Annual flow of net benefits over 30 years (undiscounted)



The key variable that drives the value of the program's net benefit is the lift in the rate of genetic gain attributable to the use of genetic markers and technologies.

COST BENEFIT ANALYSIS FOR GENETIC MARKERS AND BREEDING STRATEGIES

Analysis assumptions

Risk

- All cereal breeders in Australia have adopted the use of genetic markers to some extent, so the likelihood of achieving project success at some level is 100%.

Successful commercialisation

- All future release varieties are assumed to have benefited to some degree from the application of molecular genetics. Not all of this will have come from MPBCRC.
- The attribution of the efforts of the CRC will decay over time as the technologies are replaced. In essence the markers and processes will deliver a 'spurt' of yield increase.
- The benefits fall first to the breeding sector in the form of costs savings (efficiencies) and/or increases in the rate of delivery of improved varieties. Value to growers is derived from the increase in the rate of genetic gain of released varieties, resulting in an increase in yield per hectare.

Impact

- All the markers and technologies arising from this project have been placed in the public domain for breeders to access at minimal cost.
- The annual rate of genetic improvement in wheat and barley is estimated to steadily increase from 1.0% to 1.5% per year over the next five years.
- It is assumed that 50% of the increase in genetic improvement in the future can be ascribed

to the use of markers and genetic technologies. In making this assumption it is further assumed that wheat and barley will not derive significant genetic gain from either genetic modification or hybridisation technologies.

- It is calculated that the lift in farm profit from an increase in genetic gain (yield) of 0.5% per year is approximately $31 million annually.

Adoption

- It is assumed that the current dramatic fall in DNA sequencing costs will produce a ten-fold reduction in the cost of genotyping data over the next five years, thereby dramatically diminishing the cost of adoption by breeders.
- Adoption of particular trait associated markers or novel breeding strategies depends to some degree on the confidence breeders have of their 'validity' or field effectiveness. Validation can take several years to establish after the association has been identified by researchers.
- New varieties (whose development will have benefitted from the application of genetic markers and technologies) will be adopted across 100% of the crop area over a period of 12 years. That is, varieties, which are the vector for the lift in the rate of genetic gain, are adopted over 12 years. This lag affect is the subject of a sensitivity test.

Market size

- MPBCRC contributed 30% of the marker and genetic technologies available to breeders as at June 30 2010. This proportion will fall steadily over 20 years from 30% to 10% as the MPBCRC contribution becomes diluted by subsequent contributions from other parties after the CRC's wind up.

Table 9 Cost benefit outcomes for Genetic Markers and Breeding Strategies

Discount rate	5%	8%
Base case contribution to 0.5% annual lift in genetic gain		
Present Value Benefits	$13,206,000	$7,363,000
Present Value Costs	$11,827,000	$10,516,000
PV CRC Costs	$11,238,000	$10,066,000
Net Present Value	$1,379,000	($3,153,000)
Benefit / Cost ratio	1.1	0.7
NPV per $ invested by MPB CRC	$0.12	($0.31)
Sensitivity Testing NPV and BCR		
More rapid dissemination of traits so that 0.5% takes effect in 5 years	$10,224,000 1.9	$10,066,000 1.3

This program will continue in the future through MPBCRC participants the University of Adelaide, SARDI and DPI Vic after the CRC's wind-up. The relatively low benefit cost ratio highlights the importance of government funding for this path to crop improvement.

4.6 OUTPUT 6: MOLECULAR MARKERS FOR PASTURE PLANT IMPROVEMENT

Project **Molecular markers for pasture plant improvement**

- *The breeding of forages has a shorter and more recent history than cereals. Knowledge of forage plants is lower but opportunities for improvement are greater.*
- *The application of molecular genetics ('marker assisted breeding') has the potential to substantially accelerate genetic gain and increase the range of traits that can be optimised – hence providing greater improvements to cultivars more rapidly.*
- *Australia's livestock industries are largely broad acre and pasture fed, and thus more productive pastures are a source of national competitive advantage.*

Background The historical rate of progress in genetic improvement in pasture plant breeding (PPB) is generally regarded as low, with estimates of up to 7% per decade for perennial grasses (Fennessey & Smith 2010). The purpose of this project was to Develop technology to offer real improvements in the rate of genetic gain to PPB companies. The benefits to farmers will be via greater improvements to cultivars and more rapid delivery of these cultivars to end users such as dairy farmers.

Project cost $12,728,366

Outcomes

- **The outputs of the project are marker technologies for use in pasture breeding.**
- **The program focused on low lignin and high fructan as exemplar traits in perennial ryegrass.**
- **Resulting cultivars will help secure Australia's advantage in livestock production, through the enhancement of pasture production.**

Commercial plan

The markers will be used by the pasture breeding sector in their operations.

Potential impact

Fennessy & Smith (2010) have estimated that a 1% change in yield generates a 1% change in gross farm gate returns in dairy systems and a 1.3% change in sheep and beef systems.

> *The benefits in terms of a profit figure are estimated to be between $61 and $121 per hectare for a dairy enterprise, and between $27 and $55 per hectare for sheep and beef enterprises.*

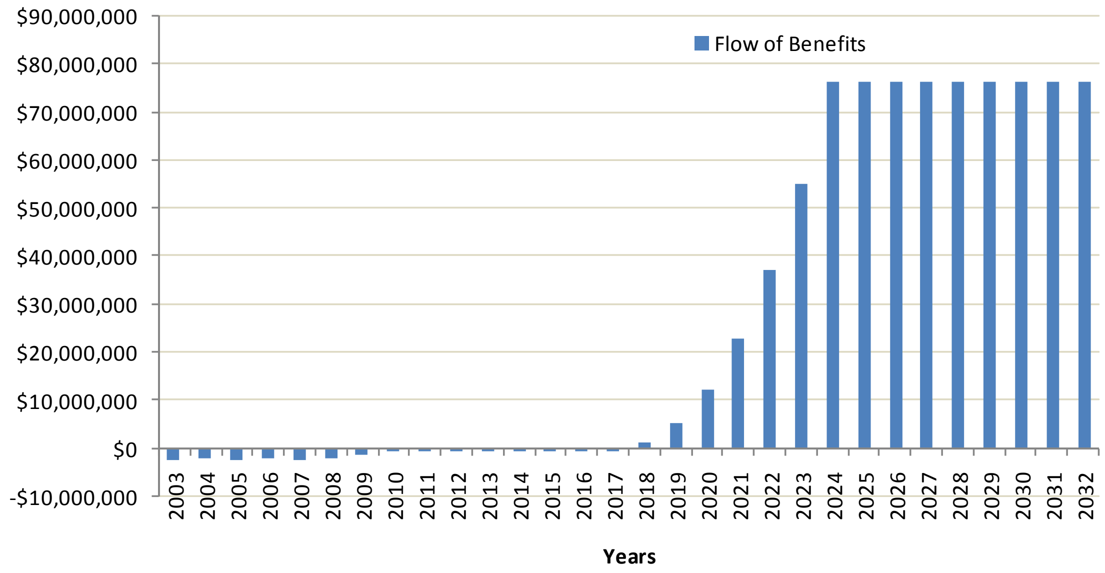
The program focused on low lignin and high fructan as exemplar traits in perennial ryegrass. Perennial ryegrass grows in temperate grazing zones (ie. southern Victoria, Tasmania, lower south-east South Australia and the south coast of Western Australia.)

Table 10 Current usage of proprietary ryegrass seed sold and the areas sown

	Proprietary ryegrass seed (tonnes/year)		Area of improved pasture sown (hectares/year)		Sowing rate (kg/hectare)	
	Perennial	Short-term	Perennial	Short-term	Perennial	Short-term
Dairy	2,000	4,500	100,000	180,000	20	25
Sheep & beef	400	2,500	20,000	100,000	20	25
Total	2400	7000				

Source: Fennessy P. and Smith K. (2010).

Figure 13 Output 6: Annual flow of net benefits over 30 years (undiscounted)



The key variables that drive value of the program net benefit are the update of new varieties and the rate of genetic gain.

COST BENEFIT ANALYSIS FOR MOLECULAR MARKERS IN PASTURE PLANTS

Analysis assumptions

Risk

- The success in the lab is close to 100%.
- All pasture breeding companies are investigating the application of genetic markers in their breeding programs, and while it is expected that they will all adopt marker assisted selection to some degree over the next decade, for the purpose of this analysis their likelihood of adoption has been set at 70%.

Successful commercialisation

- Even if the new methodology was adopted immediately, the first commercial release of a new variety is unlikely to occur in less than eight years.

Impact

- It is assumed that a pasture plant breeding company would seek to build its whole genetic improvement program around the new methodologies. Hence over time – assumed to be eight years in the example - virtually all proprietary cultivars sold would be bred using new methods. These would be markedly superior to varieties bred using current methods.
- A 1% change in pasture yield translates to a profit increase of $121 per hectare for dairy enterprises and between $55 per hectare for sheep and beef enterprises.

Adoption

- Adoption by growers is assumed to occur at the rate that current varieties are replaced, 7 years for dairy and 20 for sheep and beef. . Costs to achieve adoption will be about $500,000 per year for the next five years and then $300,000 per year thereafter.
- New superior varieties will be adopted across 95% of the potential growing area over a period of six years from release for improved pastures used for dairy. The adoption is assumed to be slower in sheep and beef enterprises with 70% of pastures replaced based on improved varieties by year 7.

Market size

- The annual hectares sown in the dairy industry are 280,000 ha and in the sheep and beef industries, it is 120,000 ha.

Table 11 Cost benefit outcomes for Molecular Markers in Pasture Plants

Discount rate	5%	8%
***Base case** 95% adoption in 8 years*		
Present Value Benefits	$204,883,000	$103,254,000
Present Value Costs	$19,334,000	$16,539,000
PV CRC Costs	$15,737,000	$14,184,000
Net Present Value	$185,549,000	$86,715,000
Benefit / Cost ratio	10.6	6.2
NPV per $ invested by CRC	$11.79	$6.11
Sensitivity Testing NPV and BCR		
Adoption half (adoption reaches 47.5% for dairy pastures and 35% of new pastures in sheep and beef)	$83,107,000 5.3	$ $35,088,000 2.5

The value is sensitive to the rate of adoption by breeding organisations.

This program will continue after the wind up of the MPBCRC through DPI Vic and its commercialisation arm Agriculture Victoria Services Pty. Ltd., the Dairy Futures CRC, and dairy and livestock industry partners.

4.7 OUTPUT 7: TRAINING RESEARCHERS

Project **Training Researchers** for increasing skills and knowledge capital in plant research and breeding.

- *Overall the MPBCRC has produced 43 graduates, 9 of which are working in plant science.*
- *The MPBCRC will provide 4 plant breeders and 20 plant scientists by 2015.*
- *Scientists from the training program have experience in 'fundamental' and 'strategic applied' research in plant sciences and the use of molecular techniques in these fields.*
- *The MPBCRCs training program will supply two-thirds of the Australian crop breeding industry demand for scientists and a third of the demand for breeders between 2010 and 2015.*

Background The number and age of skilled researchers in plant breeding fields in Australia is rapidly declining. In 2006, 60% of the academic staff in agriculture in Australian universities (Hugo 2008) and over 54% of the 184 biologists working in crop variety R&D (Fellowes 2006) were aged 50 years or more. In crop breeding, the number of breeders has halved to around 71 positions in the last 20 years with 48% being over 50 years of age.

A core aim of the MPBCRC was to contribute to the nation's human capital for plant research and breeding by providing a significant number of researchers trained in molecular plant breeding technologies, with a view to providing a pool of replacements for staff currently approaching retirement. Quantifying this benefit is difficult and was done by contemplating the impact on the rate of genetic gain from a severe shortage of plant breeders.

Additional benefits include the actual research performed by the students and the increased skills and experience they develop which continue through their working life. These benefits were not included in this report.

Outcomes

Prior to the commencement of MPBCRC in 2003, the preceding CRC (CRCMPB) had 15 student completions. In July 2003, with the commencement of MPBCRC, 19 students from CRCMPB and two from other organisations were transferred into MPBCRC. MPBCRC then recruited a further 28 students, giving it a total of 49 students. By June 30 2010, 43 students had completed their PhDs and the remaining six will complete by the end of 2011.

Table 12 Overview of training outcomes

	Cereals		Pastures		Total
	Markers & Breeding	Genes & Genomics	Markers & Breeding	Genes & Genomics	
Disease resistance	1	4	1	0	6
Abiotic stress tolerance	1	3	1	1	6
Quality/safety	2	4	1	7	14
Tools/traits for breeding/genetic modification	5	6	4	2	17
Total	26		17		43

Of the 43 graduates at June 30 2010, four are (or will be) working specifically in plant breeding in private Australian breeding companies (1 pastures, 3 wheat), 16 in plant science in Australia, and 9 are working in plant science internationally.

Other employment destinations include: one science teacher, one science communicator, one working for a government based agricultural industry organisation, and one working in the agribusiness sector. Two are working in other scientific fields within Australia, and one in science internationally. Seven are either currently not working due to personal circumstances or their work is unknown.

Program inputs

Under its Education and Training Program, the MPBCRC provided student stipends, operating cost support, travel grants and professional development opportunities. The MPBCRC also provided additional student supervision, with approximately 20 staff members contributing to the supervision of PhD students and 65% of students also benefitting from non-academic / industry supervisors.

Project cost $10,388,247

Activities

- Supervision of students: project management, proof reading, administration, mentoring and guidance meetings, data interpretation.
- Technical training of students: specific laboratory or field techniques, data analysis, experimental design (as shown in Table 12).
- Professional development training, support for conference presentations, seminars, and networking.

Potential impact

Without the injection of additional capacity into plant breeding and research, it is likely that the level of cultivar output will drop and with it the rate of genetic gain. If the MPBCRC did not produce the additional skilled personnel institutions and companies would have to recruit from the broader pool of science graduates and conduct their own training. This would be relatively inefficient as the skills required in the prebreeding and breeding sectors are quite specialised.

> *It is estimated that the MPBCRC will have provided four plant breeders (three in field crops) and 20 plant scientists by 2015.*

MPBCRC PhD graduates will mainly work within the pre-breeding and breeding sectors as the skills are specialised and graduates have established networks within the sector.

The Fellowes report (2006) suggests that an additional 90 plant scientists and 35 breeders will be needed by 2020. This equates to 30 plant scientists and 12 breeders every five years between 2005 and 2020, to maintain the nation’s capacity and enable productivity of its crop agriculture. MPBCRC will have supplied two-thirds of that demand for plant scientists and one-third of the demand for breeders in the period 2010 to 2015.

COST BENEFIT ANALYSIS FOR TRAINING OF RESEARCHERS

Analysis assumptions

Without replacement of retiring scientists and breeders the rate of genetic gain would fall from 1% in five years time to 0.5% over the seven years. This dip could be addressed by alternative educational efforts beyond the life of the CRC. The MPBCRC has provided a medium term solution to a looming skills crisis within the breeding sector.

The valuation was performed on a relatively narrow basis as there are numerous other additional benefits that have not been included in the calculation. The valuation was made using the following assumptions:

- Typical gross value of wheat and barley production in Australia is $6.25 billion.
- Current rate of genetic gain: 1%.
- Value of genetic gain per year at risk as a decrease of 0.5% is $31 million per annum.
- The analysis also assumes that no other group would have been likely to instigate a comparable project.

Figure 14 Output 7: Annual flow of net benefits over 30 years (undiscounted)

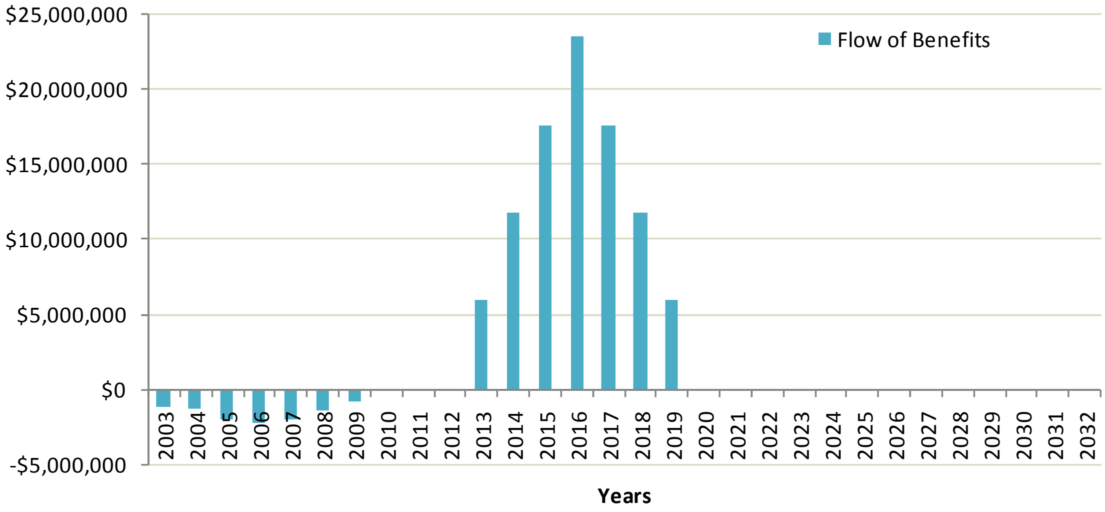


Table 13 Cost benefit outcomes for Training Researchers (over 30 year period)

Discount rate	5%	8%
Base case		
Present Value Benefits	$47,511,000	$32,169,000
Present Value Costs	$9,294,000	$8,363,000
PV CRC Costs	$9,294,000	$8,363,000
Net Present Value	$38,217,000	$23,805,000
Benefit / Cost ratio	**5.1**	3.8
NPV per $ invested by CRC	$4.11	$2.85
Sensitivity Testing NPV and BCR		
Genetic gain decay of 0.25% avoided	$23,756,000	$16,084,000
	2.6	1.9

Note: Assessment based on activities to date and associated benefits into the future.

4.8 OUTPUT 8: COMMUNITY EDUCATION PROGRAMS

Project	**Community Education Programs** to raise awareness and understanding of molecular plant breeding technologies.

- *Approximately 42,000 people became aware of MPBCRC research and applications via its education programs.*
- *The MPBCRC education programs covered 40 community events and 25 grower events, and performed over 50,000 DNA extraction demonstrations.*
- *Over 10,500 students and teachers have attended the 'Get into Genes' education program.*
- *The risk of community rejection of genetically modified wheat has reduced substantially during the time of MPBCRCs educational programs, arguably from 80% to 20%.*
- *Bringing genetically modified technologies to market faster provides huge global benefit. MPBCRCs education program is part of a multi-faceted approach to this issue by many organisations.*
- *The scale of benefit from a notional 5% yield increase in wheat (through genetic modification) is so large that the time-value benefit of bringing its introduction forward by five years from say, 2022 to 2017 is over $10 million.*

Background

As part of its community education program, the MPBCRC set about providing information to grower and consumer communities to enable informed decision-making on the role of gene and molecular technologies in the production of food and drink. The engagement strategies included:

- Communication with growers,
- Communication with metropolitan consumers,
- Communication with rural consumers, and
- Communication with future consumers through school and teacher workshops. This communication had dual objectives in that it also sought to expose and attract students to plant science.

It is expected that the engagement activities of the MPBCRC in conjunction with parallel efforts by other groups, will accelerate the adoption in Australia of genetically modified crops and particularly wheat.

A number of the education programs have been conducted in partnership with other organisations, such as the Australian Centre for Plant Functional Genomics (ACPFG).

Project cost

$780,012

Outcomes

The education and communication programs of the MPBCRC during 2003-2010 were extremely diverse and reached students, farming communities, teachers, tertiary students, and community members.

Approximately 42,000 people became aware of MPBCRC research and its application to crop and pasture improvement via the programs. The engagement products and programs covered:

- **Educational roadshows (eg. In2Science)**
- **National Science Week events (eg. Gene Juice bar)**
- **Workshops (eg. Recognising Rural Women workshops)**
- **Online resources and training activities (eg. 'Molecular Training Techniques DVD')**
- **Student retreats and laboratory research tours**
- **Field days, Agricultural shows (eg. Royal Adelaide show exhibition and presentations)**
- **Community panels, discussions and online forums (eg. At Rotary clubs)**
- **'Get into Genes' educational workshops for students/teachers (eg. 'Get into Genes' workshops for Malaysian teachers)**
- **Career expos (eg. Wimmera careers fair)**
- **Professional development days for teachers (eg. Research overviews from MPBCRC and ACPFG)**
- **Crop and research updates (eg. GRDC crop updates).**

Potential impact

The Education Programs will have far reaching benefits to different target groups. These include:

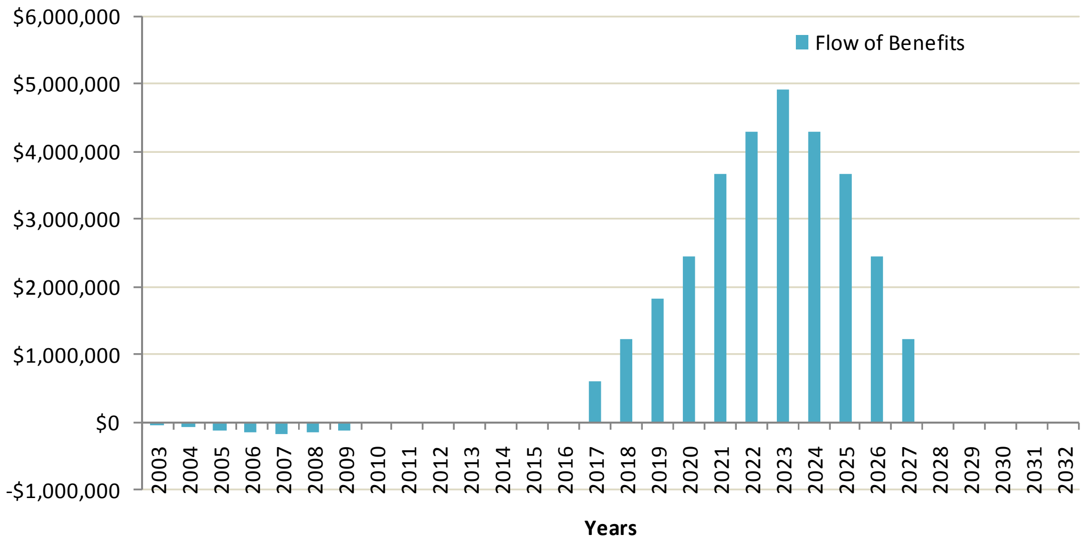
- Metropolitan community - to enable the community to make informed decisions about the role of gene technology in food production. Well educated community members are more likely to participate in discussions and increase the reach and acceptance of research.

- Growers and rural community members - to assist these communities to make informed decisions about the role of gene technology in food production. In addition, there will potentially be a sense of "ownership" or contribution to the work effort in improving crops and pastures.
- School teachers - educational programs provide an increase in confidence in teaching agricultural biotechnology. This will increase the ability of their students to evaluate information and to understand the applications of agricultural biotechnology.
- School students - there is direct benefit in helping students understand terms and skills within the curriculum to boost their levels of learning. There is also a longer term benefit as students become consumers.

It is anticipated that when the Community is better able to evaluate the potential benefits of molecular plant breeding technologies and understand the processes in place to manage the risks there will be more community support in the application of these technologies to crops, and less consumer resistance overall.

Increased community acceptance will facilitate adoption and enable greater economic benefits to be generated.

Figure 15 Output 8: Annual flow of benefits over 30 years (undiscounted)



Even with a modest "time value of money" the economic benefits that arise from a shortening of the delay in the deployment of genetically modified varieties is high. When combined with the low costs of work carried out by the MPBCRC this delivers a very high benefit-cost ratio (16.9:1), even with only a small attribution (5%) of cause to MPBCRC.

Community Attitudes to Genetic Modification

Community attitudes influence the use of genetic modification (GM) technology in agriculture through:

- Their direct role in the value chain as potential consumers of products derived from genetically modified crops and pastures, and
- Their indirect social and political role influencing acceptance and regulation of biotechnology, and funding of research and commercial production of genetically modified crops and pastures.

In 2003, community attitudes were not strongly in favour of the use of gene technology in the production of food and drink. A Biotechnology Australia 2003 survey found:

- 51% of respondents agreed that the technology was useful,
- 54% agreed that it was morally acceptable to use gene technology in food and drink production,
- 41% of respondents were interested in finding out more, and
- 38% were concerned about agricultural applications of gene technology.

Growers' attitudes were also not strongly in favour of genetically modified food crops in 2003. In addition to agronomic concerns, issues of market access, moratoriums and consumer concerns rated highly as the main impediments to growing genetically modified crops (Cormick, 2003).

In 2007, Biotechnology Australia studies indicated that both the perceived usefulness and acceptability of modifying the genes of plants to produce food has increased.

- 87% saw making plants drought resistant as somewhat or very valuable.

In 2008 the moratoria on genetically modified canola was lifted in New South Wales and Victoria allowing commercial production of GM food crops. This saw the uptake of genetically modified canola in New South Wales increase by 400% between 2008 and 2009 (ISAAA, 2010).

Acworth *et al* (2008) estimated that adoption of genetically modified oilseeds and wheat in Australia would boost Gross National Product by $912 million by 2018 (assuming unrestricted market access for genetically modified crops).

COST BENEFIT ANALYSIS OF EDUCATIONAL PROGRAMS

The cost benefit analysis of the educational programs has been quantified by measuring the economic impact of bringing forward the introduction by 5 years of a notional genetically modified-based wheat variety that delivers a 5% yield improvement.

Analysis assumptions

Market size/Impact

- Average Australian production of wheat: 19,409,600 tonnes per year.
- Value of wheat: $250 per ton.
- Lift in rate of cereal yield from introduction of genetic modification: 5%.
- Value of the genetic gain per year: $441 million.
- Liao and Martin (2009) reported that 31% of broad-acre farms in 2006-2008 introduced new crop cultivars so novelty per se is unlikely to be an impediment to adoption of genetically modified varieties. In fact, the promise of improved performance appears to induce a high level of experimentation on farms.
- Once approved by regulatory authorities, adoption of genetically modified varieties is assumed to increase linearly from 10% to 50% of the cropping area over five years.

Adoption

- MPBCRC has been one of a number of groups engaging with the community on the role of gene technology in agriculture. MPBCRC has contributed to community acceptance through both the trialing of drought tolerant genetically modified wheat, and proactive participation in the media and community outreach programs. It is assumed this has enabled the release of genetically modified based varieties earlier than would have otherwise been possible.
- The risk of community rejection of genetically modified wheat has reduced substantially in that time, arguably from 80% to 20%.
- It is assumed that this work plays a role in bringing forward the successful introduction of genetically modified varieties into the field by 5 years.
- The attribution to the MPBCRC to this effort is minor at 5%.

Table 14 Cost benefit outcomes for Educational Programs (30 year period)

Discount rate	5%	8%
***Base case** 5% contribution accelerating adoption by 5 years*		
Present Value Benefits	$11,288,000	$6,385,000
Present Value Costs	$668,000	$590,000
PV CRC Costs	$668,000	$590,000
Net Present Value	$10,620,000	$5,795,000
Benefit / Cost ratio	**16.9**	10.8
NPV per $ invested by CRC	$15.90	$9.82
Sensitivity Testing NPV $ and BCR		
Adoption brought forward by 3 instead of 5 years	$6,432,000 10.6	$3,531,000 7.0

The Get into Genes program will continue with the Dairy Futures CRC and the Australian Centre for Plant Functional Genomics.

5 SUMMARY OF ECONOMICS ASSESSMENT

5.1 MPBCRC PROGRAM INPUTS

The total R&D, education and commercialisation costs for the projects assessed in this analysis were $83 million. The projects selected for this analysis represent half of the total cash and in-kind expenditure of the MPBCRC.

Table 15 MPBCRC costs (cash and in-kind) for the projects assessed

Projects	CRC costs ($)	Percentage
Drought tolerant wheat	$6,760,000	4.2%
High energy (high fructan) perennial ryegrass	$13,878,000	8.7%
High digestibility (low lignin) forages	$13,967,000	8.7%
Salt-tolerant wheat & barley germplasm	$6,399,000	4.0%
Genetic markers and breeding strategies	$12,728,000	8.0%
Pasture markers	$17,559,000	11.0%
Trained researchers	$10,388,000	6.5%
Community education programs	$780,000	0.5%
All other CRC expenditure	$77,334,000	48.4%
Total	$159,793,000	100%

5.2 NET PRESENT VALUE OF PROJECTS

Table 16 Project BCR and NPV (5% discount rate)

Projects	BCR	NPV ($)
Drought Tolerant Wheat	8.58	$76,045,000
High energy (high fructan) perennial ryegrass	3.66	$38,518,000
High digestibility (low lignin) forages	7.31	$91,425,000
Salt-tolerant wheat & barley germplasm	3.99	$23,395,000
Genetic markers and breeding strategies	1.12	$1,379,000
Molecular markers in pasture plant improvement	10.60	$185,549,000
Trained researchers	5.11	$38,217,000
Community education programs	16.90	$10,620,000
BCR and NPV of All Projects Assessed	**6.00**	**$439,162,000**

Based on this analysis of key projects and assuming its new technologies are adopted in the manner described in the preceding sections, the MPBCRC through the selected projects alone will have invested $83 million to deliver over $439 million in economic improvement to Australian agriculture.

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APPENDIX 1 - DRIVERS FOR INCREASING YIELD AND PROFITABILITY

- *A focus for MPBCRC was in developing technologies to underpin prospects of yield gain in wheat, barley and selected pastures.*
- *Agricultural productivity increase is the key to maintaining low food prices.*
- *Improvements in plant varieties are a significant source of productivity gain.*
- *An increase in the rate of genetic gain will result in an increase in farm yield.*
- *The need for a sustained increase in genetic gain and associated yield increases is recognised by the industry as critical for long-term profitability.*

Definitions of Yield and Productivity Terms

Term	Symbol	Definition
Total factor productivity	TFP	The ratio of a quantity index of all marketable outputs to the corresponding quantity index of all marketable inputs
Average farm or on-farm yield	FY	Average yield achieved by farmers in a defined region over several seasons
Economically attainable yield given current markets and institutions	AYa	Optimum (profit maximising) yield given prices paid/received by farmers, taking account of risk and existing institutions
Potential yield	PY	Maximum yield with latest varieties, removing all constraints, including moisture, at generally prevailing solar radiation, temperature, and day length
Water-limited potential yield	PYw	Maximum yield under normal rain fed conditions, removing all constraints as for PY except for moisture
Theoretical yield	TY	Maximum theoretical yield for prevailing solar radiation based on prevailing knowledge of crop physiology and photosynthetic efficiency

Based on Fischer et al (2009).

AUSTRALIAN PRODUCTIVITY

Agricultural productivity increase is the key to maintaining low food prices and ensuring that food does not take a relatively larger share of income over time. Australia's agricultural productivity is growing but the rate of growth is declining (Kokic *et al.* 2006). An overview of productivity for Australian agriculture is shown in Table 18.

Summary of productivity improvements

Author	Data period	Area	Data	Enterprise	Total Factor Productivity % pa
Kokic et. al.	1988-89 to 2003-04	Australia	ABARE	Grains industry	2.6
Coelli and Kingwell	1952/53 to 1987/88	Western Australia	ABARE	Wheat, sheep	2.7
ABARE	1976-77 to 1993-94	Australia	ABARE	Grains industry	3.8

There are several factors affecting productivity including: cultivar development, advances in practices, and utilisation of machinery. Improvements in plant varieties are a significant source of productivity gain, especially for the Australian wheat industry over the last 50 years.

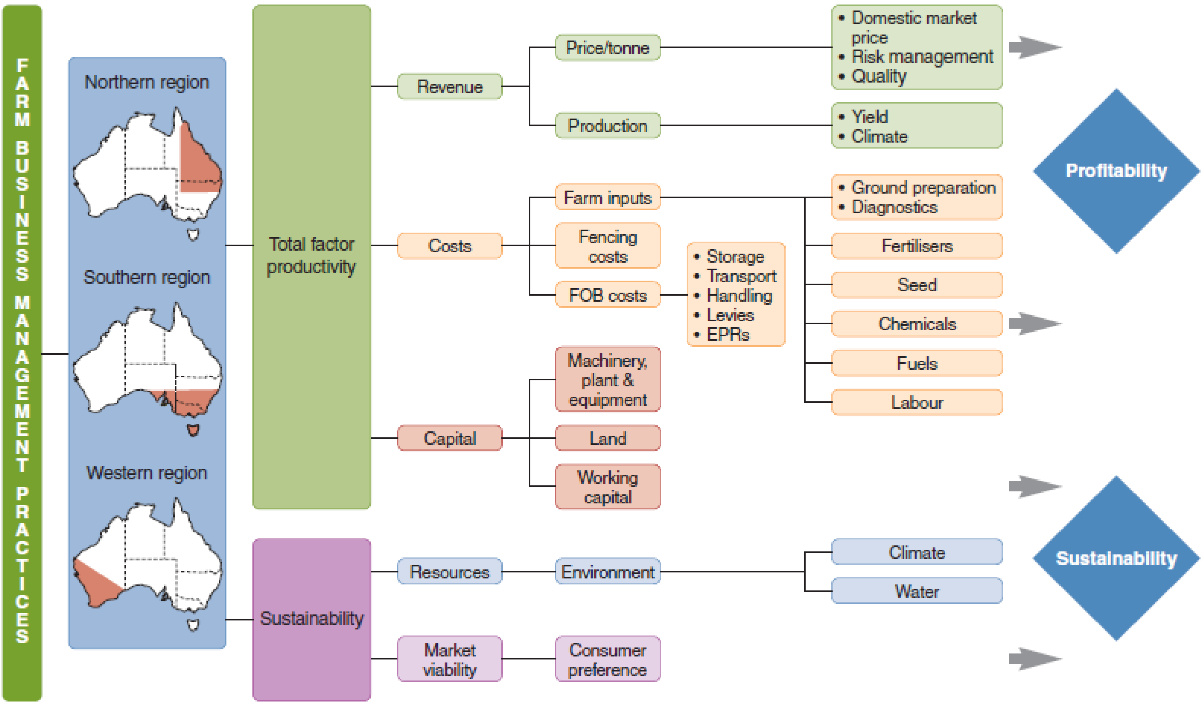
Livestock industries benefit from improved pasture varieties as well as improved animals. To date, most of the effort to generate productivity increase in livestock has been focused on genetic improvement of the livestock to increase yields, improve quality of product and improve feed base utilisation. This means there remains substantial opportunity to improve the quality of the pasture.

DRIVERS FOR INCREASING YIELD AND PROFITABILITY

A focus for MPBCRC was to develop technologies to underpin yield gain in wheat, barley and selected pastures.

A useful overview of the drivers of business profitability in cereal production is provided in Figure 18. New wheat varieties have the potential to affect revenue, costs and also protect the resource base.

Grains value driver analysis



Source: GRDC.

Figure 18 provides an overview of the factors affecting cereal farm productivity. Varietal improvement primarily affects the 'green' elements: yield, quality, and risk. In the majority of cases an increase in the rate of genetic gain will result in an increase in yield, which of course translates into increased revenue if prices remain constant.

Genetic gains in yield can translate directly into gains in *partial factor productivity (PFP)*, provided that farmers continually adopt newer varieties. Gains can also lead to improvements in *total factor productivity (TFP)*.

INCREASING YIELD POTENTIAL (PY)

> *The use of molecular tools for selection will increase breeding efficiency* (Fisher *et al.* 2009)

Yield is a broad term and can be influenced by breeding programs in several ways. Fisher *et al.* (2009) have split the term into: *farm yield (FY); attainable yield (AY, as reached with the best technology and prudent economics), and potential yield (PY, yield with the best varieties and agronomy and no manageable biotic or abiotic stresses).*

Progress in lifting Farm Yield is a function of progress in PY and in closing the gap between PY and FY. Definitions of yield measures are in Table 17 at the start of this Appendix.

In a 1999 review, Rejesus *et al.* (1999) found that wheat breeders were successful in raising wheat yields in a wide range of environments and time periods. The review of 40 global wheat studies found an average annual increase in yields of approximately 1%. Rates of genetic gain in yield also tended to be higher in more favourable, better watered environments than in drier areas (all other factors being equal).

A decade later Fisher *et al.* (2009) estimated that global wheat annual yield increases (as a percentage of current yield) are falling, and are now just below 1%. For wheat, global annual Potential Yield progress is estimated to average 0.5%.

The yield gap is estimated at 40%, though this ranges from 25 - 50%. Fertilizer use plays a significant role in reducing the gap between Farm Yield and Potential Yield.

Fisher expects that the use of molecular tools for selection will increase breeding efficiency, but anticipates the marginal cost of yield gains is likely to rise. Table 19 provides the yield improvement targets set for the breeding industry by the Grains Research and Development Corporation (GRDC).

> *The need for a sustained increase in genetic gain and associated yield increases is recognised by the industry as critical for long term profitability.*

GRDC Australian grain industry technical breeding targets

	Annual yields as measured in NVT trials increase
Barley and Wheat	1.0%
Canola	1.5%
Pulses	2.0%
Sorghum	1.5%

Source: GRDC (2006).

The time lag between varietal release and eventual adoption may also affect wheat varietal replacement and productivity in the future. The duration of the time lag in varietal replacement is heavily influenced by:

- the economic policies and institutions that affect varietal diffusion;
- development of seed distribution systems; and
- development of related input delivery systems.

However, the cereals industry in particular, and sections of the pasture industry, are mature and have a strong history of disseminating genetic material to growers, which may alter this time lag.

APPENDIX 2 - BARRIERS TO A SUSTAINED INCREASE IN THE RATE OF GENETIC GAIN

- *Future growth in Potential Yield is probably going to depend more on breeding than on new developments in crop agronomy.*
- *Marker-assisted selection (MAS), marker-assisted recurrent selection (MARS) and genetic modification (GM) are being integrated with conventional breeding approaches to accelerate progress.*

GENETIC GAIN

Genetic gain is the process to increase potential yield. Most plant research considers the limitations breeders face in increasing genetic gain, and the potential for molecular genetics to overcome these limitations (until the naturally available genetic diversity has been fully exploited).

Potential Yield (PY) increases principally through breeding, but is backed by improved agronomy. In the past, this has driven Farm Yield (FY) growth. Fischer *et al.* (2009) suggests future growth in PY is probably going to depend more on breeding than on new developments in crop agronomy. Projections of PY in wheat estimate it is possible to achieve 19 t grain/ha under well watered conditions.

> *The challenge for the pre-breeding and breeding sector in Australia is to achieve a sustained lift in the rate of genetic gain.*

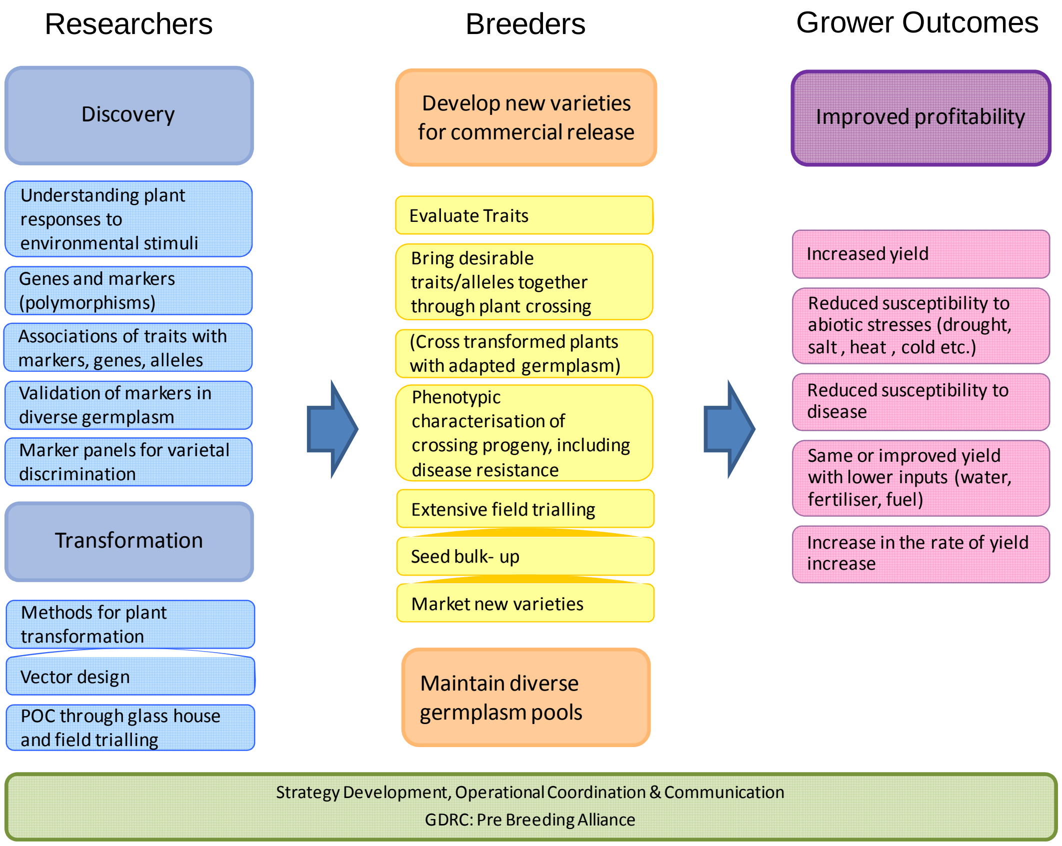
Conventional plant breeding is a relatively slow process. It depends on large investments in empirical yield testing, and on accessing existing genetic diversity by effective wide crossing (Fischer *et al.* 2009).

Molecular breeding technologies offer the possibility of accelerated progress. These technologies, most notably *marker-assisted selection (MAS), marker-assisted recurrent selection (MARS) and genetic modification (GM)* are now being integrated with conventional breeding approaches.

THE GENETIC PIPELINE IN AUSTRALIA

There are a number of contributors to the breeding pipeline in Australia. The sectors across the pipeline are: pre-breeding, breeding, and distribution. The activities are illustrated in Figure 19.

Schematic of the Sectors and Activities undertaken to deliver genetics



APPENDIX 3 - VALUATION SOLUTIONS -COST-BENEFIT ANALYSIS METHODS

This report examines the economic impact of the MPBCRC on the cereal and pasture industries in Australia. Despite the likely adoption of some of these technologies in other countries with the possibility of royalty benefits flowing back to Australia, these off-shore benefits were not included in the analysis because the primary focus of the CRC was to develop technological solutions to underpin the success of the Australian cereals and pasture industries.

In principle, Australian growers can ultimately derive benefits from MPBCRC's research in four possible ways:

- *decreases in the costs of production;*
- *increases in the supply of Australian products;*
- *increases in the prices received for Australian production, such as through quality improvements; and*
- *decreases in operational variability (risk) leading to increased profit and/or in income variability.*

In practice most farmers are price takers, and while premiums are available for product quality, the actual price the farmer receives is strongly affected by global supply and demand. In this context yield becomes a far more important outcome for growers.

For clarification we should note that crop farmers typically regard their volume of grain per hectare as 'yield' and naturally seek yield improvement. Breeders and researchers on the other hand generally operate in more controlled conditions such as glass houses and they strive to develop plant varieties that produce the greatest mass of seed under optimal conditions. In this context breeders and researchers often refer to this pursuit of maximum possible performance as 'genetic gain'. To a large extent the terms 'yield improvement' and 'genetic gain' can mean the same thing and can be used interchangeably; for more information on these term definitions see Appendix 2.

There are four main mechanisms used by the MPBCRC to lift genetic gain.

1. Identification and deployment of genetic materials from the global germplasm pool. These deliver desirable plant properties and increase yield under Australian conditions.
2. Technology improvements to increase rate of genetic gain. These will be deployed in the genetic pipeline by research and breeding entities.
3. Development of genetically modified material and processes for release.
4. Improvement in human skills and capacity.

Cost benefit analysis methodology

The Commonwealth Government through its Department of Innovation, Industry, Science and Technology recently introduced a model system for estimating the prospective economic impact of new CRC proposals. This framework is used in this report.

A Cost Benefit analysis requires a comparison of the costs and benefits for the cereal and pasture industries 'with' the CRC and a hypothetical base case 'without' the CRC. This helps to identify the difference made through activities of the CRC.

For both the 'with' and 'without' scenarios the costs and benefits are determined and the net benefit (or cost) is calculated. The two net benefits (and/or costs) are compared to ascertain the overall impact of the CRC.

Costs and benefits do not necessarily occur in the same place, so an analysis should assess the benefits producers and consumers receive. As the Australian cereal industry has a large export component, this analysis focuses on the benefits to producers (growers) rather than the benefits to consumers.

The principal benefits anticipated to flow to farmers from MPBCRC's activities and used in this analysis were increases in production (i.e. increases in tonnes of wheat, or per hectare, or litres of milk per cow per day). On a project by project basis other benefits were also relevant. For example, the ability of plants to tolerate unexpectedly low rainfall decreases operational variability. Higher malting quality barley increases the price received.

The quantification of benefits also requires an assessment of the time expected to be taken for the benefit to occur. It assesses the time between the development of the technology and its use in a commercial environment. In the case of plant breeding, product development cycles can take 10 years, so the time lags can be substantial. This has a significant impact on the calculation of value, as cash flows in the future must be discounted to take account of the time value of money.

For the purpose of this analysis discount rates of 5 and 8% were used which is in line with the principles of Government investment in basic agricultural research which has elements of private and public goods. As many of the MPBCRC's technologies are still in development or testing phases, any assessment of their value must make an allowance for the risk that the project may fail. This was accommodated in this analysis by multiplying the expected future revenue by a "likelihood of successful deployment" that was estimated for each project.

Finally, all successful technologies have a lifespan that is limited by the introduction of newer technologies. Furthermore, their value may not be constant over that life span. For each of the projects in this analysis an estimated life span was determined and an assumption made regarding the expected shape of the revenue profile. These assumptions were made on a project by project basis.