



**Forest & Wood
Products Australia**
Knowledge for a sustainable Australia

**INVESTMENT PLAN
FOR GENETIC IMPROVEMENT
TO INCREASE PRODUCTIVITY &
WOOD QUALITY, & MANAGE
RISKS
JULY 2010**



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1. OBJECTIVE

To direct investment in tree breeding and deployment research to increase industry profitability and reduce risk.

To verify this has occurred.

2. INTRODUCTION

Tree improvement programmes in Australia, in both hardwoods and conifers, have provided increased tree productivity and more lately improvements in wood properties. This has resulted in increased industry profitability. Gains have been impressive and investment in research has more than paid its way. The general consensus is that appropriately targeted research focussed towards operational tree breeding will continue to provide improvement in productivity and commercially important wood properties in the future.

A challenge in tree breeding is that tree generations are long and genetic gains calculated now may not be verified operationally until many years, perhaps decades later. FWPA wants its investment in forest genetics and tree breeding to demonstrate real and verifiable gains at the operational scale.

There are several challenges for the future that need to be addressed. Some in the tree breeding community consider that present breeding programmes do not sufficiently conserve the genetic variability needed to cope with changes in biotic factors (e.g. pests and pathogens) and abiotic factors (e.g. changes in temperature and water availability consequent to climate change) and including factors as yet unforeseen. Further, it is important that genetic variability be conserved to meet wood property specifications for changes in product mix (e.g. increasing solid wood from hardwood plantations). Indeed this could mean evaluation of new species and an increased focus on tropical and sub-tropical species. Gene conservation is likely to be an important priority for the future.

Another priority is to better establish economic values of breeding traits and to have these driving breeding programmes. There has been considerable excellent research in this area but the job is not finished, particularly for solid wood regimes in hardwoods. However, the projection of economic values of traits into the future is subject to error.

An example of this is the new ability of softwood sawmills to process trees with considerable sweep. In earlier years, sweep was considered a very negative trait and trees with sweep were excluded from breeding programs even if they were otherwise acceptable. This is no longer necessary and by neglecting sweep, gains for other traits should be greater as a consequence.

There is a strong case that tree breeding and silviculture should be considered together and not in isolation. Appropriate matching of silviculture with genotype is the best aim. Some genotypes can take advantage of increased silvicultural inputs whereas others cannot. It is an economic decision whether supplying increased inputs is justified. It is probably true that management decisions on such matters change more quickly than a rotation or a breeding cycle. Genetic changes are cumulative and gains made each breeding generation are available to all future generations whereas silvicultural inputs must be made anew each rotation. Each generation of breeding builds on the gains made in earlier ones. A logical place to start breeding for disease resistance is in the population already bred for appropriate wood properties. New genes can be sought in conservation populations, but care should be taken not to discard gains made in other relevant traits.

Engineering solutions should be considered alongside conventional tree breeding initiatives in optimising uniformity and stability in wood processing. Genetic modification is a tool that should not be ignored.

3. EVALUATION OF PAST AND CURRENT INVESTMENT BY FWPA

A summary of research projects 2004-2009 is given in Table 1. The total FWPA (and FWPRDC) investment was \$4.4 million allocated by species in descending order as radiata (40%), temperate eucalypts (30%), slash/caribaea/hoop (27%) and other species (3%) (Figure 1). Approximately 34 % was invested in tools (including software, databases and genetic analysis systems), 33% in genetic evaluation and quantitative genetics, 27% in molecular approaches and 6% in gene conservation (Figure 2). These figures are approximate because several projects had a mixture of several categories. There was no funding allocated to reproductive biology or to propagation. The proportion of funding allocated by FWPA (33.5%) was spread evenly across research categories (Figure 4) but was higher for alternative species (50%) than other species categories (average 33%) (Figure 3).

Agtrans (2008) did a cost benefit analysis of the pine breeding research (*Pinus radiata*; and *Pinus elliottii* and *pinus caribaea* and their hybrid) supported by FWPA including *Pinus* projects in Table 1 plus earlier ones. They concluded that the funds invested in pine breeding improvement will generate a substantial return. They estimated a net present value (NPV) of \$239 million for improvement in stiffness. They further estimated that without the government contribution to the levy this would have fallen to \$96.6 million. The largest investment made by FWPA was the Juvenile Wood Initiative (JWI). This estimated an NPV of more than \$A400 million for selection from progeny of the second generation to third generation of the radiata breeding population for STBA members and more than \$A800 million for the entire radiata pine plantation estate. Even although these predictions were developed in consultation with industry, these predictions are yet to be confirmed.

There was considerable investment (30% of total) in the cool temperate pulp species (*Eucalyptus globulus* and *Eucalyptus nitens*). Breeders have predicted significant gains in pulp yield and in some instances, in contrast to solid wood regimes, these gains have been verified. Research in pulp species has been progressing over several decades and has incrementally reached relative maturity. This has demonstrated the effectiveness of targeted research funding that has produced real benefit to levy payers.

Propagation and reproductive biology are conspicuously absent from the FWPA research portfolio in forest genetics and tree breeding. FWPA received no requests for funding in these areas over the period 2004-2009. There are well-established vegetative propagation

techniques for the major commercial species but not for emerging solid wood species.

Deployment should properly be defined as producing vegetative or sexually reproduced planting stock, establishing the plants in the field and ensuring they survive. Nursery management and field survival are important latter stages of this process, probably better considered as part of silviculture research. Some growers are now expressing concerns about reduced survival rates, which they presume are caused by drying environments.

Table 1: FWPA (and FWPRDC) research projects in genetic improvement 2005 – 2009

Project number	Title	FWPA budget	Total budget
PN06.3016	Resource characterisation of slash pine wood quality	\$200,000	\$669,000
PNC050-0304	Juvenile wood initiative	\$1,310,000	\$4,293,950
PNC052-0708	The hottest 100: improving pulp yield of plantation eucalypts by gene printing	\$393,182	\$988,185
PNC069-0708	Breeding radiata pine to maximise profits by incorporating risk traits	\$98,023	\$435,495
PNC070-0708	Review of alternative pine species for low rainfall zones of Australia	\$75,000	\$218,500
PNC001.96	Breeding objectives and selection criteria	\$150,000	\$880,122
PN01.1904	Breeding radiata pine to maximise profits from solid wood products	\$458,176	\$866,351
PN01.3601	Towards the development of heartwood-free eucalypts	\$350,000	\$772,360
PN03.1915	An advanced genetic evaluation system for forest tree improvement (TREEPLAN)	\$433,680	\$1,445,059
PN04.3003	Genetic variation in wood properties of <i>Eucalyptus dunnii</i> relevant to solid wood	\$70,000	\$141,891
PN05.3008	Sourcing of <i>Eucalyptus</i> plantation and regrowth timber with verifiable genetic traits	\$153,000	\$403,750
PN05.3012	Establishing a National Genetic Resource Centre	\$200,000	\$600,000
PN06.3014	Benchmarking the wood properties of radiata pine plantations. Stage1: Tasmania	\$110,000	\$323,362
PN07.3020	Hoop pine resource evaluation (resource and processing properties of <i>Araucaria</i>)	\$180,094	\$327,640
PN07.3023	Optimal deployment of genetic gains in wood quality across southern Australian pine	\$40,000	\$133,408
PN07.4025	Genetic gain optimisation in tree breeding (MATEPLAN) and deployment (SEEDPLAN)	\$150,000	\$465,926
PR08.4034	Genetic architecture of <i>Eucalyptus globulus</i> for breeding and deployment	\$60,000	\$247,820
		\$4,431,155	\$13,212,819

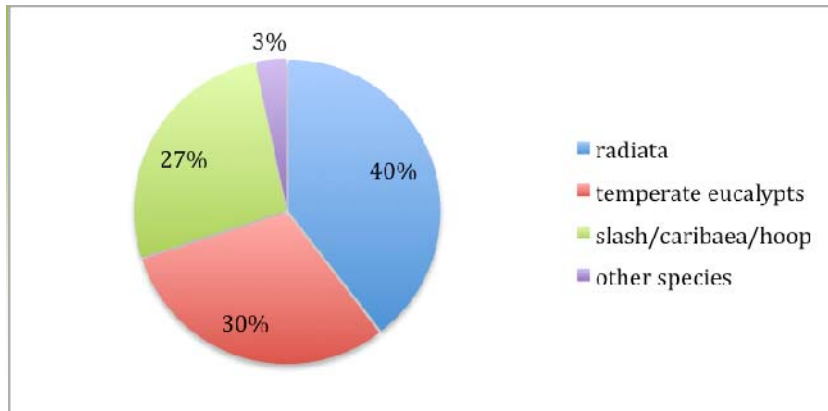


Figure 1. FWPA investment 2004-2009 by species groups

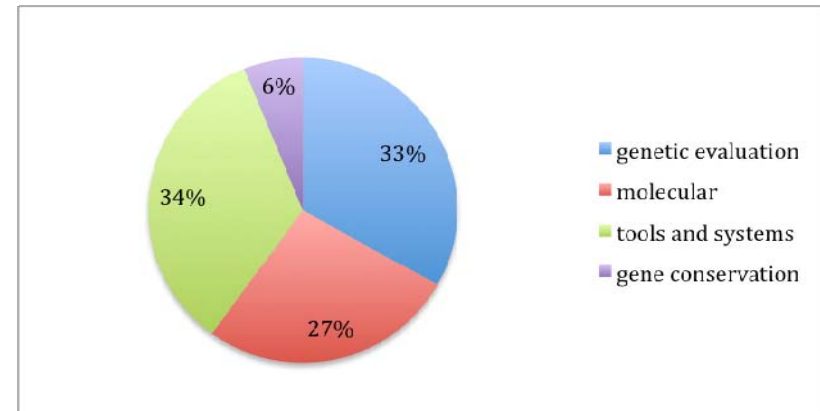


Figure 2. FWPA investment 2004-2009 by research categories

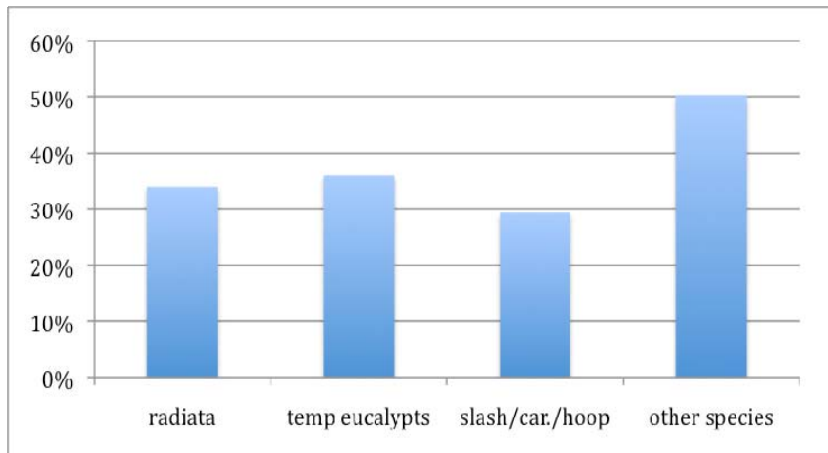


Figure 3. Relative proportion of FWPA funding 2004-2009 to total funding by species groups

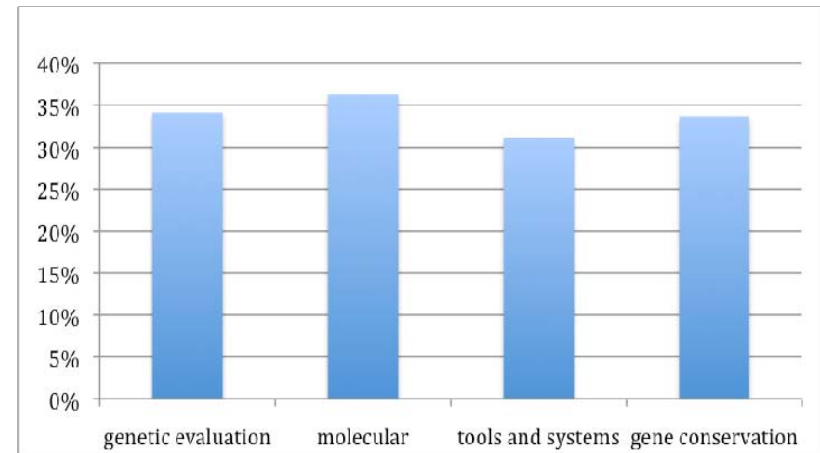


Figure 4. Relative proportion of FWPA funding 2004-2009 to total funding by research categories

4. SWOT ANALYSIS

Category	Strengths	Weaknesses	Opportunities	Threats
Genetic gain and the economic value of traits	<p>Good tools for predictions of economic gains for pines and hardwood pulp species.</p> <p>Considerable genetic gains have been achieved in growth and wood quality traits.</p> <p>Increase in profitability to industry</p>	<p>Lack of information on the actual economic gain at the operational scale</p> <p>Desirable wood quality traits and their heritability unknown for most hardwood plantation species grown for solid wood</p> <p>Little known about the economic value of solid wood traits for hardwoods</p>	<p>Target breeding to optimise value recovery</p> <p>Evaluate additional species</p> <p>Evaluate carbon sequestration and biomass as traits</p>	<p>Climate uncertainty</p>
Tree breeding	<p>Well-developed programmes in most commercial species</p> <p>Excellent national systems for genetic analysis, breeding and deployment</p> <p>Opportunity to exploit non-additive genetic effects</p>	<p>Limited knowledge about alternative species</p> <p>Some small and inefficient tree breeding groups</p> <p>Adverse genetic correlations</p> <p>Juvenile wood</p> <p>Inbreeding depression</p> <p>Lack of uniformity and stability in processing plantation grown hardwoods</p> <p>Inbreeding could be linked with more general non-additive genetic effects</p>	<p>Focus on important wood quality traits to optimise value recovery and increase industry profitability</p> <p>Cope with multiple and complex traits</p> <p>Association genetics to assist in selection</p> <p>Opportunity to form research partnerships with industry</p>	<p>Lack of qualified quantitative geneticists</p> <p>Lack of coordination in tree breeding programmes</p> <p>Climate uncertainty</p> <p>Pitch pine canker, western gall rust, <i>Phytophora pinifolia</i> and other pests and diseases</p> <p>Fluctuating ability of industry to invest in long-term breeding</p>

Category	Strengths	Weaknesses	Opportunities	Threats
Molecular breeding and genomics	<p>May increase the efficiency of tree breeding</p> <p>Marker aided selection may increase the intensity and accuracy of selection</p> <p>Association genetics can cope with multiple and interacting traits</p> <p>Molecular techniques are becoming less expensive</p>	<p>Actual assistance to operational tree breeding and consequent benefit to industry has not yet been established</p> <p>Expensive (but becoming less so)</p> <p>Possible unknown (e.g. epistatic) interactions between SNPs</p>	<p>Link to operational tree breeding</p> <p>Applying marker aided selection</p> <p>Association genetics in population based studies to be linked to operational tree breeding</p> <p>Pedigree reconstruction may reduce the need for fully-controlled two-parent crossing.</p> <p>Determine the genetic basis for inbreeding depression and adverse genetic correlations</p> <p>Identification of genes with stable phenotypic effects across climatic ranges</p> <p>Investigation of problems in reproductive biology, phenology and tracing of genotypes</p>	<p>That it will continue to produce good science but with little or no benefit to the industry</p>
Genetic x environment x silviculture x processing interactions	<p>Many species</p> <p>Many established trials covering a range of environments</p>	<p>Lack of breeding information on drier warmer environments</p> <p>Silviculture and processing have not been seriously considered as interacting factors in GxE research from a tree breeding perspective</p>	<p>Evaluate additional species</p> <p>Breeding to cope with climatic uncertainty</p> <p>In combination with best silviculture to optimise water use efficiency</p> <p>Dryland species for carbon sequestration and biofuels</p> <p>Trees on farms</p>	<p>Climate uncertainty</p> <p>Pests and diseases</p> <p>Competition with agriculture</p>
Gene flow	<p>Well-developed understanding for <i>E. globulus</i> and <i>E. nitens</i></p> <p>Assessment strategies for <i>E. globulus</i> and <i>E. nitens</i> in place</p>	<p>Little known about other native species</p>	<p>Commercially useful hybrids</p> <p>Development of risk assessment and management strategies</p>	<p>Gene pollution in native populations</p> <p>Weediness of <i>Pinus radiata</i></p>

Category	Strengths	Weaknesses	Opportunities	Threats
Gene conservation	Extensive native genetic resources including a network of base population and breeding trials The 1978 radiata pine collection Excellent genetic resources in <i>Khaya senegalensis</i> (but, see threats)	Insufficient gene conservation of <i>Pinus radiata</i> to meet potential biotic and abiotic risks Many native species have discrete small populations that are at risk Loss of old trials	Embed greater variability in breeding populations to safeguard against biotic and abiotic risks	Climatic uncertainty Threats from pests and diseases Pests and diseases Wildfire, agriculture, urban encroachment, invasive pests Irreplaceable loss of genetic resources in <i>Khaya senegalensis</i> Gene flow
Sub-tropical and tropical environments	Quality tree breeding programmes Range of quality species	Many species to evaluate Little known about the desirable wood traits and their economic values for some of these species	Breeding for high value products in hardwood plantations Establishing dryland species Gene conservation	Gene flow Future sale of plantation assets Unknown intent of future owners Climate uncertainty
Reproductive biology	Well known for pines, and temperate eucalypts	Not well known for sub-tropical and tropical hardwoods		
Propagation and deployment	SEEDPLAN	Research activity low Emerging problems in radiata rooted cuttings Physiological ageing	Review the state of embryogenesis and tissue culture for potential use in Australia Rejuvenation of clones	Climate uncertainty
Tools and systems	STBA PLAN series well established Acoustic tools well established NIR is operational		Further develop NIR Further develop SEEDPLAN	Loss of SilviScan as a tool to service research Threat to access to ANU X-ray room for WinDendro analyses
International collaboration	Some international collaboration	Insufficient international collaboration	Collaborate with other countries to ensure there are sufficient genetic resources for <i>E. globulus</i> and <i>E. nitens</i>	
Capacity building	Quality professional researchers Good collaborative research links between research providers and with industry	Insufficient quantitative geneticists working and staying in the forestry sector Insufficient capacity in propagation and reproductive biology of hardwood species other than <i>E. globulus</i> and <i>E. nitens</i>	Provide scholarships to train quantitative geneticists (and opportunities once trained) Regain expertise in propagation and reproductive biology National sharing of information	Deteriorating training options for forest scientists

5. CONTEXT

5.1. Genetic gain and the economic value of traits

There are many estimates of the economic value of tree breeding to the industry over the years and these range from promising to spectacular. For example, realized volume gains of up to 33% have been claimed for the first breeding population of radiata pine and more than 10% is predicted for the second. Gains can only be verified after many years, even decades. Verification is no trivial exercise. It will be complicated by differences in site, climate, silviculture and stand management as well as technical changes in processing. An inevitable difficulty is that by the time gains have been verified decades later, tree breeders have moved on to future generations.

Estimates of gain can and have been made as functions of breeding values. Currently, verification of gains at the operational level is considered to be a grower responsibility. However, in order to properly verify genetic gains, estimates would need to be tracked in well-designed field trials across a number of environments and with varying silviculture. If the estimates were confirmed in field trials, this would provide a level of confidence that they would be realised in plantations. Actual verification of the gains in plantations is very difficult to achieve as indicated above and methodology for doing so would require collaborative research with industry. Such trials would need the support of FWPA and would need to be independently conducted. Consultation is required to determine whether FWPA in collaboration with growers would wish to proceed, keeping in mind the risks and the costs involved in such a venture.

Ideally, tree breeding should be end product driven. In the past the objective was to breed an all-purpose tree that would do a reasonable job over the whole range of end-uses (and the whole range of environments). This had the advantage of simplicity and economies of scale. It also coincided with an industry not being quite sure about what it actually wanted as an end product and, as such, a fast-growing straight tree with reasonable wood properties made some sort of sense. This time is past. Emphasis is now placed on traits that affect wood properties and fitness for purpose. Industry, some parts of it at least, has a better idea of what it requires in its end product and is in a better position to inform tree breeders of both the quality and diversity of its end products and how these might change in the future.

A problem in the pine industry is that processors and growers do not communicate. Many of the long-term contracts held by growers are based on volume alone. There is no premium for superior wood properties and no incentive for growers to take breeding for superior

wood properties seriously. This is a major constraint. This could be overcome to some extent if stand growth models predicted added value from improved wood quality. Perhaps FWPA could sponsor a seminar to bring growers and processors together.

The tree breeding community is evaluating many traits. Growth rate, tree straightness and wood basic density were the traditional first traits examined but this list has grown to include (or at least consider) many more traits such as wood stiffness, microfibril angle, branch size and distribution, resin pockets, reaction wood, checking, amount and number of rings of juvenile wood, heartwood formation, sapwood to heartwood transition, disease resistance, water use efficiency, pulp yield, biomass potential, carbon sequestration – and this is not a complete list. It is important to know not only the genetic gain that can be achieved in breeding for multiple and interactive traits, but to be able to place an economic value on them at operational scales. There are many species and many different end uses. Breeding needs to consider multiple traits and their potentially complex genetic correlations. Tree breeding programmes can deal with this diversity especially if there is a coordinated national effort. However, there is a danger in considering too many traits. The most important heritable traits should be identified and research concentrated on these. Each trait added to a fixed-size selection program reduces the gains in other traits unless traits are exactly correlated. It is assumed this is overcome in pine breeding programs by breeding for value rather than for gain in any one trait. Overall value is assumed to be a linear combination of the values of individual traits, that losses in one will be more than made up by gains in another and that gains are additive across traits. Some simulation should be carried out to see the effects of increasing numbers of traits on genetic changes in any one trait using real examples.

The major traits for pine are volume growth, stiffness, sweep, knot size and distribution, and proportion of juvenile wood. The objective is to increase value recovery at the sawmill. There has been considerable work, partly sponsored by FWPA, in estimating the economic value of traits in pines.

Adverse genetic correlations between traits in pines remain a problem. It is more difficult (although not impossible) to breed simultaneously for gains in two adversely-correlated traits, e.g. high productivity and superior wood stiffness. The aim should be a compromise that maximises value recovery. A significant problem in maximising value recovery in pines is to reduce the proportion of juvenile wood. There has been considerable investment by FWPA into finding a tree breeding solution to this problem. The potential for breeders to substantially improve value by reducing juvenile wood has been predicted but not yet realised. There is still some way to go. Stiffness of

juvenile wood can be improved by selective breeding but the amount (number and width) of juvenile rings remains a problem. It is unrealistic and unreasonable to expect tree breeders alone to solve this problem. Appropriate silviculture and stand management will inevitably play a part. For example, a silvicultural regime that de-emphasizes early growth rate and emphasizes later growth rate could be worth pursuing. Care must be taken in this case when making selections and estimates of gains in such regimes compared with selection and estimates in other regimes. Also there may be potential engineering solutions to this problem.

Pitch canker, western gall rust and *Phytophthora pinifolia* are potentially serious problems for the pine industry. Australian pine genetic material should continue to be evaluated in countries with these diseases so that disease resistant material can subsequently be identified and conserved in Australia.

The traits for pulpwood production from eucalypts are volume growth, basic density and pulp yield. Research on genetic gain and economic value of traits for pulpwood production is quite mature and has demonstrated significant operational gains. This industry sector is a major levy payer and their interests need to be maintained.

In general, the traits required for hardwoods for solid wood mainly concern stability and uniformity. The important traits are knot size and distribution, degrade on drying, and strength. There are significant differences in behaviour between species. For example, *E. globulus* is sufficiently hard for most purposes, has significant problems with tension wood but, in the absence of tension wood, does not suffer much degrade on drying. By contrast, *E. nitens* lacks strength, has little tension wood but suffers serious degrade on drying. There are many species that are being considered for solid wood, particularly in the tropics and sub-tropics. Each species needs to be considered as a special case. There is little known about the desirable solid wood traits in many of these species. The economic value of solid wood traits has not been seriously evaluated in any hardwood species, including *E. globulus* and *E. nitens*. The largest areas of eucalypts planted to hardwood regimes are *E. globulus* and *E. nitens*. Ironically, they are unlikely to be the most suitable hardwoods for the purpose. There is optimism (although no coordinated policy) that Australia can support a viable solid wood industry from hardwood plantations and on this basis investment in tree breeding research to define appropriate traits, embed them in breeding programmes and determine their economic value should have a high priority.

Wood properties appropriate for pulp wood are not necessarily those appropriate for sawn timber. For example, trees selected solely for pulp yield may well have higher levels of tension wood that can cause

deformation in boards when dried. Changing the focus of a breeding program takes decades to realise rather than months or years. Provenances of *E. globulus* that are superior for growth and pulp yield may well not be superior for sawn timber because of the levels of tension wood. Breeding programs may well have to begin again at the provenance level of selection before any progress can be made. This is possibly another case of antagonistic traits where gains for one purpose can be made only at the expense of gains for another. However, if the desired genetic parameters for solid wood have been measured and are in the breeding population, then modern tools such as the STBA PLAN series can circumvent the time delay.

Some of the newer hardwood species being planted, particularly in tropical and sub-tropical environments, are at the beginning of domestication, and adaptation and volume yield are fundamentally important traits. Also, high value tropical species need to have a high proportion of quality heartwood.

There is growing interest in planting trees to sequester carbon and also for biofuels. The objective for carbon sequestration is to maximize stem biomass production and this trait is already well represented in breeding programmes of the major species. However, alternative species, and particularly for drier areas, should be evaluated. Wood for biofuels will come from processing waste but may also come from biomass plantations established for the purpose. In order for biomass plantations to be viable without subsidy they will need to be fast growing and ideally managed as coppice. Eucalypts are an obvious choice and species evaluation is required. Also there may be some as yet undetermined desirable wood traits for the production of biodiesel or other liquid or gaseous fuels. This is a developing field and at the moment the tree breeding community should keep a watching brief.

5.2. Tree breeding

Tree breeding is defined here as genetic improvement by phenotypic selection, progeny testing, controlled crossings of superior individuals leading to subsequent generations of progeny tests and deployment to seed orchards and clone banks. This is the mainstay of the tree breeding industry and it will remain fundamentally important. From the perspective of FWPA, research investment should be in the research side of tree breeding and operational tree breeding should be the responsibility of the forest growers. Tree breeders calculate selection indices and breeding values, which are used to breed and deploy appropriate genetic stock for use by the industry to meet their particular requirements. Currently genetic improvement focuses on multiple and composite traits with complex inheritance with the objective of improving wood properties and value recovery.

There are many tree breeding programmes of various scales being carried out for a range of species across the country. A major challenge is efficient handling of data. The two major tree-breeding cooperatives, STBA and RPBC, are the main commercial breeders and repositories of data for radiata pine. STBA is the main breeder of *Eucalyptus globulus*. Queensland has a long history of tree breeding in subtropical and tropical species especially *Pinus elliottii*, *Pinus caribaea* and their hybrid. Western Australia has a programme in *Pinus pinaster* as well as *Pinus radiata*. Gunns is the major grower and breeder of *Eucalyptus nitens*. Fragmentation across the country is inefficient and coordination of tree breeding, genetic analysis and field-testing of like species makes a lot of sense. STBA covers about one half of the radiata estate in Australia and Forests New South Wales (FNSW) and Western Australia the other half. FNSW gets its genetic material via the RPBC. There is a compelling case that, at the very least, there should be sharing of genetic information across Australia in the genetic resources of radiata pine. However, some smaller tree breeding programmes cannot see an economic advantage in joining a large co-operative. Other companies who dominate the knowledge, experience and intellectual property for a particular species (eg *Eucalyptus nitens* and *Pinus pinaster*) see no value in joining a large cooperative. Some competition between breeders is healthy but overdone can reduce efficiency and economic value. Researchers sometimes have their own breeding programmes. This poses the question of should researchers also be breeders? There is a strong argument that genetic data, where appropriate, should be shared and national databases and breeding programmes should be supported. There are numerous small tree-breeding programmes covering a range species, (including species that are likely to become more important in the future) in sub-tropical and tropical environments.

FWPA has invested in the development of DATAPLAN (database), TREEPLAN (breeding values), MATEPLAN (tree breeding) and SEEDPLAN (deployment). These STBA initiatives are very much respected by industry and have made a return on investment. STBA wishes to broaden the application of MATEPLAN and SEEDPLAN to enhance breeding and deployment outcomes.

Tree-breeding should focus on traits affecting yield, end-product quality, stability, uniformity and value recovery. Inbreeding and adverse genetic correlations remain a problem in advanced generations. An important challenge is to accelerate tree breeding so that verifiable genetic gains can be achieved in shorter time.

5.3. Molecular tree breeding and genomics

Traditional tree breeding based on phenotypic selection is slow due to the constraints of reproductive biology and the fact that many traits of

interest are not expressed in the phenotype until later age. Molecular markers provide the possibility of identifying desirable traits much earlier in commercial breeding programmes thereby allowing more intensive and accurate selections. Marker aided selection could simultaneously determine pedigree and thereby reduce the need for, and expense of, fully controlled two-parent crossings. Molecular selection could also provide a means of overcoming adverse genetic correlations, as some alleles controlling such traits appear not to exhibit adverse relationships.

Selection of trees for use in plantations directly or indirectly via a breeding program has been carried out on the phenotype – what a tree looks like (usually by measurement). Progeny testing allowed breeders to observe how the measured properties of a tree are passed to its offspring and gave a closer view of the genotype (i.e. the genes the tree carries) than the phenotype of the tree itself. Predicted breeding values make use of information from all relatives of a tree rather than just its offspring and are therefore closer still to the genotype. It has been a dream of geneticists since at least the 1930s to use the genes themselves for selection rather than some obscured view via the phenotype. The problem has been that although there is a genetic component to all (or close to all) the traits observed, very little is known about how that component is controlled, how the genes interact with each other and with the environment to produce the phenotype. In the mid 1970s variation in isozymes associated with variation in quantitative traits was observed but the variation was too coarse to use in practice. This was also true of other classes of markers such as microsatellites and RFLPs. They could be used within families, but this would have been too expensive for practical and wide-scale use. Each new class of markers brought closer the realisation of the dream of selecting on genotype. The ultimate level of genetic markers or tags has now been reached with SNPs (single nucleotide polymorphisms) occurring within genes of known function. It is now possible to mark particular alleles with observable SNPs and to select desirable forms (i.e. alleles) of the genes for breeding purposes. The problem now is that not enough is known about which genes to select for. The genetic architecture of quantitative traits is little better known than decades ago when breeding began. Research on SNPs has focused on genes known to affect a particular trait and has been very effective and valuable in producing knowledge of SNPs and how they operate. But this approach has focused on the wrong end from a breeder's point of view. It has focused on gene sequences known to have an effect on a trait or process rather than beginning with the way variation in the trait is made caused by variation in the genes. The proportion of the genetic variation in most traits that can be explained by the known gene sequences is very small indeed. Most variation is caused by genes known nothing about. This may be because they are of vanishingly small effect (the old quantitative gene idea) or the

appropriate genes have not been sequenced or their effect discovered. Should searching the genomes for sequences that might affect traits of interest be continued? It is likely that observed phenotypes are more likely the result of interactions between quite large numbers of genes than results of main effects of small numbers of the genes themselves. If this is true, then searching for SNPs within isolated gene sequences can only be a means to an end rather than the end itself. Knowledge of the SNPs and the sequences they mark are useful only when combined together in known interactive combinations. However, investment in continuing this line of research is warranted, indeed essential. Precision of marker-aided selection will only be achieved when SNPs from relevant sequences are used together (association genetics).

There are deep divisions within the tree-breeding community on the value or otherwise of molecular breeding. Research in genomics and in molecular breeding has promised much and so far delivered little if anything to operational tree breeding. However, industry by and large realises that it needs a long-term point of view and supports some investment in this area. Research in molecular breeding is high risk but promises high returns and great efficiencies. It has been expensive in the past but the costs for sequencing have been greatly reduced. Currently, association genetics is being widely used in breeding programs for a wide range of plants and animals. Many of these have been through a large number of breeding generations and the utility of association genetics has reached or is close to a practical and economically desirable outcome. By comparison, tree breeders are still dealing with relatively wild populations and the likelihood that molecular research will produce a significant practical outcome within the next five years is low. However, the probability that it will do so in the longer term is real and it is important, therefore, to support some research in this area. In the long-term, Australia could well regret it if they did not provide continuing support to molecular breeding and genomics. Realistically, molecular breeding (genotypic selection) should be used as a complementary tool to breeding programmes based on phenotypic selection. Preoccupation with SNPs could come at some risk. Possible unknown interactions (e.g. epistasis) could be seen as a weakness to the association genetics approach. Probably the use of molecular tools should be widened to investigate problems in reproductive biology, phenology, parentage verification and tracing of genotypes.

It is incumbent on researchers to provide credible analysis of the potential benefits and risks of their research. FWPA investment in molecular breeding and genomics can direct research towards a commercial objective. Without FWPA funding this may not occur. Also, an argument, made by some, is that without FWPA investment in this area the research providers could be forced to move away from

trees to agricultural plant species. A relatively small amount of funding can leverage larger amounts and ensure the research is directed towards FWPA's interests. It is important that molecular breeders coordinate closely with the commercial breeding programmes and that they work together. A limitation to research in molecular breeding is the availability of suitable trials and appropriate genetic resources in the ground. The level of FWPA funding for molecular breeding and genomics will be contentious because of the polarised opinions within the tree breeding community on its value. (FWPA funding in molecular breeding for 2010-2014 is recommended at about 20% of total funding. Funding for 2004-2009 was 27%).

The constraints on genetic engineering as a valuable tool in tree breeding for specific traits are social and political rather than scientific. However the barriers appear to be breaking down. Perhaps this is an area where the tree breeding community and associated industry should now be bolder. There are no recommendations to pursue genetic engineering for the 2010-2014 period but it is worthwhile keeping a watching brief.

5.4. Genotype x environment x silviculture interactions

Growing environments are changing as a result of changes in climate. On average the climate is predicted to be warmer. Some growing zones will probably become drier (mainly in the south) and some wetter (mainly in the north and in Tasmania). As a result, silvicultural research aimed at increasing water use efficiency (WUE) at the stand level should have high priority. New pest and diseases may emerge. New species may need to be assessed or re-assessed. The nature of competition for land between forestry and agricultural enterprises may change. Forestry may be forced onto less fertile land.

The evidence for human-induced global warming is compelling. Predictions of what will happen in a particular region in the future as a result are less certain. From the point of view of a long-term enterprise such as forestry, it is best to consider the future in terms of climate uncertainty (wetter, drier, cooler, warmer) and to conserve genes to cope with an uncertain future. Several growers are concerned about the impact of a decade or more of drought on their bottom line and with the expectation it will get worse rather than better. This is a problem in *Pinus radiata*, and in *Pinus elliottii*, *Pinus caribaea* and their hybrid. *Eucalyptus globulus* is at risk in parts of mainland Australia but probably not in Tasmania. Indeed Tasmania is likely to become warmer and wetter and *Eucalyptus globulus* might replace *E. nitens* to some extent.

Significant GxE interactions are common in breeding populations. Rather than trying to breed for a specific GxE, it makes more sense to

deploy stock from the breeding population known to be suited to a particular environment. The challenge is optimal deployment rather than tree breeding per se. For example, it makes little sense to breed for water use efficiency (WUE). Any gains are likely to be modest at best. Rather stock should be deployed from the breeding population that is known to perform in drier environments. Even then, it is unlikely there will be an increase in WUE. There is no such thing as a rapidly growing tree that uses negligible water. A tree species growing in drier environments will grow more slowly than the same species in more favourable environments. This is an undeniable biological constraint. There may be alternative species/provenances that will grow better than the standard species in drier environments and so the search for alternative species/provenances for such environments should continue. For example, the Guadalupe and Cedros provenances of *Pinus radiata* could well grow on sites where the current breeding stock would not. Alternative species are very likely to be necessary to make plantations in drier areas viable. This requires cooperation between research organisations engaged in the search for suitable species, but it must be undertaken in collaboration with the industry that is to process the wood. The experience with *Eucalyptus dunnii* in northern NSW is a case in point. Silvicultural interventions such as spacing, thinning, weed control and manipulation of leaf area are likely to be very effective in extracting value in drier environments, particularly when matched with appropriate planting stock.

There are several approaches to dealing with significant G x E. One is to subdivide the breeding population so that each component of the 'E' is supplied with a different (and well-characterised) 'G' so production is maximised. The advantage of this is that sites are matched to genotypes – more easily carried out in a clonal program in which clonal characteristics must be very well known. A second approach is to use the greater selective power of a larger undivided breeding population and select genotypes (or families etc) for deployment based on their site requirements. This still matches 'G' to 'E', but no progressive gains are made from generation to generation because the matching between site and genotype is done at deployment rather than at the breeding stage. The economics of each approach depends on how important the G x E is in the larger scheme of things.

The ultimate objective, over all environments, is to deploy stock that is site specific, i.e. the best stock for a particular site under prevailing silviculture. FWPA will support the development or refinement of tools to achieve this objective.

5.5. Gene flow

When plantation species are grown outside of their natural range, there is the potential for the plantation species to hybridise with adjacent native species and change the composition of adjacent forests and endanger native species. The CRCF (Cooperative Research Centre for Forestry) has an on-going research programme looking at the extent to which this may or may not be a problem in *Eucalyptus globulus* and *Eucalyptus nitens* plantations. The extent to which this may or may not be a problem for other plantation species in other regions is not known and is causing concern.

Hybridisation between eucalypts is a common occurrence. For example, in Western Australia, *Eucalyptus camaldulensis* hybridises with *Eucalyptus rudis*, and this is just one of many examples across the country. The propensity for hybridisation between eucalypt species should be seen as an opportunity. Some hybrids may be commercially valuable. However, the risk of pest susceptibility and the high propagation costs of hybrids need to be considered. Many researchers in this area suggest that effort should be focussed on the major commercial species rather than promoting and evaluating hybrids. *Corymbia* hybrids are very promising and are an important exception.

5.6. Gene conservation

There should be a nationally co-ordinated arrangement for conserving genes of commercial forest species and also those that may become so following climate change and climate uncertainty. Trees are harvested, die, or are burnt or otherwise cleared. The object in gene conservation should be to conserve genes rather than trees. This will become increasingly difficult with the move towards more private ownership of forest resources.

For *Pinus radiata*, this means taking full advantage of the 1978 collection. The establishment by STBA (with support from FWPA) of the National Genetic Resource Centre goes some way towards doing this. STBA and RPBC are convinced there is adequate genetic variability in the *radiata* pine breeding populations. However, there is an impression by others in the tree breeding community that this in itself is insufficient and that more attention should be given to conserving genetic resources of *Pinus radiata* by planting in a wider range of environments and carrying the genes through to future generations. They argue that these resources should be further evaluated for traits of significance, including traits for climate uncertainty (wetter, drier, warmer, cooler) and disease resistance. The best and safest way to conserve *Pinus radiata* genes is to protect, conserve and regenerate the remnant planted stands of the native populations in Australia as we can no longer access them in USA and Mexico. Already, all unique alleles in

the Guadalupe, Cedros and Cambria populations have been lost from the STBA breeding population as they were never included.

There are differences of opinion about the need to conserve genes of native species and this is due to regional and species differences. One point of view is that the native forests are so large and well distributed that there is little chance of losing genetic variability. Others point to small discrete isolated populations that are endangered by fire, climate uncertainty, agricultural encroachment or gene flow. The case for gene conservation should be extended to species that are not currently of commercial significance but may well become so as a result of climatic uncertainty. The best way to conserve genes is to ensure that native populations as well as base population and breeding trials are conserved.

Australia has a wide variety of tree species that are of interest to the rest of the world. Australia is the natural home to genus *Eucalyptus* and has many examples of *Acacia* and *Casuarina* and other dryland species. Australia has an obligation to conserve as wide a range of genetic variability as possible in its native tree flora, although this is hardly the responsibility of FWPA.

Australia has made very comprehensive collections of provenances of African Mahogany (*Khaya senegalensis*) from native sources in Africa and arguably has the greatest pool of genetic diversity worldwide. However, there is the real danger that these genetic resources will be lost if there is no coordinated plan to ensure that the genes are conserved.

Because of differences in opinion about the current state of gene conservation in Australia, and particularly within the main commercial species, FWPA could sponsor a discussion between interested parties.

5.7. Tropical and subtropical environments

Tropical and subtropical environments may become more important as a result of climate uncertainty. Wetter rather than drier conditions are predicted in some areas. There may be a new suite of desirable species that will need to be genetically evaluated. African Mahogany (*Khaya senegalensis*) is promising and the full range of genetic material from the extensive range of provenances already in Australia needs to be conserved, evaluated and used for breeding. *Corymbia* spp. and their hybrids are important plantation species aimed at producing structural and higher value timber. The extensive lower rainfall savannah environments have potential for carbon sequestering but there has been little genetic research directed at this. Also growing trees on farms could be used to offset greenhouse gas emissions from

ruminants should agriculture become included in carbon trading (this of course applies to all of Australia and not just the north).

5.8. Reproductive biology

There has been considerable work on the reproductive biology of the main commercial plantation species but not of the suite of hardwood species being evaluated for solid wood, particularly in the north. Effective deployment of genetic material means that appropriate pollination strategies will need to be developed for each species under consideration.

5.9. Propagation

Appropriate vegetative propagation technologies have not been developed for some species and this is hampering tree improvement programmes. Considerable time and money has been spent on promoting rooted cuttings in *Eucalyptus nitens* and in *Pinus pinaster* but to no avail. Perhaps molecular techniques could be used here to weed out rootable material but this would be at the risk of losing genetic variability and arguably not worth the effort.

Substantial gains can be achieved through clonal deployment in both pines and eucalypts and it is probable this will increase in importance. Rejuvenation of clonal material is a problem. This can be managed to some extent by tissue culture and somatic embryogenesis, which allows material to be bulked up and stored in the juvenile state. Globally there has been considerable research into somatic embryogenesis and tissue culture and growers and breeders would do well to review the applicability of these technologies.

5.10. Tools and systems

SilviScan has proved itself as an invaluable tool in measuring key wood traits for tree breeding programs and this is now a mature technology. However, its viability as a service to tree breeding research is seriously threatened by CSIRO's downsizing of forest products research. The other X-ray densitometry system (WinDendro) is also under threat as access to the ANU X-ray room (possibly the only such facility in the country) may become difficult or impossible. Acoustic tools for the measurement of stiffness are also now operational and probably need no further development. NIR (near infra red spectroscopy) is also operational for measuring pulpwood properties, but there is scope for further refinement. It has the potential for assessing tension wood in *Eucalyptus globulus*.

Several growers have requested that a graphic user interface should be added to MATEPLAN and SEEDPLAN. This would allow the growers instant access to these tools at their desk rather than sending away their information and having their calculations made remotely.

The development of strategies and tools to provide early selection for traits (e.g. NIR) is important. Current NZ research on bending radiata and eucalypt seedlings to determine key wood properties at an early age is very exciting.

5.11. International collaboration

Eucalypt breeding is advanced in both South Africa and several countries in South America. Australia is the depository of natural eucalypt genetic variation but collaboration will assist all countries. Australia should collaborate to ensure that comprehensive genetic resources are available for *Eucalyptus globulus* and *Eucalyptus nitens*. Australia also shares genetic variability and genetic information on radiata pine with New Zealand. Collaboration rather than competition should advantage both countries.

5.12. Capacity building

The research community in forest genetics and tree breeding in Australia is of high quality. However, there is a shortage of quantitative geneticists actively working in the forestry sector and very few younger scientists are showing any interest. Quantitative genetics is the mainstay of operational tree breeding and this shortage needs to be addressed. Also there appears to be a shortage of scientists with an interest in propagation and, outside Tasmania, in reproductive biology.

The fragmentation or disappearance of research groups remains a problem (for example, the downsizing and possible elimination of forest products research in CSIRO is a tragedy for forest industry). FWPA cannot fix this but can be aware of the implications when assessing research proposals. Similarly, destructive competition between research groups is not in the national interest and FWPA will, as best it can, encourage meaningful collaboration. FWPA should take a leadership role in establishing a strategic relationship with research providers. This would allow projects of greater scope and with longer-term objectives.

5.13. Licence to operate

The tree breeding community needs to have high quality, objective, evidence-based knowledge to respond to community concerns, irrespective of whether these concerns are scientifically respectable or

otherwise. Three examples are genetic engineering, gene flow and the recent issue of 'toxic nitens' in Tasmania.

6. RESEARCH AND DEVELOPMENT INVESTMENT PLAN 2010-2015

The research context outlined in Section 5 addresses national issues and highlights areas in which research is needed. However, FWPA can realistically only support a small proportion of these and must allocate priorities that are in their interests. The recommendations below are a balance between two selection criteria:

(1) research directed towards increasing the profitability of the industry and reducing risk for those species of commercial importance which significantly contribute to the national economy.

(2) research to promote the development of the industry in areas that may become important in the future and where research is lacking.

In particular they address the need to accelerate genetic gain by industry, to breed for stability and uniformity of product, to facilitate best regional deployment of planting stock and to recognize the complementary role of silviculture and engineering in meeting these objectives.

FWPA research priorities

Research recommendations are divided into two categories, primary and secondary. The primary recommendations are outcome-oriented and FWPA will support these as best it can within financial constraints. FWPA will consider secondary recommendations if they are a sub-set of, or directly address the primary recommendations.

Primary recommendations

1. FWPA will invest in research that facilitates deploying the most appropriate genetic stock for a particular environment and silviculture. This will include research aimed at optimizing productivity in drier environments and may include the evaluation of alternative species.

This recommendation is directed towards reducing risk, diversifying risk and maintaining profitability. It is not specifically directed towards increasing industry profitability because the expected impacts of climate uncertainty, particularly reduced water availability, on plantation productivity in most plantation areas in Australia are

predicted to be negative. However, increased profitability could be realised in more favoured environments. The outcome of this research will be deployment of planting stock best suited to a particular environment and silviculture. It may well make the difference between success and failure in marginal environments. It will assist growers in making informed decisions about replanting current areas and investing in new ones. Tree breeding alone cannot eliminate risk from climate uncertainty. Research needs to be done in collaboration with silviculture.

2. FWPA will support the development of tools aimed at accelerating breeding and deployment.

This recommendation is directed towards increasing industry profitability. The objective is to achieve genetic gain earlier. There is a range of tools, molecular and non-molecular. It is unlikely that industry will see any increased profitability from investment in molecular tools within the five-year term of this investment plan. However, continued investment in the expectations of significant gains in the future is justified. There has been a good return on investment in non-molecular tools in the past and there is every good reason to expect this to continue and for gains to be realised, or at least set in train, within the next 5 years. These tools include the STAB PLAN series, NIR, seedling bending and engineering solutions, rejuvenation and advanced propagation technologies. The expectation is that the rate of genetic gain, in both softwoods and the major commercial hardwoods, will be increased by an average of at least 20% as a result of investment leveraged by FWPA over the period 2010-2015. The economic benefit is obvious.

3. Genetic research that addresses the desirable traits for solid wood from hardwood plantations will be supported. This should cover both the main species currently planted and alternative species under consideration. Emphasis should be placed on uniformity and stability in processing. The economic value of these traits is largely unknown and should be determined.

This recommendation foreshadows Australia developing a plantation-based resource of solid wood from hardwoods that is of sufficient size and quality to support a viable and sustainable industry. If this is to eventuate, tree breeding to maximise economic value is not only justified but should be immediate. Besides growth and form, the desirable traits are largely to do with wood physical properties and challenges in processing. Engineering solutions (e.g. sawing and drying technologies) are very important but many of the desirable traits are heritable and tree breeding will play a part. Potentially there are many species, with varying traits of importance and covering a wide geographical area. Consequently there is the risk that fragmentation

could reduce the effectiveness of research to deliver significant benefit to industry. Ideally research should concentrate on winners and economies of scale. The identification of this is a research topic in its own right. At the very least, FWPA should expect an economic analysis of the contribution that tree breeding can make to improving the profitability of a yet to be developed industry.

4. Research directed towards increasing stability and value recovery in pines will have a high priority. This will include increasing stiffness and reducing the proportion of juvenile wood. This should be in collaboration with appropriate silviculture.

This recommendation comes with unanimous support from softwood growers and processors. There is, however, a difference of opinion across the research community on the extent to which tree breeding research can deliver further gains. Agtrans (see Section 3) concluded that past FWPA investment in improving stiffness generated substantial returns (NPV of \$239 million for improvement in stiffness). The most optimistic predictions are that further research will deliver similar benefits. For example there are claims that research resulting in reducing the number of juvenile rings in the radiata pine estate can deliver an NPV of \$189 million due to higher premiums and improved structural grade board recovery. The differences of opinion in the research community are whether tree breeding can actually produce the required reduction in juvenile rings to achieve this. The balance of informed opinion is that further investment in increasing stability and stiffness and reducing juvenile rings will continue to add value. An expectation that investment leveraged by FWPA over 2010-2015 will produce an increase in NPV of \$100 million is not unrealistic.

5. Initiatives to ensure that breeding to improve wood properties is accepted by industry and translated into increased profitability for both growers and processors will be strongly encouraged. In particular, meaningful dialogue and action between growers and processors will be strongly encouraged to ensure that improving wood properties through breeding is in their mutual best interests.

This is a technology transfer issue rather than a research one and consequently there is no budget provision for recommendation 5 in this plan. However, it is important this should be considered as a very high priority in the technology transfer programme of FWPA. There are two barriers to effective technology transfer here. The first is dialogue between R&D and operational industry, and the second, and perhaps more important, the dialogue between growers and processors. Currently there is little incentive for sawmillers to produce higher quality wood. Many growers have long term contracts based on volume alone. Without a premium for quality offered to growers, investment in recommendation 3, and particularly recommendation 4, is unlikely to

achieve any economically measurable benefit at all. The pulp industry has a mature relationship between grower and processor (between supplier and customer) where there is a premium for quality (pulp yield). There is no reason why this also cannot be the case for solid wood. If the market cannot support a premium for higher quality across the value chain, then there is little reason to consider improving wood properties at all. Economic analyses of the benefits of improving wood properties are based on the assumption that they will be embraced by industry right through the value chain. This is not happening. One way to kick start this process would be to encourage and support an ongoing program of industry forums, conferences and workshops that bring all relevant industry parties together. Recommendation 5 is fundamentally and critically important to the creation of industry impact and benefit directly linked to the R&D outputs of this investment plan.

Secondary recommendations

These will not be funded as stand alone proposals, but will be considered as part of a proposal that directly and seriously addresses the primary recommendations.

6. FWPA will encourage genetic research that aims to optimise multiple traits, reduce the impact of adverse genetic correlations and reduce inbreeding depression.

7. FWPA will encourage research that identifies molecular markers that have stable phenotypic effects across climatic ranges. This may assist in breeding for climatic uncertainty.

8. Research that addresses the reproductive biology of mainstream and alternative species will be encouraged.

9. Research into vegetative propagation will be encouraged. This may include a review of the applicability of somatic embryogenesis and tissue culture techniques in the Australian environment. Research aimed at exploiting clonal deployment will be encouraged.

10. Projects that foster national and international collaboration in risk management, value adding and gene conservation will be encouraged.

11. Initiatives that encourage capacity building in quantitative genetics, reproductive biology and propagation technologies will be supported.

7. GUIDELINES FOR INVESTMENT

FWPA will allocate \$3.5 million over the five-year period 2010-2014. Successful proposals will require co-investment from industry. Nominal expectations for investment are one-third each from FWPA, research provider and industry. It is imperative that processors, growers and breeders consult to ensure that breeders develop the best product for processors and that growers are given incentives to grow them. Verification of genetic gains at the operational level is an important issue for industry.

A broad guideline for investment by primary recommendations is 30% each for recommendations 1 and 2 and 20% each for recommendations 3 and 4. Recommendation 2 includes both molecular and non-molecular tools. A broad guideline for investment by species is 45% for all softwoods, 25% for pulp species and 30% for solid wood from hardwood plantations. This emphasizes the rising significance of hardwood solid wood regimes and acknowledges the relative immaturity of research in this area. FWPA investment is summarised in Table 2 on the basis that \$3.5 million is invested over the period 2010-2014. It will be impossible to get a perfect match and some flexibility is required.

Table 2: Notional FWPA investment by primary recommendations and by species categories, 2010-2014

	FWPA funding (millions of \$)
Primary recommendations	
Recommendation 1	1.050
Recommendation 2	1.050
Recommendation 3	0.700
Recommendation 4	0.700
<i>total</i>	<i>\$3.500</i>
Species	
Conifers	1.575
Hardwoods for solid wood	1.050
Eucalypts for pulp	0.875
<i>total</i>	<i>\$3.500</i>

8. OUTCOMES AND INDICATORS OF SUCCESS

The objectives of FWPA investment in tree breeding and genetics research are to increase industry profitability and reduce risk, and measure the extent to which this has been achieved at the operational scale. The success or otherwise of achieving this needs to be quantified as far as possible. The difficulties in doing so have been foreshadowed. First there is the situation that genetic gain arising from tree breeding initiatives in the past has not been verified, for the most part, at the operational scale. Secondly, the genetic gain predicted from current tree breeding initiatives cannot be verified for many years into the future and thirdly the opportunity to achieve added value in both softwoods and hardwoods is seriously hampered by a lack of communication and cooperation between growers and processors. By default, the extent to which the objectives can be achieved and measured within the five year framework of this investment plan must come from realistic and credible predictions.

Expected outcomes from investment are summarised as:

- (1) Accelerated genetic gain with consequent added value to the main commercial species.
- (2) Identification of stock that can be deployed to specific environments consequent on climate uncertainty.
- (3) Added value to emerging solid wood regimes in hardwoods.

Genetic gain can be predicted from breeding values. The rate of genetic gain is best considered as genetic gain per unit of time rather than per breeding generation. Calculating the economic value of traits and predicting added value at the operational scale, although complex and challenging, is important. The ultimate objective is that genetic gain and consequent added value can be incorporated in company balance sheets. Industry collaborators (growers and processors) will need to be meaningfully involved in the research if this is to be achieved. The lack of communication and collaboration between researchers and industry and particularly between growers and processors is a serious constraint in achieving these outcomes.

Research providers will need to indicate in applications for funding the process by which the success or otherwise of their research can be measured. When reporting they will be required to predict, as far as possible, the outcomes in terms of increased industry profitability and reduced risk.

9. ABBREVIATIONS

CRCF	Cooperative Research Centre for Forestry
CSIRO	Commonwealth Scientific and Industrial Research Organization
FNSW	Forests New South Wales
FWPA	Forests and Wood Products Australia
FWPRDC	Forests and Wood Products Research and Development Corporation
JWI	Juvenile Wood Initiative
NPV	Net Present Value
R&D	Research and Development
RPBC	Radiata Pine Breeding Company
RFLP	Restriction Fragment Length Polymorphism
SNP	Single Nucleotide Polymorphism
STBA	Southern Tree Breeding Association
WUE	Water Use Efficiency